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Review Article

A Review of Range Based Localization Techniques in Wireless Sensor Networks

Abha Tiwari[1], Manish Kumar[2]

[1]*Research Scholar, Department of Electronics and Communication Engineering, School of Engineering, Babu Banarasi Das University, Lucknow, Uttar Pradesh, India*
[2]*Professor, Department of Electronics and Communication Engineering, School of Engineering, Babu Banarasi Das University, Lucknow, Uttar Pradesh, India*

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Abstract *- With recent development in Wireless Sensor Networks ignited an important aspect in the location of the sensor. The location of the sensor inherently provides an accurate view of the sensor field. The tracking of certain objects in the monitoring and surveillance applications requires the location of an object to be incorporated with the tracking algorithms. To find out the position of a node, various localization algorithms are used. This requirement motivates the development of an efficient and effective Localization protocol for Wireless Sensor Networks. The paper presents an overview of various localization techniques used in Wireless Sensor Networks and presents a detailed comparison of various Range Based Localization methods, which will help in understanding and selecting the best range-based algorithm for Wireless Sensor Network Applications.*

Keywords - *WSN, Localization, Beacon nodes, RSSI, GPS.*

I. INTRODUCTION

In modern wireless communication systems, Real-time Localization and Position-Based Services is of utmost importance [1]. The Wireless Sensor Networks (WSNs) have a wide range of applications that require Real-time Localization like Target Tracking, Health Monitoring, Natural Resource Investigation, Early Flood Detection, Underwater Tracking, Military Applications, etc. The various applications are briefly explained in [13]. Localization is one of the key techniques for finding the location of the wireless node in WSNs. Here the location of the node is required to cover, detect and track its position. Hence, Localization is one of the most important research areas. Hence location estimation is one of the prominent challenges for the researcher. A Wireless Sensor Network (WSN) consists of multiple sensor nodes (low-cost), and the process of determining the location of these unknown sensor nodes with the help of some reference nodes is termed as localization. These reference nodes are known as beacon nodes whose locations are known [2].

Localization methods can be broadly classified into two protocols, one as Range Based and the other as Range-Free Localization [7]. Range Based localization like RSSI, TOA, TDOA, and AOA [1], rely on range measurements for distributed location, whereas range-free localization techniques technique does not follow any specific ranging measurements techniques. They follow the connectivity information to calculate location. However, the available traditional method for localization is GPS. But due to high power consumption and high cost for implementation makes it unsuitable for WSNs [3]. Additionally, it is practically impossible to implement it in a shadowing environment as it requires line of sight communication.

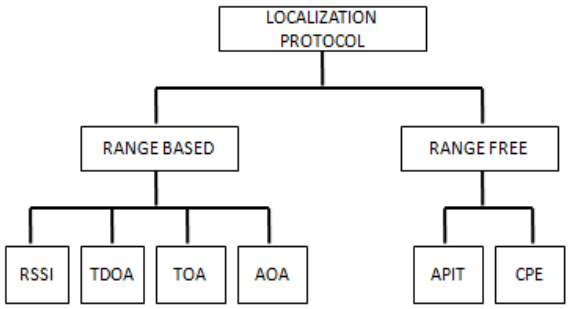


Fig. 1 Localization Classification

In this paper, we reviewed various range-based localization techniques. The reason for choosing range-based techniques over range-free techniques is that they provide more accurate location information of the unknown nodes. On the other hand, due to ranging measurements, it consumes more energy and hence is costlier to implement. The rest of the

paper is organized as Section II discusses various range-based localization techniques. The next Section III compares different range-based techniques, Section IV discusses the basic algorithms, and Section V concludes the paper.

II. REVIEW OF LOCALIZATION TECHNIQUES

In WSNs, the tracking of certain objects for monitoring and controlling applications requires location information of sensor nodes. The location of these unknown nodes can be gathered by distance estimation methods.

There are two types of localization techniques, i.e., Range Based and Range Free. Range-based methods require the presence of beacon nodes (nodes with exact location). With the help of information provided by these nodes, other nodes in the network estimate their location. Several ranging methods being described in this paper are Received Signal Strength Indicator (RSSI), Angle of Arrival (AoA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) [10]. The range-free methods do not require distance estimation, but beacon nodes are required. Some of the methods that provide the location of unknown nodes are Convex Position Estimation (CPE) and Approximate Point in Triangle (APIT) [15], which are based on distance measurement. Also, there are four categories in which Range free localization algorithm can be divided, i.e., connectivity localization algorithm, centroid localization algorithm, energy localization algorithm, and region overlap localization algorithm [12].

The high accuracy in range-based techniques makes it suitable for various localization techniques. However, the additional hardware requirements make it much expensive and difficult for large networks [5]. At the same time, range-free techniques use the hop count for distances between the unknown node and beacon nodes [8]. This does not require any additional hardware that makes it cost-effective. But the accuracy is compromising. The basic characteristics of range-based and range-free techniques are shown in Table I.

Table I Comparison between Range Based and Range Free Techniques

Parameters	Range based	Range free
Additional Hardware	Required	Not Required
Cost	Expensive	Less Expensive
Deployment	Hard	Easy
Accuracy	High	Low
Power loss	High	Minimum
Robustness	High	Low

A. Received Signal Strength Indicator RSSI

Received Signal Strength Indicator (RSSI) is the most common range-based technique that uses the Trilateration Algorithm as its basis to find the position of the target node [2]. It is considered that each node of the network is equipped with a radio to calculate the received signal strength. It does not require any additional hardware to perform localization and hence is cost-efficient. There are three parameters that are used to estimate the distance between transmitter and receiver. They are (i) Power of the received signal (ii) Multipath fading (iii) Path loss model.

The Trilateration algorithm uses the RSSI to estimate the position of an unknown node [15]. It uses three nodes with known locations. Each node has its own radio range for communication that is shown by a circle in figure 2. The intersection of these circles is the point whose location is to be determined with the help of distance measurement, i.e., the radius of these three circles. Due to ranging error, the perfect location of sensor nodes is not feasible. Therefore, to improve accuracy, additional nodes may require.

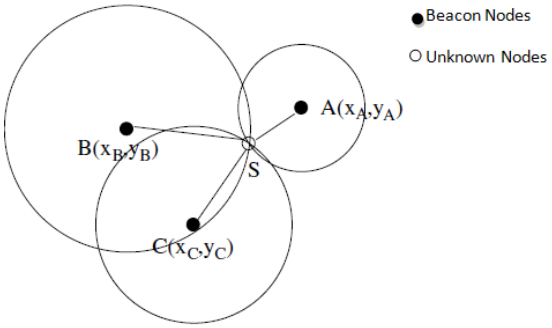


Fig. 2 RSSI Method using Trilateration

One of the major challenges with RSSI-based techniques is multipath fading [5][6]. If a sensor node is out of the line of sight of the beacon node, it will receive the signal through multiple reflections that will result in the inaccurate location of the sensor nodes. Another challenge with techniques is estimation errors in the parameters of the channel model, e.g., antenna gain may differ from node to node. So, to estimate this parameter, pre-deployment calibration is required.

Furthermore, there are several other algorithms for RSSI-based distance measurements [7]. They are (i) Maximum Likelihood (ii) Min-Max (iii) Multilateration (iv) Ring Overlapping based on Comparison of Received Signal Strength Indicator (ROCRSSI) [1]. A comparison between various RSSI-based algorithms by table II.

Table II RSSI Based Algorithm Comparison

ALGORITHM	ACCURACY	ERROR	COMPLEXITY
Min Max	Low	Low	Low
Multilateration	Medium	High	Medium
Maximum Likelihood	High	Low	High
ROCRSSI	Medium	Medium	High

B. Time of Arrival

Distance between the two can be calculated with the help of the velocity of the known signal and measured propagation time of the signal. Time of Arrival (ToA) techniques is based on the timing measurement of the two signals. The accuracy of the result needs synchronization between the signals. There are two types of measurement performed to calculate the distance: (i) One-way Time of Arrival (ii) Two-way Time of Arrival [2]. In the case of One-way Time of Arrival, the signal is propagated from transmitter to receiver so that the delay between the two nodes has been estimated. It requires high synchronization between sender and receiver. The distance between two nodes is calculated as

$$d_{ij} = (t_2 - t_1) * v$$

Here d_{ij} Represents the distance between node i and j. The $t_2 - t_1$ is time ellipse in transmission and reception of the signal, and v is signal propagation speed.

In two ways, in Time Arrival, the receiver transmits a ranging packet, which is immediately responded to by a neighbor node to calculate the round trip time between the two nodes. The distance is calculated as:

$$d_{ij} = \frac{(t_4 - t_3) + (t_2 - t_1)}{2} * v$$

Where d_{ij} represents the distance between transmission and reception of a signal in Two-way Time of Arrival and t_1, t_2, t_3 and t_4 represents the time of transmission and reception of the signal.

Figure 3 shows the transmission and reception signal timing diagram.

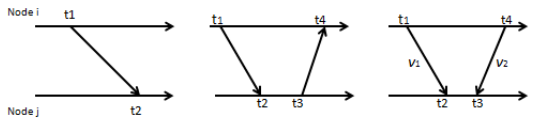


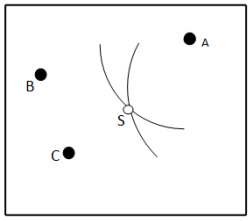
Fig. 3 Timing diagram of ToA technique

C. Time Difference of Arrival (TDoA)

In the Time Difference of Arrival (TDoA), the distance between the unknown node and the beacon node is measured with the help of the time difference between the receive times of two signals. This technique can be classified into two ways: (i) Multi-node TDoA (ii) Multi-signal TDoA.

Multi-node TDoA is based upon ToA measurement to calculate the arrival times of signals sent by beacon nodes. At least three beacon nodes are used to measure the time difference of arrival.

In Multi-signal TDoA, a beacon node sends two different kinds of signals with different velocities to estimate the distance between the beacon node and neighbor node. So, to calculate the accurate time difference of arrival of these signals, synchronization between beacon nodes is necessary. This is also shown in figure 4(b).



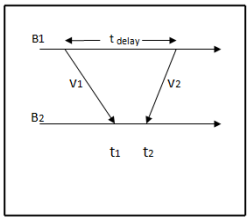


Fig. 4(a) Multi-node TDoA Fig. 4(b) Multi-Signal TDoA

The multi-signal TDoA provides accurate results with the line of sight conditions, whereas various propagation delays are provided in the case of non-line of sight communication [3]. But TDoA techniques require additional transmitter and receiver pairs in each node, resulting in an increase in the overall cost of the system. There are several algorithms that aim to achieve a high degree of accuracy, as shown in Table III.

Table III Comparison of Algorithms

ALGORITHM	COMPLEXITY	ACCURACY	% OF ERROR
Analytical Method (AM)	Low	Low	Low
Approximate Maximum Likelihood (AML)	High	High	Low
Taylor Series (TS)	High	High	Low
Two-stage Maximum Likelihood (TSML)	Medium	Medium	Medium
Genetic Algorithm (GA)	Low	High	Low

The door is applicable to applications where accuracy is not the major concern, and less accurate measurement results can be tolerated.

D. Angle of Arrival (AOA)

This is another technique to find the location of unknown nodes. Here the Angle of Arrival (AoA) of signals from the beacon node is estimated with the help of the directional antenna or special multiple antennae [14]. Here, the three

beacon nodes, A, B, C, send signals. Node S is an unknown node that receives these signals and calculates the angular distances from the beacon nodes. AoA measurements combined with their locations help in estimating the location of unknown node S. Figure 5 illustrates the process of the AoA Method.

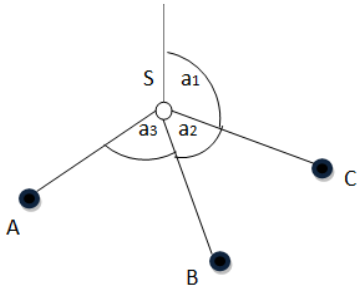


Fig. 5 AoA Measurement

The main advantage of AoA techniques is they provide high accuracy. Whereas, the disadvantage associated with them is that they require an array of antennae for directional measurements, which results in increased overall system cost.

III. COMPARISON OF RANGE-BASED TECHNIQUES

Table IV compares the Range Based localization methods for WSN and shows that the RSSI-based localization is based on the signal strength measurements for the location, which is affected by shadowing and multi-path reflection, and hence accuracy is affected does not require special hardware results, cost reduction.

Table IV Comparison between different Range-based Localization Techniques

TECHNIQUES	PRINCIPAL OF OPERATION	COST	SPECIAL HARDWARE	ACCURACY	ATTENUATION
RSSI	Signal Strength Measurement	Low	Not Required	Medium	High
TOA	Time of Arrival	Medium	Required	High	Low
TDOA	Time difference in propagation at different points	Medium	Required	High	Low
AOA	Angle of signal arrival	High	Required	High	Medium

In addition, ToA and TDoA techniques provide less attenuation and medium system cost, but both require additional hardware. The accuracy of ToA depends upon the accuracy of the hardware. TDoA provides more accurate results under Line-of-Sight conditions. However, non-line of sight communication provides high localization errors, just like in RSSI.

On the other hand, the AOA technique provides high accuracy [14]. Highly complex directional antenna arrays increase the overall cost. It also suffers from environmental conditions like multi-path, scattering, and non-line of sight conditions, and errors are severe than RSSI or TDoA based techniques.

IV. LOCALIZATION ALGORITHM

To find out the exact location of a node, various ranging measurements are performed between a given node and its neighboring nodes. Basically, there are three main algorithms to perform range-based localization. They are Trilateration, Triangulation, and Multilateration [9][10].

A. Trilateration

To determine the location of a node using distance measurement from its neighbors, the trilateration technique has been used. This technique is mostly applied in RSSI [5]. Here, at least three nodes with known locations are required to localize a node. As shown in the figure, each circle defines the range of the node with radius as distance measurement from the neighbor node. The exact location of the node is provided by the intersection point of three circles formed by the three nonlinear neighbors.

B. Triangulation

Triangulation is basically applied where angle information is needed. In the AoA technique, angle information given by two beacon nodes is used to localize the node [4]. A triangle is shown in Figure 6(b), which is formed by two beacon nodes and one unknown node. By using various basic trigonometry laws and angular measurements, the position of the unknown node is calculated.

C. Multilateration

Multilateration is a popular technique that uses time differences in the arrival of multiple signals to localize the exact location of an undetermined node. In the case of a noisy environment, trilateration does not provide accurate results. So here, we require more than three neighbor nodes to incorporate distance measurements. In this case, the difference between measured distance and estimated distance is minimized to localize the node [5].

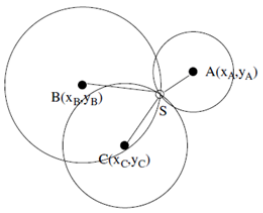


Fig. 6(a) Trilateration

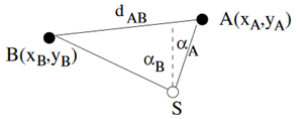


Fig.6 (b) Triangulation

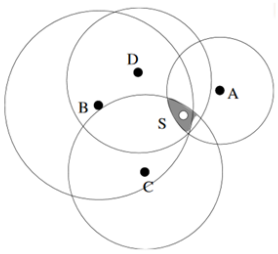


Fig. 6(c) Multilateration

V. CONCLUSION

WSN has become an important research area for research groups that are interested in the development and modification of localization protocols. This paper would be proven a helping hand for these research groups. As in this paper, we have provided an overview of Range-based localization techniques with their corresponding algorithms. A comparison has also been done which shows that none of them is best, but each one of them has its own advantages and disadvantages. On the whole, we can say that Range based techniques provide an accurate position of a node but require an expensive installation, whereas Range free techniques are cheaper in terms of installation, but they are imprecise. Regardless of this review work, some unsolved issues are still there on which future work could be implemented.

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