A Survey on Wireless Sensor Networks Localization Technology

Zhihao Zhang, Wenju Liu

***Abstract*— With the increasing demand for location services, low-cost, adaptable wireless sensor network localization has attracted more and more attention. Wireless sensor networks have been widely used in various fields, affecting people's daily lives in many aspects. In this article,firstly, the basic knowledge of wireless sensor networks localization technology is introduced. Then, the main positioning methods of wireless sensor networks are summarized and compared. Two positioning methods based on range-based methods and range-free methods are emphasized. Finally, the improved version of range-based positioning algorithms are classified and summarized.**

***Index Terms*—wireless sensor networks, range-based method, range-free method, coordinate calculation method**

I. INTRODUCTION

Since the beginning of the research on distributed sensor networks initiated by the US Department of Defense in the late 1990s, wireless sensor networks (WSN) have become one of the most important technologies for the future development of human beings [1]. In recent years, with the rapid development of embedded computer, communication and sensor technology, wireless sensor networks are gradually being widely used in many industries, such as data collection, personnel positioning, environmental monitoring, military reconnaissance, urban traffic management, agriculture, etc. [2]. With the increasing demand for positioning, the application of wireless sensor networks has penetrated into all areas of life. Location-based services have great application prospects. How to obtain accurate location information is generally considered to be crucial [3-5]. As an important supporting technology of WSN, positioning technology has attracted extensive attention from scholars and attracted many scholars to participate in the research in this field. Due to the low hardware configuration of the node, the limitations of energy, computing, storage and communication capabilities, it poses a major challenge to node location [6]. The accuracy of positioning has always been a major challenge for wireless sensor networks, and accurate location information is critical for location-related applications.

The early method to locate wireless sensor networks is to use GPS receiver for nodes to obtain the node position. However, because of factors such as cost, power consumption, and GPS deployment conditions, the feasibility of the solution is relatively poor. Therefore, it is generally possible to acquire the coordinates of the node itself by means of a small number of nodes carrying GPS or by pre-deploying in a specific location. In addition, domestic and foreign research has proposed positioning methods and systems based on radio frequency identification (RFID), Bluetooth, Wireless Local Area Networks (WLAN), WiFi and other technologies, some of which have been commercially available. However, due to the influence of complex and diverse environmental factors, different positioning technologies also have different shortcomings and limitations. The study of location problems in WSN involves many technical and theoretical issues [7]. Its node positioning performance is affected by many factors, such as positioning accuracy, anchor node density, network adaptability, power consumption and cost. How to balance the various relationships is very challenging for wireless sensor networks positioning [8]. The positioning performance of wireless sensor network nodes plays a decisive role in its application prospects. No matter it is in a static sensor network or a mobile sensor network, Location-based application services have a wide range of needs, and these services are based on location technology. Therefore, it is not only necessary to study the problem of node localization, but also has important practical significance and value [9].

In this paper, the basic concepts of wireless sensor network location technology are briefly summarized. Then, the principle of several main positioning methods is introduced and classified. Finally, the algorithm's optimization schemes for positioning accuracy and robustness in various application environments are summarized.

II. THE CONCEPT OF WSN POSITIONING

2.1 Related terminology

1) In the wireless sensor network positioning method, the sensor node is divided into anchor nodes (also called beacon nodes) and normal nodes (also called unknown nodes) according to whether the node knows its own position.

2) Neighbor nodes are other nodes within the communication range of the sensor node which can be reached by one hop.

3) Hop count is the number of nodes on the way where a node passes to another node. It can be called the hop count between two nodes.

4) Hop distance is the product of the hop count of the distance between two nodes and the distance per hop. It is called the hop distance between two nodes.

5) Infrastructure refers to a fixed device, such as a satellite or a base station, that assists the sensor node in locating and knowing its own location.

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2.2 Performance evaluation standard

The characteristics of WSN make the positioning algorithms generally evaluated from the following aspects, such as positioning accuracy, scale, anchor node density, common node density, fault tolerance and adaptability, power consumption, and cost.

1) Positioning accuracy. The primary evaluation index of positioning technology is positioning accuracy. It is divided into two categories: absolute precision and relative precision. The former is the deviation between the predicted coordinates and the actual coordinates. The latter usually refers to the ratio of the error value to the wireless range of the node.

2) Scale. Different positioning systems or algorithms can be positioned in a building, a floor or just a room. In addition, given a certain amount of infrastructure or time, how many targets a technology can locate is also an important indicator of evaluation.

3) Anchor node density. Anchor node positioning typically relies on manual deployment or implementation using GPS. The manual deployment method is not only limited by the network deployment environment, but also severely restricts the scalability of the network and applications. With GPS positioning, although the positioning accuracy is high, the cost will increase. In addition, the positioning accuracy increases with the increase of the density of the anchor node, and will not increase when it reaches a certain level [10].

4) Common node density. It usually refers to the average connectivity of WSN. Moreover, it also affects the accuracy of many positioning method.

5) Fault tolerance and adaptability. Both positioning systems and algorithms require an ideal wireless communication environment and reliable network node equipment. In practical applications, the situation is often complicated. Therefore, the positioning system and algorithm must have strong fault tolerance and adaptability, and can manage faults in wireless sensor networks [11] to reduce the impact of various errors.

6) Power consumption. Due to the energy limitation of the sensor nodes, the design and implementation of low-power algorithms are also one of the important factors affecting the positioning performance of wireless sensor networks under the premise of ensuring the positioning accuracy.

7) The cost. The cost of a positioning system or method can be evaluated in terms of different aspects of time cost, space cost, and capital cost.

The above performance standards are not only the criteria for evaluating the positioning system and algorithm of the wireless sensor network, but also the optimization goal of its design and implementation. These performance metrics are interrelated and must be weighed to suit the specific needs of the application to design the appropriate positioning technology [12].

III. MAIN POSITIONING METHOD

In the WSN positioning technique, the anchor node is pre-configured in the WSN and obtains its own coordinate position in a specific manner. Unknown nodes are randomly distributed in the nodes of the area to be monitored, and have the ability to transmit and receive signals. According to different classification criteria, the node location technology can be divided into different algorithm groups. For example, according to whether the anchor node is needed in the network, it can be divided into anchor node location and anchor node location. According to the calculation method, it can be divided into centralized positioning and distributed positioning. According to node connectivity and topology classification, it can be divided into single-hop algorithm and multi-hop algorithm. According to the distance measurement or not, it can be divided into ranging positioning and non-ranging positioning [2].

The algorithms based on range-based method and range-free method are widely used and the algorithm classification is clear. This paper mainly introduces the current main WSN positioning algorithm in this classification. In addition, most of the range-free algorithms are theoretical studies, and the positioning accuracy and practicability are not as good as those of the range-based algorithm. In this paper, we will focus on the range-based positioning method.

3.1 Range-based Localization Technology

The range-based method usually have two steps. Firstly, a certain measurement method is used to obtain the distance or angle between the nodes. Then, The obtained value is used to calculate the coordinates of the nodes.

3.1.1 Ranging model

1) Time of arrival (TOA) method. The propagation speed of the signal is known, and the distance between the nodes is calculated based on the propagation time of the signal. The TOA-based positioning method has higher accuracy, but it requires accurate time synchronization between nodes. Therefore, there is a high requirement for the hardware and power consumption of the sensor node. The most typical application is the GPS system. The distance measurement can be derived from equation (1).

$$d = (T_1 - T_0) * V \quad (1)$$

The earliest TOA distance estimation algorithm was measured using a symmetric two-way ranging protocol in a non-time-synchronous network [13]. Literature [14-15] summarizes the complexity and experimental results required for various TOA distance estimation methods for both line-of-sight and non-line-of-sight situations.

2) Time difference of arrival (TDOA) method. The anchor node simultaneously transmits two different signals, generally using radio frequency signals and ultrasonic signals. The time difference is converted into a distance based on the time difference between the two signals received and their speed. The measurement accuracy of TDOA is generally better than that of TOA, and it is used more in the positioning research of wireless sensor networks. It only requires the node to have the ability to sense at least two different signals, and the propagation distance of the ultrasonic signal is very limited. The Cricket indoor positioning system developed by MIT first adopted the TDOA ranging technology combining RF signal and ultrasonic signal. In the range of 2 m×2 m×2.5 m, the positioning accuracy of the system is below 10 cm, and now it has become Commercial products of Crossbow [16]. The distance measurement can be derived from equation (2).

$$d = [(T_3 - T_1) - (T_2 - T_0)] * \frac{V_{RF} * V_{US}}{V_{RF} - V_{US}} \quad (2)$$

3) Angle of arrival (AOA) method. AOA ranging technology requires an antenna array or a combination of multiple ultrasonic receivers, which requires additional hardware to meet the requirements. Moreover, AOA technology is susceptible to external environmental influences, such as noise and NLOS problems, which will have different effects on measurement results.

4) Received signal strength indicator (RSSI) method. The transmit power is known, and the received power is measured at the receiving node to calculate the propagation loss. A theoretical or empirical signal propagation model is used to convert propagation loss into distance. The RSSI values between the nodes are simulated using an empirical wireless signal propagation model, as shown in equation (3).

$$P_r = P(d_0) + 10n * \lg\left[\frac{d}{d_0}\right] + \xi \quad (3)$$

The early RSSI distance measurement method has the indoor positioning SpotON tags system designed by Hightower [17], and the RSSI method is used to estimate the distance between two points, and the mutual position between the nodes is used for positioning.

In general, the above several ranging methods have their own advantages and disadvantages. In the TOA and TDOA methods, the beacon node and the unknown node need to be consistently synchronized, and the AOA technology needs to add an additional antenna array. All three methods require additional device support, and the structure is complicated and the cost is high. In the RSSI method, the node itself has a wireless communication function, and has the advantages of simple signal measurement, no additional hardware conditions, simple structure, and low cost. However, its disadvantage is that it is susceptible to external environmental factors during wireless signal transmission, and its channel fading results in poor accuracy of RSSI signal measurements [18].

3.1.2 Coordinate calculation method

In wireless sensor network positioning, after obtaining the distance or angle between nodes by the above method, the coordinates of the unknown node are generally calculated by the following method.

1) Trilateration. It determines the node coordinates based on the distance from the nodes of the three known coordinates to the unknown nodes. It is known that the coordinates of the three nodes A, B, and C are (x_a, y_a), (x_b, y_b) and (x_c, y_c), respectively. Their distances to the unknown node $D(x, y)$ are d_a, d_b and d_c, respectively. The schematic diagram of the principle of trilateration is shown in Figure 1.The coordinates of unknown nodes can be calculated by formula (4).

$$\begin{cases} (x - x_a)^2 + (y - y_a)^2 = d_a{}^2 \\ (x - x_b)^2 + (y - y_b)^2 = d_b{}^2 \\ (x - x_c)^2 + (y - y_c)^2 = d_c{}^2 \end{cases} \quad (4)$$

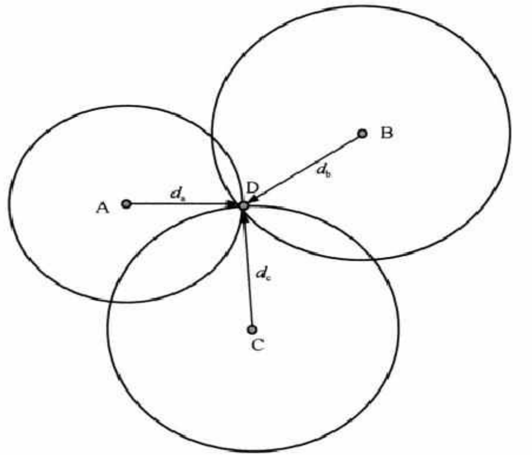

Fig 1. Schematic diagram of the trilateration method

2) Triangulation. The principle of triangulation is shown in Figure 2. This method is mainly used in the case of measuring the angle of arrival of the signal, and the position of the node can be obtained by the sine and cosine laws in the triangle. The sine theorem is shown in equation (5), and the cosine theorem is shown in equation (6).

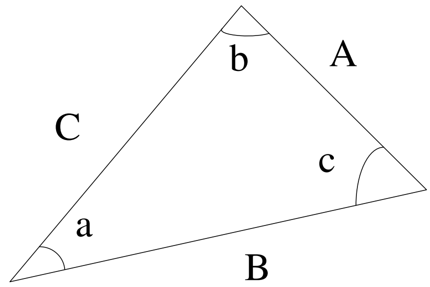

Fig 2. Schematic diagram of triangulation

$$\frac{A}{\sin a} = \frac{B}{\sin b} = \frac{C}{\sin c} \quad (5)$$

$$\begin{cases} A^2 = B^2 + C^2 - 2BC\cos a \\ B^2 = A^2 + C^2 - 2AC\cos b \\ C^2 = A^2 + B^2 - 2AB\cos c \end{cases} \quad (6)$$

3) Maximum Likelihood Estimation. The principle of this method is similar to the trilateration method, except that the coordinates and corresponding distances of more than three points are known, as shown in Figure 3. Suppose the coordinates of n beacon nodes are $(x_1, y_1), (x_2, y_2), \cdots (x_n, y_n)$.The corresponding distance are $d_1, d_2, \cdots, d_n$, The coordinates of the unknown node U are (x, y), Then the coordinate calculation method is as shown in equation (7).

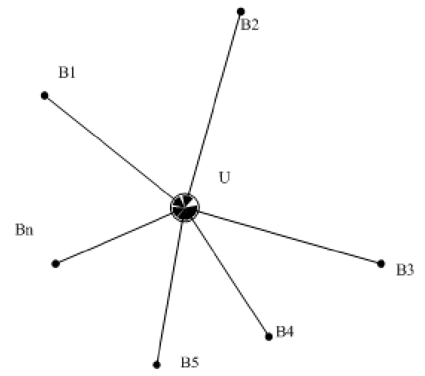

Fig 3. Schematic diagram of the principle of maximum likelihood estimation

$$(x - x_i)^2 + (y - y_i)^2 = d_i^2 \qquad (7)$$

3.2 Range-free Localization Technology

The difference between non-ranging positioning technology and ranging positioning technology is that it is not necessary to directly measure the distance between nodes, but to estimate the position coordinates of unknown nodes through information such as the connectivity of the network and the position of the anchor nodes. There are many non-ranging positioning technologies [19-26], among which centroid positioning, DV-Hop, and APIT positioning are widely used. The three classic non-ranging positioning technologies are introduced below.

1) Centroid positioning. This algorithm was proposed by Bulusu et al. at the University of Southern California [20]. The centroid algorithm is a positioning algorithm that only needs to rely on the connectivity of the network, without the need to additionally increase the cost of the wireless sensor network. When the anchor nodes in the network are evenly distributed and have high density, they have a good positioning effect. However, when the density of anchor nodes in the network is low and the anchor nodes in the network are unevenly distributed, the positioning error is very large.

2) DV-Hop algorithm. The algorithm is one of a series of distributed localization algorithms (collectively referred to as "APS" algorithms) proposed by Niculescu et al. [21] according to the principle of distance vector routing. In addition to the DV-Hop algorithm, the APS algorithm also includes DV-distance, Euclidean, and DV-coordinate. The core idea of the DV-Hop algorithm is that the unknown node “measures” the minimum hop count between the node and the guide node through the routing method, and calculates the average distance per hop, which is the product of the minimum hop count and the average hop distance. Estimation of the distance between the unknown node and the guide node.

3) APIT algorithm. The idea of the APIT algorithm is a triangle cover approximation, in which the unknown nodes are in overlapping portions of multiple triangle coverage areas. The unknown node selects 3 nodes from the set of all neighbor guide nodes, tests whether it is inside the triangle composed of these 3 nodes, repeats the process until all the ternary combinations are exhausted or the desired precision is reached, and then all the unknowns are calculated. The center of gravity of the overlapping portion of the triangle of the node is used as its position estimate.

IV. THE IMPROVEMENT ALGORITHM

In recent years, various improved algorithms for improving positioning accuracy and robustness in different application environments have emerged. However, these algorithms have their own advantages and disadvantages. For different application environments, different solutions are adopted, and most of them are limited to improving a certain stage of positioning [27]. These improved algorithms can be mainly divided into two categories: improvements to the ranging model and improvements to the coordinate calculation method.

The algorithm for improving the ranging model mainly focuses on optimizing the RSSI ranging accuracy, but this method of adding filtering algorithm does not change the RSSI ranging model. The literature [28-32] uses the Kalman filter algorithm to process the received RSSI values for predicting the position of the target node. The Kalman filter algorithm is a recursive method that causes the variance of the error and the distance to fall regularly until it finally reaches convergence. However, this algorithm is not suitable for nonlinear systems.

The algorithm for improving the coordinate calculation method is practical. In the transmission process, the signal is easily interfered by environmental factors, which may cause inaccurate ranging accuracy and affect the performance of the positioning algorithm. Literature [33] proposed the concept of minimum condition, which is used to judge whether the node is out of the group, and to eliminate the outliers to achieve the purpose of improving the positioning accuracy of the nodes. Reference [34] compares the performance of the three-sided measurement with the Min-Max positioning algorithm, but the study needs to be performed in a specific indoor environment.

CONCLUSION

In this paper, combined with the application status of wireless sensor network positioning technology, the basic concepts, evaluation criteria, measurement models in WSN and some common positioning technologies of wireless sensor network positioning are summarized and introduced. The paper focuses on the comparison and analysis of wireless sensor network location algorithms based on ranging and non-ranging, and classifies and summarizes related improved technologies. Although some current positioning technologies are mature, there are still many problems need to be solved in node positioning, such as node power consumption and ranging accuracy. As people's positioning accuracy and location service requirements continue to increase, WSN positioning technology will be further developed. The integration of positioning algorithms, the combination of positioning technology and machine learning, and the development of security positioning technology will be more and more widely concerned by scholars [35-37].

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