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USN을 위한 시간 동기화 프로토콜의 구현 및 평가

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Implementation and Evaluation of a Time Synchronization Protocol for USN

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요 약

다수의 독립적인 시스템들이 네트워크를 통해 구성하는 분산 처리 환경에서 시간에 대한 일치성을 유지하는 일은 매우 중요하면서도 어렵다. 특히, 에너지가 제한되어 있고, 통신 기능이 연약한 USN 환경에서 의 시간 동기화는 더욱 어렵다. 이러한 어려움에도 불구하고, USN에서 요구되는 시간 동기화 정밀도는 인터넷과 같은 일반적인 분산 처리 환경에서보다 더 높다. USN에서 매우 엄격한 시간 동기화를 요구하는 전형적인 응용 영역으로 TDMA MAC을 들 수 있다. 이 논문에서는 USN을 위해 최근에 제안된 FTSP (Flooding Time Synchronization Protocol) 시간 동기화 알고리즘을 개선한 새로운 알고리즘 HTSP(Hierarchical Time Synchronization Protocol)을 제안하고 평가한다. HTSP의 시간 동기화 정밀도는 FTSP와 동일하지만, 동기화를 위한 방송 메시지 수를 줄임으로써 에너지 소모를 FTSP보다 절약한다. 평가를 위한 시뮬레이션 결과, FTSP 대비 HTSP의 에너지 절약 비율이 약 26% 정도로 나타났다.

Abstract

In a distributed processing environment composed of many independent systems connected by networks, it is very important and difficult to make time synchronization between the systems. Especially in the USN environment the time synchronization is still more difficult than in general distributed processing environment because energy is limited and communication function is feeble. Even though of these difficulties, the USN environment requires higher precision of time synchronization. One of the typical applications requesting very strict time synchronization in USN is TDMA MAC. This paper proposes and evaluates a new time synchronization protocol HTSP(Hierarchical Time Synchronization Protocol) which is an advanced version of the FTSP(Flooding Time Synchronization Protocol) published recently. The time synchronization precision of the HTSP is equal to that of the FTSP, but the energy consumption of the HTSP is lower than that of the FTSP owing to the reduced number of broadcast messages. The simulation results show that the energy consumption ot the HTSP is only 74% of that of the FTSP.

▸ Keyword : USN, time synchronization, RBS, TPSN, FTSP

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Ⅰ. Introduction

Progress of science promoted development of devices with less power which can sense environment by around and can communicate with each other, so come into being Ubiquitous Sensor Network (USN)[1]. USN have emerged and received many researchers' attention, because sensor network combine technology of sensor devices, technology of embedded computing, technology of wireless communication and technology of distributed processing system and so on, which is a technology of cutting-edge science in the recent world. Applications of wireless sensor networks have very broad prospects in the future, such as military applications: target tracking[2], environment monitoring applications: the Great duck Island[3], biomedical, smart office and smart home and so on. In the future, we can feel development of USN continually and more and more USN applications in our daily life. USN would give progress of our society a great push forward.

Time synchronization is one of the most important technologies in the USN, and many USN applications depend on mechanism of time synchronization. Because many common services in USN, such as coordination, communication, security, power management also depend on global time. In this paper, we introduce a new time synchronization protocol which is called Hierarchical Time Synchronization Protocol(HTSP). The objectives of our design are to achieve network-wide time synchronization and less energy cost in whole run time. We propose a structure of hierarchy for multi-hop topology and utilize algorithm that is similar to FTSP[4] for the relevant error sources by utilizing time-stamping[5] in the MAC layer and the compensation with linear regression[6]. These technologies have been utilized first. In the end, we utilize simulator of time synchronization which is called SIMSYNC[7] to implement and evaluate the proposed HTSP.

The structure of this papers is as follows: the related works in the time synchronization is introduced in section 2. The proposed HTSP algorithm is described in section 3. In the section 4, SIMSYNC is utilized to evaluate the HTSP and an evaluation is made for the HTSP. In the section 5, a conclusion for this paper and a discuss for future work is proposed.

Ⅱ. Related Works

2.1 Influence Factors of Time Synchroni- zation in USN

In general wireless sensor netwok, a packet of message is transmitted through the process of Fig. 1[8].

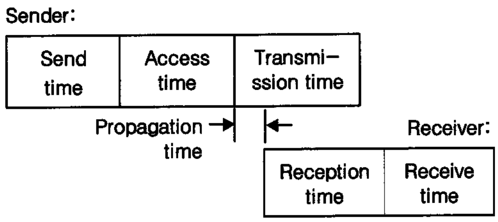

Fig. 1 Decomposition of Packet Delay in USN
그림 1. USN에서 패킷 전송지연 요소

Send time: the time spent in assembling the packet and delivering MAC layer the packet in sender. It depends on the system call overhead of the operating system and the load of processor. It is non-deterministic.

Access time: the time spent in waiting for access to the wireless channel. It is the least deterministic part of packet delay.

Transmission time: the time it takes for sender to transmit the packet bit by bit at the physical layer. It depends on the length of the packet and the transmission baud rate.

Propagation time: the time spent in transmitting between sender and receiver. It depends on distance between nodes, and it is deterministic.

Reception time: the time it takes for one bit in packet to MAC layer. It is the same as transmission time, it also depends on the length of the packet and the transmission baud radio. It is deterministic.

Receive time: the time spent in processing the incoming packet, and delivering applications in higher layer the packet. It similar to send time and it is non-deterministic.

2.2 Mechanisms of Time Synchronization

These years, many universities and research institutions in the world have researched in depth for mechanisms of time synchronization in the USN, and have been put forward many mechanisms of time synchronization. Three of the most prominent mechanisms of existing time synchronizations protocols for USN are Reference Broadcast Synchronization(RBS) [6], Timing-sync Protocol for Sensor Networks(TPSN)[5] and Flooding Time Synchronization Protocol(FTSP)[4].

RBS utilized a broadcast message as a reference message for receivers to regulate their local time to synchronize the local clock of nodes in the network. RBS adopted a mode of receiver-to-receiver. The main advantage of RBS is that it eliminates non-determinism in the sender side. In other words, RBS eliminates completely send time and access time. The disadvantage of RBS is that it has to exchange additional message with other receivers, and it can not be adapted for a large multi-hop network.

TPSN adopted a mode of sender-to- receiver and mechanisms of two-way handshake. It is consisted of two main phases. In the first phase(level discovery phase), is created topology of a spanning tree. In the second phase(synchronization phase), each node gets synchronized by exchanging sync-message with its reference node on level higher in the spanning tree. The protocol of TPSN utilized mechanisms of time-stamping to eliminate send time, access time and reception time. So, TPSN has improved accuracy greatly, and has achieved two times better performance than RBS. The disadvantage of TPSN is that it can not estimate the clock drift of nodes, and can not handle dynamic topology change.

III. Proposed Hierarchical Time Synchronization Protocol(HTSP)

3.1 Structure of Time Synchronization Packet

In this section, the algorithm of the Hierarchical Time Synchronization Protocol (HTSP) is proposed with details. The HTSP is designed on the basis of the Flooding Time Synchronization Protocol(FTSP). Owing to that the FTSP had adopted the mechanism of flooding message, and had required each node in the sensor network to broadcast the packet of time synchronization to the network in every period of time synchronization. This feature of FTSP increases energy expenditure for the whole sensor network. However, limited energy is one of the most important problems in the USN[1]. So the concept of hierarchy is adopted, and the hierarchy concept is used in collecting statistics for the number of child nodes of each node in the network. If a node doesn't have any child node, i.e. a leaf node, the node doesn't broadcast any time synchronization packet to network. The objective of this design is not only to acquire accuracy as the precision of the FTSP, but also to cost less energy than FTSP, thus it can increase dramatically lifetime of the whole sensor network and make it more adaptive for the demand of actual application.

Time synchronization packet format is one of the most important aspects of the HTSP. The original synchronization packet of the FTSP contains three fields as is shown in Fig. 2: Root-Id, Time-Stamp, Sequence- Num. Time-Stamp denotes the global time estimate of the sender when the packet is broadcasted. Sequence-Num denotes a sequence number and incremented by the root. We added one field on the basis of the FTSP time synchronization packet, Layer-Num. The Layer-Num denotes the level of each node in the network. At the beginning, Sequence-Num, Layer-Num are all initialized to zero.

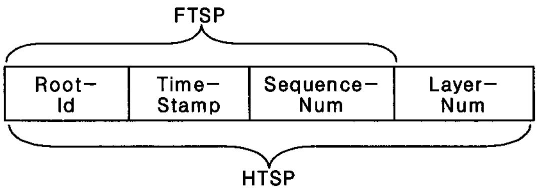

Fig. 2 Structure of the Time Synchronization Packet
그림 2. 시간 동기화 패킷 구조

3.2 Synchronization for Hierarchy and Sta- tistics

In the FTSP algorithm, root node is auto-selected by timeout event. At the beginning, the sink node is selected as a unique root node and it broadcasts synchronization message periodically. All other nodes waits the message for a given time, and if they can't receive any message for the time, they act as a root individually until they receive other message from more plausible node. The priority for a root can be graded by node id, where id of sink node is 0. The neighbor nodes of roots receive the synchronization packets and compare the value of Root-Id in the packets with their own root, myRoot-Id. If the Root-Id from a packet is less than myRoot-Id, then they replace the value of myRoot-Id with the value of Root-Id. According to this mechanism of auto-select root, only a single root is selected in the whole sensor network.

After the root is selected, it began to broadcast time synchronization packet to the network. At this point, the Layer-Num of the of the packet is set to 0 by the proposed HTSP. If a node receives directly the packet from the root, it broadcasts the packet again with adding 1 to the value of Layer-Num. At the same time, according to the algorithm of liner regressions it calculates the value of offset and skew[4], and then regulates the local clock to the global time from the root.

The proposed HTSP does two functions with the synchronization packet: firstly, it discovers next layer and synchronizes it's layer to higher layer. E.g. if a node receives directly a packet from a node in layer n, then it sets it's Layer-Num to n+1. Secondly, it collects statistics for the number of child nodes from the over-heard packets broadcasted by nodes in lower layer. E.g. if a node in layer n over-hears one packet from a node in layer n+1, then it add 1 to it's myChild-Num. With these two functions of the HTSP, all nodes in the whole sensor network are arranged in hierarchy towards to root

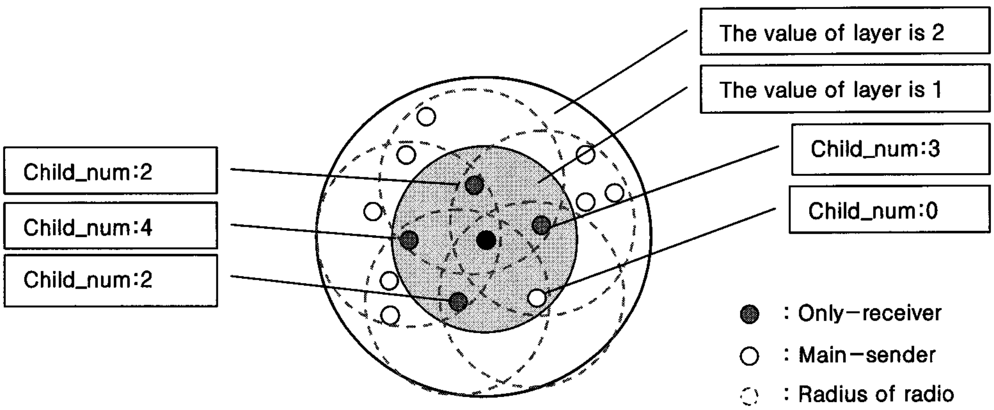

Fig. 3 A Topology of Two-hop Sensor Network for the HTSP
그림 3. HTSP에서 2 홉 센서 네트워크 토폴로지

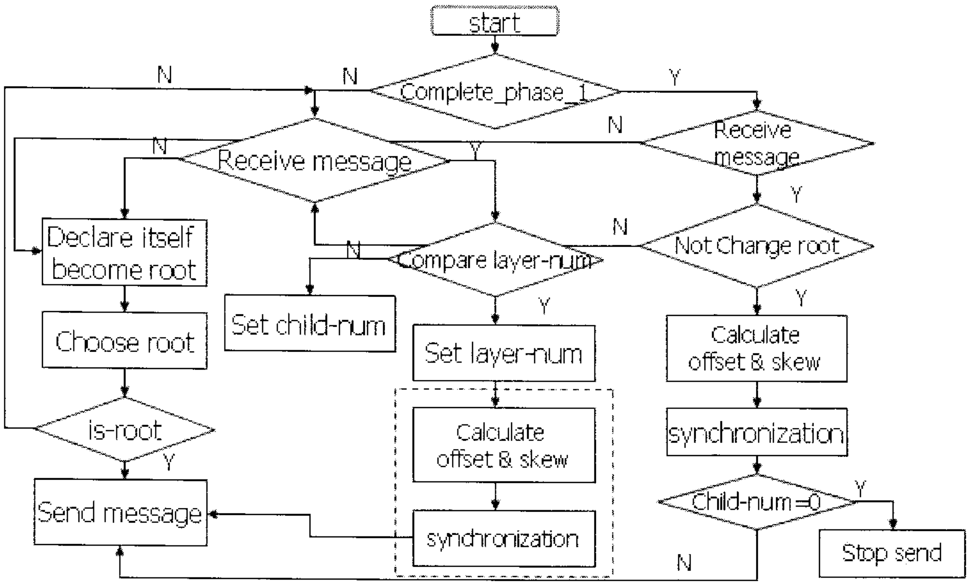

Fig. 4 Algorithm of the HTSP
그림 4. HTSP 알고리즘

and each node knows about the number of child nodes of itself.

3.3 Time Synchronization of Each Node

In this phase, time synchronization packet is broadcasted in terms of myChild-Num collected in the earlier phase. With the myChild-Num, the HTSP introduces two types of node in the network, firstly, only-receiver nodes which only receive packets from neighbor nodes, but do notbroadcast the packets, secondly, main-sender nodes which not only receive packets from neighbor nodes, but also send packets to network.

The HTSP divides the nodes in the network into the two types. In the first, the HTSP collects nodes of which the value of myChild-Num is zero, and groups these nodes into the only-receiver type. Because the value of myChild-Num of these nodes are zero, they have no child nodes in it's lower layer. In other words, none of nodes in the network wants the packets broadcasted by these nodes. Secondly, the remained nodes of which the value of myChild-Num is non-zero are collected into main-sender type. In the end, all nodes are divided into two types according to the HTSP mechanism. In the whole network, only these nodes which belong to the type of send-main send synchronization packets to the network. If the root is not changed, then we can expect that the structure of hierarchy and the group of send-main type nodes would be unchanged for a long time.

Fig. 3 shows a topology of two-hop sensor network with the HTSP. It denotes the process of the HTSP, auto-select root, phase of synchronization of hierarchy and statistics and phase of time synchronization of each node. In this figure, only 5 nodes including the root send time synchronization packets to the network, and the remaining 9 nodes belonging to receiver-only type does not send any synchronization packet. So the HTSP costs less energy than FTSP. The algorithm of the HTSP is in Fig. 4.

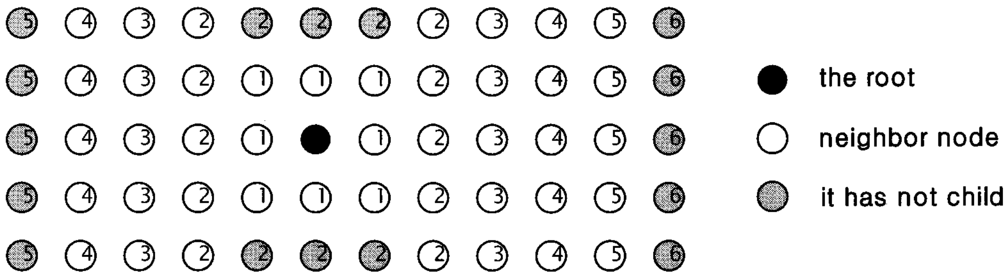

Fig. 5 Network Topology for the HTSP Simulation
그림 5. HTSP 시뮬레이션을 위한 네트워크 토폴로지

Table 1. Typical Energy Expenditure in USN
표 1. USN에서의 전형적인 에너지 소모량

Operation for packet	Energy expenditure /mAh
send a packet	20.00
receive a packet	8.00

Ⅳ. Evaluation of the HTSP

We utilized SIMSYNC[7] which is a simulator of time synchronization to test the

performance of the proposed HTSP. We have designed the HTSP algorithm in C++ and simulated 60 nodes deployed in a 5*12 grid in such a way each node can communicate with its neighbors only. The same network topology of [4] was adopted to compare with the FTSP algorithm. In the Fig. 5, a black solid point denotes root in the sensor network, each node has at most 8 neighbors.

In the implementation of the HTSP algorithm, at the first phase, not only were all nodes synchronized to the root in the whole sensor network, but also each node in the network set the layer number and collected statistics about its own number of child nodes. The layer number of each node is depicted in Fig. 5. This figure shows that the topology of the whole network is divided into 6 layers and there are 16 nodes of which the value of myChild-Num is zero. If the root is not changed, then these leaf nodes only receive packets from the upper layer since the second phase. In a period of time synchronization, the HTSP sends 44 packets while FTSP sends 60 packets.

AA batteries were widely used in the recent sensor network. In the case of 3V, power of AA batteries is about 2,200mAh [3]. Process of sending packet is the most energy costing in the sensor network. Mcia2, a popular node design, costs as many energy as those in Table 1 for the processes of sending and receiving a packet[9].

In the simulation experiment, we calculated energy expenditure of the HTSP according to the number of packet transmission. In the HTSP, the number of packet transmission is 44 in a period of time synchronization (except the first period), so 44*20 = 880mAh is needed. While in the FTSP, owing to that it had adopted the mechanism of flooding message, every node in the network is required to broadcast the synchronization packet. So, 60*20=1,200mAh is needed.

Obviously, the HTSP algorithm decreased about 26.67% of energy expenditure of the FTSP algorithm. Furthermore, the more the number of period

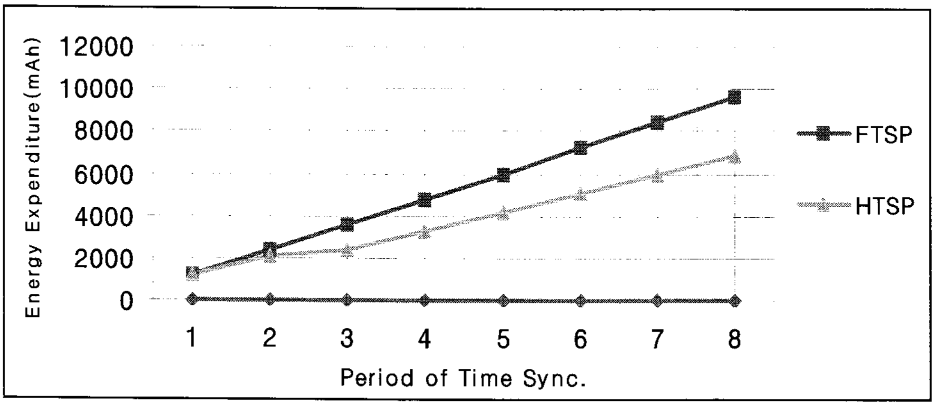

Fig. 6 Comparison of Energy Expenditure Between the FTSP and the HTSP
그림 6. FTSP와 HTSP의 에너지 소모량 비교

increases, the more energy is saved(See Fig. 6).

Time synchronization precision of the HTSP is similar to that of the FTSP because both of them had adopted the same algorithm of compensation for the relevant error sources[4]. In this paper, the focus of the HTSP design is in less energy expenditure.

V. Conclusions

We have designed the Hierarchical Time Synchronization Protocol(HTSP) for USN. The proposed HTSP is based on the FTSP, i.e, the concept of hierarchy was introduced into the FTSP, and the hierarchy concept was used in collecting statistics for the number of child nodes of each node. With the collected number of child nodes, the HTSP could reduce the number of packet transmission. The HTSP was implemented on the SIMSYNC simulator. The results showed that HTSP not only had acquired precision of time synchronization similar to FTSP, but also had conserved 26.67% of the FTSP energy expenditure in every time synchronization period(except the first period).

Our plan is to conduct experiments in the real hardware nodes, and verify the performance of the HTSP in a real-world application. In addition, we also plan to conduct experiments with hundreds of nodes.

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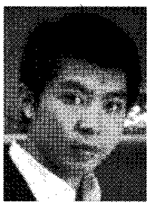

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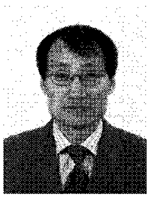
관심분야 : USN(Time Synchronization Protocol)



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