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Survey on Localization Techniques in Wireless Sensor Networks

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Abstract:
Wireless Sensor Network (WSN) is most prominently used in many applications because of their low cost, less weight, and real-time response. Sometimes, the sensor nodes may not be aware of their location. Thus, in order to know the position of the sensor nodes, localization techniques came into existence. Earlier, the location is calculated using GPS, but, it is not feasible to all the applications due to multiple reasons. This paper discusses various localization algorithms along with their advantages and disadvantages, based on the classification made. The localization techniques are classified into centralized and distributed, where distributed techniques are categorized as range-based approach and range-free approach.

Keywords:*Localization, Sensor nodes, Wireless sensor networks, Range based technique, Range free technique.*

I. INTRODUCTION

Wireless Sensor Networks are dominantly used in many applications from home to industries and from medical to military. Some of the extensive applications involve object tracking and monitoring, location monitoring, automated vehicles, and fire detection [1]. It is mostly used because of its low cost, high performance, low power consumption, and multifunctional abilities. Wireless Sensor Network primarily consists of a number of sensor nodes, which can be used to transmit or to receive the information through a wireless communication link. These sensor nodes are made up of a microcontroller for processing the data, sensors for various applications, memory elements, a transceiver for communication and a battery. It will collect the information by measuring the parameters like temperature, humidity, pressure, sound, vibration, light intensity, etc. and process the data for certain application. In order to receive the data, the sensor node must know its position from where the data have been transmitted in the network.

Localization is the process of determining the position and direction of orientation of the sensor nodes in a wireless sensor network. Localization of sensor nodes is done of by various methods. In general, GPS is used by sensor nodes to get the location. However, there are some drawbacks involved because of their high cost, complex hardware, and energy problems [2]. Moreover, it is practically unworked in indoor environments such as inside a room, in dense forest location, etc. as it is mainly dependent on satellites functionality [4].

The alternate solution for the GPS system to find the approximate location of a sensor node is obtained by the usage of beacon nodes coupled with some localization algorithms. Beacon nodes are also known as anchor nodes, which knows its position initially and act as reference nodes for the unknown sensor nodes. It may not use any localization algorithm to know its position; it is either provided with GPS or placed in known coordinate's position. Blind or Dumb nodes are those nodes which are not aware of their location [3]. These nodes know their position relative to the nearest beacon node. Therefore, localization is one of the most important aspects in Wireless Sensor Networks and the following section discusses the various localization algorithms and its classification.

January - February 2020
ISSN: 0193 - 4120 Page No. 2766 - 2772

II. CLASSIFICATION OF LOCALIZATION TECHNIQUES

The localization techniques are generally classified into two types: Centralized technique and Distributed technique. Distributed Technique is also known as the Decentralized scheme and it is again classified into Range based and Range Free based approaches.

1. Centralized localization technique

A central processor is involved to calculate the sensor node position, which is termed a base station (BS) [8]. The transceiver sends the required data and parameters for calculation from the distant nodes to the base station. Then, BS performs calculation and all the nodes positions has been estimated, then acknowledgment and results are sent to all nodes. The advantage of this technique is to avoid the problems related to bandwidth and latency of sensor nodes. The major disadvantage is that a very huge communication overhead demands large amount of power for transmission. If in any case, the central unit fails to work, the entire process will be terminated.

2. Distributed localization technique

In this approach, there is no central processor or base station is involved. Nodes have the capability to perform local processing in order to estimate their position. Generally, the blind nodes get the data or required parameters from the neighboring nodes and also from the beacon nodes. Then, by adopting any localization algorithm based on the requirement, the unknown sensor nodes can determine their position. When compared to the centralized approach, there is less communication overhead. The localization technique in distributed approach is categorized into two types: 1. Range-based localization technique and 2. Range-free localization technique.

2.1) Range-Based Localization Techniques

Range based localization uses the relation between the beacon node and the dumb node. The relation may be the geometrical distance or the angle measured between the known and the unknown nodes respectively. It mainly involves two steps: Position estimation and Distance estimation.

Position Estimation

2.1.1) Trilateration

When the distance between the anchor node and the dumb node is used as a primary parameter, it is termed as lateration [18]. In two dimensional space, it is not possible to use only one anchor node, at least three anchor nodes are needed in order to estimate the position of the dumb node. Thus, trilateration is the process of determining the position of a sensor node by using three anchor nodes as reference. Three imaginary circles with known coordinates of the anchor node as a center are constructed, and the point of intersection of those three circles will provide the position of the required node [5].

The equation for first circle with center at (x_1, y_1), (is given by $d_1{}^2 = (x - x_1)^2 + (y - y_1)^2$

Similarly for second and third circles,

$d_2{}^2 = (x - x_2)^2 + (y - y_2)^2$ and $d_3{}^2 = (x - x_3)^2 + (y - y_3)^2$

By solving the above equations , the point of intersection is given by equation (1) as shown below:

$$\begin{bmatrix} 1 & -2x_1 & -2y_1 \\ 1 & -2x_2 & -2y_2 \\ 1 & -2x_3 & -2y_3 \end{bmatrix} \begin{bmatrix} x^2 + y^2 \\ x \\ y \end{bmatrix} = \begin{bmatrix} d_1{}^2 - x_1{}^2 - y_1{}^2 \\ d_2{}^2 - x_2{}^2 - y_2{}^2 \\ d_3{}^2 - x_3{}^2 - y_3{}^2 \end{bmatrix} \quad (1)$$

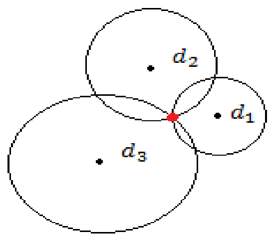

Fig 1: Trilateration

Treat the above equation as A. x = B form

In order to get the solution, solve the above equation using least square method as shown in equation (2).

Therefore, $\hat{x} = (A^T.A)^{-1}A^T.$ (2)

January - February 2020
ISSN: 0193 - 4120 Page No. 2766 - 2772

2.1.2) Multilateration

In a practical scenario, distance measurement using three circles may bring out more than one point as a result. [18] So, this can be reached out into a three-dimensional space by including the fourth anchor node, so that four spheres can be formed for the estimation of the position of unknown node. Thus, multilateration is the usage of more than three beacon nodes to calculate the position of the node.

2.1.3) Triangulation

When the measurement of the angle is used to calculate the position of the sensor node, it is known as angulation technique. Consider a triangle whose vertices are two known beacon nodes and one unknown dumb node. From those two known positions of the beacon node, the distance between them is calculated, which is one side of a triangle. The angle formed by the dumb node with the beacon nodes is calculated, and thus ultimately a dumb node information is found out with this information. This method is known as triangulation.

Distance estimation

2.1.4) RSSI (received signal strength indicator)

Received signal strength measurement is used to estimate the distance between the two sensor nodes based on the received signal strength. When the signal travels from the transmitter to receiver, it gets attenuated. The attenuation is high when the distance traveled by the signal is large and vice versa. Thus, the distance estimated from the RSS is a monotonically decreasing function. The distance can be estimated by considering the information from the transmitted and received power and path loss model (which is the difference between the transmitted and received powers respectively). [15] Therefore, the relation between distance and received power can be given by equation (3):

$$(d) = P_L(d_0) + 10\ \beta \log(\frac{d}{d_0}) + X_\sigma \qquad (3)$$

Where,

P_L(d) is given by path loss in specific distance, d (in decibels) and is given by

$$P_L(\text{d}) = \log(\frac{trasmitted\ \ power}{received\ \ power}).$$

P_L(d) is the path loss at a reference distance, d_0(practically $d_0$is about one meter).

β is the path loss exponent, which measures the rate at which the RSS decreases with increase in distance.

X_σ is a zero mean Gaussian random variable with standard deviation σ, it accounts for the random effect caused by shadowing.

Both β and X_σ are environmental dependent. Thus distance is measured by the above relation and localization algorithm is applied for this distance, position is estimated by following any position estimation techniques.

The advantage of this localization based on RSSI is no need for additional hardware circuitry as most of the sensor nodes have built-in circuitry, thus size and weight of sensor nodes is reduced. It also uses less power than other localization techniques [16].The fundamental assumption for this scheme is that the constant attenuation is suffered by signal for the same amount of distance travelled, which is not practical in actual scenario due to fading and shadowing. If there is no line of sight between beacon node and the dumb node i.e., any obstacles appear, the signal suffers more attenuation because of missing of line of sight between them, which is the main drawback for this localization scheme.

2.1.5) TOA (Time Of Arrival)

This technique is based on distance estimation which depends on the time taken by a signal that travels from anchor node to the blind node and also the propagation speed of the signal. It is also known as time of flight technique. The relation for finding the distance is given by equation (4):

$$d = s * t \qquad (4)$$

where, s is the signal speed, t is the total time taken in transmission and d denotes distancd between the known and unknown sensor nodes.

There are two types involved in this technique:

- One-Way Time Of Arrival:

In this approach, the difference between the broadcast time and acquired time of the beacon node

January - February 2020
ISSN: 0193 - 4120 Page No. 2766 - 2772

and dumb node is respectively used to estimate the position [11] It is also called as the passive time of arrival localization as the receiver node calculates its position without revealing the position information to the beacon node. In this case, the distance between the two nodes is given by equation (5):

$$d = s * (t_r - t_t) \quad (5)$$

where, t_r is the receiving time at dumb node and t_t is the transmitting time at beacon node.

In general, an ultrasonic pulse or an RF signal is used to estimate distance. However, the major limitation in this technique is that, it requires the synchronization between the transmitting time and receiving time. If there is any small difference involved in between the timings, it results in a large error in estimating distance and position. At the speed of light, a very small synchronization error of about 1 ns, results in an error of about 0.3m in distance estimation. Thus, to achieve synchronization, extra circuitry such as highly accurate clocks need to be added to the sensor nodes, which also increases the cost and weight to the sensor nodes.

- Two-Way Time Of Arrival:

In this approach, the transmitter gets the signal back from the receiver. Thus, distance is estimated based on the time taken for the two-way trip between the beacon and dumb nodes. [11] There is no need for synchronization, because same clock is used at the transmitting sensor node to measure the time difference.

Therefore, total round time by eliminating delay = $(t_{t2} - t_{t1}) - (t_{r2} - t_{r1})$

One-way time of arrival = $\frac{(t_{t2} - t_{t1}) - (t_{r2} - t_{r1})}{2}$

Hence, distance between two nodes is given by equation (6),

$$d = \frac{(t_{t2} - t_{t1}) - (t_{r2} - t_{r1})}{2} * s \quad (6)$$

Where, t_{t1} is the transmitting signal from beacon node, it reaches the receiver node at time t_{r1}. The dumb node broadcasts the signal back at a later point of time t_{r2} and it reaches the beacon node at time t_{t2}.

The error occurs in the case of delay required by the dumb node to handle the signal, process it and send back to beacon node.

2.1.6) TDOA (Time Difference Of Arrival)

Time difference of arrival of signal measurement is easier than the measurement of time of arrival of the signal. [11] The disparity between the TOA of transmitting at two separate receivers is measured in this method. The receivers must be in synchronization and their positions are known before the measurement. Minimum three receivers are needed to estimate the position of the transmitter. A pair of two receivers is taken; say R1 and R2, which defines the branch of hyperbola where a transmitter is located. Similarly, consider the other case by taking R2 and R3, which defines the second hyperbola. The position of the dumb node is given by the intersection point of the two hyperbolas The accuracy is sometimes affected by synchronization error and multipath effects, thus, it can be improved by increasing the distance between the transmitter and receiver, which results in an increase in the time of arrival differences.

2.1.7) AOA (Angle Of Arrival)

In this technique, the position of the sensor node is estimated based on the angle of arrival of the signal from the transmitting node [16]. The direction of the signal from the beacon node is calculated by taking the angle measurements with respect to a reference direction or some orientation. Minimum three beacon nodes are needed, where the time and angle of arrival of the signal are taken to estimate the position of an unknown node by using the triangulation technique.

The most common way is to arrange antenna arrays on the sensor node to get the angle of the arrival signal to measure. Since the arrays are arranged independently at known positions, the disparity between the TOA of the signal from various antennas is measured. The other way is to use directional antennas fixed on the sensor nodes which are used for both transmission and reception of signals. In order to serve multiple nodes, the directional antenna is rotated about its axis, to transmit or receive in all directions. High accuracy is achieved; however, complex hardware is needed. Furthermore, multipath fading, shadowing will affect accuracy.

2.2) Range Free Localization Techniques

Range-free localization does not use distance related parameters, instead, it uses the geometrical interpretation of beacon nodes in the proximity of dumb nodes. Thus, these techniques are also named as proximity or connectivity based localization approaches. This is less accurate when compared to range-based approach, but no additional hardware is needed for sensor nodes, thus, cost-effective and power saving localization is achieved. Range-free techniques are mainly classified into two types: Anchor based approach and Anchor free approach.

Anchor Based Approaches

This kind of techniques depending on the anchor node which includes centroid, APIT, DV-Hop, Multi-Hop and they are described below:

2.2.1) Centroid

In this technique [9], a number of anchor nodes are considered where the transmission range for these nodes creates a common area for transmission and reception of signals. In order to estimate the position of the unknown node, take the average as shown in equation (7) of all the anchor nodes in the nearest proximity.

Therefore,

$$(X_k, Y_k) = \left(\frac{\sum_{i=1}^{n} X_i}{n}, \frac{\sum_{i=1}^{n} Y_i}{n}\right) \qquad (7)$$

Where, n is the number of anchors with high proximity

X_k, Y_k is the location of the unknown node,

X_i, Y_i is the location of anchor nodes ($1 \leq i \leq$ n).s

2.2.2) APIT (Approximate Point In Triangle)

In this approach, all the anchor nodes are equipped with high power transmitters and their positions are known with the help of GPS or some other way. The entire grid is sectioned into triangular zones with anchor nodes. The sensor node location is estimated based on its vicinity inside and outside of the triangle. The nodes area is narrow downed with all possible sets of anchor nodes until it reaches the satisfactory accuracy. For any three given anchor nodes, the Point-In-Triangulation (PIT) test is performed to find out whether an unknown sensor node is inside that triangle or not. This PIT test is performed with all other anchor node sets until the sets are completed or the required accuracy is achieved. At last, center of gravity with all the required coordinates of the triangles is calculated and then the position is estimated.

2.2.3) Ad-Hoc Positioning System

This range free technique uses hop by hop distance estimation of anchor nodes. Minimum three or more anchor nodes are required to calculate the distance and later on the node performs multilateration to improve its location estimation. Each node propagates information to its neighbor node in the flood of network by sending the packet of information and counter value which is initialized. The shortest path for the sensor node and the anchor node has been recognized. There are three basic techniques involved to estimate the distance of the sensor nodes and they are given by DV-Hop propagation method, Euclidean Propagation method and DV-Distance method.

- Distance Vector hop method is a basic localization technique which works efficiently in isotropic networks. Every sensor node maintain their positions and the respective hop count values. The counter value in the message has been incremented each time when the hop gets transmitted by beacon node to its neighbors. The average size of the beacon node is calculated by using the equation as shown in (8), when the beacon node which is a known sensor node i has acquired positions and hop counts for all other beacon nodes j.

$$c_i = \frac{\sum \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}}{\sum h_i} \qquad (8)$$

January - February 2020
ISSN: 0193 - 4120 Page No. 2766 - 2772

Where, c_i is known as the correction factor. Thus by knowing the correction factor and beacon node positions, the unknown sensor node estimates its position multilateration. The main advantage lies in its simplicity and low amount of processing requirements and high affordability in terms of costs.

- DV-Distance propagation method works by the accumulating the estimated distance instead of hop count. In this method, distance is estimated using RSSI measurements rather than using average size of the hop counts.than using average size of the hop counts.
- A near-to-accurate distance can be obtained by Euclidean propagation method compared to other two DV methods. A dumb node can know its location by using the absolute Euclidean distance

Anchor Free Approaches

This kind of technique will not depend on the anchor nodes. A centralized technique called MDS-MAP forms the relative maps that represent the location of the sensor nodes in the closest sensor network [8]. It has the disadvantage to calculate the position of sensor node in denser networks.

III. CONCLUSION

Wireless sensor networks are considerably using in many applications because of their low cost and size. In this survey paper, the various localization techniques were analyzed and discussed. Each technique has its own advantages and disadvantages and the selection of the technique is based on the particular application. Many parameters like accuracy, power consumption, cost, bit error probability, etc. need to consider. Range based techniques involve more cost and are limited in certain conditions, whereas, range free techniques highly depends on node density and low accuracy. Accuracy is the key for any localization technique, thus, range based techniques are more appropriate to use, however, the equipment cost has to decrease.

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