NODE LOCALIZATION IN WIRELESS SENSOR NETWORKS - AN OVERVIEW

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Abstract- When we talk about the improvement in the wireless communication technologies, we come across the topic of wireless sensor networks (WSN). Sensor nodes have evolved from just giving out information, to processing information and communicating with the different nodes of a network. The bulky structure of the node is reduced to a miniature one, also their resistance to various environmental conditions. Basically, the sensor nodes are designed to sense the physical phenomenon, process the data and transmit to the base station. Earlier the location of the sensor was known and hence there was an ease of operation. For various applications, the locations of nodes are not predetermined and are deployed randomly. Thus, their exact locations must be known. Localization information represents the geographic coordinates of the physical location of the node. In other words, we determine the position of nodes for communication and detection.

Keywords- Wireless Sensor Networks, Sensor Nodes, Node Deployment, Localization.

I. INTRODUCTION

Recent years have witnessed an increased interest in the use of wireless sensor networks (WSNs) in numerous applications such as forest monitoring, disaster management, border protection, and battlefield surveillance. In these applications, miniaturized sensor nodes are deployed to operate in unattended environments. In addition to the ability to probe its surroundings, each sensor has an onboard radio to be used for sending the collected data to a base-station. To react to the information sent by the node, we must know its location. Hence localization comes in to the picture.

The location can also be determined with help of GPS, the power consumption of each node which uses the GPS facility also increases and there is a probability of less accurate results as the GPS module may not work in various typical environmental conditions and has many other disadvantages. Hence localization removes the excessive usage of GPS mechanism by using various techniques and algorithms, which helps the nodes to determine their location. The determination of location requires an reference i.e. an exact location of node must be known, so that the other nodes deployed randomly will trace their locations accordingly. Such nodes are mounted with an GPS receivers and are called as beacon or anchor nodes. In this paper we elucidate the localization process, concepts, technologies used. We briefly describe the classification of localization algorithms based on some important factors.
II. LOCALIZATION PRELIMINARY

The localization system can be divided into three main steps. Each step has its own importance and purpose. These steps are:

a. **Position computation**: This step allows the nodes to calculate their positions. Here we use various concepts or technologies such as received signal strength (RSSI), time of arrival (TOA), time difference of arrival (TDOA) and angle of arrival (AOA). Also we need to know the locations of the reference nodes i.e. the location of anchor or beacon nodes.

b. **Localization algorithms**: This is the main part where the information calculated, based on the position computation techniques is processed and the nodes establish their own locations accordingly. There are various algorithms classified on the basis of nodal communication, position of beacon nodes, environment, etc.

c. **Refinement**: At this step the location data is intensified for more accuracy.

III. LOCALIZATION METHODS

Earlier the locations were roughly known by the usage of these techniques. Most of these techniques are still followed. This section briefly explains them.

a. **Received Signal Strength**: This technique was introduced to find the distance between two nodes. The signal transmitted by one node is received by other node placed at some random distance away from it. Based on the received signal strength the theoretical calculations and the practical ones are compared and the most accurate result is obtained. The received signal strength is physically represented by the received signal strength indicator (RSSI). The power of the received signal is directly proportional to the distance the signal has travelled and its transmitted power. Considering the distance between two nodes is d, the received signal strength is given by $1/d^n$, where $n$ is the exponent of signal attenuation ranging from 1 to 6 [1]. This technique does not require any additional equipment as the sensors use radio frequencies. However, the signal transmitted are affected by factors such as path loss [2] etc.

b. **Time of Arrival (ToA)**: This technique uses the concept of time of arrival of a signal [3]. We know that distance is directly proportional to time, in the same way the time taken for the signal to arrive at the receiver node, gives the distance between the transmitter and the receiver nodes. Also the speed of the signal is to be considered. if a signal was sent at time $t1$ and reached the receiver node at time $t2$, the distance between sender and receiver is $d = s(t2 – t1)$, where $s$ is the propagation speed of the radio signal. There must be synchronization between the transmitter and receiver, so as to determine the exact time duration between the transmission and reception. This requires a proper communication between the local clocks of nodes. So as to increase the accuracy, additional equipment required will increase the cost of this technique, also the network complexity increases.

![Figure 2. Time of Arrival](image-url)
c. **Time Difference of Arrival (TDoA):** Time difference between the receiving of two signals at a node is easier to measure compared to time of arrival of a signal. This time difference information can then be used to estimate the distance between the two nodes. We consider two cases:

1. The difference in the times at which a single signal from a single node arrives at three or more nodes.
2. The difference in the times at which multiple signals from a single node arrive at another node.

![Figure 3. Time Difference of Arrival](image)

Advantage of using time difference instead of time of arrival is that errors in time difference measurement are tolerable and do not have a pronounced effect on the accuracy of estimation of distance between two nodes. As a result, the hardware required for time measurements is less complex and less costly and hence the method is also efficient in terms of energy consumption.

d. **Angle of Arrival (AoA):** The estimation of the AoA is done by using directive antennas or an array of receivers usually three or more that are uniformly separated [4]. When using directional antennas, these can be mounted on the beacon nodes. To serve multiple nodes, a directional antenna mounted on a beacon node rotates about its axis thereby transmitting beacon signals in all directions. A normal node may use a similar directional antenna configuration to receive the beacon signals. Based on the arrival times of the signal at each of the receivers, it becomes possible to estimate the AoA of this signal. Practical use of this technique is limited due to the complexities of deployment of special antennas. For example, mounting rotating directional antennas on tiny nodes is problematic and the rotating components are more prone to failure. Hence it is not frequently used.

![Figure 4. Angle of Arrival](image)

**IV. POSITION COMPUTATION TECHNIQUES**

Based on the localization technologies and concepts above few techniques were formulated to find out the location of a normal node deployed randomly. These techniques are improvised so as to get the accurate location of the node, with respect to the nearby beacon nodes. Below are some of the most frequently used ones.
a. Triangulation: In triangulation information about angles is used instead of distances. Position computation can be done remotely or by the node itself; the latter is more common in WSNs. In this last case at least three reference nodes are required. The unknown node estimates its angle to each of the three reference nodes and, based on these angles and the positions of the reference nodes (which form a triangle), computes its own position. This technique is similar to trilateration. In fact, based on the AoAs, it is possible to derive the distances to reference nodes. This position is obtained using simple geometric relationships based on the laws of trigonometry of sines and cosines as follows:

\[
\begin{align*}
A^2 &= B^2 + C^2 - 2BC \cos \alpha \\
B^2 &= A^2 + C^2 - 2AC \cos \beta \\
C^2 &= A^2 + B^2 - 2AC \cos \gamma 
\end{align*}
\]  

(1)

![Figure 5. Triangulation](image)

Triangulation technique has great location accuracy, but it is very easily affected by the multipath reflection and environmental conditions.

b. Trilateration: When distance is used as a primary means to determine node location, this is termed as lateration, and when angle information is used for localization, it is known as angulation. For node localization in a plane, precise distance measurements from at least three beacon nodes are required and we use trilateration for position estimation of a node. This method allows each unlocalized node to compute its position from distance measurements of three anchor nodes that are not collinear. The position of the node is the intersection of circles of these three anchors. The distance is measured using the RSS, TOA or TDOA technologies. The distance measurements are really noisy; hence, they need more than three anchor nodes to get more accurate localization.

![Figure 6. Trilateration technique](image)
c. **Multilateration**: Multilateration is the improvised version of trilateration. In trilateration we use 3 beacon nodes and in multilateration the numbers of nodes are increased. The error between the estimated distance and the measured distance is minimized. The accuracy of this method depends on the number of beacon nodes involved in the localization process [5]. More the number of beacons, more is the accuracy.

![Multilateration Diagram](image1)

**Figure 7. Multilateration**

**d. Bounding Box**: Similar to the trilateration concept, we have seen that the technique uses circles as the ideal coverage area of a beacon node [6]. In the bounding box technique, we use squares to bound the possible positions of a node, thereby covering most of the area which is not provided by trilateration method. The position of a node is taken as the centroid of the intersection area of all bounding box of the beacons. The accuracy of this approach depends heavily on the accuracy of distance estimates; therefore, it is better when the nodes are closer to the anchors.

![Bounding Box Diagram](image2)

**Figure 8. Bounding Box**
e. Probabilistic Approaches: The uncertainty in the estimates of distance has motivated the development of probabilistic approaches to calculate the positions of nodes. In probabilistic approaches, the calculation of the position does not lead to a single point, as in other methods, but to a set of points with probabilities of being the true position for the unlocalised node. Most of the probabilistic methods have two major disadvantages. They are too expensive in computing power and require a large memory space to store information related to different possible positions of nodes.

V. LOCALIZATION ALGORITHMS

In this section we are listing out the various algorithms used to calculate or refine the accuracy of the locations of the nodes, with respect to the beacon nodes. Their classification is based on the factors such as, network architecture, mobility, range etc. Each classification and its algorithms are briefly explained.

a. Based on network architecture: Here, Localization algorithms are classified according to sensors, data measurement processing. There are two main categories, namely centralized and distributed. In centralized algorithms (MDS-MAP), all inter-node data are collected at a central point. This central point is a base station, which is responsible to produce a global localization map of the network. In distributed algorithms (MDS-MAP(P)) each node calculates independently its own position using the location information collected from its neighbors.

b. Based on range technology: This algorithm uses one of the localization technologies to estimate distances or angle to the nodes. We have range-based and range-free algorithms. Range-free approaches do not need the distance or angle information of sensors. They collect the information between nodes to obtain their estimated locations. Range-based schemes have highly accurate positioning as they require complex hardware to obtain angle and/or distance measurements. They can be implemented by measuring the RSS, TOA, TDOA and AOA of signal. Various algorithms were derived on the basis of range technology.

c. Based on the connectivity: The normal nodes placed randomly try to connect with the beacon nodes and with the help of the connectivity information, it establishes its own location. The connectivity is measured in terms of hop. A hop is the minimum distance required between two nodes for a proper connection to be made. There is single hop algorithm, where the normal node tries to connect with the anchor in a single hop, though there is a poor connection between them. In the multi-hop algorithm (DV hop), the node connects with two or normal nodes, forming a network which will help them in determining their coordinates.

d. Based on anchor nodes: We usually find out the location of a random node with respect to the nearby anchor, almost all the algorithms are derived from the fact that the reference location is provided by the anchor. The anchor themselves have a GPS module placed on them to find out the exact coordinates. Considering the fact that the GPS module on the anchor might fail, most of the researchers prefer algorithms which have less dependence on the anchor such algorithms are anchor-free and are less costly (APIT).

e. Based on mobility: Due to various applications we require nodes to be mobile. This makes the assessing of the location of a particular node very difficult. Thus the classifications of such algorithms are based on the mobility of normal node and anchors. Following are they:

i. Static sensors and static anchors.
ii. Static sensors and mobile anchors.
iii. Mobile sensors and static anchors.
iv. Mobile sensors and mobile anchors.
VI. REFINEMENT

There are various methodologies which can be used to refine or make the resultant location of normal nodes more accurate. Every algorithm used does not produce the approximate result, hence the refinement iterations takes place to minimize the error in them. Refinement includes the comparison with the theoretical measurements and grid scanning.

VII. CONCLUSION

The localization problem in Sensor Networks is still an active research area. There are significant contributions and ongoing research programs in this field. This paper is an overview of the technologies used and the techniques adopted. Further, we have stated the classification of algorithms; there are more algorithms which are improvised versions of the classified ones.

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