Time Synchronization Strategies in Wireless Sensor Network: A Review

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***Abstract*—Lately, Wireless Sensor Networks are getting lot of attention by research community. It consists of small devices distributed over geographical areas and each device has sensing, computing and communicating components. Time synchronization is vital to schedule communication and distributed measurement tasks. It targets at equalizing the local times for all nodes in the network. It has been observed from the literature survey that the task of time synchronization mainly focus on two things, firstly drift from master oriented towards master less synchronization and secondly energy efficiency techniques. Various techniques purposed in the literature have been thoroughly covered in this survey paper and related issues and challenges have been highlighted.**

Keywords: Wireless Sensor Network, Time Synchronization, Energy Efficiency

I. INTRODUCTION

Wireless sensor network is a network which is consisting of distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure etc. and to cooperatively pass their data through the network to a main position [10]. It consists of nodes which vary from a few to several hundreds or even thousands, where each node is linked to one (or may be several) sensors. The main components of sensor node are a microcontroller, transceiver, external memory, power source and one or more sensors [16]. The controller performs tasks, processes data and controls the functionality of other components in the sensor node. The functionality of both transmitter and receiver is combined into a single device known as a transceiver. Memory requirements are very much application dependent. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating and data processing.

Time synchronization means to scale all nodes of network towards common clock time so that communication is effective. Since all hardware clocks are imperfect, those at different nodes may drift away from each other in time. For this reason, the observed time or durations of time intervals may differ for each node in the network. However, for many applications or networking protocols, it is required that a common view of time exists and is available to all or some of the nodes in the network at any particular instant. Many strategies are available having their respective pros and cons. The diversity between strategies is basically on the factors like using master node or not, energy efficiency, scheme used for waking and sleeping time of nodes etc. The traditional basic protocol is Two Way Message Exchange Synchronization [6]. It is base of many protocols which are described in this paper.

Moreover, rest of the paper is organized as: Section II describes the basis of time synchronization. Section III presents various time synchronization strategies. Based on the literature survey, the important issues of time synchronization have been discussed in Section IV, before the paper is finally concluded in Section V.

II. BACKBONE OF TIME SYNCHRONIZATION

Time synchronization in wireless sensor network has basic requirements as computer clock, knowledge of sources of synchronization errors and needs of synchronization algorithms [6]. These basic requirements are as discussed below:

A. *Computer Clock*

Computer clock circuits consist of an oscillator and a counter. Depending on the oscillator's angular frequency, the counter increases its value to represent the local clock C(t) of a network node. In ideal situations, angular frequency is constant. The angular frequency changes and computer clocks drifts due to physical variations, like temperature, vibration and pressure. Approximation of local clock can be made as [11]:

$$C_i(t) = a_i t + b_i \tag{1}$$

Where a_i is the clock drift, and b_i is the offset of node i's clock. Drift represents the rate of the clock, and offset means the difference in value from real time t. Using (1), local clocks of two nodes in a network can be compared, say node 1 and node 2 as in [12]:

$$C_1(t) = a_{12}.\, C_2(t) + b_{12} \tag{2}$$

We call a_{12} the relative drift and b_{12} the relative offset between the clocks of node 1 and node 2. If two clocks are perfectly synchronized, then their relative drift is 1, meaning the clocks have the same rate. Their relative offset is zero, meaning they have the same value at that instant. Few strategies are designed to adjust offsets of nodes.

B. *Sources of Synchronization Errors*

The following elements contribute to the synchronization errors [6]:

1. Send time which is the total time of building the message and transfer it to the network interface to

be sent. This time highly depends on the operating systems in use.

2. Access time which is the time needed to access the channel. Every network employs a medium access control (MAC) scheme.
3. Propagation time which is the time required to propagate the message through the air from network interface of the sender to the network interface of the receiver.
4. Receive time which is the time spent in receiving the message by network interface and transferring it to the application layer of the host.

C. *Needs of Synchronization Algorithms*

While designing time synchronization algorithm, wireless sensor network limitations enforce certain requirements that need to be met [8]. These are accuracy, robustness, scalability, longevity, energy efficiency, cost, scope, delay which has been briefly discussed below:

1. *Precision:* It means how accurately the algorithm is performing its task which varies from application to application.
2. *Robustness:* In case of harsh environment, synchronization scheme should be functional.
3. *Scalability:* Synchronization scheme should tolerate the change in the number of nodes in the network.
4. *Longevity:* It means synchronization scheme must be able to work as long as operation of the network.
5. *Energy Efficiency:* Energy is very critical part of node in wireless sensor network so synchronization scheme must conform to energy efficiency.
6. *Cost:* Sensor nodes are very small and inexpensive devices so attaching high cost hardware for synchronization process do not make any sense.
7. *Scope:* The time synchronization scheme aims at common time scale for all nodes in the network. Network can be global or local but its difficult to implement such algorithms in case of global network.
8. *Delay:* Time synchronization must be done in small time as possible for some critical applications such as gas leak detection.

III. SYNCHRONIZATION STRATEGIES FOR WIRELESS SENSOR NETWORK

A. *Reference Broadcast Synchronization for Wireless Sensor Network*

To get rid of overhead of sender in sender-receiver synchronization, receiver-receiver synchronization was proposed named as Reference Broadcast Synchronization [16] which concentrate on synchronizing a set of receivers with one other rather than synchronizing a sender with a receiver. In this scheme, nodes send reference beacons to their neighbors. A reference beacon does not include a timestamp. Instead, its time of arrival is used by receiving nodes as a reference point for comparing clocks. In this, reference sender remains unsynchronized because in doing so more energy is wasted.

B. *Lightweight Tree-Based Synchronization*

Lightweight Tree-Based Synchronization [14] is based on construction of tree which is constructed each time whenever synchronization is to be performed. Once the tree has been constructed, the reference node initiates pair-wise synchronization with each of its children. Then each child repeats this step for its respective children and this repetitive process is performed until all nodes of the tree have been synchronized. It aims at attaining minimum complexity for providing a given precision.

C. *Time-Sync Protocol for Wireless Sensor Network*

Lightweight tree based synchronization aims at a particular precision rather than very high precision which may not be suitable for some applications. For achieving higher precision Time-sync [13] was proposed. It is a sender-receiver synchronization approach. It has two steps to be implemented. First step is Level Discovery and second is Synchronization. Level Discovery focuses on creating the hierarchical topology in the network, where each node is assigned a level. Where only one node is assigned level 0 which is known as root node. In the second step, node at level i synchronizes with node at level i-1. At the end of hierarchy, all nodes in the network are synchronized to root node. It has two times more precision than Reference Broadcast Synchronization. Its shortcoming is less accuracy as it does not estimate the clock drift of nodes.

D. *Flooding Time Synchronization in Wireless Sensor Network*

For providing a robust synchronization against link or node failure, Flooding Time Synchronization [9] abstracts the ideas of both RBS (Reference Broadcast Synchronization) and TPSN (Time-sync Protocol). It enhances the key ideas of TPSN and RBS and combines them to periodically flooding the synchronization messages to achieve network wide synchronization which is robust against link or node failure. It is a sender-receiver synchronization as in case of TPSN and also adjusts the clock drift as in case of RBS. In FTSP, all nodes in the network synchronize to a dynamically (re) elected root node by the use of controlled flooding. It uses low communication width. Its lackings are high energy consumption and poor synchronization of distant nodes.

E. Recursive Time Synchronization Protocol

To overcome the drawbacks of Flooding Time Synchronization, Recursive Time Synchronization [3] was proposed which targets at better performance than the earlier protocols. This protocol attains time synchronization by exchanging messages among nodes. Three types of messages are used which are enquiry/election of reference node, request for time synchronization and reply for time synchronization. When wireless sensor network boots up, all sensor nodes need to identify the reference node. For this purpose, these nodes sends enquiry message to their respective neighbors and wait for some time until reply is received. The node which has the smallest ID is chosen as reference node. This protocol takes responsibility of two things which are choice of reference node and compensation of offset and drift. This protocol uses seven times less energy than Flooding Time synchronization protocol in long run. By compensating propagation delay, accuracy is improved. Energy efficiency is achieved by using techniques like infrequent broadcasts by reference node, reducing number of synchronization requests.

F. Mini-Sync and Tiny-Sync

In order to attain synchronization protocol which is more constrained to communication bandwidth, Mini-Sync and Tiny-Sync[7] was proposed which aims at minimal computational and storage complexity. In this algorithm, concept of data points is used which is the tuple of timestamps. Tiny-sync is based on the concept that all data points are not useful so it applies constraints on the selection of data points. It uses low storage space as only four data points and eight time stamps are to be stored. Mini-Sync improves the accuracy of Tiny-Sync at a low computational cost as it discards only that constraint if newer constraint can eliminate the existing constraint. These protocols are suitable for sensor networks that are highly constrained in bandwidth and computational power providing tight, deterministic synchronization. No scalability and robustness is defined for these protocols. It is also tolerant of message losses.

G. Master–Less Time Synchronization for Wireless Sensor Networks

Above discussed protocols mostly uses tree based organization which includes the overhead of selecting a master node so as to synchronizing its respective children. To reduce such overhead, Master-Less time synchronization strategy [5] aims at scaling all network nodes to common clock without using any master node. All nodes periodically broadcast their own timestamps in a pseudo-periodic manner and adjust their own clock as soon as they receive the time from some other device. While working in all conditions, convergence speed and accuracy of course strongly depend on the specific scenario considered. Its main advantages are reliability and flexibility, since no special master election procedures or multi-hop synchronization protocols are required.

H. Efficient Time-Synchronization in Ring-Topology Wireless Sensor Networks

Concentrating on energy efficiency of synchronization protocols, efficient time-synchronization [4] in ring topology was designed for low duty cycle networks sensors which sleep most of the time and wake up for short periods of time to perform sensing, computing, and communication tasks. This is based on use of two software clocks for synchronization purpose. The first software clock is called Wake-up Clock (WUC). This clock controls the wake-up of the nodes for transmission and reception, according to the pre-determined schedule. The other clock is called Sync Clock (SC), and it contains the actual synchronization information. Most of the time the two clocks show the same time but there are time intervals when they diverge. Initially both clocks show the same time. The node is woken up by the WUC to receive a message. The message contains new time stamp and the node adjusts its SC accordingly. The node then transmits a message, using the content of SC for time stamping. After message transmission, but before the next message reception, the WUC is adjusted to SC, thus from now on both clocks show the same time, until the next message reception.

I. Enhanced Time Synchronization Algorithm

As network topology is not fixed, it can be ring, tree, star or any other so time synchronization with energy efficiency is required for varying network topologies and for the same reason, Enhanced Time Synchronization algorithm [2] was proposed which focuses at reducing the power consumption in the distributed network. It has mainly two parts: first is synchronization time and second is energy dissipation. In this synchronization in the network takes place by autonomous and local decisions of sensor node. There is no centralized control. In synchronization phase, node with smallest ID is selected as transmitter after node deployment. This selected node sends syn_msg to next node ID which in turn acts as receiver node and sends syn_ack back to transmitter and hence information exchange takes place. Now receiver node becomes the transmitter node and next node ID is selected a s receiver node. This process is repeated until all nodes get synchronized. After this, energy dissipation is calculated. Synchronization time slightly increases with increase in number of nodes.

J. *An Energy-Efficient Beacon Strategy for Time Synchronization in Wireless Sensor Network*

As Efficient time-synchronization in ring-topology [3] uses the concept of low-duty cycle, means including the concept of waking/sleeping modes of nodes, for attaining energy efficiency which has a significant drawback of missing synchronizing beacon due to wrong active/sleep mode of node due to clock drift. So for overcoming this drawback, An Energy-Efficient Beacon Strategy [1] was developed which is based on guard beacon. Using guard beacon, a node will send optimally scheduled beacons to minimize the idle listening time for the receiver caused by synchronization errors. It aims at reducing overall power consumption of both sender and receiver node rather than just reducing the number of synchronization messages. By sending the optimal number of beacons at the optimal times, Guard Beacon can reduce the idle listening time for coming beacon, therefore minimize the total synchronization power consumption of sending and receiving beacons. This protocol has more energy efficiency than Recursive time synchronization protocol [3] when the beacon interval is small.

All above surveyed time synchronization protocols are briefly highlighted in Table 1. In this, overview of each protocol is mentioned which includes accuracy, network topology, energy efficiency etc.

TABLE 1 VARIOUS TIME SYNCHRONIZATION STRATEGIES AT A GLANCE

Sr. No.	Strategy Name	Highlighted Points
1.	Reference Broadcast Synchronization	i. Receiver-Receiver Synchronization ii. Removes Non-Deterministic Synchronization Errors Caused by Sender iii. More Energy Wasted if Reference Node to be Synchronized
2.	Light-Weight Tree based Synchronization	i. Aims at Reasonable Accuracy ii. Based on Tree Structure iii. Accuracy Decreases as Tree Depth Increases iv. Sender-Receiver Synchronization
3.	Time-Sync Protocol	i. Works in Two Phases: Level Discover Phase and Synchronization Phase ii. Based on Tree Structure iii. Sender-Receiver Synchronization iv. Error Depends on Complexity of the Tree Structure
4.	Flooding Time Synchronization	i. Uses Ideas of Both Time-Sync Protocol and Reference Broadcast Synchronization ii. Utilizes Low Communication Bandwidth iii. Sender-Receiver Synchronization iv. Frequent Broadcast of Synchronization Messages
5.	Recursive Time Synchronization	i. Sender-Receiver Synchronization ii. Improves Energy Efficiency by Using Infrequent Broadcast of Synchronization Messages iii. Improves Accuracy by Compensating Propagation Delay iv. Better Performance than Flooding Time Synchronization

…Table 1 (Various Time Synchronization Strategies at a Glance)

Sr. No.	Strategy Name	Highlighted Points
6.	Mini-Sync and Tiny-Sync	i. Provide Tight, Deterministic Synchronization with Low Storage and Computational Complexity ii. Tolerant Against Message Failure iii. No Scalability and Robustness is Defined
7.	Master–Less Time Synchronization	i. No Need of Election of Master Node ii. The Algorithm Converges within Reasonable Time Regardless of Time-Stamping Jitter, Incomplete Node Visibility
8.	Efficient Time-Synchronization in Ring-Topology	i. Proposed for Low Duty Cycle Ring Topology ii. Very Low Synchronization Error for Neighbors iii. Saves Power as Most of the Time Nodes are in Sleeping Mode
9.	Enhanced Time Synchronization Algorithm	i. Takes Less Time for Synchronization ii. Reduces Power Consumption iii. Synchronization Time Slightly Increases with Increase in Number of Nodes
10.	An Energy-Efficient Beacon Strategy	i. Sends Multiple Beacons for Synchronization ii. Reduce Power Consumption of Both Sender and Receiver

IV. OPEN ISSUES

Based on the extensive survey done in the previous section, a lot of work has been reported in the literature. However, there is still a need of comprehensive time synchronization techniques that covers all requirements holistically. However, main issues in this have been highlighted here that includes send time, propagation time, receive time, access time which results in delay. If delay occurs in a network than clock times are not properly synchronized. Many protocols, like Reference broadcast synchronization, Flooding time synchronization have sorted out these issues so that the delay can be negligible. Another issue is energy efficiency which is very vital factor in wireless sensor network. Some protocols, like Efficient time-synchronization in ring-topology, Energy-efficient beacon strategy, exists which conform to energy efficiency to some extent but more energy efficient and high precision is still a big issue.

V. CONCLUSION

Due to challenges associated with Wireless sensor network such as energy efficiency, self-configuration, size and sensor mobility, time synchronization in wireless sensor network is more challenging as compared to other wireless networks. Time synchronization is needed to identify casual relationships between events in physical world. In this paper, time synchronization strategies have been reviewed and major issues have been identified that mainly includes delay and energy efficiency. From the survey, it has been observed that researchers have considered the solution of time synchronization from two aspects that are viz. centralized or distributed control and in the energy constraint. From the literature, it can be concluded that design innovations are needed to develop time synchronization strategies for energy efficiency and improved precision for hostile and challenging wireless sensor network.

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