An Effective Hybrid Time Synchronization Approach for Time Based Wireless Indoor Localization

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***Abstract*— Position estimation for wireless indoor applications is a challenging problem due to lack of standard positioning system in indoor environments. The performance of indoor localization is restricted with many factors such as complex structure of the building, various materials inside the building and lack of availability and accessibility of GPS. Moreover, various localization techniques and applied wireless technologies can also affect the localization capability. Recently, time based wireless indoor localization is a popular trend. Having precise time synchronization is a vital concept for getting the accurate target localization. In this paper, an effective hybrid time synchronization approach is proposed for time based wireless indoor localization which can increase the time synchronization accuracy and hence to improve the localization performance. This new approach is based on Reference Broadcast Synchronization (RBS) and Pairwise Broadcast Synchronization (PBS) protocols, in which the number of timing messages is reduced compared with some existing synchronization protocols. As well, synchronization accuracy is improved as two way message exchange method is applied for time synchronization among all nodes. In addition, transmission delay is considered by using Gaussian random variables and probability density function to improve the accuracy performance. The proposed model is simulated with python programming language to show the robustness and accuracy of this system.**

Keywords—wireless indoor localization, time synchronization, RBS, PBS

I. Introduction

Wireless indoor localization is a critical requirement for many crucial sectors such as health care sector, environmental monitoring, object tracking, military investigation, disaster management sector and rescue and recovery sector, etc. Most of the recently researches for real time indoor positioning system still need to get the high localization accuracy, low energy consumption, effective implementation cost and low computational complexity. Time synchronization is very crucial for time based indoor positioning in wireless network. It is a huge challenge for accurate position estimation whereas it can be solved using various accurate synchronization protocols in wired network [1], [2]. There have been many time synchronization schemes for wireless network which have both merits and demerits. The Reference Broadcast Synchronization protocol (RBS) is based on the receiver-receiver synchronization which has two main tasks: timing messages are broadcasted to all receivers and then time information among these receivers are exchanged [3]. In this scheme, a reference node is required to broadcast which does not need to synchronize. And, it does not need to consider nondeterministic delays caused by the send time and access time. On the other hand, it has some weak points in accuracy and use of energy [4]. Flooding Time Synchronization Protocol (FTSP), supporting multi-hop synchronization, aims to achieve a network wide synchronization using the local clocks of all member nodes [5]. In FTSP, a root node with setting global time is dynamically defined and all other nodes try to synchronize their clocks according to the time set by the root node. To do so, the nodes must organize as an Ad-hoc structure. Timing-Sync Protocol for Sensor Network (TPSN) is proposed in [6], which has two phases, first phase is level hierarchy and second phase is based on pairwise (sender-receiver) synchronization. By using the second phase concept of TPSN, Pairwise Broadcast synchronization (PBS) is proposed as an energy-efficient clock synchronization scheme for wireless sensor network [7]. Mac-Time-Stamping-based High-Accuracy Time Synchronization with 2 points Least Squares is proposed for Wireless Sensor Networks called PBS-2LS, which modifies the existing PBS scheme by applying the timestamp of MAC layer and the method of two points least squares for clock offset and clock drift calculation [8]. Receiver only Synchronization (ROS) algorithm provides bidirectional synchronization mechanism for precision [9]. With the study of the correlations of the random components among various time values in ROS algorithm, an improved IROS algorithm enhances the timing accuracy and scalability of the existing ROS [10, 11]. Reduced computational cost, low energy consumption and precise time synchronization are still challenges for implementing the time synchronization protocol for wireless sensor networks. This paper proposes a hybrid time synchronization for wireless applications combining the idea of RBS and PBS protocols. By doing this, number of timing messages and energy consumption can be reduced as well as time precision may be absolutely increased.

The organization of the paper is as follows. In section II, the main challenges and time synchronization model for wireless network are described. The proposed hybrid approach with its detailed workflow is discussed in section III. Simulations and performance analysis are presented in section IV. After that, conclusion is written in the last section.

II. Time Synchronization in Wireless Networks

In this section, the main challenges that the existing synchronization protocols for wireless network have been facing are firstly discussed. And then, the general concept to synchronize time among wireless nodes is explained.

A. Main Challenges for Wireless Time Synchronization

Precise time information in wired network can be determined by using Network Time Protocol (NTP) and Global Positioning System (GPS). In contrast, wireless time synchronization schemes have many constraints due to the limitations of cost, network size, energy, communication range and complexity. Thus, all existing time synchronization protocols for wireless cases still require to modify so that more accurate time synchronization can be defined. The main sources of synchronization errors depend on the send, access, propagation and receive time of transmitting messages. Send time is the time taken from a sender to its network interface and access time is the time taken for accessing to the transmission channel. Propagation time is the transmission time from the sender to a destination node and receive time is the time taken from receiver's network interface to its host. According to these sources, considerable delays can be classified into deterministic or fixed delays and nondeterministic or random delays. The fixed delays can be caused by transmission time and propagation time that can be computed easily by using necessary parameters. On the other hand, nondeterministic delays in the send time and receive time occur randomly.

B. Time Synchronization Model for Wireless Networks

In wireless networks, time of each node never sets equally as environmental situations such as temperature, pressure and vibration affect the frequency rate of the clock of each node. Moreover, the clock of wireless nodes will not run simultaneously. Besides, the weakness of the clock's crystal oscillator causes the value of time differences among the nodes to increase. So, for time-based wireless applications, a standard time is required to represent as reference time. Unlike wired networks in which NTP or GPS can be used to get standard time, for eg. Coordinated Universal Time (UTC), it is complicated to define the reference standard time in wireless networks. If timestamp of a wireless node is supposed as reference time, the other nodes need to know this timestamp and have to adjust their time with reference time for synchronization. There are two kinds of time differences among the wireless nodes called time offset and time skew, which are phase difference and frequency difference respectively. To form a standard time, a node's current timestamp is selected as reference time and the rest nodes can change their time to match the reference time by using the following equation.

$$n(t) = \theta * s(t) + \tau \quad (1)$$

where, $s(t)$, the time of reference node, is used to synchronize the time of other nodes, $n(t)$, with the value of time offset, θ and time skew, τ. Time skew depends on the frequency rate, thus, the value of time skew may alter as time passes even if time synchronization is done.

III. Proposed Hybrid RBS-PBS Approach

The proposed hybrid approach combines the two existing wireless time synchronization protocols, RBS and PBS, to achieve more precise time synchronization. In RBS, an extra node is required for broadcasting the timing messages to the receiver nodes which are to be synchronize. After receiving the broadcast messages, all receiver nodes exchange their time information with each other. Without considering the time information of the sender, the receiver nodes synchronize their time using the synchronization information obtained from one way message exchange. This is also called receiver-receiver synchronization. For large scale wireless networks, a higher number of time information messages among the receiver nodes are needed for exchanging. Because of eliminating the time information of sender, the synchronization accuracy is lower than the other protocols.

In PBS, both sender-receiver synchronization and receiver only synchronization are used to attain a network wide synchronization with the decreased number of timing message exchange. Firstly, one sender node and one receiver node are selected as a super node and a parent node respectively. These two nodes exchange their time information and synchronize their time using two way message exchange which is called sender-receiver synchronization. After synchronization between these two nodes, this synchronization message is broadcasted to the rest nodes for synchronization. This is called receiver only synchronization because only synchronization message is used to synchronize among the rest nodes. Due to the use of one way message exchange among the rest nodes, the synchronization accuracy is not significantly high.

The purpose of the proposed hybrid approach is to reduce implementation cost, energy consumption and to improve the synchronization accuracy by combining the concept of RBS and PBS.

A. Wireless Network Scenario for Proposed Time Synchronization

We suppose a wireless network scenario for time synchronization approach shown in Fig. 1. There are four wireless nodes with known position information called anchor nodes and one of these nodes is defined as a common node to eliminate the use of extra node for synchronization. All other anchor nodes are necessary to connect to the common node for exchanging timing information. But, they do not exchange time information with each other. By eliminating packet exchange among other anchor nodes, the number of packet transmission can be reduced even though more nodes are added to extend the network.

All computational processes for time synchronization are performed on the common node, and thus other anchor nodes become last longer and consume less energy. As well, the common node can be attached with an end device for computation in a large network.

B. Detailed Workflow of Proposed Time Synchronization Approach

Node O is assumed as a common node and other three nodes: node P, Q and R are receiver nodes located within the

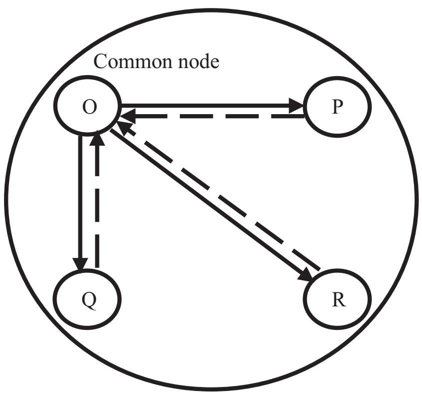

Fig. 1. Wireless network configuration for proposed time synchronization.

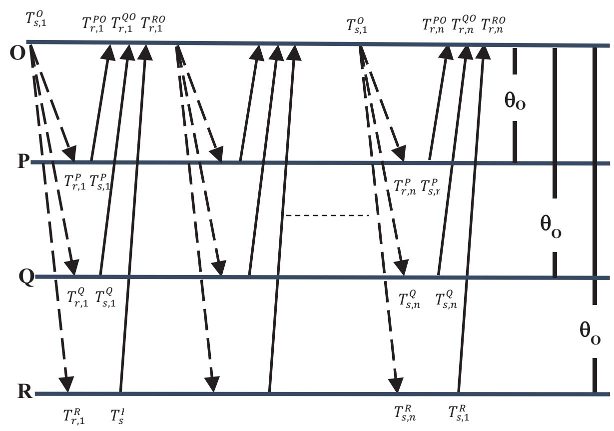

Fig. 2. Proposed hybrid time synchronization model

communication range of Node O. Fig. 2 shows how the timing messages are transmitted and received for time synchronization. Node O sends the first broadcast message containing its current timestamp $T_{s,1}^{O}$ and other anchor nodes, P, Q and R receive this message at their local timestamps, $T_{r,1}^{P}, T_{r,1}^{Q}$ and $T_{r,1}^{R}$, respectively. After receiving the broadcast message from node O, node P, Q and R record their local time of arriving broadcast message and reply the timing messages by adding the arrival time of broadcast message and their current sending timestamps, $T_{s,1}^{P}, T_{s,1}^{Q}$ and $T_{s,1}^{R}$ to the common node. Node O records the arrival time of reply messages from the receiver nodes, $T_{r,1}^{PO}, T_{r,1}^{QO}$ and $T_{r,1}^{RO}$, respectively. At that time, Node O has enough information to calculate the time offset between its local time and each receiver's local time. Node O repeats broadcasting the timing message n times to increase the time offset calculation accuracy. This time synchronization model is based on the internal synchronization since no reference time (eg. UTC) is used.

Time interval for exchanging timing message between the common node O and the receiver node P is assigned as in:

$$T^{OP} = \frac{(T_{r,1}^{P} - T_{s,1}^{O}) + (T_{r,1}^{O} - T_{s,1}^{P})}{2} \qquad (2)$$

in which $T_{r,1}^{P} - T_{s,1}^{O}$ and $T_{r,1}^{O} - T_{s,1}^{P}$ can be calculated using (3) and (4).

$$T_{r,1}^{P} - T_{s,1}^{O} = \theta_{OP} + \tau_{OP} + \beta_{OP} + \omega_{OP} \qquad (3)$$

$$T_{r,1}^{O} - T_{s,1}^{P} = \theta_{PO} + \tau_{PO} + \beta_{PO} + \omega_{PO} \qquad (4)$$

where, $T_{r,1}^{P} - T_{s,1}^{O}$ is the interval of broadcasting between two nodes and $T_{r,1}^{O} - T_{s,1}^{P}$ is the time taken for replying phase. θ_{OP} and τ_{OP} are time offset and time skew between the two respective nodes. β_{OP} is defined as fixed delay and ω_{OP} is considered as random delay. Fixed delay can be considered as transmission time and propagation delay between two nodes. It can be computed by using the distance information between these two nodes and propagation characteristics of applied wireless communication channel. Random delay is modeled by using Gaussian random variables in this research. The value of time skew, τ will alter as time passes. So, for n times of broadcast message, time skew can be computed as follows:

$$\tau = \tau_{OP}(T_{s,n}^{O} - T_{s,1}^{O}) \qquad (5)$$

Equation (5) can be also written as in:

$$\tau = \tau_{OP}\left(\sum_{i=1}^{n} T_i^{OP}\right) \qquad (6)$$

where, i is the number of broadcasting messages from 1 to n times, and t_i is total time taken for transferring all timing messages between two nodes. By substituting (6) in (3) and (4),

$$T_{r,1}^{P} - T_{s,1}^{O} = \theta_{OP} + \tau_{OP}\left(\sum_{i=1}^{n} t_i\right) + \beta_{OP} + \omega_{OP} \qquad (7)$$

$$T_{r,1}^{O} - T_{s,1}^{P} = \theta_{PO} + \tau_{PO}\left(\sum_{i=1}^{n} t_i\right) + \beta_{PO} + \omega_{PO} \qquad (8)$$

For wireless communication, transmission speed is as fast as the speed of light, so timing messages can be transferred before requiring resynchronization. That is why, the possibility of time skew is neglected in this proposed model. As the two way message exchange method is supposed in this approach, time offset between two nodes can be computed by combining (7) and (8) as follows:

$$\theta_{avg}^{OP} = T^{OP} - \beta_{avg}^{OP} - \omega_{avg}^{OP} \qquad (9)$$

where, $\beta_{avg}^{OP} = (\beta_{OP} + \beta_{PO})/2$, and $\omega_{avg}^{OP} = (\omega_{OP} + \omega_{PO})/2$. Time offset values from n times of exchange messages are used to get the optimal time offset in (10) in which k is the number of broadcasting times:

$$\theta_{est} = \frac{1}{n}\sum_{k=1}^{n} \theta_{avg}^{OP}(k) \qquad (10)$$

By using above equations, all other receiver nodes can synchronize with common node O. Despite time offset between command node and receiving node is estimated, the offset between two receiving nodes can be calculated in (11):

$$\theta_{PQ} = \theta_{OQ} - \theta_{Op} \qquad (11)$$

IV. Simulation Evaluations

Simulations are conducted by using Python language to evaluate the performance of the proposed hybrid approach compared with RBS and PBS.

A. Delay Model

To obtain the accurate synchronization information, nondeterministic delay or random delay, ω is designed using Gaussian random delay model, $z[i] \sim N(\mu, \sigma)$ with mean μ and standard deviation, σ and Gaussian probability density function. If the probability of random delay is estimated precisely, time offset between nodes can be assigned more accurately. Thus, in this simulation, the range of random delay

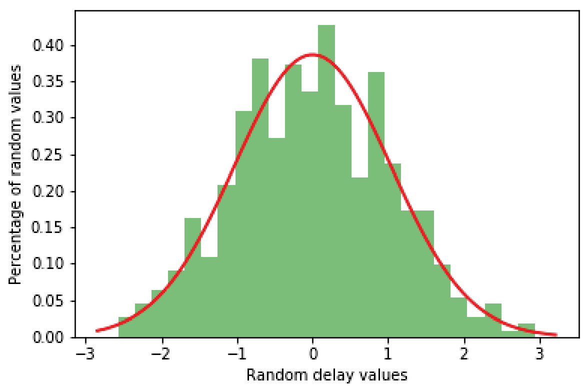

Fig. 3. Gaussian model for random delay estimation.

is assumed from millisecond level, microsecond level to second level. With the use of different random variables with appropriate range of random delay value, ω can be defined. Python language is used to evaluate the performance of the proposed model. Fig. 3 illustrates the Gaussian random delay model.

B. *Performance Comparison with RBS, PBS and Hybrid Approach*

In this section, the number of exchange messages for time synchronization are compared using RBS, PBS and proposed hybrid approaches based on the different number of wireless nodes and broadcasting times. Number of wireless nodes is supposed as l and the number of broadcasting times is set as n. For RBS, total number of exchange messages is $n + n * \{l * (l - 1)/2\}$, because an extra reference node is necessary to broadcast messages and according to the number of broadcasting time, they need to exchange timing messages to each other. Thus, the number of exchange messages is significantly high which causes high energy consumption.

For PBS, total number of exchange messages is $2* n$, since time synchronization is performed once using sender-receiver synchronization between one sender node and one receiver node, all other nodes receive this synchronization message. So, the number of exchange messages is reduced, but, synchronization accuracy may not be considerably high as receiver only synchronization is used for all other nodes.

In the proposed hybrid approach, total number of exchange messages is $n + n * (l - 1)$. Although the number of exchange messages is higher than PBS, all receiver nodes except common node do not need to perform timing information computation. Therefore, energy consumption is absolutely low at all receiver nodes except the common node. In addition, two way message exchange concept and sender-receiver synchronization are applied in this hybrid approach which can improve the synchronization accuracy. One of the significant advantages compared with RBS is that common node broadcasts the timing messages without needing any extra reference node which can reduce the hardware cost.

The number of broadcasting times, wireless nodes and total number of exchange messages for these three schemes are compared in (4) and (5). In Fig. 4, we assign the number of wireless nodes as constant and vary the broadcasting times. Vice versa, the number of broadcast messages stay unchanged and various number of wireless nodes are set in (5).

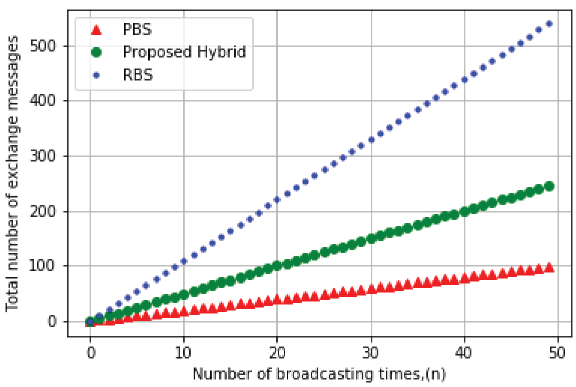

Fig. 4. Number of message exchanges over n broadcasting times.

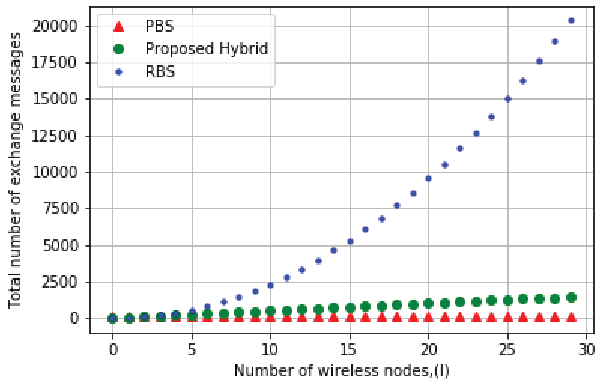

Fig. 5. Number of message exchanges over l wireless nodes.

V. CONCLUSION

In this paper, an effective hybrid time synchronization scheme is proposed for time-based wireless indoor localization. Synchronizing time among the wireless nodes is crucially required because just a slight time difference between wireless nodes can cause a large error for time based applications. By applying this proposed scheme, time synchronization accuracy is increased due to the use of two way message exchange method. Likewise, energy efficiency becomes better since the number of timing messages are reduced compared with some existing protocols. As future work, the proposed model will be applied in time based indoor localization techniques and additional experiments on wireless indoor localization will be performed.

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