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Localization techniques for wireless sensor networks

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***Abstract*— Nowadays wireless sensor networks are used in variety of applications such as military surveillance, healthcare monitoring, environmental sensing, industrial monitoring. In all these applications it is required to know the location of sensors that send the sensed data to the base station for further processing of the data. In this paper different techniques used for finding the location of sensors in wireless sensor network are discussed. And also the challenges related with these techniques are also presented here.**

***Keywords*— Trilateration; localization; anchor nodes; TOA; RSS.**

I. INTRODUCTION

A wireless sensor network (WSN) provides a bridge between the real physical and virtual worlds. It is composed of n nodes with a communication range of r, distributed in a two dimensional squared sensor field $Q = [0,s] \times [0,s]$. For any two nodes u and v, u reaches v if and only if v reaches u and with the same signal strength w [1]. We represent the network by the Euclidean graph $G = (V, E)$ with the following properties:

- $V = \{v1, v2, vn\}$ is the set of sensor nodes.
- $\langle i, j\rangle \in E$ if v_i reaches v_j; that is, the distance between v_i and v_j is less than r.
- $w(e) \leq r$ is the weight of edge $e = \langle i, j\rangle$, the distance between v_i and v_j.

The architectural diagram of a WSN is given below.

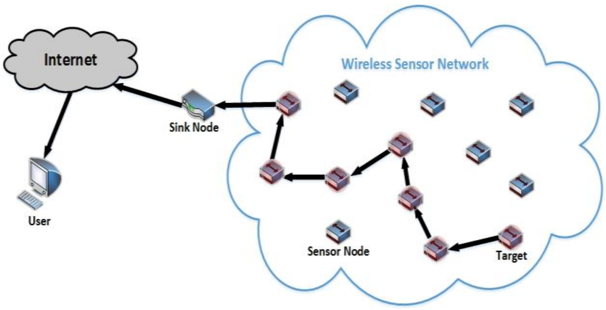

Fig. 1. Wireless sensor network architecture

A. Applications

Wireless sensor networks have a wide range of potential applications to industry, science, transportation, civil infrastructure, and security. Some of the sample applications of WSNs are:

- Seismic Monitoring
- Civil Structural Health Monitoring
- Habitat and Ecosystem Monitoring
- Monitoring Groundwater Contamination
- Rapid Emergency Response
- Industrial Process Monitoring
- Perimeter Security and Surveillance
- Automated Building Climate Control

B. Components

The main components of a WSN node are controller, communication device(s), sensors/actuators, memory and power supply which are specified using the following diagram.

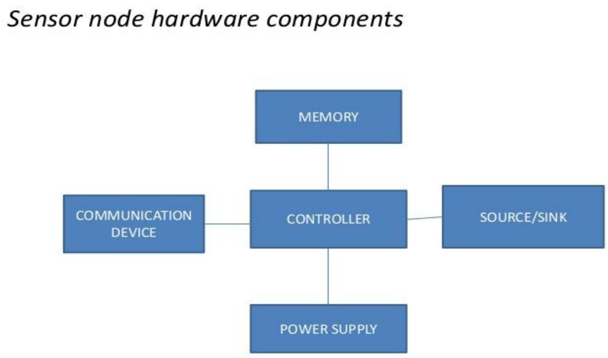

Fig. 2. Components of a sensor node

II. LOCALIZATION

Localization in sensor network estimates 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. 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. The sensors with unknown

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location information are called *non-anchor* nodes and their coordinates will be estimated by sensor network localization algorithm [2]. Patwari *et al.* described some general signal processing tools that are useful in cooperative WSN localization algorithms [3] with a focus on computing the Cram´er-Rao bounds for localization using a variety of different types of measurements.

In applications such as habitat monitoring, smart building failure detection and reporting, and target tracking, it is necessary to accurately orient the nodes with respect to a global coordinate system in order to report data that is geographically meaningful. Basic middleware services such as routing often rely on location information (e.g., geographic routing).

Ad hoc sensor networks present novel tradeoffs in system design. On the one hand, the low cost of the nodes facilitates massive scale and highly parallel computation. On the other hand, each node is likely to have limited power, limited reliability, and only local communication with a modest number of neighbors. These application contexts and potential massive scale make it unrealistic to rely on careful placement or uniform arrangement of sensors. Rather than use globally accessible beacons or expensive GPS to localize each sensor, it is preferable for the sensors to self-organize a coordinate system.

A. Localization Hardware

The localization problem gives rise to two important hardware problems. The first, the problem of defining a coordinate system and the second, which is the more technically challenging, is the problem of calculating the distance between sensors (the ranging problem).

- *Anchor/Beacon nodes*

Beacon nodes (also frequently called anchor nodes) are a necessary prerequisite to localizing a network in a global coordinate system. Beacon nodes are simply ordinary sensor nodes that know their global coordinates a priori using GPS. At a minimum, three non-collinear beacon nodes are required to define a global coordinate system in two dimensions. If three dimensional coordinates are required, then at least four non-coplanar beacons must be present. Localization accuracy improves if beacons are placed in a convex hull around the network. Locating additional beacons in the center of the network is also helpful. In any event, there is considerable evidence that real improvements in localization can be obtained by planning beacon layout in the network. GPS receivers consume significant battery power, which can be a problem for power-constrained sensor nodes. Beacons are necessary for localization, but their use does not come without cost.

- *Received Signal Strength Indication (RSSI)*

The energy of a radio signal diminishes with the square of the distance from the signal's source. As a result, a node listening to a radio transmission should be able to use the strength of the received signal to calculate its distance from the transmitter.

- *Radio Hop Count*

The local connectivity information provided by the radio defines an unweighted graph, where the vertices are sensor nodes, and edges represent direct radio links between nodes. The hop count hij between sensor nodes si and sj is then defined as the length of the shortest path in the graph between si and sj. y, If the hop count between si and sj is hij then the distance between si and sj , dij , is less than R∗hij , where R is again the maximum radio range.

- *Time Difference of Arrival (TDoA)*

In TDoA schemes, each node is equipped with a speaker and a microphone. Some systems use ultrasound while others use audible fre-quencies. However, the general mathematical technique is independent of particular hardware. In TDoA, the transmitter first sends a radio message. It waits some fixed interval of time, tdelay (which might be zero), and then produces a fixed pattern of "chirps" on its speaker. When listening nodes hear the radio signal, they note the current time, tradio, then turn on their microphones. When their microphones detect the chirp pattern, they again note the current time, tsound. Once they have tradio, tsound, and tdelay, the listeners can compute the distance d between themselves and the transmitter using the fact that radio waves travel substantially faster than sound in air.

$$d = (sradio - ssound) * (tsound - tradio - tdelay)$$

TDOA methods perform best in areas that are free of echoes, and when the speakers and microphones are calibrated to each other.

- *Angle of Arrival (AoA)*

In these methods, several (3-4) spatially separated microphones hear a single transmitted signal. By analyzing the phase or time difference between the signal's arrival at different microphones, it is possible to discover the angle of arrival of the signal.

Angle of Arrival hardware is sometimes augmented with digital compasses. A digital compass simply indicates the global orientation of its node, which can be quite useful in conjunction with AoA information.

III. LOCALIZATION TECHNIQUES

Localization is performed through communication between localized node and unlocalized node for determining their geometrical placement or position. Location is estimated using distance and angle between nodes. The following are the concepts used in localization:

1) Lateration occurs when distance between nodes is measured to estimate location.

2) Angulation occurs when angle between nodes is measured to estimate location.

3) Trilateration Location of node is estimated through distance measurement from three nodes. In this concept, intersection of three circles is calculated, which gives a single point which is a position of unlocalized node.

4) *Multilateration* In this concept, more than three nodes are used in location estimation.

5) *Triangulation* In this mechanism, at least two angles of an unlocalized node from two localized nodes are measured to estimate its position. Trigonometric laws, law of sines and cosines are used to estimate node position.

Localization schemes are classified as anchor based or anchor free, centralized or distributed, GPS based or GPS free, fine grained or coarse grained, stationary or mobile sensor nodes, and range based or range free.

- *Anchor Based and Anchor Free*

Positions of few nodes are known in anchor-based mechanisms. Nodes that do not know their location are localized using these known nodes positions. Accuracy is highly depending on the number of anchor nodes. Anchor-free algorithms estimate relative positions of nodes instead of computing absolute node positions [6].

- *Centralized and Distributed*

In centralized schemes, all information is passed to one central point or node which is usually called "sink node or base station". Sink node computes position of nodes and forwards information to respected nodes. Computation cost of centralized algorithm is decreased, and it takes less energy as compared with computation at individual node. In distributed schemes, sensors calculate and estimate their positions individually and directly communicate with anchor nodes. There is no clustering in distributed schemes, and every node estimates its own position [7-9].

- *GPS Based and GPS Free*

GPS-based schemes are very costly because GPS receiver has to be put on every node. Localization accuracy is very high as well. GPS-free algorithms do not use GPS, and they calculate the distance between the nodes relative to local network and are less costly as compared with GPS-based schemes [11,12]. Some nodes need to be localized through GPS which are called anchor or beacon nodes that initiate the localization process [6].

- *Coarse Grained and Fine Grained*

Fine-grained localization schemes result when localization methods use features of received signal strength, while coarse-grained localization schemes result without using received signal strength.

- *Stationary and Mobile Sensor Nodes*

Localization algorithms are also designed according to field of sensor nodes in which they are deployed. Some nodes are static in nature and are fixed at one place, and the majority applications use static nodes.

- *Range-Free and Range-Based Localization*

1) *Range-Free Methods*

Range-free methods are distance vector (DV) hop, hop terrain, centroid system, APIT, and gradient algorithm. Range-free methods use radio connectivity to communicate between nodes to infer their location. In range-free schemes, distance measurement, angle of arrival, and special hardware are not used [11,12].

a) DV Hop

DV hop estimates range between nodes using hop count. At least three anchor nodes broadcast coordinates with hop count across the network. The information propagates across the network from neighbor to neighbor node. When neighbor node receives such information, hop count is incremented by one [12]. In this way, unlocalized node can find number of hops away from anchor node [7]. All anchor nodes calculate shortest path from other nodes, and unlocalized nodes also calculate shortest path from all anchor nodes [13]. Average hop distance formula is calculated as follows: distance between two nodes/number of hops [6].

Unknown nodes use triangulation method to estimate their positions from three or more anchor nodes using hop count to measure shortest distance [14].

b) Hop Terrain

Hop terrain is similar to DV hop method in finding the distance between anchor node and unlocalized node. There are two parts in the method. In the first part, unlocalized node estimates its position from anchor node by using average hop distance formula which is distance between two nodes/total number of hops. This is initial position estimation. After initial position estimation, the second part executes, in which initial estimated position is broadcast to neighbor nodes. Neighbor nodes receive this information with distance information. A node refines its position until final position is met by using least square method [13].

c) Centroid System

Centroid system uses proximity-based grained localization algorithm that uses multiple anchor nodes, which broadcast their locations with coordinates. After receiving information, unlocalized nodes estimate their positions [12]. Anchor nodes are randomly deployed in the network area, and they localize themselves through GPS receiver [6]. Node localizes itself after receiving anchor node beacon signals using the following formula [13]:where and are the estimated locations of unlocalized node.

d) APIT

In APIT (approximate point in triangulation) scheme, anchor nodes get location information from GPS or transmitters. Unlocalized node gets location information from overlapping triangles. The area is divided into overlapping triangles [13]. In APIT, the following four steps are included.(i)Unlocalized nodes maintain table after receiving beacon messages from anchor nodes. The table contains information of anchor ID, location, and signal strength [13].(ii)Unlocalized nodes select any three anchor nodes from area and check whether they are in triangle form. This test is called PIT (point in triangulation) test.(iii)PIT test continue until accuracy of unlocalized node location is found by combination of any three anchor nodes.(iv)At the end, center of gravity (COG) is calculated, which is intersection of all triangles where an unlocalized node is placed to find its estimated position [13].

e) Gradient Algorithm

In gradient algorithm, multilateration is used by unlocalized node to get its location. Gradient starts by anchor nodes and helps unlocalized nodes to estimate their positions from three anchor nodes by using multilateration [6]. It also uses hop count value which is initially set to 0 and incremented when it propagates to other neighboring nodes [6]. Every sensor node takes information of the shortest path from anchor nodes. Gradient algorithm follows fes steps such as the following:(i)In the first step, anchor node broadcasts beacon message containing its coordinate and hop count value.(ii)In the second step, unlocalized node calculates shortest path between itself and the anchor node from which it receives beacon signals [14]. To calculate estimated distance between anchor node and unlocalized node, the following mathematical equation is used [14]: where is the estimated distance covered by one hop.(iii)In the third step, error equation is used to get minimum error in which node calculates its coordinate by using multilateration [6] as follows: where is the estimated distance computed through gradient propagation.

2) Range-Based Localization

Range-based schemes are distance-estimation- and angle-estimation-based techniques. Important techniques used in range-based localization are received signal strength indication (RSSI), angle of arrival (AOA), time difference of arrival (TDOA), and time of arrival (TOA) [11-14].

a) Received Signal Strength Indication (RSSI)

In RSSI, distance between transmitter and receiver is estimated by measuring signal strength at the receiver [7]. Propagation loss is also calculated, and it is converted into distance estimation. As the distance between transmitter and receiver is increased, power of signal strength is decreased. This is measured by RSSI using the following equation [6]:where = transmitted power, = transmitter antenna gain, = receiver antenna gain, and = wavelength of the transmitter signal in meters.

b) Angle of Arrival (AOA)

Unlocalized node location can be estimated using angle of two anchors signals. These are the angles at which the anchors signals are received by the unlocalized nodes [13]. Unlocalized nodes use triangulation method to estimate their locations [6].

c) Time Difference of Arrival (TDOA)

In this technique, the time difference of arrival radio and ultrasound signal is used. Each node is equipped with microphone and speaker [35]. Anchor node sends signals and waits for some fixed amount of time which is , then it generates “chirps” with the help of speaker. These signals are received by unlocalized node at time. When unlocalized node receives anchor’s radio signals, it turns on microphone. When microphone detects chirps sent by anchor node, unlocalized node saves the time [14].

d) Time of Arrival (TOA)

In TOA, speed of wavelength and time of radio signals travelling between anchor node and unlocalized node is measured to estimate the location of unlocalized node [6]. GPS uses TOA, and it is a highly accurate technique; however, it requires high processing capability.

GPS-based localization mechanisms are less energy efficient while RSSI-based mechanisms are highly energy efficient.

IV. CONCLUSION

In this paper, different localization techniques are discussed in detail. Localization is a mechanism in which nodes are located. There are many approaches for localization; such approaches are desirable which are capable to take care of limited resources of sensor nodes.

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