The Time synchronization of Wireless Sensor Networks

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Abstract: Time synchronization Protocol in the distributed network is an essential element, there are greater differences to achieve high precision clock synchronization algorithm in limited energy wireless sensor networks and cable network. In this paper, on the basis of an analysis for time synchronization and network delay, exposition for the clock synchronization of major wireless sensor network, example for RBS, TPSN, DMTS, Continuous clock synchronization protocol, etc, and compared and analyzed its protocol's characteristics and application.

Keywords: sensor networks; time synchronization; data fusion

1 Introduction

The aim of Design and implementation of Wireless Sensor Networks is detecting and monitoring the physical world around us, combine with the existing information world of logical and the physical world of objective, further changes in the information exchange style of human and material world. Different from existing wireless ad hoc networks, each network node in Wireless Sensor Networks has many restrictions, such as computing power, communications capability, storage capacity, charged capacity, and the wireless network is based on data-centric and dynamic ad hoc. Because of its existence characteristics, a lot of existing sophisticated network protocols are no longer suitable for wireless sensor networks, time synchronization protocol is one of them.

2 The Similarities and Differences of Time Synchronization in Cable Networks and Wireless Sensor Networks

As a large range of distributed network, like the rest of the networks, Wireless Sensor Networks often also need a time synchronization request, so as to achieve coordinated control system of the event and the correct data fusion. But because its energy supplies, the node computing power, the link quality's limit, the existing time synchronization protocol has reconsider to analysis and re-assessment. Example for NTP(Network Time Protocol), applied to Internet, using hierarchical structure, the sub-layer node achieves the upper formation node clock synchronization through two package exchanges. However, because of its operation's order of complexity, and needs a more stable network structure as a support, thus not suited to wireless sensor networks which energy, volume, computing power has limits and strong dynamic.

3 The Basic Concepts of Timing-sync in Wireless Sensor Networks

3.1 Related definitions

Analysis clock deviation, give the following definitions:

Time: \( C_p(t) \) expresses the time of network node \( p \), when \( C_p(t) = t \), this clock is the standard time.

Shake frequency: The clock’s shake frequency, when the time is \( t \), node \( p \) node’s clock frequency is \( C_p(t) \).

Clock deviation: Expresses deviation of some clock and the standard clock, \( C_p(t) - t \). Two different clocks in the time \( t \)’s deviation may be represented that as Offset = \( C_p(t) - C_l(t) \).

Frequency deviation: Expresses frequency deviation of one clock and the standard clock. Two different clocks’ Skew = \( C_p(t) - C_l(t) \). If the frequency deviation limits in \( \rho \), the standard clock rate is 1, then the clock frequency will change between \( 1 - \rho \) and \( 1 + \rho \). As shown in Figure 1.

Clock excursion: Expresses clock function’s second derivative \( C_p(t)'' \), two different clocks’ Drift = \( C_p(t)'' - C_l(t)'' \).
From Figure 1 may discover, even if the clock is synchronize at the beginning, after a period of time because of the different clock frequencies, continue to accumulate clock deviation will become increasingly evident.

3.2 Analysis of Network Delay

The network transmission is always accompanied by message delay, this causes, node’s timestamp when arrives at opposite party node has not been able to represent own time. This needs to make sufficient analysis of network delay, to determine the source of the error caused by delay. In Wireless Sensor Networks, message delay has happened in mang links, and mainly exists in the send time, the access time, the transmission time, the broadcasting time, the receive time, the accept time, the interrupt processing time, the code time, the decode time. And each link possibly brings the time delay error, only full and accurate estimate to the error can design clock synchronization algorithm with high precise and low load.

3.3 Analysis of Time Achronization Protocol for Wireless sensor Networks

Jeremy Elson and Kay Romer first proposed and elaborated in the Wireless Sensor Networks’ time synchronization mechanism research subject in HotNets-I international conference in August, 2002, has aroused the attention in the sensor network research area. At present proposed the basic synchronized mechanism has RBS, TPSN, DMTS and so on, simultaneously the new algorithm unceasingly was still emerging, like TINY/MINI-SYNC, FTSP.

3.4 Time Synchronization Protocol of RBS

J. Elson et al. proposed RBS (Reference Broadcast Synchronization) is the use broadcast Channel’s characteristic in wireless link level, a node transmission broadcast message, thought that simultaneously receives the broadcast message in identical broadcast territory's other nodes, and records this node’s timestamp, in the later time, the receiving node exchanges their timestamp through the message, then compare and compute, so achieves the highly precise clock synchronization. This protocol proposed the concept of the time critical path as shown in Figure 2, compared the difference of non-decisive error with the traditional transmission - receive timing-sync mode. Now eliminated the time of transmission and access has demonstrated the RBS merit.

In time synchronization protocol of RBS, for possibly appears to the network in the nondeterministic delay makes the corresponding compensation, use the scheme that send many times and averaging. The RBS’s time deviation is: \( \text{Offset}[i, j] = \frac{1}{m} \sum_{k=1}^{m} (T_{i,k} - T_{j,k}) \). \( i, j \) represents the different node, \( K \) is the data packet serial number, \( m \) expresses the greatest number of times.

Another character of RBS is not has local clock emendation, but calculates the numerical value of clock deviation and the frequency deviation, then save to a table. When other nodes read local time, the local node will inquire about the correct time that the table translate. This is mainly consideration from the reduction energy consumption. In addition the RBS protocol has also used the sub-synchronous mode that is only run in the time synchronization needs, so this is greatly reduced energy consumption. RBS is also application for multi-hop network.

3.5 Time Synchronization Protocol of TPSN

TPSN (Timing-sync Protocol for Sensor Networks) is similar to traditional protocol of NTP, uses two hand-shake exchange timestamp which as shown in Figure 2 to achieves timing-sync. Supposition \( t \) is time deviation between the server and the client, \( d \) is round-trip time of them.

Calculating clock deviation, then local clock synchro
nize to upper layer node after make corresponding adjustment. In order to reduce the time delay error which the access time brings, when MAC starts sending, TPSN marked the transmission timestamp. Test result of the Mica platform indicated that the timing-sync of TPSN’s average deviation is 16.9us, but RBS is 29.13us, obviously TPSN has the more precise capacity of time synchronization. Time synchronization of TPSN’s process divides into two stages: The first stage is the layer discovery stage, this stage is hierarchization network nodes after the network deployment, divides into 0 to n layer; The second stage is time synchronization stage, after hierarchical structure establish, through synchronized broadcast package, clock synchronized layer-by-layer from 0 layer to n layer. The protocol of TPSN can support the external clock source, let the entire wireless sensor networks synchronize with the external clock, usually its root node is equipped with synchronized equipment of GPS.

3.6 Time synchronization protocol of DMTS

DMTS(Delay Measurement Time Synchronization) designs the algorithm of time synchronization through reasonable estimate network delay. The steps of time synchronization are: First step, chooses a master node in all nodes; Second step, the master node broadcasts his local clock, and when transmits the leader frame and the leading symbol made the timestamp t0, the leader frame and the leading symbol is mainly uses for receiving node in synchronization; Third step, made the timestamp t1after the receiving node ingather into the broadcast grouping, and made timestamp t2 before adjusting own clock. In this process, supposition that send 1 bit need time t, number of send information bit is n, then the receiving node should adjust own clock to t0+nt+(t2-t1).

The protocol of DMTS’s accuracy mainly decides in the precision of delay measure, it is one kind of clock synchronization mechanism which is nimble, the light-weight, the energy use factor highly. This mechanism can apply in wireless sensor networks which request is not too high in timing-sync. It can also better support with the external clock source synchronization, with multi-hop point a synchronization.

3.7 Continual Time Synchronization Protocol

In the time synchronization protocol, the request is not to adjust the clock backward by readjusting the clock, clock’s adjustment needs to be gradually process, thus maintains system event's continuity. If in 18:00 synchronization once, in the 20:00 synchronization second, but some system event decides occur in 19:00, if uses the instantaneous synchronization, system will neglect this event, lead imperfection of the data. The continual time synchronization protocol expanded the standard of IEEE802.11, increased or reduces the clock frequency in order to adjustment local clock synchronized to clock source.

In the continual time synchronization protocol that shown in Figure 5, the master node prepares an instruction grouping in the time of t1, broadcast to neighbor node in the time of t2; Suppose that neighboring nodes received the grouping in time, received the grouping in the time of t3, and record local timestamp in the time of t4; master node will transmit a confirmation grouping in the time of t5. Finally each receiving node calculate clock deviation with master node, and adjustment local clock in the time of t6. The local clock refers to the hypothesized clock which corresponds with the local physical clock.

4 Comparisons of Protocols

The above protocol’s consideration has its different emphasis point, therefore with many merits, also carry on some inadequacies. Then when choice related protocol or designs new protocol must consider these factors. The following is the comparison of merits and defects for these protocols.

In clock synchronization protocol of RBS, time deviation, between transmission and media access, is the biggest clock source had removed. Clock’s adjustment can not affect the clock deviation’s computation, because this protocol will not adjust the local clock, but has maintained a clock deviation table. The protocol of RBS is not only apply in the wireless network, but also apply in wired network. The RBS’s defects are also many, most important one is has time complexity of O(N2), it is the biggest energy expenses regarding the wireless sensor networks of limited energy.

In clock synchronization protocol of TPSN, time deviation, between transmission and media access, is the biggest clock source had removed. Clock’s adjustment cannot affect the clock deviation’s computation, because this protocol will not adjust the local clock, but has maintained a clock deviation table. The protocol of RBS is not only apply in the wireless network, but also apply in wired network. The RBS’s defects are also many, most important one is has time complexity of O(N2), it is the biggest energy expenses regarding the wireless sensor networks of limited energy.

The clock synchronization protocol of TPSN has obtained more precise clock synchronization effects that compared to the RSB, and facilitates support for synchronization with external clock source. But its energy expenses are quite relatively big, the biggest defect is not
conducive to dynamic change of network based on the situation of layer model, but one of wireless sensor network's character is the network dynamic.

Compare the clock synchronization protocol of DMTS to another two kinds of protocols, DMTS needs less message to transmit, the energy expenses are few, may clock synchronization in the entire network, and support synchronization with external clock source. But, this algorithm has made a compromise in the energy expenses and the synchronized precision, therefore the precision was weak, so it can apply in some wireless sensor networks which requirement of accuracy is not high.

The continual clock synchronization protocol in the situation of small transmission delay, may achieve the requirement of high accuracy. The time complexity is also very small, a synchronization only needs send a package. Especially in favorite of the method that consecutively adjust clock, let the continuity which the system event controlled to be able to guarantee.

Similarly, other clock synchronization protocols also has like this or such merits and defects, these factors are also decide by the design platform of protocol and system's application domain.

5 Conclusion

The clock synchronization protocol is an essential factor of wireless sensor networks, provides a unified time axis for system's other functions, like event's coordinated, node localization, system safety and so on. Therefore the research and innovation of time synchronization in wireless sensor networks have the important significance.

References