A Review on Localization in Wireless Sensor Networks

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Abstract. Localization is extensively used in Wireless Sensor Networks (WSNs) to identify the current location of the sensor nodes. A WSN consist of thousands of nodes that make the installation of GPS on each sensor node expensive and moreover GPS will not provide exact localization results in an indoor environment. Manually configuring location reference on each sensor node is also not possible in the case of dense network. This gives rise to a problem where the sensor nodes must identify its current location without using any special hardware like GPS and without the help of manual configuration. Localization techniques makes the deployment of WSNs economical. Most of the localization techniques are carried out with the help of anchor node or beacon node, which knows its present location. Based on the location information provided by the anchor node or beacon node, other nodes localize themselves. In this paper we present a succinct survey on the localization techniques used in wireless sensor networks covering its problems and research gap.

1 Introduction

Wireless sensor devices have a wide range of application in surveillance and monitoring. Most of the devices or nodes in wireless sensor network are made up of off-the-shelf materials and deployed in the area of surveillance and monitoring. The responsibility of each sensor node is to identify the changes in its particular region or area. The changes are like movement of animals, increase or decrease in temperature or rainfall and these changes are periodically reported to the aggregation point or the central server. The central server or the

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aggregation server identifies the area with the help of the location reference sent by the sensor node.

Initially during deployment each sensor nodes are given their location reference. This is done either manually or the sensor nodes automatically calculate the distance with the help of GPS devices attached to it. Installing a GPS device or manually calculating the location may not be possible in the context of large network because of the excessive cost and workforce involved, respectively. To overcome this sensor nodes are made to identify their locations with the help of neighbouring nodes. This paper focuses on the localization techniques used by the sensor nodes to identify their location. Several researches are going on in the field of localization to identify the exact location.

The location of the nodes plays a significant role in many areas like routing, surveillance and monitoring, and military. The sensor nodes must know their location reference in order to carry-out Location-based routing (LR) [1 - 4]. So as to find out the shortest route, the Location Aided Routing (LAR) protocol [5 - 7] makes use of the locality reference of the sensor nodes. In some industries the sensor nodes are used to identify minute changes like pressure, temperature and gas leak, and in military, robots are used to detect landmines, where in both the cases location information plays a key part.

Organization of the paper - Section 2 and 3 covers the concepts and problems in localization. Section 4 covers the localization techniques. Section 5 and 6 presents the performance, discussion and future events. Section 7 concludes the paper.

2 Concepts and Properties of Localization

In most of the localization techniques, localization is carried out with the help of neighbouring nodes. Initially few nodes are made available with their location reference either by manual configuration or using GPS devices. Several localization techniques are discussed in this paper. Fig. 1 illustrates the different techniques or methods used to identify the location of the nodes.

The localization can be classified as known location based localization, proximity based localization, angle based localization, range and distance based localization. In fig. 1 the range and distance based localization are categorized separately, though both are same. For range based localization, special hardware is required to find out the range, however it is not required for distance based localization.

2.1 Known Location Based Localization

In this type of localization the sensor nodes know their location in prior. This is done either by manually configuring or using a GPS [8 - 12] device. Manual configuration of the sensor node is done with the help of GPS. The GPS device can be effective where there are no reference nodes available to

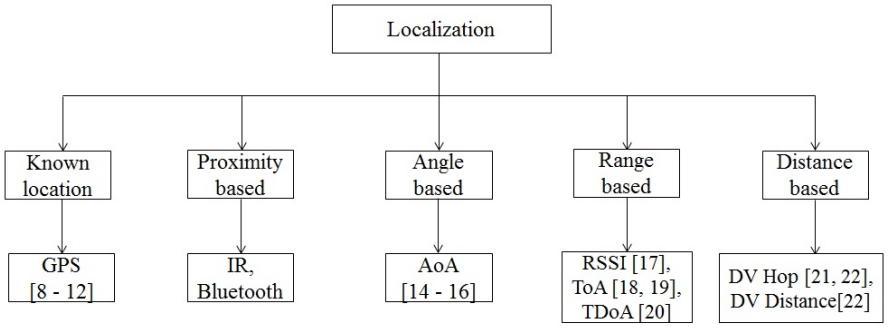

Fig. 1 Overview of localization

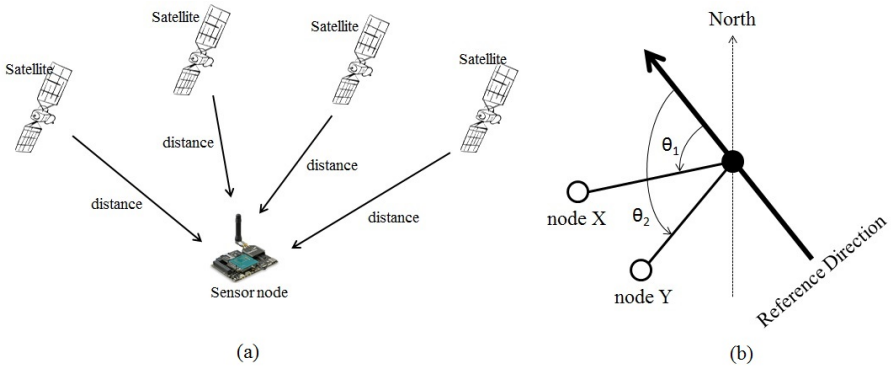

Fig. 2 (a) Working of GPS receiver installed in a sensor node. (b) Localization using triangulation with orientation information.

get localized. The location of the sensor node is calculated with the help of GPS satellites. A minimum of four satellites are required to calculate the location of the GPS receiver. Fig. 2a shows the working of GPS receiver.

The distance between the GPS receiver and the GPS satellites are calculated using the time taken for the signal to reach the device. Once the distances are known, the GPS receiver uses triangulation [24] or trilateration [29] technique to determine its location. It has a good accuracy with a standard deviation of 4 to 10 meters.

2.2 Proximity Based Localization

In this type of localization the wireless sensor network is divided into several clusters. Each cluster has a cluster head which is equipped with a GPS device. Using Infrared (IR) or Bluetooth, the nodes find out the nearness or proximity location. When comparing proximity based localization with range

based localization, proximity based localization does not suffer fading [30]. Proximity based localization will not be applicable when the power threshold drops below a threshold value i.e., the range or power (signal strength) of the central node. Consider two nodes X and Y with a power threshold P_1, then the localization eligibility is calculated as follows: [30]

$$Q_{x,y} = \begin{cases} 1, P_{x,y} \geq P_1 \\ 0, P_{x,y} < P_1 \end{cases}$$

where,
$P_{x,y}$ is the measured received power at node X transmitted by node Y.

2.3 Angle Based Localization

Angle based localization uses the received signals angle or Angle of Arrival (AoA) [14 - 16] to identify the distance. Angle of Arrival can be defined as angle between the received signal of an incident wave and some reference direction [14]. The reference direction is called orientation, which is a fixed direction and against that the measurement of AoA is carried out. Placing antenna array on each sensor node is the most common approach. Using antenna array with orientation can be used to identify the angular sector of the signal. Once the AoA is determined, triangulation [24] is used to identify the location co-ordinates. Fig. 2b shows the localization using triangulation with orientation information.

2.4 Range Based Localization

This localization is carried out based on the range. The range is calculated using the Received Signal Strength Indicator (RSSI) [17] or Time of Arrival (ToA) [18, 19] or Time Difference of Arrival (TDoA) [20]. In RSSI based localization the receiver sends the signal strength with reference to the sender, and sender calculates the distance based on the signal strength. ToA and TDoA use timing to calculate the range. Time synchronization is an important factor when using ToA and TDoA.

2.5 Distance Based Localization

Distance based localization technique uses hop distance between the sender and receiver node to identify the location reference. It uses DV-hop propagation method [21, 22] or DV-distance [22] propagation method for localization.

3 Problems in Localization Techniques

There are few limitations encountered during localization. The problems are listed as follows,

3.1 Known Location Based Localization

The cost of a GPS device is around $500 - $1000, and installing a GPS for all the nodes is a dense network is not recommended. There are some situations where the GPS fail to find out the exact location reference such as in an underground, underwater or indoor environment. A small amount of accuracy can be reduced due to multipath propagation. Satellite availability also plays a key role in location estimation.

3.2 Proximity Based Localization

In this type of localization the nodes estimate the proximity location with the assistance of a central node. Larger the range of central node smaller is the accuracy. Localization is not achievable when the central server is down. This technique is an economical one with less accuracy.

3.3 Angle Based Localization

Special antennas are required for Angle based localization. The node that wants to localize does it with the help of three or more nodes, which have the special antenna installed in them. The angle measurement error can vary from 1° to 25° as an effect of noise. As angle based localization technique requires special antenna's that are expensive, AoA is generally used in Base Station's (BS) or cell phone tower's.

3.4 Range Based localization

Link reliability and noise interference plays a significant role in reducing the accuracy of range measurements. Other factors like multipath fading and environmental changes also decrease the accuracy in range measurement.

3.5 Distance Based Localization

In this type of localization the accuracy can be improved only if the network is dense. For a sparse network the localization accuracy is reduced considerably.

4 Localization Techniques

The localization techniques can be grouped into two types namely range based and range free approach. Fig. 3 shows the localization techniques grouped into different types.

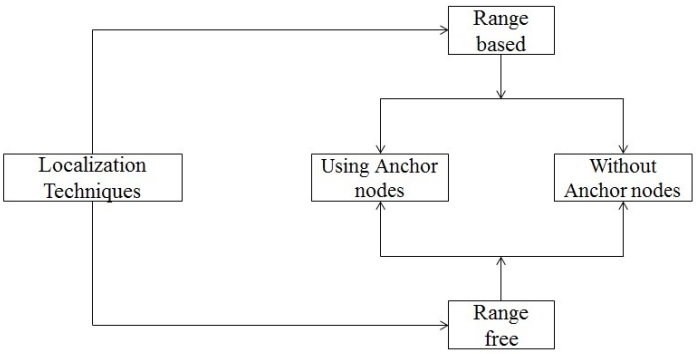

Fig. 3 Categorizing localization techniques

4.1 Range Based Approach

This method uses the range information to calculate the distance between each node. The localization can be carried out with or without the anchor nodes.

4.1.1 Using Anchor Nodes

During the deployment of wireless sensor network, few sensor nodes are made configured with their location reference either manually or using GPS. These nodes act as the anchor nodes. Other nodes localize themselves with the support of anchor nodes.

Localization is carried out using the range or angle based techniques discussed in the previous section. Each sensor node must be equipped with special hardware to achieve localization. In RSSI based distance measurement, the distance is calculated with respect to the sender's signal strength. A node can calculate the distance using the signal strength measurement received from the sender. The signal strength gradually decreases as the node moves away. Fig. 4a shows the typical signal strength or coverage area of a node.

Next type of localization technique that uses range to identify the distance is ToA based localization. The nodes that use ToA for localization must be time synchronized. The transmitted and received time are used by the sender to calculate the distance. Fig. 5a shows the working of range estimation using

ToA. The distance between the sender and receiver are calculated as follows: [19]

$$d_{xy} = \frac{1}{2}\left[(T^x_{recv} - T^x_{trans}) - (T^y_{trans} - T^y_{recv})\right]$$

where,
d_{xy} is the distance between node X and node Y,
T^x_{recv} is the received power of node X,
T^x_{trans} is the transmitted power of node X,
T^y_{recv} is the received power of node Y,
T^y_{trans} is the transmitted power of node Y.

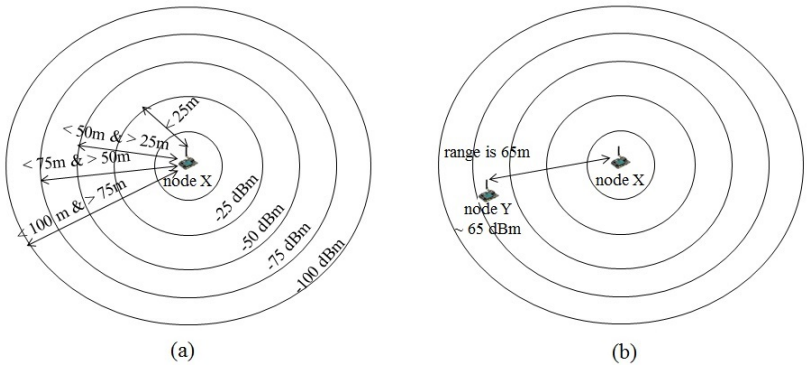

Fig. 4 (a) Typical signal strength or coverage area of a node. (b) Range estimation using RSSI.

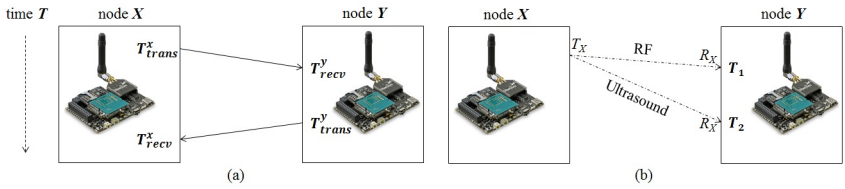

Fig. 5 (a) Range estimation using ToA. (b) Range estimation using TDoA.

Once the distances are discovered, multilateration or trilateration [29] technique is implemented to find out the location reference of the node. RF signal travel at the speed of light, this make the RF propagation to get varied in indoor environments and gives rise to a high localization overhead. In order to overcome the RF propagation in indoor environment, in [13], a combination of RF signals with Ultrasound was proposed. The speed of Ultrasound is less when compared to the speed of light. Based on the TDoA of the two signals, the distance is calculated. Fig. 5b shows the working of range estimation using TDoA. Another method for locating a node using TDoA is

done by observing the time for a signal to reach two or more receivers. It is made sure that all the receiver nodes are time synchronized. The TDoA is calculated as follows: [23]

$$\tau = \frac{(r_2 - r_1)}{c}$$

where,
τ is the TDoA,
$r_1 \& r_2$ are the range from the transmitter to the two receivers,
c is the speed of propagation.

4.1.2 Without Using Anchor Nodes

A device that has GPS attached need not require a support from anchor nodes for localization. Triangulation [24] technique is used in GPS to identify the location of the node. The assistance of satellites are required for finding out the location of the sensor node that has a GPS device installed.

4.2 Range Free Approach

There are few localization techniques that do not require special hardware for localization, they compute their distance using on DV hop or DV distance. The range free approach can be broadly classified into two types as follows:

4.2.1 Using Anchor Nodes

Techniques, namely Probability Grid [21] and Kcdlocation [24] works on DV based distance localization. In these techniques few nodes act as anchor nodes, which in turn are used by other nodes for localizing themselves. Ad Hoc Positioning System (APS) [22] can be used as an extension for GPS and its uses hop by hop positioning algorithm. In APS few nodes act as the anchor nodes, based on which other nodes localize using hop by hop positioning technique. Fig. 6 shows the DV hop localization technique. The average distance for one hop is the distance between the anchor nodes over the total number of hops between the anchor nodes. The equation to compute average distance for one hop is as follows: [22]

$$H_d = \frac{\sum \sqrt{(A_i - A_j)^2 + (B_i - B_j)^2}}{\sum h}$$

where,
H_d is average distance for one hop,
$\sum h$ is the total number of hops,
$(A_i, B_i) \& (A_j, B_j)$ are the location co-ordinates of the anchor nodes.

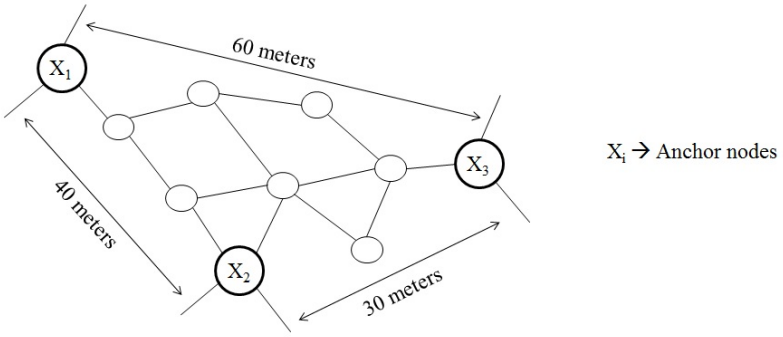

Fig. 6 Hop by hop localization technique

4.2.2 Without Using Anchor Nodes

Convex Position Estimation technique [28] works without an anchor node. The network is modelled by a central sever giving equations for relating the distance between the nodes. It uses a good optimization technique to find out the location of the nodes based on the equations.

5 Performance of Localization Schemes

Table 1 shows the performance comparison of different localization schemes. Each localization techniques serve different purposes. More the number of anchor nodes, less the localization error. In a closed environment with more obstructions, the localization error tends to increase. This can be controlled by making the network dense.

Table 1 Comparison of localization techniques

Localization Techniques used	**Accuracy (in meters)**	**Limitations**
GPS	2 to 15	Indoor localization is not possible in many cases
Proximity based	1 to 30	Depends on the range of the signal used
Angle based approach	1 to 8	Require special antenna
Range based approach	4 to 10	Require special hardware and time synchronization
DV based approach	10 to 20	Accuracy can be improved in a dense network

6 Discussion and Future Events

The localization techniques discussed identifies the distance between two nodes. Only the distance between the anchor node (or the node that knows its location) and the requesting node (node that needs to find out its location) is obtained with the help of range and distance based localization techniques. So, the same method is carried out by the requesting node with three or more different anchor nodes. Once obtaining three different range's i.e., from three different anchor nodes, trilateration or triangulation or multilateration technique [24, 29] can be used to identify the location reference or location coordinate. Among these three techniques, trilateration [29] is generally preferred. In the present scenario there is a trade-off between localization accuracy and algorithm runtime. The localization techniques discussed here are based in the consideration of a static network. Monitoring and surveillance has become painless because of wireless sensor network.

Several researches are being carried out in the field of localization. Few future events still remain unaddressed in the 3-D localization, security, mobility and energy conservation. 2-D scenario is generally used for localization and there will be a requirement for new localization techniques for 3-D scenario. As most of the localization techniques require the help of neighbouring nodes to identify their localization, there must be a surety that the neighbouring nodes are valid. Localization fails in presence of a mole in the network. Several security measures are required to secure the network as well as the sensor node from attacks. Localization can be easily carried out for fixed nodes. There exist a dire fall in localization accuracy, for mobile sensor nodes. Designing an energy efficient localization technique is an essential consideration for wireless sensor network.

7 Conclusion

There is a considerable rise in the use of wireless sensor network because of their cost and size. The localization techniques discussed in this paper, help in reducing the deployment cost of dense wireless sensor networks. Several techniques with abridged hardware which can identify their current location has been discussed in this paper along with their key features and drawbacks. Since a wireless sensor nodes are provided with limited resources there is a need in designing an intelligent power aware and secure localization approach in both 2D and 3D scenario.

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