An Improved RBS-PBS Based Wireless Time Synchronization Approach

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***Abstract*— Time synchronization in wireless network plays an essential aspect for real time environments in which high developed technologies are applied. In accordance with the requirement of definite time synchronization for wireless network, several researches on wireless time synchronization are performed using various wireless time synchronization protocols which are applied on different wireless communication technologies. Due to the limitations of wireless network, such as battery life time, network configuration, investment cost, and so on, many researches that had been proposed may not support the best solution for precise time synchronization among wireless nodes. Nowadays, wireless time-based applications are widespread in used for many societies and thus, more and more enhanced researches on wireless time synchronization are required to propose. In this paper, a new hybrid synchronization approach for wireless network is proposed which is based on two existing protocols, Reference Broadcast Synchronization (RBS) and Pairwise Broadcast Synchronization (PBS). The purpose of combining the basic concepts of two existing synchronization protocols is to provide better synchronization performance. By using Gaussian distribution model for random variable series, synchronization accuracy is absolutely increased. Comparisons and evaluations simulated with Python programming language are to highlight the improved results on synchronization.**

Keywords- Wireless time synchronization, RBS, PBS

I. INTRODUCTION

Real-time wireless applications are recently developed by means of the state-of-the-art technologies and methodologies. For some time-based wireless applications, environmental monitoring and tracking system, health care system, and indoor localization system, the main restriction of these applications is how to set definite time among the wireless nodes. Traditionally, Network Time Protocol (NTP) or Coordinated Universal Time (UTC) can be provided for time synchronization in wired network. On the other hand, in wireless network, some issues such as network size, energy consumption, computational complexity and implementation cost are required to consider. Due to these limitation of wireless network, it is still a challenge to design an effective time-based wireless application. To define the equal time value among wireless nodes, various wireless time synchronization protocols can be applied on different wireless communication technologies, for example, WiFi, ZigBee, Bluetooth, Ultra Wide Band (UWB), etc.

Generally, time synchronization protocols for wireless network can be distinguished based on receiver-receiver synchronization (RRS), sender-receiver synchronization (SRS), and receiver only synchronization (ROS) [4], [7], [9]. Reference Broadcast Synchronization (RBS) [1], one of the wireless time synchronization protocol, acts as receiver-receiver synchronization and it requires an extra reference node to broadcast beacons to all nodes to be synchronized. Timing-Sync Protocol for Sensor Network (TPSN) [2] is traditional sender-receiver based protocol for large wireless network. In TPSN, synchronization process is divided into two working steps, level discovery phase and pairwise synchronization phase. Flooding Time Synchronization Protocol (FTSN), which is modified on TPSN, performs periodic flooding of synchronization messages in order to improve synchronization performance [6]. Tree Structured Referencing Time Synchronization (TSRT), based on the idea of pairwise synchronization phase of TPSN, is aimed to reduce complexity and overhead for global time synchronization [8]. In Pairwise broadcast synchronization (PBS), sensor nodes are synchronized using timing information of a pair of sensor nodes with the purpose of better energy efficiency [3]. By enhancing PBS protocol, PBS-2SL improves synchronization accuracy than original PBS in which least square method is employed [11]. In order to achieve the robustness of synchronization algorithm, Improved Receiver Only Synchronization (IROS) is presented in [10]. According to the limitations of wireless network, all of these wireless time synchronization protocols may not be considered as the standard one. That is why, a hybrid synchronization approach is proposed to improve the synchronization performance with the existing ones.

The followings are the organization of the proposed paper. Section II describes about the wireless time synchronization briefly. In section III, it presents its workflow, and design process in details. Simulations and performance comparisons are conducted in section IV. The final section discusses the conclusion and further consideration of the proposed one.

II. WIRELESS TIME SYNCHRONIZATION

Wireless time synchronization represents that it defines a common or standard time frame among wireless nodes by transferring the timing messages with each other to adjust their time. In wireless network, time of each node runs separately due to the external conditions such as temperature, pressure, humidity and frequency rate of clock.

Four main sources that may cause the problem during synchronization are send time, access time, propagation time and receive time of the transmission messages [5]. The time the sender spends to contribute the messages and to transfer it to the network interface is assumed as send time. Access time means the time for waiting to access the message to be sent to the transmission channel. Propagation time includes the time taken to propagate and transmit the message from the sender to the receiver through the transmission channel. Receive time is the time taken to receive the message from the network interface to its host. Send, access and receive time are also called random or nondeterministic delay which can only be estimated approximately whereas propagation time is named fixed or deterministic delay that can be computed using necessary parameters. To take control of the inequality of time among wireless nodes, it is necessary to execute the time difference values among these nodes. Generally, two kinds of time difference values called time offset and time skew are needed to compute for wireless time synchronization. Time offset and time skew are the phase difference and frequency difference between two wireless nodes respectively. To achieve time synchronization, one of wireless nodes is supposed as a reference node whose time is defined as reference time. And, every rest node has to adjust their time with this reference time to get standard time frame among them by using (1).

$$n(t) = \tau * s(t) + \theta \tag{1}$$

where, $s(t)$, is reference node and $n(t)$ is the node to be synchronized with the values of time offset, θ, and time skew, τ. So, these time difference values can be executed by using various wireless time synchronization protocols.

III. PROPOSED HYBRID RBS- PBS APPROACH

The proposed hybrid approach is aimed to attain better synchronization performance by estimating more accurate timing values required for time synchronization. Two main issues are provided in this section that are the background theory of proposed hybrid approach and detailed process of proposed one.

A. *Introduction to Proposed Hybrid Approach*

By combining the basic concepts of two existing protocols, RBS and PBS, a new hybrid synchronization approach is proposed with the aim of better performance. In RBS, time synchronization is based on receiver-receiver synchronization. An extra reference node is required to broadcast timing message to all wireless nodes to be synchronized. Then, every two wireless nodes are grouped as a set. The member nodes within each set exchange their timing messages with each other. By doing so, send time and access time can be eliminated for synchronization but it causes lower synchronization accuracy compared with others.

In PBS, time synchronization is based on both sender-receiver synchronization and receiver-only synchronization. Firstly, two of the wireless nodes are assigned as super node and parent node which are the sources for synchronization. These two nodes transfer timing messages with each other to synchronize time between them. After that, synchronized timing messages are broadcast to all rest nodes by these two nodes. In this way, the requirement of extra node is solved.

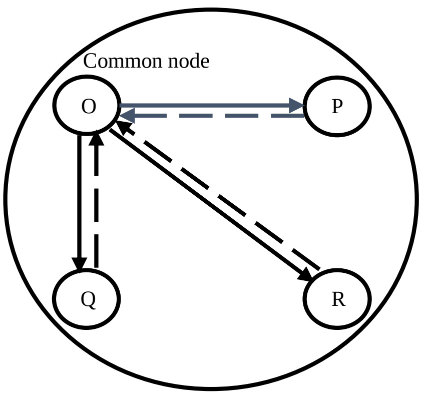

Figure 1. Wireless network scenario for proposed approach

Synchronization accuracy is improved for two reference nodes but it is absolutely decreased for the rest nodes which are based on receiver-only synchronization. The proposed hybrid approach is based on sender- receiver synchronization for all wireless nodes. Initially, a wireless network is configured as in Fig. 1. In this scenario, as example, four wireless nodes, (O, P, Q, and R) with known position called anchor nodes are located at the corner of the interest area. All these nodes are in the same communication range. One of these nodes, O, is selected as a common node to discard the necessity of extra node. All calculation for synchronization will be done by the common node so that all other nodes can save the energy consumption.

B. *Process of Proposed Hybrid Approach*

The process of proposed synchronization approach is mainly divided into two steps. As a first step, a common node broadcasts the timing messages to all other nodes. And, the second step is to retransmit the timing messages from all receiver nodes to common node. Fig. 2 shows the process of broadcasting and transferring timing messages for synchronization. At first, common node O sends a first broadcast message containing its current timestamp $T_{s,1}^{O}$ and three receiver 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 that, these three nodes record the time of arriving broadcast message and then reply the timing messages 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 O. Node O also saves the arrival time of reply messages from the receiver nodes at $T_{r,1}^{PO}, T_{r,1}^{QO}$ and $T_{r,1}^{RO}$. After doing so, all necessary timing information are obtained by common node O to calculate the time difference required for time synchronization.

In (2), broadcasting time interval from common node O to the anchor node P, $T_{r,1}^{P} - T_{s,1}^{O}$, is computed and period for replying timing messages from P to O, $T_{r,1}^{O} - T_{s,1}^{P}$, is calculated in (3).

$$T_{r,1}^{P} - T_{s,1}^{O} = \theta_{OP} + \tau_{OP} + \beta_{OP} + \omega_{OP} \tag{2}$$

$$T_{r,1}^{O} - T_{s,1}^{P} = \theta_{PO} + \tau_{PO} + \beta_{PO} + \omega_{PO} \tag{3}$$

where, θ_{OP} and τ_{OP} are considered as respective time offset and time skew values between two nodes. β_{OP} and ω_{OP} are defined as fixed delay and random delay consecutively. Fixed delay, β_{OP}, can be computed as in (4).

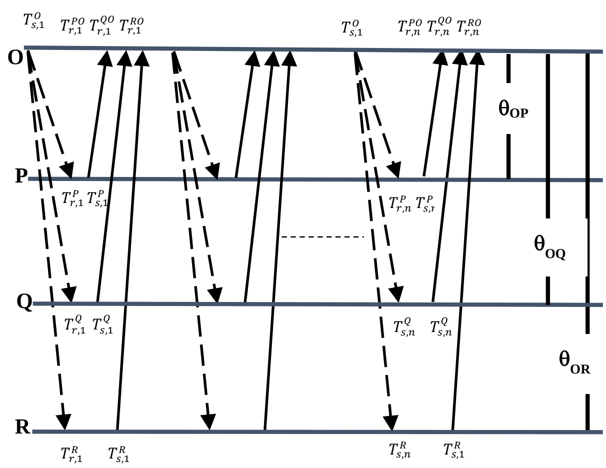

Figure 2. Proposed hybrid synchronization approach

$$\beta^{OP} = \frac{Packet\ size}{Bandwidth} + \frac{Distance}{Propagation\ speed} \quad (4)$$

Random delay, ω_{OP}, is difficult to compute but it can be approximated by means of different distribution models. Thus, time interval for exchanging timing message including broadcasting and retransmitting between two nodes, O and P, can be derived in (5).

$$T^{OP} = \frac{(T_{r,1}^{P} - T_{s,1}^{O}) + (T_{r,1}^{O} - T_{s,1}^{P})}{2} \quad (5)$$

For time synchronization in wireless network, the possibility of time skew can be ignored. This is because transmission speed in wireless network is as fast as the speed of light, and time skew value may alter as to the frequency rate of the clock oscillator which speed is 10^{-4} to 10^{-6}. So, timing messages can be exchanged before requiring resynchronization which is caused by time skew. Time offset between two nodes can be computed as follows in (6).

$$\theta_{avg}^{OP} = T_{avg}^{OP} - \beta_{avg}^{OP} - \omega_{avg}^{OP} \quad (6)$$

in which, $\beta_{OP} = \beta_{PO}$, and $\omega_{avg}^{OP} = (\omega_{OP} + \omega_{PO})/2$. To achieve more precise time offset value, several number of timing messages are needed to broadcast. The optimal time offset value for n broadcasting times is calculated as in (7).

$$\theta_{est}^{OP} = \frac{1}{n}\sum_{i=1}^{n} \theta_{avg}^{OP}(i) \quad (7)$$

Likewise, optimal time offset values for common node O and Q, and O and R, can be resulted as in (8) and (9).

$$\theta_{est}^{OQ} = \frac{1}{n}\sum_{i=1}^{n} \theta_{avg}^{OQ}(i) \quad (8)$$

$$\theta_{est}^{OR} = \frac{1}{n}\sum_{i=1}^{n} \theta_{avg}^{OR}(i) \quad (9)$$

In this way, all extended nodes can be synchronized using above equations. Moreover, time offset value between two anchor nodes can be presented as in (10).

$$\theta_{PQ} = \theta_{OQ} - \theta_{Op} \quad (10)$$

IV. SIMULATION EVALUATIONS

To demonstrate the performance improvement of proposed hybrid approach, simulations are performed by using Python programming. As required parameters for simulations, four number of anchor nodes (O, P, Q, R) are located at the corner of interest area 50 m x 50 m. Communication range for these nodes is about 60 m. Node O is 40 m apart from node P and node Q associatively and 56 m far from node R. 50 timing messages are broadcast in order to estimate more accurate time offset values which is required for time synchronization. For comparisons, actual time offset values for three pairs of nodes, (O and P), (O and Q) and (O and R) are assigned as 5 ms, 7 ms, and 9 ms resceptively.

First of all, random delay must be estimated before calculating the time offset value. By using Gaussian distribution model for random variable series, $z[i] \sim N(\mu, \sigma)$, absolutely accurate random delays can be predicted. The required mean and standard deviation can be assigned with the results of OMNET simulator tool. By applying the estimated random delay values in the calculation process, estimated time offset values can be computed for RBS, PBS and proposed hybrid approaches. Fig. 3, Fig. 4 and Fig. 5 illustrate the estimated time offset values, $\hat{\theta}$, over actual values, θ = 5 ms, 7 ms, and 9 ms respectively over RBS, PBS and proposed hybrid approach.

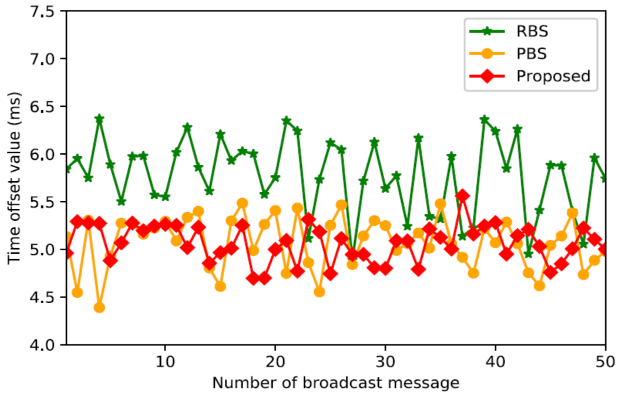

Figure 3. Comparison of estimated time offset value over θ = 5 ms

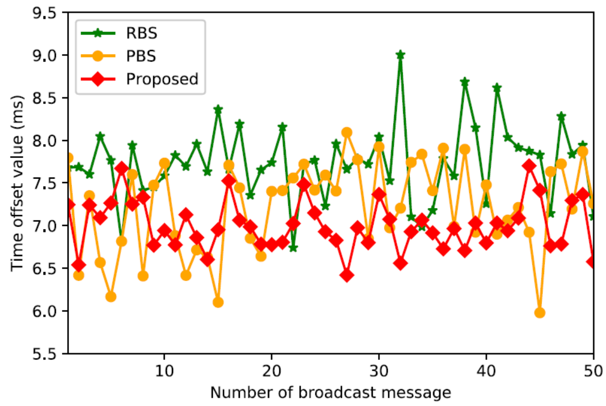

Figure 4. Comparison of estimated time offset value over θ = 7 ms

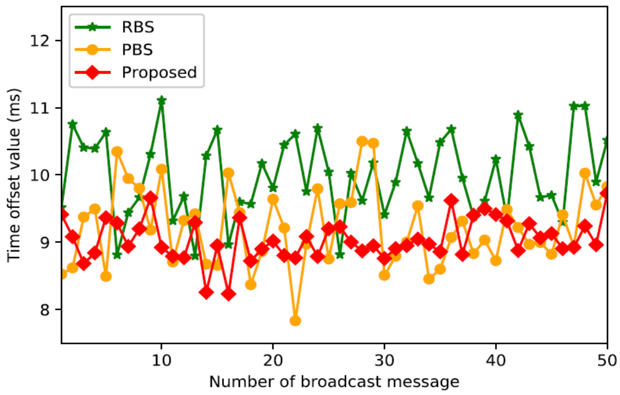

Figure 5. Comparison of estimated time offset value over θ = 9 ms

Root Mean Absolute Error (RMSE) of 50 estimated time offset values, θ_{RMS}, is calculated using (11) in which θ_j is the assigned time offset value, $\hat{\theta}_j$ is the estimated time offset value and z is the number of exchanging timing messages. Using (12), standard deviation of estimated time offset values, θ_{SD}, is derived in which $\hat{\theta}$ is the estimated time offset value, n is the number of estimated time offset values, and $\widehat{\theta_m}$ is mean of n estimated time offset values.

TABLE I. COMPARISONS OF ESTIMATED TIME OFFSET ERRORS AND STANDARD DEVIATION

Applied approach	θ_{RMS}			θ_{SD}		
	(O and P)	***(O and Q)***	***(O and R)***	***(O and P)***	***(O and Q)***	***(O and R)***
RBS	866.06 μs	858.13 μs	1167.49 μs	375.17 μs	417.39 μs	564.93 μs
PBS	279.92 μs	573.02 μs	619.96 μs	149.86 μs	294.84 μs	380.74 μs
Proposed hybrid	202.98 μs	288.13 μs	306.98 . μs	113.45 μs	175.43 μs	197.87 μs

Table. 1 compares θ_{RMS} and standard deviation, θ_{SD} for RBS, PBS and proposed hybrid approaches. It conducts that proposed hybrid approach significantly decreases the RMSE of estimated time offset values than RBS and PBS.

$$\theta_{RMS} = \sqrt{\frac{1}{z}\sum_{r=1}^{z}(\left|\theta_j - \widehat{\theta_j}\right|^2)} \quad (11)$$

$$\theta_{SD} = \sqrt{\frac{\sum(\hat{\theta} - \widehat{\theta_m})^2}{n}} \quad (12)$$

V. CONCLUSION

To conclude, this paper proposes an improved hybrid RBS-PBS based time synchronization approach for wireless network. In accordance with the simulation results, the proposed hybrid approach improves higher synchronization accuracy as well as better performance. As explained in this paper, precise time synchronization is very important for time-based wireless applications. That is why, by applying the proposed one as an effective synchronization approach for wireless applications, it can provide many benefits for our environments. As further extension, the proposed approach will be employed in time-based wireless indoor localization scheme with simulation evaluations as well as experimental ones.

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