# Diverse Synchronization issues in Wireless Sensor Networks

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***Résumé*—clock synchronization gained momentum in the recent years and became a part and parcel in the deferents distributed system including wireless sensor network, and extended its application to a sundry of industries and application fields such as military, medical, transportation to name a few. This article propose an in depth study and analysis of the different problems and hardware limitations that may be encountered and lead to the malfunctioning or non-accessibility to seamless Wireless network, hence, putting its uptime reliability in jeopardy. This paper emphasis the role of clock synchronization in a number of fundamental operations that enhances the stability between sensors and ultimately increase the lifetime and stability of wireless sensor networks. In addition, it provides an insight and reference guide for future researches to tackle time synchronization issue from a different angle(Clock drift) to suggest a practical and viable trouble shooting guides and solutions.**

**Key Words : Clock synchronization, Wireless Sensor Network, Synchronization Problem.**

## I. INTRODUCTION

Wireless sensor networks (WSNs) have received an increased attention due to their promising applications in a variety of areas such as traffic monitoring, surveillance, acoustic and seismic detection, environmental monitoring, etc [13]. The ultimate objective of synchronization is to offer a solution that keeps a stability between the sensors throughout the network operation. Synchronization is ranked among the major problems of research in distributed system including sensor networks, the majority of research has been focused on the study protocol and algorithms that addresses these issues to resolve.

Clock synchronization has an essential role in a number of fundamental operations, such as power management, data fusion, and transmission scheduling[25]. Time synchronization in a wireless sensor network is important for routing and power conservation. The lack of time accuracy can significantly reduce the network's lifetime. Global time synchronization allows the nodes to cooperate and transmit data in a scheduled manner. Energy is conserved when there are less collisions and retransmissions There are several reasons for addressing the synchronization problem in sensor networks. First, sensor nodes need to coordinate their operations and collaborate to achieve a complex sensing task. Data fusion is an example of such coordination in which data collected at different nodes are aggregated into a meaningful result. For example, in a vehicle tracking application, sensor nodes report the location and time at which they sense the vehicle to a sink node that in turn combines this information to estimate the location and velocity of the vehicle. Clearly, if the sensor nodes lack a common timescale (i.e., are not synchronized) the estimate will be inaccurate[17].

Second, synchronization can be used by power saving schemes to increase network lifetime. For example, sensors may sleep (go into power-saving mode by turning off their sensors and/or transceivers) at appropriate times and wake up when necessary. When using power-saving modes, the nodes should sleep and wake up at coordinated times, such that the radio receiver of a node is not turned off when there is some data directed to it. This requires precise timing between sensor nodes.

The rest of this article is organized as follows. We describe a model of computer clocks and study most common existing time synchronization approaches . We also present common sources of error/inaccuracy in synchronization systems in this section. We present motivations for studying time synchronization in sensor networks. The conclusions of our article are given in Section 6.

## II. RELATED WORK

There is no optimum resolution which resolve all constraints together but it address only one specific constraint at a time. Although this specification does not always give an answer to the original hypotheses or expected results, which give a significant importance to the synchronization issue.

Most of the work on synchronization in ad-hoc networks has concentrated on delay uncertainty ; recent algorithms reduce it to a few microseconds [1], [2], [3], [8]. They then achieve good synchronization by continued and frequent communication, which keeps the impact of clock drift negligible.

Time synchronization in sensor networks has attracted attention in the last few years. Such diversity of sensor network applications translates to differing requirements from the underlying sensor network. To address these varying needs, many different network models have been proposed, around which protocols for different layers of the network stack have been designed. We started with older protocol like Network Time Protocol(NTP) proposed by Mills[10]. The NTP clients synchronized their clocks to the NTP 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 resources, typically using GPS.

Most of the work on synchronization in ad-hoc networks has concentrated on delay uncertainty, recent algorithms reduce it to a few microseconds like :

Reference Broadcast Synchronization [8], every node keeps the relative drift between its local clock and every other clock in the network. By comparing the timestamps of periodic broadcast messages, the nodes calculate the clock offsets between the receiving nodes, thus successfully eliminating any transmit latencies. Only processing delay at the receiver and the difference in propagation delay between the nodes are potential error sources.

Timing-Sync Protocol for Sensor Networks (TPSN) [1] aims to provide network-wide time synchronization is based on similar methodology as the NTP. The TPSN algorithm elects a root node and builds a spanning tree of the network during the initial level discovery phase. In the synchronization phase of the algorithm, nodes synchronize to their parent in the tree by a two-way message exchange. Using the timestamps embedded in the synchronization messages, the child node is able to calculate the transmission delay and the relative clock offset. However, TPSN does not compensate for clock drift which makes frequent resynchronization mandatory. In addition, TPSN causes a high communication overhead since a two-way message exchange is required for each child node.

the lightweight tree-based synchronization (LTS) protocol [3], [26], is to minimize the complexity of the synchronization. The scheme assumes that there are some reference points which have the accurate time in the network. It is also assumed that the clock drift rates are bounded. Based on these assumptions, two synchronization algorithms are proposed to synchronize nodes in pairwise. The first one is a centralized scheme, where a spanning tree is constructed from the reference point (the root of the tree). Then pairwise synchronization is done from the root to the leaves. The other algorithm is a distributed algorithm in which a node gets synchronized on demand by sending a synchronization request to the reference point. All the nodes along the route will get synchronized.

The goal of The Flooding Time Synchronization Protocol (FTSP) [2], to achieve network-wide time synchronization with error in the micro-second range and scalability up to hundreds of nodes, while being robust to network topology changes and link and node failures. The proposed algorithm compensates for the relevant error sources by utilizing the concepts of MAC layer time-stamping and skew compensation with linear regression.

## III. NETWORK RELATED PROBLEM

There are several reasons to study in detail the problems of synchronization in wireless sensor network :

First, the clock of different n device must be set at the same reference time. To work better this time scale, we must synchronize the clock of each node has a reference time source. So the local time provided for each system element must be the same.

Synchronization plays an important role in wireless sensor networks because it allows the entire system to cooperate and accomplish a complex task of data transfer. So, we can cite as an example of this coordination the data collected at different nodes which are grouped into is a significant result despite the difference of the clocks of the nodes of the system and this difference was due as a result of the nodes represents different times and can begins to communicate a different times. In addition, the clock variable may change over waiting because of environmental conditions. Second, synchronization can be used to save energy to increase the lifetime of the network. for example, the sensors can sleep at appropriate times and wake up if necessary. When is the aim of saving energy, the nodes must go to sleep and wake-up time interval ordinates such as the radio receiver of a node that has not put out that there are data that are sent and 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, NTP (Network Time protocol) that works well on Internet to synchronize computers not intended because needs a large energy. Thus, GPS (Global Positioning System) can be too expensive to be fixed on a low-cost devices and services not be available everywhere as well as inside buildings or under water. Also in some middle GPS can not be trusted.

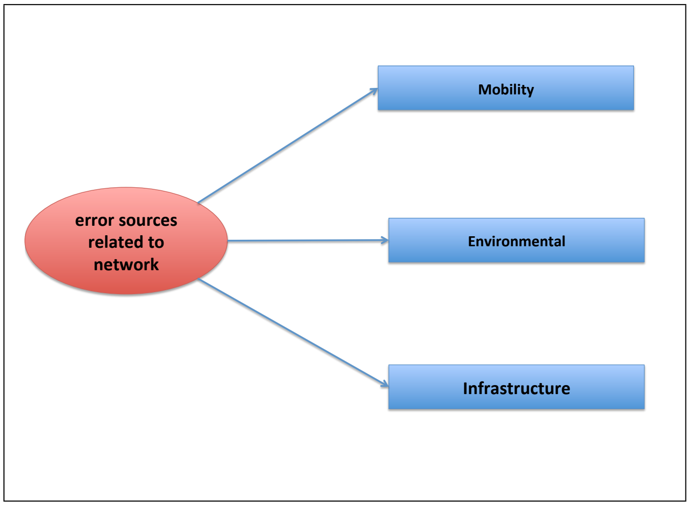

FIGURE 1. Main error sources related to network

### A. *Mobility*

hese constraints exists especially in the aquatic environment (submarine) Which is characterized by deteriorating Movements. The binding nature of the mobile environment imposes several challenges faced by mobile units which needs to be whitewashed. Indeed, thesis units must be very effective for coordination and exchange of messages perspective between the different units despite the changes in architecture / topology. For example The communication range of the mobile sensors is very limited (Roughly 20 to 100 m), Which Makes message exchange between sensor nodes difficult. Of course, the Internet suffers from quick link failures, but it works most of the time.

Mobile units must have the possibility to discover automatically and independently the parameter allowing them to integrate into the mobile environment and are capable to self-configure to become operational without any administrator intervention.

In addition, these units must have all the necessary knowledge necessarily related to their location and operating environment textbfLocation and Context Awareness, adaptability to changing conditions of communication channels **Time Varying Radio Channels** Is another important feature of their mobile units that can operate in irregular environments.

Finally, the security, as much as it is important in the wired network, it is of paramount importance in mobile wireless networks. It includes both the protection of data against loss and corruption(integrity), as well as its confidentiality. However, the conventional techniques (encryption, signature, SSL certificates...) used in fixed environments is still far from evident in mobile networks.

### *B. Hardware limitation*

Depending on the size of the sensor we may confront materiel problems that limit predicted goals and utilization scope, which is mainly due to low storage capacity and limited battery life duration, for instance a typical sensor node like the Berkeley Mica2 mote [7] has a small solar battery, an 8-bit CPU that runs at a speed of 10MHz, 128KB to 1MB memory, and a communication range of less than 50 meter.

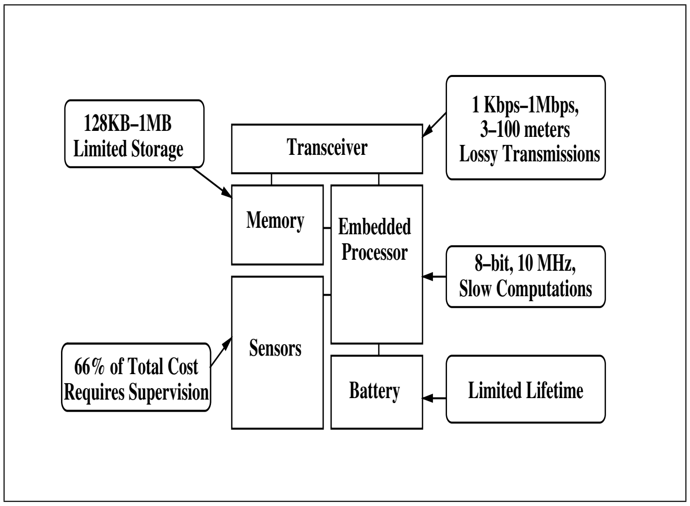

FIGURE 2. Sensor node hardware for Mica mote[7]

### *C. Environmental Problems*

It is among the constraints that must not be forgot as these effects touch every distributed system including sensor network. We detail these effects with some illustrative example, such as temperature adversely affects the quality of synchronization since it touches electronic components such as oscillator. The frequency generated by a quartz oscillator is affected by a number of environmental factors : the voltage applied to it, the ambient temperature, acceleration in space (e.g., shock or attitude changes), magnetic fields, and so forth. More subtle effects as the oscillator ages also cause longer-term frequency changes. The inexpensive oscillators commonly found in computers have a nominal frequency accuracy on the order of between $10^4$ to $10^6$ N that is, two similar but un-calibrated oscillators will drift apart between 1 and 100 microseconds every second, or, between about 0.1 and 10 seconds per day. In view to the large price bracket, ranging from as little as few dollars for the low stability oscillators used in digital circuit boards, to an exorbitantly high price tag for the finest stability temperature controlled devices, makes crystal oscillators an ideal solution for many applications.

Although, the XO's presents drawbacks such as the temperature dependence ( 1 x $10^6$/ $C^\circ$), and the large aging rate ( as big as $10^6$ / Day). The usage of improved clean room techniques and careful attention to crystal mounts and housings, may mitigate the latter disadvantage and bring the aging rates down to as small as 2 x $10^{11}$ / Day, hands making it less expensive and smaller than oven controlled oscillators.

As regards to the problematic of temperature sensitivity, it can be addressed by temperature compensation(or control). A temperature compensated crystal oscillator(TCXO) offer excellent temperature characteristics with low power consumption and fast warm-up(stabilization), and usually uses temperature dependent components external to the resonator in order to closely cancel the temperature related frequency to 1 37° Celsiusx $10^7$ / Day over 50° temperature range, providing a much higher levels of temperature stability than are possible with a normal crystal oscillator.

The temperature dependence of a TCXO it is not linear, it is usually quoted as a maximum change over a temperature range, instead of a coefficient, since the temperature coefficient of the crystal changes with temperature, and the slope may vary considerably over temperature range of interest[6], [7].

The challenge for underwater sensor nodes is sensor node failure due to environmental conditions. Underwater sensor nodes must be able to self-configure and adapt to harsh ocean environment.

### *D. Infrastructure*

For several applications, sensor Networks have to be deployed in complex conditions which impacts its proper functioning and reception of signals, for example GPS receiver requires the undisturbed signal from at least 4 GPS satellites. These signals propagate from the satellite to receiver antenna along the line of sight and can not penetrate water, walls, or other obstacles very well. therefore GPS can not be used for subsurface marines, navigation for underground positioning, and surveying ? for example in mines and tunnels, the signal can be obstructed by trees, buildings, and bridges.

In many cases this signal shading will be transitory, and therefore will not severely hamper positioning. However, the signal can be obstructed for extended period of time or even continuously unavailable, hence, can severely impact signal integrity.

Another example that clearly explains the constraints is the Network Time Protocol(NTP) as proposed by Mills[10]. The NTP clients synchronized their clocks to the NTP time servers which are typically using GPS.

## IV. CLOCK ISSUES

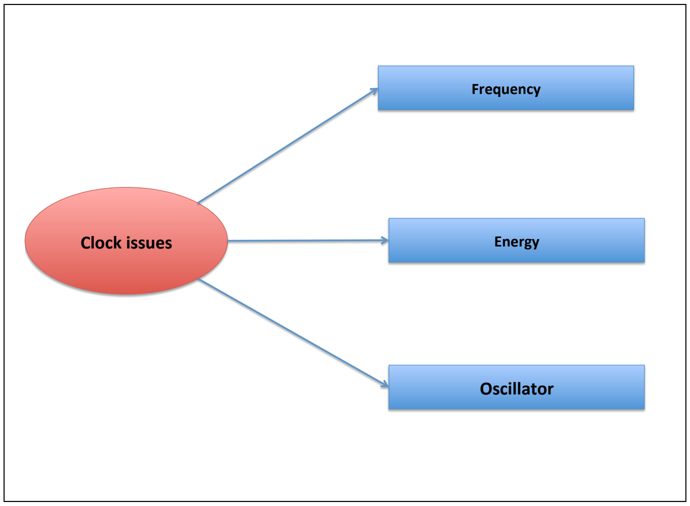

FIGURE 3. Main error sources related to network

### A. *Oscillator & Frequency*

The main problem of synchronization is to guide all the clocks so that every moment has shown that the same time meaning you to give all nodes in networks a common time scale.

The time of a computer clock is measured as a function of the hardware oscillator.

$$C(t)=K \int_t^{t_0} w(\tau)d\tau + (Ct_0)$$

Where $w(\tau)$ is the angular frequency of the oscillator, *k*is a constant for that oscillator, and *t* is the time. the change of the value $Ct_0$ leads to the events that can be captured by the sensor.

The clocks in a sensor network can be inconsistent due to several reasons.

1) The quartz crystals at each of these nodes might be running at slightly different frequencies, causing the clock values to gradually diverge from each other (termed as the skew error).
2) The nodes in a sensor network may not be synchronized well initially, when the network is deployed.
3) The sensors may be turned on at the different times and their clocks may be running according to different initial values.
4) The frequency of the clocks can change variably over time because of aging or ambient conditions such as temperature (termed as the drift error).

The results of events on specific sensors may also affect the clock. For example, the Berkeley Mote sensors may miss clock interrupts and the chance to increase the clock time value when they are busy handling message transmission or sensing tasks[23].

### B. *Energy*

The only way to have energy for wireless sensor network is by using a small batteries with limited power source(<5 Ah, 1.2v)[17] from this feature we can notice that we are face to face with limited energy. So the limited time present some constraints of interrupted routing information that represent a complementary relation between energetic conservation and synchronization to increase the life time of the network. In addition, energy is saved when nodes are duty-cycled[9](Sensor nodes are duty-cycled to save energy. In duty-cycle, the sensor node would periodically turn its radio off to save energy and on to participate in network communication.)

the energy constraints on sensor nodes require that the necessary improvement in synchronization be achieved while at the same time limiting message overhead. Several time synchronization algorithms are provided here that try to meet these goals simultaneously. Some synchronization schemes require extra, energy-hungry equipment (e.g, GPS receivers). Others may have virtually no energy impact (e.g, listening to existing packets already being transmitted for other reasons). the energy spent synchronizing clocks should be as small as possible, bearing in mind that there is significant cost to continuous CPU use or radio listening.

Energy efficient protocols are designed to minimize the energy consumption for network activity. Therefore, sensor network architectures and applications, as well as deployment of strategies, must be developed with low energy consumption as one of the important requirements. We can dispose the example of The hybrid algorithm proposed in [10] chooses RBS over TPSN based on receiver threshold and number of receivers. The results from Table 3.1. show that RBS's energy consumption is more dependent on the density of sensors in a given area. In contrast, TPSN and the hybrid algorithm are less affected by the size of the network. When the network size increases from 250 sensors to 500 sensors (for the same area of 1 km2), RBS becomes less energy efficient than TPSN. The hybrid algorithm still outperforms TPSN by 12.7 %. Since RBS consumes more energy, the hybrid algorithm now outperforms it by 32%. Hybrid algorithm, the power reduction is even more drastic in large multi-hop sensor networks.[10], [11].

## V. OTHER REASONS

### A. *Limited bandWidth*

Typically, Wireless Sensor Network operating in areas larger than the radios of diffusion of a node, over the wireless communication is restricted to a data rate in the order of 10-100 Kbits/second such as Pottie and kaiser showed [22], [23] the energy required to transmit 1 bit over 100 meters, which is 3 joules, can be used to execute 3 million instructions.

TABLE I
AVERAGE ENERGY CONSUMPTION (MW) IN RBS, TPSN AND HYBRID SYNC METHODS[13]

| | AVERAGE ENERGY CONSUMPTION | | | |
|---|---|---|---|---|
| #Sensors | 250 | 500 | 750 | 1000 |
| RBS | 446 | 1046 | 1844 | 2762 |
| TPSN | 511 | 983 | 1434 | 1885 |
| Hybride | 404 | 828 | 1253 | 1672 |
| Saving over RBS | 9.29% | 20.8% | 32.0% | 39.4% |
| Saving over TPSN | 20.8% | 15.7% | 12.7% | 10.1% |

This bandwidth limitation affects directly on the exchanges of messages between the sensors and timing. For example a challenge in underwater acoustic communication is the limited bandwidth, long propagation delay, and signal fading issue.

### *B. Uncertainties In Radio Message Delivery*

Non-deterministic delays in the radio message delivery in WSN can be magnitudes larger than the required precision of time- synchronization. Therefore, these delays need to be carefully analyzed and compensated for. We shall use the following decomposition of the sources of the message delivery delays. The authors in (Kopetz et al, 1989) divide them into four different categories[3], [21] :

- Send Time : time used to assemble the message and issue the send request to the MAC layer on the transmitter side. Depending on the system call overhead of the operating system and on the current processor load, the send time is nondeterministic and can be as high as hundreds of milliseconds.
- Access Time : delay incurred waiting for access to the transmit channel up to the point when transmission begins. The access time is the least deterministic part of the message delivery in WSN varying from milliseconds up to seconds depending on the current network traffic.
- Transmission Time : the time it takes for the sender to transmit the message. This time is in the order of tens of milliseconds depending on the length of the message and the speed of the radio.
- Propagation Time : the time it takes for the message to transmit from sender to receiver once it has left the sender. The propagation time is highly deterministic in WSN and it depends only on the distance between the two nodes. This time is less than one microsecond (for ranges under 300 meters).

### *C. Overhearing*

It occurs when node receives data packets which he is not the destination. Thus, it utilizes energy to received signals which are useless. To meet the energy needs of sensor network MAC protocols must take into account these sources of loss in trying to limit.

### *D. Transmission Media*

In a multihop sensor network communicating node are linked by a wireless medium. These links can be formed by radio infrared or optical media. To enable global operation of these networks the chosen transmission medium must be available worldwide. Much of the current hardware for sensor node is based on RF circuit design.

The AMPS wireless sensor network use a Bluetooth compatible 2.4GHZ transceiver with an integrated frequency synthesizer.

Another mode of internode node communication exist in sensor networks is by infrared.

### *E. Collisions*

If two or more nodes transmit messages simultaneously, interference (collision) will take place which requires retransmissions resulting high energy-consuming. Take the example of two nodes N1 and N2 which communicate through mediator(N3) because distance between N1 and N2 is greater than their coverage area, both the nodes N1 and N2 are in range and can communicate with node N3 seamlessly. In this case, if N1 and N2 want to simultaneously send data to node N3, a packet collision will take place as N1 and N2 determine that the channel is free as a result they do not see. In the literature, this phenomenon is called Hidden station[23]. To avoid collisions, several protocols use control packets by performing a coordination between the net[17].

## VI. SOLUTION VERSUS SYNCHRONIZATION PROBLEMS

In this section, we propose the efficiency of the most common solutions (algorithms) and Cause/Effect analyzes of the major glitches preventing the detectors proper functioning, and which among them managed to overcome many of these constraints. Many different network models have been proposed we started with the most robust solution against the big number of issues. FTSP prove a good precision despite failures link and dynamic topology, it save the initial phase and establishing the tree with high energy efficiency with less resources then other solution in same categories like TPSN and RBS. Also FTSP prove a good results not only on a fixed network s hierarchy but updates it continuously, it supports network topology changes including mobile nodes.
Another solution that provided high precision is the TPSN. Although it provided a good precision in order of $16.9\mu s$ , still the TPSN operates on a fixed infrastructure (hierarchical structure), structure increases as consumption increase.
RBS or popular synchronization algorithm are characterized by ability to eliminate the uncertainty of sender by removing the sender from the critical path(way of sending) that give value of precision with a value of High energy consumption over RBS gives good results with the fixed architecture of networks.
Another protocol proposed by which requires high power because the stations(nodes of Networks) 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 (i.e. the number of messages exchanged during synchronization). A third synchronization algorithm 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 performed on local clock of

sensors while achieving synchronization. In addition, it is not recommended to use in mobile networks because it requires a hierarchical infrastructure with high mobility. The simulation results show that the accuracy of LTS is about 0.5 seconds.

Like DMTS the Miny and Tiny Sync is not applicable for the mobile sensor networks but characterized by low complexity and less power consumption as compared to other solutions. It is also noted that recent solutions like SLTP and TRST are studying the problem of energy consumption and mobility for the general development of all in the military field, for example sensors that can be mounted on the soldiers, and medical staff that requires some mobility.

At the end of this section, it can be clearly seen that all solutions provided until now have in common is a good precision levels but requires high level of energy consumption, which opens the doors for more work and research on synchronization timing issues to come up with a solution that is very accurate, low in energy consumption, and cost effective. The following table summarizes the capability of each solution with the major criterion for the best timing as needed :

Table II
Protocols classification as per synchronization problem

| | Application characteristics | | | |
|---|---|---|---|---|
| Protocol | Energy Consumption | Dynamic | Complexity | Clock Correction |
| RBS | High | No | High | No |
| TPSN | High | No | Low | Yes |
| FTSP | High | Yes | High | Yes |
| GTSP | High | No | Average | Yes |
| Miny-Sync | High | No | Low | Yes |
| LTS | low | Yes | Low | Yes |
| DMTS | Very High | NO | Low | No |
| TDP | Average | Yes | High | Yes |
| TSRT | Low | Yes | Average | No |
| SLTP | High | YES | Average | Yes |

## VII. Conclusion

A family of the popular time synchronization algorithms are studied and a comparative summary has been presented in this paper.

We have surveyed in this reference issues on two deferents categories (1) Problems related to the network (2) Problems related to the sensors. We have summarized and compared deferents proposed schemes with some major constraints in synchronization(Energy consumption, Mobility, Complexity, etc)

I hope that this paper provided a reference to the clock synchronization problems of wireless sensor networks.

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