An Accurate Global Time Synchronization Method in Wireless Sensor Networks

Bilal Ahmad(✉), Ma Shiwei, Fu Qi, Wang Meixi, and Rui Ling

Shanghai Key Laboratory of Power Station Automation Technology,
School of Mechatronics Engineering and Automation,
Shanghai University, No. 149, Yanchang Road, Shanghai 200072, China
{abilali,masw}@shu.edu.cn,
{18818218275,meixifly,ruiling0812}@163.com

Abstract. Time synchronization is a hot research topic for data fusion, localization, duty cycle scheduling, and topology management. Global time synchronization is preferred to bring all sensor nodes of a wireless sensor network (WSN) on a common notion of time in the applications (surveillance and target tracking) where coordinated actuation and cooperative communication is desired for the meaningful coordination and data consistency. In this study we proposed an accurate global time synchronization method in WSNs based on a single reference node. We have checked its performance in terms of accuracy and simulation results prove it accurate as end to end latency and jitter decrease as the number of observations increase.

Keywords: Time synchronization · Wireless sensor networks · Accuracy · End to end latency

1 Introduction

1.1 Basics of Wireless Sensor Networks

Sensor is a tiny device with a small hardware and very limited memory. It runs on a minute battery. It changes a physical phenomenon into a signal for its meaningful processing. Sensor nodes being smaller and cheaper, and because of their various usages are rapidly making their place in the present day scientific technology like MEMS (Micro Electro Mechanical System). We can monitor the condition at any location with the help of these small sized devices. Architecture of a wireless sensor node is represented in Fig. 1.

A sensor network is composed of sensor nodes, sink, sensor field and controller. Nodes operate by gathering and routing the information before transferring it to the sink. A simple WSN architecture is shown in Fig. 2. The information is transferred in very few messages leading to reduced energy consumption. WSNs have both advantages as well as disadvantages. Among the advantage, their implementation cost is less, the network may be deployed anywhere and they can be monitored through a global monitoring system. The disadvantages include inadequate security, difficulty in configuration and reduced speed as compared to a wired network. Sensor nodes which are densely

L. Zhang et al. (Eds.): AsiaSim 2016/SCS AutumnSim 2016, Part I, CCIS 643, pp. 17–24, 2016.
DOI: 10.1007/978-981-10-2663-8_2

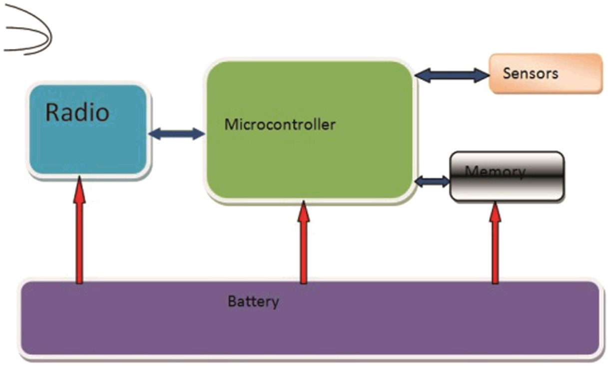


Fig. 1. Architecture of a wireless sensor node

deployed, deployment may be random or deterministic, for deterministic deployment routs are predefined while for premier case it's really very challenging. Few of them are control nodes also referred as base stations. These nodes are connected with each other wirelessly and base station connects them with some other network.

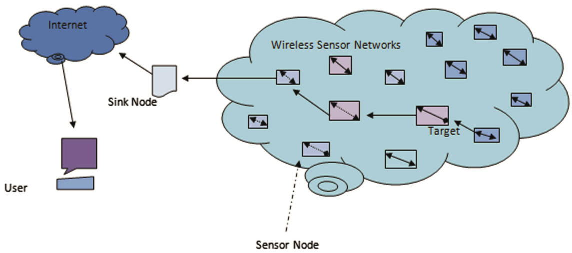


Fig. 2. Architecture of a wireless sensor network

1.2 Time Synchronization and Its Pre-requisites

Time synchronization is the backbone for almost all wireless sensor network applications. Because if the ordering of event is not correct, there is delay in transmission or nodes are not synchronized with each other, then information packet will be lost. For low duty cycle applications and time related events nodes must keep precise time synchronization for significant information processing. They should sleep and awake together so that periodic messages exchange can hold successfully, otherwise duty cycle will be high and more energy will be consumed as number of timing messages increase. Time synchronization protocols should more or less fulfill the following characteristics:

Scalability: Some WSNs applications require hundreds and thousands of nodes. Time synchronization protocols should be scalable to be implemented on larger networks.

Robustness: Time synchronization protocols should be robust, as robustness also increases quality of service.

Energy efficiency: Energy is a big concern for sensor nodes as they have small batteries. For their long life operations energy efficient time synchronization protocols are required to be designed.

Accuracy: Law enforcement applications (object tracking and battlefield surveillance) need accurate time synchronization protocols. Because basic demand of such applications is reduced end to end latency and reduced jitter.

Flexibility: The wide ranges of applications require flexible and adaptive time synchronization mechanism. Each application demands a different behavior so time synchronization protocol must be flexible to cope with each application for meaningful processing of data.

Security: Wireless nodes are prone to faults and data fetched by them is easily accessible by attackers so time synchronization protocols should be secure. Researchers these days are paying attention on it with high level encryption and decryption keys. Due to the failure of sensor nodes the network topology may change, so time synchronization algorithms must be dynamic so that network operation is not affected.

Our proposed method adopts centralized synchronization mechanism. Because it is easy to control centralized synchronization schemes to achieve maximum benefits and the centralized synchronization methods are not topology sensitive. Root/reference node broadcasts timing message to the other node residing in its communication range, which compares its clock value and adjusts its clock with the root node's local clock value. Then it sends ACK message to the root node. To reduce the round trip time; second node shares root node's timing information and computed offset value to the next hop and other nodes set their local clock upon global time initiated by the root node. By means of similar approach whole network get synchronized through periodic messages exchange.

The rest of the paper is organized as: Related work is discussed in Sect. 2, measurement model and simulations are represented in Sect. 3, and finally research work is concluded in the Sect. 4.

2 Literature Review

Time synchronization is essential for TDMA based applications like, duty cycling, data fusion and object tracking. This is an operation in which it is ensured that all physical distributed processors are functioning at a common notion of time. This function is useful for security and fault tolerance. The data of all nodes is collected in order to arrange a meaningful result. That is why clocks are synchronized at a common time. Two basic features must be taken into account for stable/useful time synchronization i.e. clock offset and clock skew. Figure 3 represents the time synchronization phenomenon.

Clock of a sensor node is shown in Fig. 4. Frequency is measured instead of time in time keeping scenarios. In ideal cases time intervals between the events are constant but in practical situations different clocks exhibit different time due to their internal properties of the local oscillator and manufacturing. Due to the defects in crystal oscillator, local clocks of the sensor nodes drift from each other and clock offset increases linearly between the nodes. For accurate fetching of information data sensed by a sensor node

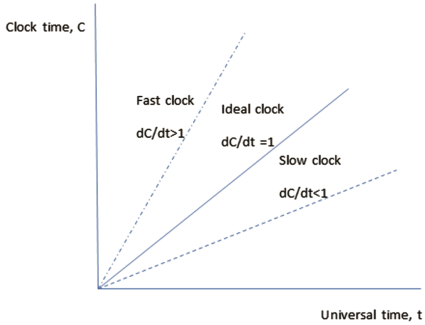


Fig. 3. Time synchronization

is required to be time stamped. This time stamping is either performed at the time of information collection or at the time of collected data processing.

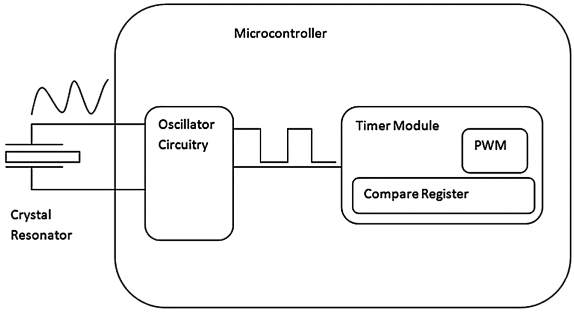


Fig. 4. Clock structure of a sensor node

Time synchronization is the fundamental problem of the WSNs due to the resource constraints WSNs (smaller hardware and limited energy at the end sensor node). Local clocks of the sensor nodes must be synchronized not only because of specific application requirements but for the channel access also [1]. Nodes use crystals to count the frequencies and various factors (e.g. aging, temperature, environmental factors) affect it as a result local clocks of the nodes run at different rate so there is natural difference in the clock of two nodes [2].

There are three basic ways to synchronize the clocks of the sensor nodes (a) via an intermediate node [4], (b) through pairwise synchronization assuming that clock drift and clock offset are linear as mentioned in [3] and (c) through a leader and all other nodes synchronize their clocks upon it [5].

Getting accurate time synchronization in the presence of non-deterministic delays is very difficult. The delays are categorized as send time, access time, transmission time, propagation time and reception time [3, 4] and these uncertainties are minimized by MAC layer time stamping [3, 5]. Accurate time synchronization protocols are under research these days due to their verity of application for the efficient completion of their operations [6–8]. Higher accuracy is achieved in [9] through lower communication overhead and topology is maintained stable through resynchroniztion mechanism. In [10] authors conducted a brief survey to represent the secure time synchronization in hostile environment where compromised/malicious nodes may exist.

3 Performance Evaluation

In this section we present the system model for time synchronization to achieve high accuracy through a new messages exchange mechanism, which has low messages complexity. Moreover we will discuss the simulation results and discuss the reduced end to end latency with the passage of number of rounds of messages exchange.

3.1 Synchronization Framework

Node A is the reference node and is responsible for the mutual time consensus in the sensor network. It broadcasts timing information to the node B which compares and adjusts its clock value as per the received timing information and sends acknowledgment back to the root node. Meanwhile to reduce burden on the root node, node B shares the computed values to the next hop and node C also adjusts its time on the global time. Synchronization procedure is represented in Fig. 5.

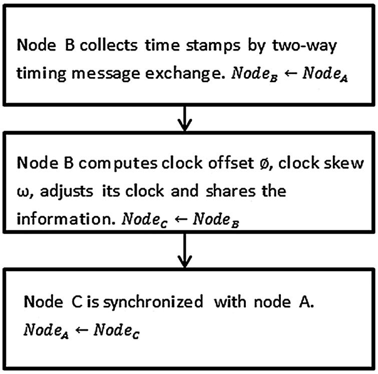


Fig. 5. Flowchart representation of the proposed scheme

Messages exchange mechanism for the communicating nodes is described in Fig. 6 below.

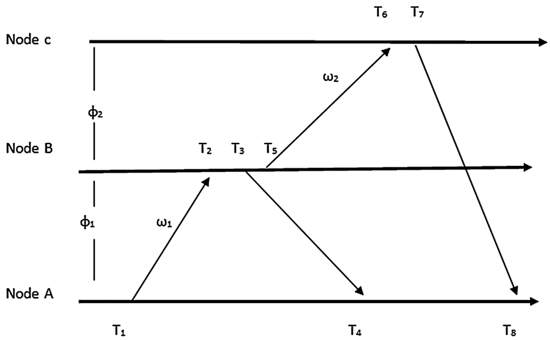


Fig. 6. Timing messages exchange mechanism

Where Ø1 is the phase/clock offset between node A and node B whereas Ø2 is the clock offset between node B and node C. Similarly ω1 represents the clock skew between node A and node B while ω2 is the clock skew between node B and node C. The general clock equation is shown below:

$$T(t) = \emptyset + \omega t \tag{1}$$

Clock offset is the delay of a clock source. It may be known or unknown and it is measured in time units. Every sensor node has its own internal clock and due to manufacturing defects clocks may differ from each other and it produces clock skew. In other words clock skew is the time gap between actual arrival of the clock and the expected arrival. It is measured in parts per million (ppm).

Clock offset between the two nodes is defined in Eq. 2 and T represents local (send/receive) time at the nodes.

$$\emptyset = \frac{(T2 - T1) - (T4 - T3)}{2}. \tag{2}$$

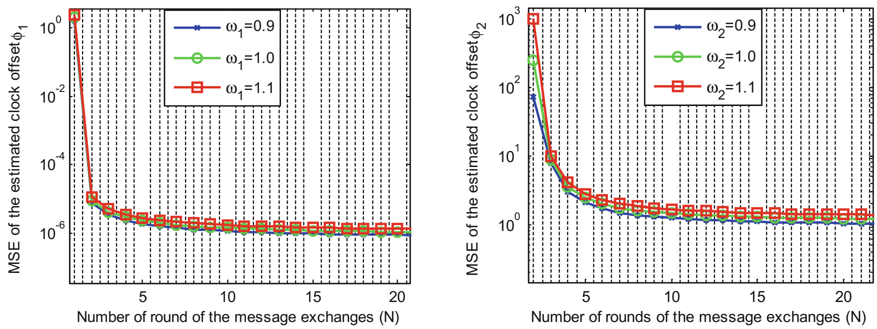
3.2 Simulations and Discussions

Simulations are carried out through MATLAB for the set of communicating sensor nodes shown in Fig. 6. The parameters set up for the simulations are shown in Table 1.

Table 1. Simulation parameters

Parameter	Symbol	Values
Number of observations	N	25
Fixed propagation delay	d	0.2–0.6
Clock offset	$\emptyset_1$ and $\emptyset_2$	1.5–3
Clock skew	ω_1 and ω_2	0.9–1.1

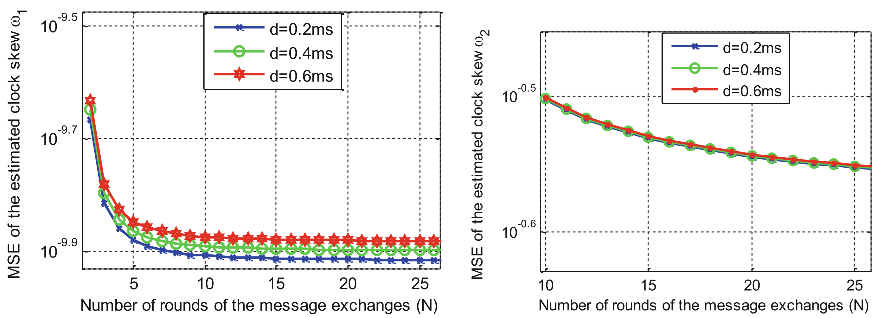
As mean square error (MSE) is the better performance index to judge the performance of any proposed estimator. Figure 7 illustrates the MSE of the estimated clock offset Ø1 and Ø2 versus the number of rounds of messages exchange. Curves in both plots for the values (0.9, 1.0, and 1.10) of ω1 and ω2 clearly show that the MSE of the estimated clock offset have decreasing pattern and converges as long as the number of rounds of messages exchange increase and it establishes the effectiveness of proposed method. It is also obvious the simulation results prove the fact that the MSE of the clock offset is directly related to the clock skew values i.e. higher is the clock skew value, higher will be the MSE of the estimated clock offset and vice versa. MSE of the clock offset is lowest without clock skew error (ideal case: for ω = 1).



(a)MSE of the estimated clock offset $Ø_1$ (b) MSE of the estimated clock offset $Ø_2$

Fig. 7. MSE of the estimated clock offset

The MSE of the estimated clock skew ω1 and ω2 versus the number of rounds of messages exchange is shown in the Fig. 8. The fixed propagation delay *d* is set to 0.2 ms, 0.4 ms and 0.6 ms. We can see from both the figures that MSE of the clock skew converges with the passage of timing rounds. From the MSE of the estimate clock skew another fact is also validated that the distance between the nodes is directly concerned with the fixed propagation delay. Larger is the distance between sensor nodes higher will be the fixed propagation delay and higher is the MSE of the estimated clock skew.



(a) MSE of the estimated clock skew ω_1 (b) MSE of the estimated clock skew ω_2

Fig. 8. MSE of the estimated clock skew

4 Conclusions and Future Work

This paper presents the performance of our proposed method during round trip synchronization. The proposed method is computationally simple, includes skew compensation even for the higher values of the clock skew like 1.10, accurate and easy to implement. It is obvious from the simulations that it reduces end to end latency and convergence pattern of the MSEs, reflects that our method deals the jitter in an efficient way. Message complexity is low and as a result accuracy is high. Simulation results clearly validate the facts i.e. (i) MSE of the estimated clock offset $\propto$ clock skew and (ii) The fixed propagation delay $\propto$ MSE of the estimated clock skew.

As our future work we are focusing on robustness for the topology changes, accuracy and energy consumption tradeoff during the synchronization periods and evaluation of non-deterministic delays.

Acknowledgement. This work was financially supported by Shanghai Science and Technology Foundation (13510500400).

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http://www.springer.com/978-981-10-2662-1

Theory, Methodology, Tools and Applications for
Modeling and Simulation of Complex Systems
16th Asia Simulation Conference and SCS Autumn
Simulation Multi-Conference, AsiaSim/SCS AutumnSim
2016, Beijing, China, October 8-11, 2016, Proceedings,
Part I

Zhang, L.; Song, X.; Wu, Y. (Eds.)

2016, XXXV, 711 p. 159 illus., Softcover
ISBN: 978-981-10-2662-1