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Low Energy Consumption and High-Precision Time Synchronization Algorithm Based on Improved TPSN in Wireless Sensor Networks

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Abstract—Targeting transmission delay error and energy consumption when TPSN exchanges messages between adjacent nodes, an improved time synchronization algorithm is proposed for wireless sensor networks(WSNs). In the hierarchical discovery and establishment phase, hierarchical broadcast messages are clustered and the LEACH algorithm is used to obtain the optimal cluster-head node. In the synchronization phase, Bayesian estimation is used to implement the whole-network node synchronization. Simulation experiment shows that, compared with the TPSN algorithm, this method improves time accuracy and reduces energy consumption.

Keywords- TPSN; Clustering; Time Precision; Bayesian Estimation; Low Energy Consumption

I. INTRODUCTION

Time synchronization technology is an indispensable technology in WSNs, and its algorithm can be roughly divided into three categories: Based on the Receiver to Receiver's time synchronization mechanism; Based on the Sender to Sender's time synchronization mechanism; Based on the Sender- Receiver's time synchronization mechanism.

The typical TPSN (Time Synchronous Protocol for Sensor Networks) algorithm is based on the sender-receiver's time synchronization mechanism. When applying the TPSN algorithm, further the node is from the base station, the time accuracy of the node is lower. Also, the energy consumption is large, and the time deviation is large. Due to these shortage, recent years, a series of improved algorithms have been proposed. Literature [1] proposes a self-recovery time synchronization (SRTS) for medical IoT sensor networks. Literature [2] proposed a robust time synchronization for IIoT. Literature [3] proposed an adaptive clock offset prediction model for wireless sensor networks. Literature [4] proposes a secure time synchronization model for large-scale Internet of Things. Literature [5] proposed a nearest neighbor node clustering algorithm.

The improved algorithm proposed in this paper is to establish hierarchical broadcast messages in clusters during hierarchical discovery and establishment. LEACH algorithm is used to obtain optimal cluster-head nodes. In synchronization phase, Bayesian estimation is used to achieve node synchronization in the entire network.

II. TPSN ALGORITHM

The TPSN algorithm[6] is proposed by the American scholar Ganeriwal et al. in 2003. Using the way of both-way communication between nodes to realize time synchronization, which was mainly two phases.

A. Hierarchical discovery and establishment phase [7]

Each node is assigned a level, and the root node assigns the highest level to the 0th level. The broadcast of the root node includes the ID and level of the sending node. When the neighbor node of the root node receives the message, it updates its own layer number plus 1 as its own layer number and broadcasts a new message packet. This process is repeated until all nodes have defined their own layer numbers. As shown in Figure 1.

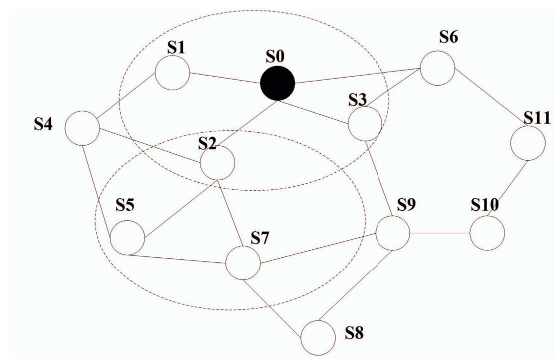

Figure 1. Level stage establishment

B. Synchronization phase

In the synchronization phase, the first-level node synchronizes to the root node, the first-level node synchronizes with the second-level node, and synchronization is continued. The node at the i-th level synchronizes to a node at the (i-1)th level, and finally all the nodes Synchronize to the root node to achieve the time synchronization of the entire network. Figure 2 shows the synchronization message exchange process between adjacent nodes.

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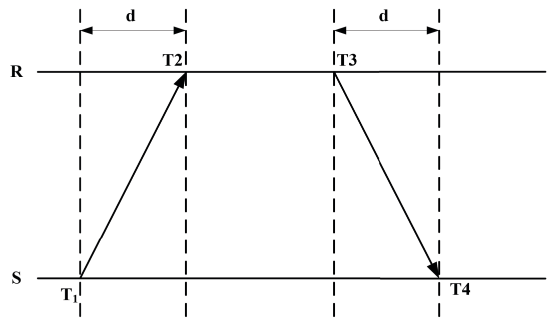

Figure 2. Synchronization message exchange between adjacent nodes

In Figure 2, if two adjacent nodes are to achieve time synchronization. Assuming that the above node is R, the following nodes is S, R level is higher than S. The local clock of T_1 ,$T_4$for sending nodes， T_2 ,T_3 is the local clock of the receiving node. At the time T_1 node S sends a synchronization request packet to the node R , Group S level and T_1contained in time, node R receives the packet at time T_2 . Then send the reply packet to node S at T_3 time, grouping contains the level of node R, T_1, T_2 and T_3, node S receives the reply at T_4 time. It is assumed that the transmission delay is the same throughout the process, recorded as d , the time offset between two nodes is represented by Δ. It can be obtained:

$$T_2=(T_1+d+\Delta) \tag{1}$$

$$T_4=(T_3+d-\Delta) \tag{2}$$

It can be launched:

$$\Delta=\frac{(T_2-T_1)-(T_4-T_3)}{2} \tag{3}$$

$$d=\frac{(T_2-T_1)+(T_4-T_3)}{2} \tag{4}$$

After node S computing time deviation, synchronize time to node R.

III. IMPROVEMENT OF ALGORITHM

At present, there are many researches on time synchronization technology. Which are typical RBS algorithm[8], TPSN algorithm, DMTS algorithm[9] and FTSP algorithm[10]. The performance comparison is shown in table 1:

Table 1 Performance comparison of each algorithm

Algorithm	Precision	Energy consumption	Scalability
RBS	higher	big	good
TPSN	higher	big	unavailability
DMTS	low	small	good
FTSP	high	big	good

A. Improvement of hierarchical discovery and establishment phase

Traditional TPSN algorithm discovers and establishes the network level, and sending a large number of data packets consumes more energy. Therefore, hierarchical broadcast messages are clustered and the LEACH [11] algorithm is used to obtain the optimal cluster head node. Specific steps are as follows:

Step1 The base station is set to the root node (Sink node), and its level is set to 0.

Step2 The optimal cluster head is selected, the root node broadcasts the build layer information, the cluster head node receives the message, and the received layer number is incremented by one. The message includes a layer number and ID message data packet.

When the cluster heads are elected, the node randomly generates a 0~1 number, and the random number is less than the predetermined threshold value $T(n)$. Secondly, the node's own energy is more than the energy of all the surviving nodes, and the node will be selected as the cluster head, and $T(n)$ is defined as follows:

$$T(n)=\begin{cases} \frac{p}{1-p\times(r \bmod 1/p)} & n\in G \\ 0 & n \notin G \end{cases} \tag{5}$$

In this case, the probability that the p stands for the node as a cluster, r for the current round, $rmod\ (1\ /\ p)$is the number of nodes in the cluster, and G is the node set that has been elected to zero cluster heads.

Step3 The cluster level node number is 1 broadcast level and ID. The cluster header node that receives the packet updates the level number plus 1.

Step4 Repeats the second and third steps. the cluster head node continuously updates the hierarchy number, and the unique hierarchy number is determined.

Step5 After completing the above, the latest hierarchy is formed.

B. Improvement of synchronous phase

In the second stage of the TPSN algorithm, there are two parts of the deterministic and non-deterministic errors in the traditional time synchronization algorithm. The non-determinism results in the low synchronization accuracy due to the transmission delay of the information exchange between each pair of synchronization nodes. Therefore, Bayesian is introduced. Estimation [12] is optimized and the process is as follows:

Assuming the TPSN algorithm is now T_j .The optimized synchronization time obtained by Bayesian estimation is $T_j^{'}$. Bayesian estimation time for the next node is $T_{j-1}^{'}$， Obeying normal distribution $N(0,\sigma_j^2)$， after optimization of the Bayesian estimation of $N(T_j^{'},\sigma_j^{'2})$. As a result, the formula can be obtained:

$$\sigma_j^{'2}=\frac{\sigma_{j-1}^{'2}\sigma_j^{'2}}{\sigma_{j-1}^{'2}+\sigma_j^{'2}} \tag{6}$$

$$T'_j = \frac{\sigma_j'^2}{\sigma_{j-1}'^2 + \sigma_j'^2} T'_{i-1} + \frac{\sigma_j'^2}{\sigma_{j-1}'^2 + \sigma_j'^2} T'_j \quad (7)$$

After obtaining the result, make $T'_1 = T_1$, $\sigma'_1 = \sigma_1$. Among them, T_1 is the standard starting time, while σ_1 is the resolution of the root node clock. The upper node sends the estimated time T'_{j-1} and the standard deviation σ'_{j-1} to the lower node. The next node checks the local time T_j and gets the standard variance σ_j^2. Thus, T'_j and σ'_j can be obtained by formula (6) and (7). All nodes are synchronized according to this procedure.

IV. SIMULANTION AND PERFORMANCE ANALYSIS

To verify the precision of improved algorithm in synchronization, Matlab2015 was used to carry out a simulation experiment. The site of simulation experiment is a square area of 100m×100m. The parameters of simulation environment are as shown in Table 2.

Table 2 Parameter setting

Parameters	Value of the parameter
Size of the network(m)	$100m \times 100m$
Number of sensor nodes (pieces)	100
Coordinates of the root node	(50,50)
Initial energy of sensor nodes (J)	0.5
Communication radius of sensor node (m)	10
Energy consumed by sending messages (J/bit)	40

A. Synchronization errors

Figure 3 shows the relationship between the number of nodes and the synchronization error. From the results of simulation experiments, the difference between the two algorithms is not significant. The maximum synchronization error of the TPSN algorithm is 0.0264ms, the mean synchronization error is 0.0201ms, the maximum synchronization error of the improved method is 0.0253ms, and the mean synchronization error is 0.0189ms. The energy consumption of the improved method is significantly lower than that of the TPSN algorithm.

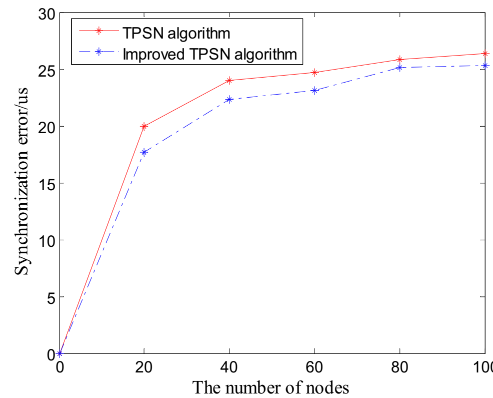

Figure 3. Synchronization error between improved algorithm and TPSN algorithm

B. Data exchange capacity

Figure 4 shows the relationship between the number of nodes and the amount of data exchanged. From the results of simulation experiments, as the number of nodes increases, the amount of data exchanged by the TPSN algorithm continues to increase, and its energy consumption also continues to increase, while the amount of data exchanged by the improved method is significantly reduced, which is more conducive to the use of low energy consumption.

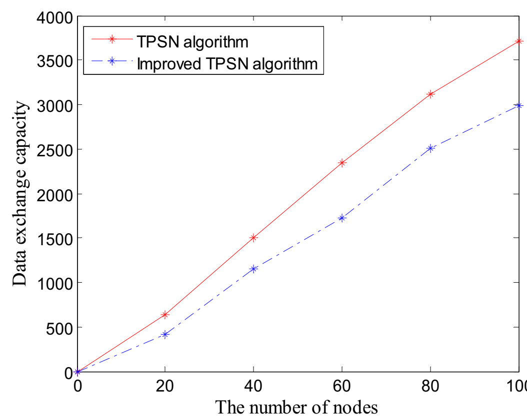

Figure 4. Data exchange capacity between improved and TPSN algorithm

C. Synchronous energy consumption

Figure 5 shows the relationship between the number of nodes and synchronous energy consumption. From the results of simulation experiments, with the increasing number of nodes, compared with the TPSN algorithm. Improved method improves the time synchronization effectively by introducing Bayesian estimation, and the energy saving effect is more obvious, thus reducing the energy consumption of the whole network to a certain extent.

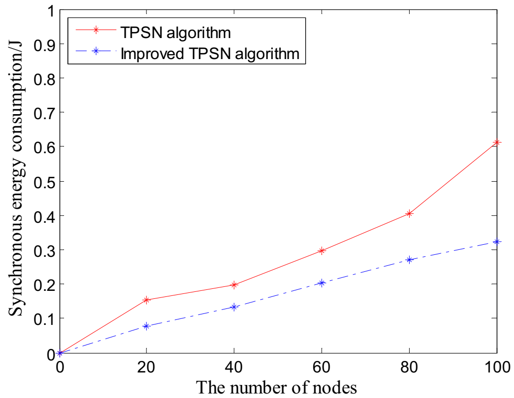

Figure 5. Energy consumption between improved and TPSN algorithm

V. CONCLUSIONS

Time synchronization algorithm for wireless sensor networks has a vital role. In this paper, TPSN algorithm is improved. Firstly, the basic knowledge is described, and then a detailed description of the two stages of TPSN. Then, the TPSN algorithm was improved, mainly in its hierarchical discovery, establishment and synchronization stages. Finally, the simulation software Matlab2015 was used for testing. In the experimental results, it can be seen that under the same conditions, the improved algorithm in this paper is significantly better than the original algorithm through comparison with the TPSN time synchronization algorithm. Performance is better than that of the original algorithm as a whole.

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