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Evaluation and Analys is Study of TSRT- Lightweight Time Stamp Synchronization Approach in Wireless Sensor Network

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Abstract

A typical WSN is composed of a large number of computing devices known as nodes embodying limited set of resources. These nodes are interfaced with sensors whose job is to sense and monitor the surrounding environment for various purposes and disseminate sensed data to some special computing devices called destination or base-stations in a coordinated manner where the destination nodes further process and analyze the reported data to draw conclusions about the reported activity. Since the sensors in Wireless sensor networks (WSNs) operate independently, their local clocks may not be synchronized with one another. This can cause difficulties when trying to integrate and interpret information sensed at different nodes. Time synchronization of WSNs is crucial to maintain data consistency, coordination, and perform other fundamental operations. Synchronization is considered a critical problem for wireless adhoc networks due to its de-centralized nature and the timing uncertainties introduced by the imperfections in hardware oscillators and message delays in both physical and medium access control (MAC) layers. All these uncertainties cause the local clocks of different nodes to drift away from each other over the course of a time interval. Therefore, Time synchronization is considered as an important research issue in wireless sensor networks (WSNs). Many applications based on these WSNs assume local clocks at each sensor node that need to be synchronized to a common notion of time. Features and concept of a lightweight tree structured referencing time synchronization (TSRT) approach to achieve a long-term network-wide synchronization with minimum message exchanges and exhibits a number of attractive features such as highly scalable and lightweight is presented in this paper. We have also shown evaluation, analysis and comparison study of TSRT with existing synchronization protocols.

Keywords: Ad Hoc Tree Structure; Clock synchronization; Wireless sensor networks, Hierarchical sensor network.

Introduction

Wireless Sensor Networks (WSNs) are considered as the enabling technologies to increase coordination between the physical and virtual world. Typical WSNs is composed of a large number of computing devices known as nodes embodying limited set of resources such as a microcontroller, short range radio transceiver, and a long-lasting battery as energy supply. These nodes are interfaced with sensors whose job is to sense and monitor the surrounding environment for various phenomenon such as temperature, sound, pressure etc and disseminate their sensed data to some special computing devices called sinks or base-stations in a coordinated manner where the sink nodes further process and analyze the reported data to draw conclusions about the reported activity [1]. WSNs are considered as a special category of ad-hoc networks which are characterized by the de-centralized infrastructure-free operating mode where nodes self-configure themselves upon deployment and carryout dual jobs of sensing and forwarding each other's data in a coordinated manner thus forming a multi-hop communication setup. However, nodes in WSN have their own unique characteristics that distinguish them from ad-hoc networks. Typical characteristics of WSN are limited energy resource, large scale deployment, cheaper but unreliable nodes and long operating/duty time. WSNs have got numerous applications and to name a few they have been very successful in enemy intrusion detection, precision agriculture, traffic control, infrastructure and machine health monitoring and patient's remote health monitoring.

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difficulties when trying to integrate and interpret information sensed at different nodes. Time synchronization of WSNs is crucial to maintain data consistency, coordination, and perform other fundamental operations. Time synchronization is also considered as a critical problem for WSNs due to its decentralized nature and the timing uncertainties introduced by the imperfections in hardware oscillators and message delays in both physical and medium access control (MAC) layers. All these uncertainties cause the local clocks of different nodes to drift away from each other over the course of a time interval. Therefore, Time synchronization is considered as an important research issue in wireless sensor networks (WSNs). Many applications based on these WSNs assume local clocks at each sensor node that need to be synchronized to a common notion of time.

Features and concept of a lightweight tree structured referencing time synchronization (TSRT) approach [2] to achieve a long-term network-wide synchronization with minimal Message Exchanges and exhibits a number of attractive features such as highly scalable and lightweight is presented in this paper. We have also shown evaluation, analysis and comparison study of TSRT with existing synchronization protocols and found more efficient and light weight as per as energy consumptions are concerned.

This paper is organized in several Sections. Section 2 contains the review of existing synchronization protocols. We present brief description of Tree Structured Time Synchronization scheme in Section 3. The evaluation study of TSRT scheme along with experiment results discussed in Section 4. Finally, Section 5 contains the conclusion of the paper.

Existing approaches to time synchronization

Time synchronization algorithms providing a mechanism to synchronize the local clocks of the nodes in the network have been extensively studied in the past. The most widely adapted protocol used in the internet domain is the NTP devised by Mills [3]. The NTP clients synchronize their clocks to the time servers with accuracy in the order of milliseconds by statistical analysis of the round-trip time. The time servers are synchronized by external time sources, typically using GPS. The NTP has been widely deployed and proved to be effective, secure and robust in the internet. In WSNs, however, non-determinism in transmission time caused by the Media Access Channel (MAC) layer of the radio stack can introduce several hundreds of milliseconds delay at each hop. Therefore, without further adaptation, NTP is suitable only for WSN applications with *low precision* demands.

Two of the most prominent examples of existing time synchronization protocols developed for the WSN domain are the Reference Broadcast Synchronization (RBS) algorithm [4] and the Timing-sync Protocol for Sensor Networks (TPSN) [5].

In RBS, a reference message is broadcasted. The receivers record their local time when receiving the reference broadcast and exchange the recorded times with each other. The main advantage of RBS is that it eliminates transmitter-side non-determinism. The disadvantage of the approach is that additional message exchange is necessary to communicate the local time-stamps between the nodes. In the case of multi hop synchronization, the RBS protocol would lose its accuracy. Santashil PalChaudhuri et al [6] extended the RBS protocol to handle multi hop clock synchronization in which all nodes need not be within single-hop range of a clock synchronization sender.

The TPSN algorithm first creates a spanning tree of the network and then performs pair wise synchronization along the edges. Each node gets synchronized by exchanging two synchronization messages with its reference node one level higher in the hierarchy. The TPSN achieves two times better performance than RBS by time-stamping the radio messages in the MAC layer of the radio stack and by relying on a two-way message exchange. The shortcoming of TPSN is that it does not estimate the clock drift of nodes, which limits its accuracy, and does not handle dynamic topology changes.

TinySeRSync [7] protocol works with the ad hoc deployments of sensor networks. This protocol proposed two asynchronous phases: Phase I –secure single-hop pair wise synchronization, and Phase II–secure andresilient global synchronization to achieve global time synchronization in a sensor network.

Van Greunen et al [9] Lightweight Tree-based Synchronization (LTS) protocol is a slight variation of the network-wide synchronization protocol of Ganeriwal et al. [8]. Similar to network-wide synchronization the main goal of the LTS protocol is to achieve reasonable accuracy while using modest computational resources. As with network-wide synchronization, the LTS protocol seeks to build a tree structure within the network. Adjacent tree nodes exchange synchronization information with each other. A disadvantage is that the accuracy of synchronization decreases linearly in the depth of the synchronization tree (i.e., the longest path from the

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node that initiates synchronization to a leaf node). Authors discuss various ideas for limiting the depth of tree; the performance of protocol is analyzed with simulations.

FTSP [10] proposed in 2004 and shown 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.

It is suggested in [11] that use of method of collecting (Clustering) and linear regression, reduces energy consumption of network. SLTP works in two phases, phase one concerns the configuration for static and dynamic network in which determines the node group leader and members The second phase allows timing synchronization network after selecting the group leader and then the network initiates the synchronization.

TSRT approach

In this Section we proposed Tree Structured Referencing Time Synchronization (TSRT) scheme [2] [12] [13], which aims to minimize the complexity of the synchronization. The synchronization accuracy is assumed as a constraint, and the targeted to achieve network wide synchronization with minimal complexity.

The goal of the TSRT is to achieve a network wide synchronization of the local clocks of the participating nodes. It is assumed that each node has a local clock exhibiting the typical timing errors of crystals and can communicate over an unreliable but error corrected wireless link to its neighbors. The TSRT synchronizes the time of a sender to possibly multiple receivers utilizing a single radio message time stamped at both the sender and the receiver sides. MAC layer time-stamping can eliminate many of the errors, as observed in [9]. However, accurate time-synchronization at discrete points in time is a partial solution only. Compensation for the clock drift of the nodes is inevitable to achieve high precision in-between synchronization points and to keep the communication overhead low. Linear regression is used in TSRT to compensate for clock drift as suggested in [4].

Ad Hoc Tree Construction Phase

Adhoc Tree Construction algorithm proposed in [14], is used to create a logical tree structure of network before the sensors can be synchronized. The first each sensor node floods the network to form a logical hierarchical structure from a designated source point. Each sensor is initially set to accept fd_pckt (flood packets) for first time, but will ignore subsequent ones in order not to be continuously reassigned as the flood broadcast propagates. When a node receives or accepts the fd_pckt then first it set to its parent as source of broadcast after that level of current receiver node will be assigned one more than the level of parent node and then it broadcast the fd_pckt along with node identifier and level. If a node receives the ack_pckt, the variable *no_receiver* increments to keep track of the node's receivers.

Time Synchronization Phase

The first component of TSRT's bidirectional time synchronization service is the push-based [15] Hierarchy Time Synchronization (HTS) Scheme. The goal of HTS is to enable central authorities to synchronize the vast majority of a WSN in a lightweight manner. This approach particularly based on pair wise synchronization with allusion to single reference node.

Single Reference Node

As shown in **Fig. 1,** HTS consists of three simple steps that are repeated at each level in the hierarchy. First, a Reference Node (RN) broadcasts a beacon on the control channel **(Fig. 1A)**. One child node specified by the reference node will jump to the specified clock channel, and will send a reply on the clock channel (Fig. 1B). The RN will then calculate the clock offset and broadcast it to all child nodes, synchronizing the first ripple of child nodes around the reference node (Fig. 1C). This process can be repeated at subsequent levels in the hierarchy further from the reference node (Fig. 1D). The HTS scheme is explained in more detail as follows:

Step 1: *RN initiates the synchronization by broadcasting the syn_begin message with time t1 using the control channel and then jumps to the clock channel. All concerned nodes record the received time of the message announcement. RN randomly specifies one of its children, e.g. SN2, in the announcement. The node SN2 jumps to the specified clock channel.*

Step 2: *At time t3, SN2 replies to the RN with its received times t2 and t3.*

Step 3.1: *RN now contains all time stamps from t1 to t4. It calculates clock drift* Δ *and propagation delay d, as per equation (2) and (3), and calculate* $t2 = t1 + \Delta + d$*, and then broadcasts it on the control channel.*

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***Step 3.2**: All involved neighbor nodes, (SN2, SN3, SN4 and SN5) compare the time t2 with their received timestamp t2'.*

i.e. SN3 calculates the offset d' as:

d' = t2 - t2'

Finally, the time on SN3 is corrected as:

T = t + d +d'

Where t is the local clock reading.

***Step 4:** SN2, SN3, SN4 and SN5 initiate the syn_begin to their downstream nodes.*

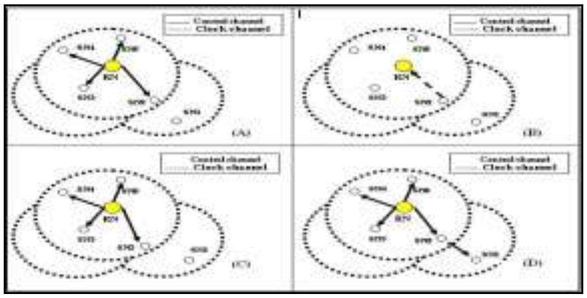

Fig. 1 (A) Reference node broadcasts (B) A neighbor replies (C) All neighbors are synchronized (D) Repeat at lower layers

We assume that each sensor node knows about its neighbors when it initiates the synchronization process. In Step 1, the response node is specified in the announcement. It's the only node that jumps to the clock channel specified by the RN. The other nodes are not disturbed by the synchronization conversation between RN and SN2 and can conduct normal data communication while waiting for the second update from the RN. A timer is set in the RN when the syn_begin message is transmitted. In case the message is lost on its way to SN2, the RN goes back to the normal control channel after the timer expires and thus avoids indefinite waiting.

As the synchronization ripple spreads from the reference node to the rest of the network, a multi-level hierarchy is dynamically constructed. Levels are assigned to each node based on its distance to reference node, i.e. number of hops to the central reference point. Initiated from the reference nodes, the synchronization steps described above are repeated by the nodes on each level from the root to the leaves.

Evaluation of TSRT

Synchronization protocols in WSNs differ broadly in terms of their computational requirements, energy consumption; precision of synchronization results, and communication requirements. In [16] [17] authors suggested, there is no protocol clearly performs the others in all possible applications of wireless networks. Relatively, it is quite likely that the choice of a protocol will be based on the characteristics and requirements of each application.

This section presents a performance comparison study TSRT with various synchronization algorithms for WSN's based on different principal factors such as the accuracy, the energy efficiency, the mobility and the complexity which is verified theoretically with the existing results.

It is important to note that the recent works as well as TSRT, SLTP, FTSP have dealt with the problems of mobility and energy consumption, which is major attraction to provide the efficient solution for synchronization in WSNs. Table-1 summarizes, the performance comparison study of the most common protocols and analyzes the performance differences based on different principal factors and functionalities.

Comparison study has shown that FTSP and TSRT prove good results not only on a fixed networks hierarchy but updates it dynamically; it supports network topology changes including mobile nodes. Other solutions that provided high precision are the SLTP and TPSN. RBS or popular synchronization algorithms are based on fixed architecture of networks, which is cause for High energy consumption. LTS protocol which requires high power because the nodes used to discipline the local time of the nodes in the network, this value increases if working in a mobile network and characterized by a high complexity. LTS is as important as the aforementioned solutions, but because of its high energy consumption it is not very effective as it requires a physical clock correction to perform on local clock of sensors while achieving synchronization. TSRT achieved a long-term network-wide synchronization with minimal message exchanges and exhibits a number of attractive features such as fixed networks hierarchy but updates it dynamically, highly scalable, lightweight and energy efficient.

Table 1. Performance Comparisons of Protocols.

Protocols	Accuracy	Energy Efficiency	Overall Complexity	Mobability
RBS 2002	High	Low	High	No
TPSN 2003	High	High	Low	No
LTS 2003	Average	Low	Low	Yes
FTSP 2004	High	High	High	Yes
TinySeR Sync 2006	High	High	Low	No
SLTP 2007	High	High	Average	Yes
TSRT 2011	High	High	Low	Yes

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Experimental Results

In our research work we compare TSRT with RBS and TPSN protocol in terms of number of messages required to synchronize the entire network. In our study, we constructed logical network models for single hop four nodes network and multi-hop nine nodes network model. These network models applied for TSRT and step wise number of message exchanges required to synchronize the entire network are counted. The same network models are applied for RBS and TPSN schemes, to count the number of message exchanges required to synchronize the network. Finally the comparison with existing scheme are presented.

Fig. 2 summarizes that TSRT required reduced number of message exchanges to synchronize the network. In TSRT only elected node from each level of network hierarchy participated in message exchanges, therefore, through TSRT it is possible to synchronize any arbitrary number of nodes in the nework with reference to elected node's clock with only three Packet Transmissions. TSRT is suggested more precise, low complex, scalable and energy efficient approach which shows that proposed approach is an excellent conciliation among synchronization accuracy, computational complexity and convergence time.

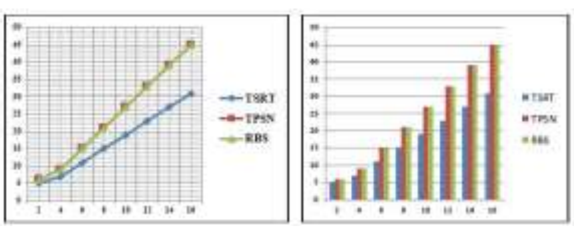

Fig. 2 Number message exchange required vs number of nodes in WSN

Conclusion

WSNs have tremendous advantages for monitoring object movement and environmental properties but require some degree of time synchronization to achieve the best results. The proposed TSRT synchronization approach is able to produce deterministic synchronization with only few pair wise message exchanges. It is also shown that TSRT approach is especially useful in WSNs which are typically, extremely constrained on the available computational power, bandwidth and have some of the most exotic needs for high precision synchronization. The TSRT approach was designed to switch between TPSN and RBS. These two algorithms allow all the sensors in a network to synchronize themselves within a few microseconds of each other, while at the same time using the least amount of resources possible. In this work two varieties of the algorithm are presented and performance is verified with the existing results and compared with existing protocols. The experimental result is drawn using logical models of networks. The comparison study shows that the proposed synchronization approach is lightweight since the number of required broadcasting message is constant in one broadcasting domain to synchronize the entire network.

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