Survey of Synchronization Algorithms: Wireless Sensor Networks Case Study

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***Abstract*—Time synchronization become in recent years as a part and parcel for any distributed system such as sensors networks. Many applications of sensors networks need local clocks of sensors nodes to be synchronized and keep synchronization between sensors, to communicate with each other via radio links for sharing and treatment of reliable information. The key point of consideration in this article is to examine and evaluate the most important synchronization algorithms based on a set of factors like energy efficiency, mobility and complexity.**

key words: Time synchronization, Algorithms, wireless sensor network, Data fusion.

I. INTRODUCTION

In wireless sensor networks, the aim operation is data fusion, whereby data from each sensor is agglomerated to form a single meaningful result .

In general, the proposed technique for synchronization in sensor networks requires that all sensor nodes have a common time scale so that the central unit can coordinate and collaborate sensors to accomplish their tasks. However, it is difficult to maintain a common time scale for all sensors, so the IEEE 802.15.4 standard has not defined clearly the synchronization mechanisms.

The synchronization mechanism is a phenomenon subject to many constraints which must meet several requirements. These constraints sometimes can be contradictory, such as minimizing energy consumption, reducing the associated costs and maximizing the quality and accuracy of services provided. The problems of time synchronization have been studied thoroughly in the Internet and local networks. Several technologies such as Global position System (GPS) have been used to provide synchronization in large networks. Other protocols such as Network Time Protocol (NTP) have been developed to keep the clocks ticking in the Internet. However, the time synchronization requirements differ significantly in the context of use of sensor networks. In general, these networks are dense, composed of a large number of sensor nodes. This property engenders a lot of difficulties to keep the central synchronization. Energy efficiency is another major problem in synchronization problem due to a limited battery capacity of nodes. In this paper, we present the different existing techniques for synchronizing sensor networks. The various sections of this paper are organized as follows: Section 2, analyzes different network problems. Section 3 discusses the various existing time synchronization algorithms. Section 4 illustrates our comparison based on the existing synchronization algorithms. Finally, Section 5 contains the conclusion of the paper.

II. NETWORK RELATED PROBLEM

The importance of the synchronization problems in wireless sensor network pushes us to study deeply:

First, the clock in different devices, must be set at the same reference time. To make this time scale work better, we must synchronize each clock in node to get a reference time source. So, the local time provided for each node must be the same.

Synchronization plays a crucially important role in wireless sensor networks because it allows the entire system to cooperate and accomplish a complex task of data transfer. For instance, we can mention the data coordination collected at different nodes which is a significant result despite the system clock-difference of nodes, which can begin communicating at different times. In addition, the clock may be modified because of environmental conditions. Second, to save energy in order to increase the lifetime of the network, synchronization can be used appropriately. The sensors can sleep at appropriate times and wake up if necessary. In order to save energy, the nodes must be on and off when time interval ordinates and functions. In this respect, we can mention the radio receiver of the node, when there is data sent to require precise synchronization between the sensors.

Traditional methods of synchronization are not approved for use in the sensor network due to problems of complexity and high power consumption. For example, the Network Time Protocol (NTP) is widely used for clock synchronization on the Internet but isn't suitable in wireless networks, because it needs a large energy. In addition, GPS can be too expensive to be fixed on a low-cost devices since it cannot be available everywhere as well as inside buildings or under water. It should be noted that some middle GPS can not be trusted.

978-1-4673-1948-5/12/$26.00 ©2012 IEEE

III. Existing Approach Of Synchronization

In this section we will examine the peculiarities of the most interesting algorithms in wireless sensor networks:

A. Reference Broadcast Synchronization: RBS

Elson and al [6] have proposed the RBS approach which uses the concept of receiver-receiver synchronization. The later has been, viewed as reference to several works in the same line of research (Synchronization Solution). The RBS synchronization mechanism is based on the exploitation of the nature of diffusion of wireless medium. With this property, the nodes in the transmission range of the same location in the intersection of two neighborhoods would be synchronized. Despite the advantages of elimination of major sources of indeterminism, transmitter receive the same message with a very low offset. Considering only the time for receipt of different receptors, the RBS protocol immediately eliminates two major sources of indeterminism involved in the transmission of messages, errors and the precision of synchronization that follows. The mechanism RBS has certain limitations: it requires that the reference receivers of messages transmitted by the reference to know the real time and the advanced channel time. The only source of indeterminism that interfere in RBS synchronization are the propagation and receipt time which shall exchange times of receptions.

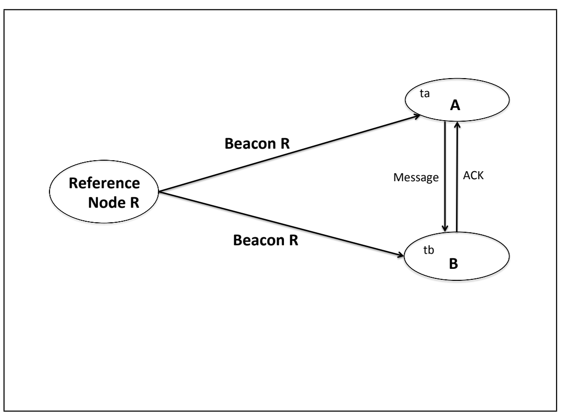

Fig. 1. State machine RBS for two nodes

Benefits

1) The largest sources of error(send time and access time) are removed from the critical path by decoupling the sender from the receivers.
2) This protocol is applicable to both wired and wireless networks.

Disadvantages

1) The energy is wasted to synchronize the reference sender.
2) Convergence time, which is the time required to synchronize the network, can be high due to the large number of message exchanges.

B. Timing-sync Protocol for Sensor Network: TPSN

Garnewel and al [5] have proposed an alternative approach to synchronization with the type Transmitter-receiver, TPSN is a hierarchical algorithm which works on two different phases: The discovery and synchronization phase. In the first phase, we give a network node level.

The node that initiates the synchronization is called the root

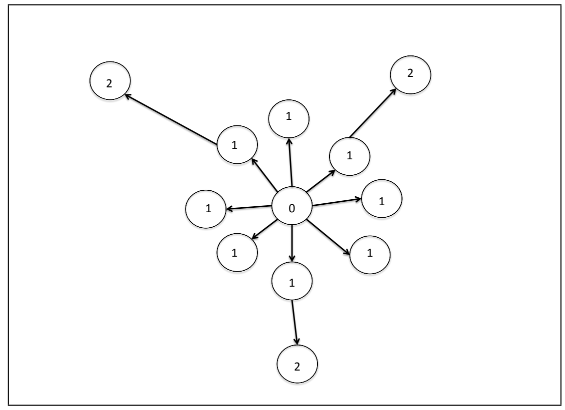

Fig. 2. Discovery Phase

node with the value of level zero neighbors with n hops (n=1, 2, 3, K) have the value of level n. This process continues until all neighbors attribute their levels. In second phase, a pair wise synchronization is performed along the edges of the hierarchical structure up to a total synchronization of the tree constructed with the message exchange mechanism.

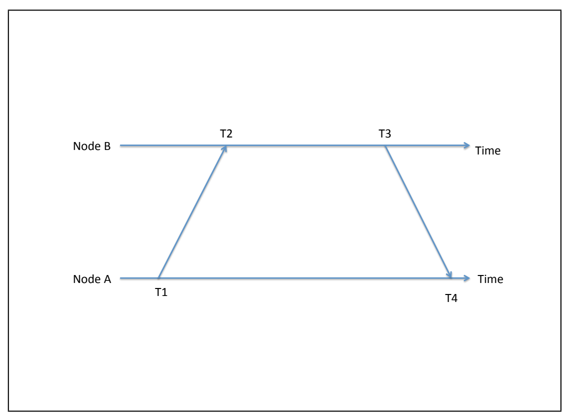

Fig. 3. Synchronization Phase

Benefits

1) The protocol is extensible and the precision of synchronization does not degrade when the network size increases.
2) TPSN achieves two times better precision than RBS.

Disadvantages

1) Energy conservation is not very effective because it requires a physical clock correction to be performed on local clocks of sensors while achieving synchronization.
2) Not effective in the case of dynamic network.

C. Flooding Synchronisation Time Protocol: FTSP

The objective of FTSP [4] is to achieve a local synchronization with local participating nodes. Assuming that each node has local clock synchronization errors, and can communicate despite the lack of reliability, the errors must be corrected with message exchange mechanism. FTSP synchronize time from a sender to multiple receivers which may be using a single radio message. This mechanism could ensure high accuracy between two sensors and keep synchronized communication. Typically, WSN (Wireless Sensor Network)operates in larger areas than the radius of a node. Therefore, the FTSP synchronizes multi-hop nodes. The root node is the only selected and dynamic node that maintains the overall time for all other nodes to synchronize their clocks. The nodes form a Ad-hoc structure to transfer the total time from the root to all nodes that keep (save) the initial phase of the tree that is more robust against failures of links between nodes and the dynamic topology change.

Benefits

1) FTSP does not rely on a fixed network hierarchy but updates it continuously, it supports network topology changes including mobile nodes.
2) FTSP also consumes less network resources than either RBS or TPSN.

Disadvantages

1) Is not applicable for large networks (thousand of sensors).
2) The radio transmitter certainly consumes a lot of energy sending each message, as the receiver does too, even when it is just listening [23].

D. Lightweight Tree-based Synchronization: LTS

Lightweight Tree-based synchronization [7] is different from other work [4], [5], [6] in the sense that its objective is not to maximize accuracy but to reduce the complexity of synchronization. Thus, the timing accuracy required is supposed to be given as a constraint and the main objective is to have a synchronization algorithm with minimal complexity to achieve given accuracy. The accuracy of the maximum time needed in sensor networks is relatively small (fractions of seconds) and we just have to use a synchronization scheme in the network. The two proposed algorithms for synchronizing multi-hop require nodes to be synchronized to some reference points such as a sink node in the sensor network. Two ways are possible as follows.

1) Centralized Multi-hop: It is a simple linear extension of single-hop synchronization that needs a spanning tree to be constructed first. In general whenever a new spanning tree is constructed each time the algorithm is executed. In order to synchronize the nodes in the tree, synchronizations are performed in pairs along the edges of T with synchronization centralized multi-hop. The reference node begins the synchronization mechanism with all the twigs mediation of T. Then pairwise synchronization is done along the $n-1$ edges of the spanning tree. This process continues until all nodes leaves of T reaches the algorithm and ends when all leaf nodes are synchronized.
The execution time of the algorithm is proportional to the depth of the tree.

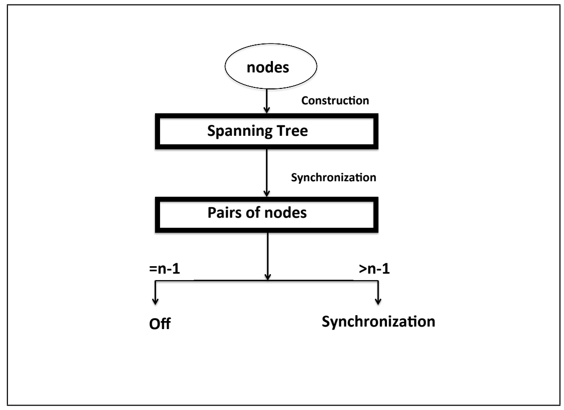

Fig. 4. State machine for Centralized Multi-hop

2) Distributed Multi-hop: It needs to build a spanning tree. This algorithm performs the synchronization of nodes in a distribution mode and doesn't use an overlay tree to direct synchronization pair. This algorithm is charged with the responsibility of synchronization from the reference node by the nodes themselves. The rate of synchronization of individual nodes can be determined using the same parameters as the reference nodes used in the central case.

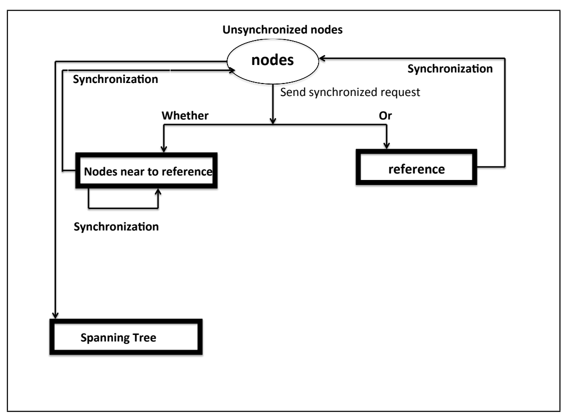

Fig. 5. State machine for Distributed Multi-hop

Benefits

1) For large networks the protocol LTS seeks to build a tree in the network
2) Avoid unnecessary synchronization.

Disadvantages

1) The accuracy of synchronization decreases linearly with depth of the tree synchronization.
2) Requires the synchronization of all nodes on the path to the node reference.

E. Tiny-Sync and Mini-Sync

The two algorithms have common characteristics [8]: they are very tolerant of loss-message

- they have limited storage and computation complexity
- they can be extended to all two-way communication of data

1) Tiny-Sync: It is based on observation. The data points obtained from the development of the estimation procedure are not all useful. Each data point consists of two constraints which are bounded by the offset and clock skew. At any time only four constraints are preserved instead of six constraints on the arrival of a new data point. The two new constraints are compared with existing data points and the four constraints resulting in the best estimates are selected by the calculation complexity of the algorithm.

2) Miny-Sync: is an extension of Tiny-Sync it finds the optimal solution with increasing complexity. The idea, to prevent the algorithm being used by some data points, has come to give strict limits. The authors develop a test to determine if there is a chance that a constraint could be useful. A constraint is eliminated if it is definitely useless (points that do not change the solution).

Benefits

1) Adopted for sensor networks with very limited bandwidth and computing power .
2) The protocols are tolerant of message losses.

Disadvantages

1) The sensor network is logically organized as a hierarchy, making it inapplicable to mobile sensor networks.
2) The drawback of the protocols is that convergence time is high.

F. Scalable Lightweight Time Synchronization Protocol for Wireless Sensor Network: SLTP

Uses the method of collecting (Clustering) and linear regression for reducing the energy consumption of network [21]. SLTP works in two phases, the first phase concerns the configuration for static and dynamic network in which determines the node group leader and members are determined.

The second phase allows timing synchronization network after selecting the group leader and then the network initiates the synchronization.

Benefits

1) Good solution for a large network to monitor a wide area.
2) SLTP will work in dynamic networks as well as in static networks.

Disadvantages

1) SLTP is huge in terms of energy consumption.
2) SLTP is sensitive to message loss, however, provisions for message loss are not considered.

G. Reference Based, Tree Structured Time Synchronization: TSRT

proposed by Surendra Rahamatkar and Ajay Agarwal [12], The aim is to minimize the complexity of synchronization. TSRT has two main steps to synchronize the network, The building of an ad hoc tree structure is the first, the second is used to synchronize the local clocks of sensors nodes followed by network evaluation phase. At the end of synchronization phase, the network realizes the wide synchronization of the local clocks of the participating nodes.

Benefits

1) TSRT avoids the problem in RBS when two neighbors of an initiating peer are hidden from each other
2) In TSRT, the sender error is eliminated by comparing the received time on each node.

Disadvantages

1) Not effective in the case of dynamic network.
2) The comparison of TSRT (2011) is made with old algorithms like RBS (2002) and TPSN (2003).

There are other interesting works by the problems of synchronization inherit all of the algorithms described above as:

- TSYNC [15]: The basic mechanism uses multi-channel nodes. It means that each node has two channels for control and clock. All nodes use one channel for control, and the other manages the traffic of all network. The protocol has two version (centralized and decentralized). The first named RHS (Hierarchy Referencing Time Synchronization Protocol) is used to synchronize the whole network and the second is ITR (Individual-based Time Request Protocol) that allows each node to synchronize on demand. Each node that wants to be synchronized sends a request message to its parent ITR and this is repeated until the request message reaches the base station and the latter returns the clock through the channel clock to the node called.
- Li.Ming [16] : It defines a synchronization protocol based on Time Synchronization Protocol for WSNs spanning tree based on a hierarchical structure. In this protocol a first spanning tree of all nodes in the network is created. It is divided into multiple subtrees and each subtree is a set of child nodes. The sub tree are identified by the father-level node is level 0. The mechanism of synchronization subtree is currency in three phases.
- Delay Measurement Time Synchronization for Wireless Sensor Networks DMTS [18] bases on a master-slave synchronization, synchronization transceiver, and the approach of clock correction. One advantage of this protocol is to avoid the round-trip time. DMTS synchronize the transmitter and multiple receivers at the same time and requires fewer message transfers of RBS. Another advantage is their self-organization and dynamic behavior. The function of self-organization implies that the network topology may change from time to time. DMTS focuses

on the scalability and flexibility, which means either to adapt or be insensitive to changes in network topology.

IV. Evaluation of Time Synchronization Algorithms

In this section we will select the different characteristics and synchronization problem of wireless sensor network during its operations. The usefulness or availability of sensor network is made to meet the needs of user requests by merging data from each sensor to provide a single result. To accomplish this task it becomes necessary for these sensors to agree on a concept like time. All active sensors (participants) can be wrapped in a common time scale either by synchronizing local clocks in each sensor either by transfer stamping. This section presented a comparison of various time synchronization algorithms for WSN's based on different principal factors such as the accuracy, the energy efficiency, the mobility and the complexity.

- Energy efficiency: This is an implicit requirement in most wireless networks in which this obligation must be executed and vary according to the demand. For example, in the case of sensor networks this requirement is strict forcing the nodes to sleep as often as possible and severely limiting the energy available for synchronization and other tasks. The main reason behind this constraint energy is the small size of the batteries in sensor nodes. This limits the amount of energy produced and stored
- Precision: Either the dispersion among a group of peers, or maximum error with respect to an external standard. The precision might be as fine as microseconds (e.g., coherent signal processing on audio signals) or as coarse as seconds set of nodes is considered the maximum deviation of a clock node whose set is relatively small [22].
- Mobile networks. In a mobile network, the sensors have the ability to move, and they connect with other sensors only when entering the geographical area of those sensors. The area of a mobile sensor is the communication range up to which it can communicate and exchange messages successfully with other sensors. Romer [21] shows the need for a robust protocol, which can handle the frequent changes in network topology due to the mobility of the nodes. The change in topology is often a problem because it requires resynchronization of nodes and re computation of the neighborhoods or clusters.

The table-I illustrates the pros and cons of the characteristics of ten different algorithms, as well as the capability and reliability of each one. It is important to note that the recent works as well as SLTP have dealt with the problems of mobility and energy consumption unlike RBS for instance, which is mainly attributed to the evolve of the daily needs and exigent requirements of modern life.

TABLE I
ALGORITHMS TAXONOMY PER SYNCHRONIZATION PROBLEM

	Application characteristics		
Algorithms	Energy efficiency	Mobility	Precision
RBS 2002	High	No	$1.85 \mp 1.28\mu s$
TPSN 2003	High	No	$16.9\mu s$
FTSP 2004	High	Yes	$0.5\mu s$
GTSP 2009	High	No	$4.0\mu s$
Miny-Sync 2003	High	No	$945\mu s$
LTS 2003	low	Yes	0.5s
DMTS 2003	Very High	No	$32\mu s$
TDP 2005	Average	Yes	$100\mu s$
TSRT 2011	Low	Yes	Unkown
SLTP 2007	High	Yes	$0.13 \mp 0.06\mu s$

V. Conclusion

To conclude, we have analyzed algorithms that most of scientist and researchers are interested in, trying to study them in details because in our research, we based our work on a comparative study on the strengths and weaknesses based on various factors including the accuracy, energy efficiency, mobility and complexity for the rapidly emerging wireless networks. This study will guide researchers in the integration features of the solution of various protocols and create a successful synchronization time for their applications.

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