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A Cross-region Wireless-synchronization-based TDOA Method for Indoor Positioning Applications

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***Abstract*—Wireless positioning technology based on TDOA is an effective supplement to GPS-denied environment. However, traditional TDOA technologies often require precise time synchronization, a process that is usually done wired. It greatly increases the difficulty of deployment and limit the scope of application of the system. At the same time, cross-regional TDOA deployment application is also the main difficulty of the current research. Therefore, a cross-region TDOA positioning method based on wireless time synchronization is proposed in this paper to achieve high-precision time synchronization and improve the positioning accuracy and robustness of the system.**

***Index Terms*—Positioning system, Time Difference of Arrival(TDOA), Cross-region, UWB**

I. Introduction

In the indoor environment such as fire scene, tunnel and mine, after the satellite signal is launched to the ground, the signal energy is easily affected by the complex environment. And it will rapidly attenuates below the receiving threshold [1]. Therefore, the application of satellite positioning in the indoor environment is relatively weak. Besides, some indoor applications needs indoor positioning technology as necessary complements, such as human motion tracking [2].As a result, the solution of indoor positioning is very important to solve the problem that GPS and other outdoor positioning technologies cannot be used in the indoor environment [3].

In wireless positioning systems, distance-based positioning methods such as TOA [4], TDOA [5] and RSS [6] are often used. Although RSS based positioning system is usually simple to established and has low cost, the RSS method is affected by the multipath effect of indoor wireless signal transmission, which makes it difficult to achieve high precision positioning [7]. TDOA is an improvement on TOA. Instead of directly using the arrival time of the signal, it uses the time difference of the signal received by multiple base stations to calculate the position of the target. Compared with TOA, TDOA positioning method only requires clock synchronization between base stations, and does not need to add additional clock synchronization equipment on the target tag, which reduces the size of the tag, conforms to the characteristics of tag miniaturization, and at the same time ensures positioning accuracy. Currently, it has become a research hotspot [8] [9] [10].

In the TDOA system, there are some aspects for improvement. First, the system needs accurate time synchronization. This is typically done in commercial applications via wire. However, it is difficult to deploy cable facilities in buildings or complex indoor environments. Therefore, the provision of wireless solutions is very necessary. Moreover, due to the limited signal coverage of wireless nodes, multiple TDOA positioning systems are required to cover most indoor positioning scenes. Therefore, the single-region TDOA positioning system that originally works independently needs to coordinate among regions. However, redundant wireless signals are likely to cause interference to the normal process, resulting in error in the positioning results, and thus reducing the reliability of the system. Therefore, it is necessary to design a reasonable cross-region transmission scheme.

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In this paper, a cross-region wireless synchronous TDOA positioning algorithm is proposed to realize multi-region coordination, expand the range of indoor positioning, and improve the efficiency and robustness of indoor positioning compared with TOA.

The structure of this paper is as follows: section 2 analyzes the system structure of cross-region TDOA. The third part describes the cross-regional TDOA ranging algorithm. In the fourth part, the actual effect of the algorithm is analyzed by real experiment. Section 5 draws a conclusion.

II. System Architecture

Reference [5] proposes a simplified synchronous single-region TDOA positioning system structure based on reference node. The system structure is shown in Fig.1, it consists of Tag and base stations. Tag is the target item to be positioned and broadcasts positioning data. The base station can be divided into Anchor Node and Reference Node (hereinafter referred to as "RN"). In Fig.1. the dotted line represents the communication range of RN. A RN equips a relatively precise clock device and is used to calibrate Anchors. Anchors receive the positioning data sent by Tag for calculating. After the positioning process is completed, the Anchors send the collected data to the server, which processes the data and presents the results.

Fig.1 shows the single-region TDOA positioning system structure [5]. Three anchors and one RN are taken as examples, which is also the minimum system structure required for the calculation of two-dimensional coordinates. Two kinds of radio frequency signals involved are UWB [11] radio frequency signals used in the positioning process and Wifi signals reported after the positioning.

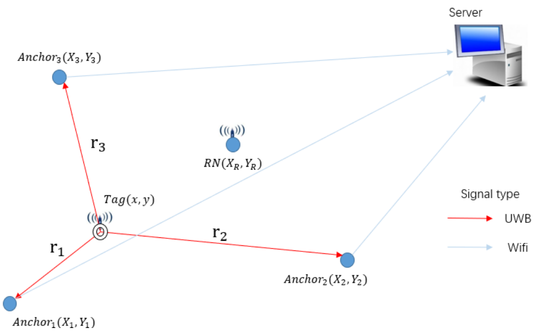

Fig. 1. Structure of TDOA single-region location system.

Fig.2 is the expected structure diagram of TDOA cross-region positioning system. A large number of base stations are used to build a positioning network in accordance with the structure of wireless sensor network [12]. In Fig.2, the dotted lines represents the communication range of RNs.

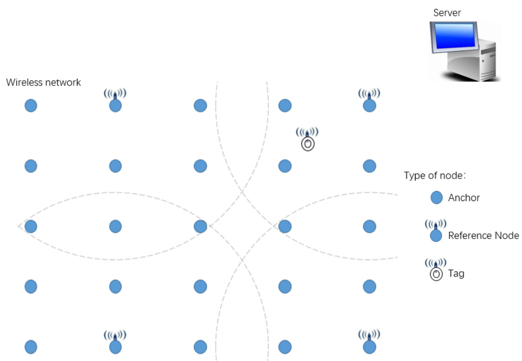

Fig. 2. Structure of TDOA cross-region location system

The hardware structure of the embedded device used in this system is divided into base station and tag. The main difference is whether there is Wifi module. Since the Tag does not need to report data to the server, no Wifi module is needed. In the base station, the MCU directly connects to UWB module, Wifi module and power. In the Tag, the MCU only connects to UWB module and power.

The MCU model of the node is STM32F103C8T6, which adopts the ARM cortex-m3 kernel, the system bus width is 32 bits, the maximum frequency of the system is 72MHz, the RAM and Flash capacities are respectively 20K and 64K. The UWB module adopts the DWM1000 module of single-chip UWB solution from Irish chipmaker Decawave [13].

The Wifi module is dt-06 wireless Wifi serial port transmission module. Based on esp-m2 Wifi module, it is often used to replace the wired serial port of embedded devices to achieve data collection and control.

III. Cross-Region TDOA Positioning Algorithm

The proposed algorithm aims to measure the time difference of arrival signal between two anchor nodes, which is sent by the same tag.The timing diagram of a single-region TDOA algorithm [5] is shown in Fig.3. The rays connected between the vertical axes are used to represent the data packets sent and received between nodes, in which the solid line represents unicast data packet and the dotted line represents broadcast data packet. . When there is no special label, the default is the Data Frame of IEEE 802.15.4-2011 protocol.

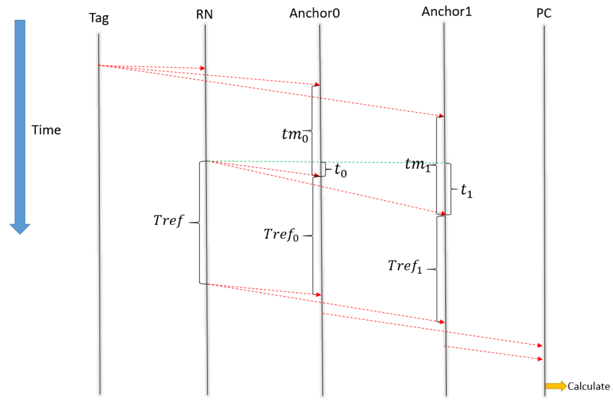

Fig. 3. TDOA single-region positioning algorithm

In Fig.3, the Tag broadcasts positioning data. Reception of tag's packet triggers a timer in the RN. After delay the node sends the packet and repeats the transmission after reference period $Tref$. Signals from the reference node after propagation spend t_0 and t_1 reaching both anchors.

Anchors measure time of arrival of all received packets and we can summarize the TDOA formula for Anchor1 and Anchor0 from Fig.3:

$$delta_t = (tm_0 - t_0) - (tm_1 - t_1) \tag{1}$$

$delta_t$ is the time difference of arrival signal between two anchor nodes, which is sent by the same tag. t_0 and t_1 are the time it takes for a signal to travel from RN to Anchor0 and Anchor1. Since their positions are known, they can be directly calculated from the distance. The tm_0 and tm_1 actually participated in the calculation are the corrected results of the measured values. Taking tm_0 as an example, the correction formula is:

$$tm_0 = tm_{0m} * (Tref/Tref_n) \tag{2}$$

$$Tref_n = Tref_{n-1} * (1 - k) + k * Tref_0 \tag{3}$$

Where, tm_{0m} is the time interval between when the Anchor receives packet from Tag and the first synchronous packet from the RN. $Tref$ is the time interval between two packets sent by RN. $Tref_0$ is the measured value of Anchor local time clock corresponding to RN clock $Tref$. $Tref_n$ is the iterative value calculated by formula (3), which is obtained by moving average calculation of the currently measured $Tref_0$ and the results of the previous iteration. k is the coefficient of moving average calculation, and it is pointed out that the correction effect is the best when set at 0.05 [5].

It is worth noting that in this scheme, only one RN is used, which is equivalent to a special base station. In essence, it still belongs to single-region positioning, and positioning can only be carried out within the coverage of RN. If it is extended to multiple regions, it is necessary to have an RN in each region.

Ideally, the Anchor in the public area will only receive a signal from RN. However, this is very difficult to achieve in this scheme. As long as a RN receives the signal of Tag, it is bound to start its positioning process. Therefore, a more realistic approach is to exit in time during the positioning process of RNs.

In this system, the automatic ACK function is used to reduce the probability of signal collision. The automatic ACK function means that when the receiver receives a packet that requires ACK reply, if the auto-ack function is opened, it will automatically reply ACK to the other side. In addition, it also uses the delayed transmission function, so that RN does not need to report data after each positioning process. The delayed transmission is equivalent to setting a timed transmission task, writing and sending data to the register in advance, and then sending the data from the antenna at a specified time. The timing accuracy is 8ns, which has little influence on the overall accuracy.

In order to solve the coordination among multiple regions, the cross-region TDOA positioning transmission algorithm as shown in Fig.4 is designed.

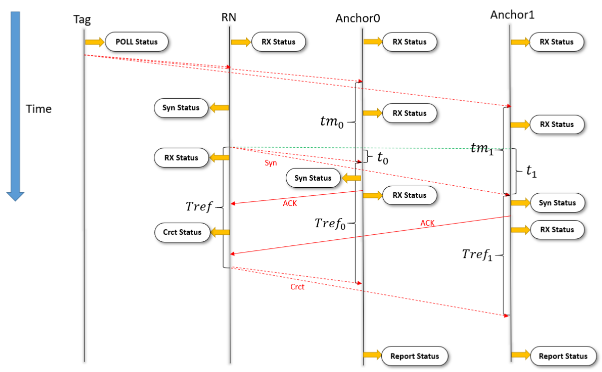

Fig. 4. TDOA cross-region positioning algorithm

The calculation formula is exactly the same as the single-region algorithm, but the difference lies in the ACK and ID confirmation mechanism. In the algorithm, Anchors measure time of arrival of all received packets.

The algorithm has several steps:

First, the Anchor turn on the auto-ack function in initial status and Tag broadcasts positioning data.

Second, reception of tag's packet triggers a timer in the RN. After delay the RN sends the Syn packet and set a delay of Tref to wait for ACK from Anchor. Anchor receive the tag's packet and Syn packet, then send ACK to RN and turn off the auto-ack function.

Third, if the RN receives ACK during Tref, it will send Crct packet to Anchor, otherwise it will go back to the initial status.

Finally, after receive the Crct packet, the Anchor will check the ID inside the Crct and Syn packet to make sure that they come from the same RN. If they come from the same RN, the Anchor will calculate (2) and (3) and send the result to the server. Otherwise, it will go back to the initial status. The server will employ a combination of Taylor and Chan method to calculate the coordinate of the target Tag [14].

ACK and ID confirmation mechanism can reduce the transmission of redundant wireless signals in the positioning process to a certain extent. It can enhance the robustness of the system.

IV. Experiments and Discussion

In experiments, a total of 6 base stations were deployed, including 4 anchors and 2 RN nodes. Their relative positions are shown in Fig.5. The identities of each node have been marked. The relative coordinates of the base stations are:

Anchor1 (0, 0.60m), RN6 (4.15m, 0.35m), Anchor2 (6.00m, 0.10m)

Anchor3 (0, 1.20m), RN5 (4.25m, 1.75m), Anchor4 (6.00m, 1.55m)

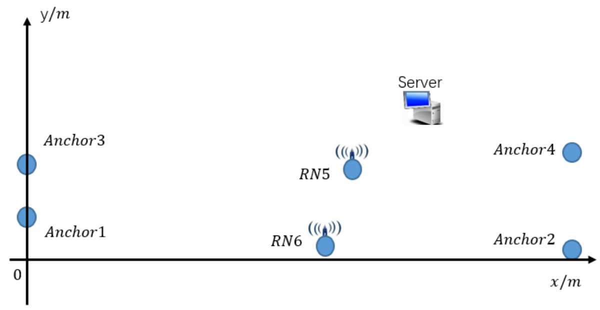

Fig. 5. Test scenarios

The performance test of TDOA positioning system mainly focuses on the positioning accuracy test, and the error is defined as the distance between the measured value and the real coordinate. Fig.6 shows the CDF of the error when Tag is placed at (4.2m, 1.2m) under the test scenario of Fig.5.

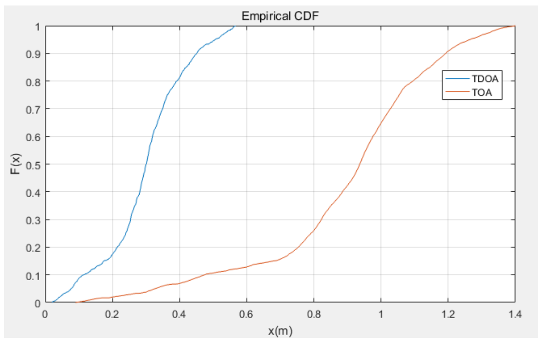

Fig. 6. CDF

As can be seen from the Fig.6, the positioning accuracy of cross-region TDOA can reach sub-meter level, and the highest can reach centimeter level. The overall error is less than 60cm and the average is about 26cm while the overall error of TOA positioning method is within 1.4m and the average is about 90cm. The results show that the system has good positioning accuracy.

V. Conclusions

This paper presents a cross-region wireless synchronous TDOA positioning algorithm to expand the range of indoor positioning, and enhance the efficiency and robustness of indoor positioning. This algorithm could significantly reduce the ranging error caused by TOA.

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