International Journal of Computer Applications (0975 – 8887)
Volume 31– No.5, October 2011

Slave Controlled Time Synchronization Scheme for Wireless Sensor Networks: A Mathematical Approach

S.Magesh
Research Scholar
SRM University
Kattankulathur, Chennai.

Dr. R. Srinivasan
Dean (Research & PG Studies)
RNS Institute of Technology
& Research Supervisor, SRM University

ABSTRACT
Developments in micro electro mechanical systems and wireless communications have led to the development of low power, low cost, multi functional, wireless sensing devices. Distributed communication network formed with the help of these sensing devices is called Wireless Sensor Network (WSN). WSN forms the fundamental infrastructure for future unique network for variety of potential and powerful applications such as defense, environmental monitoring, facilities management, manufacturing and agriculture. Many fundamental operations of WSN such as Time Synchronization among nodes and sink, routing of data, clustering of nodes, localization schemes, data aggregation and dissemination consume excess part of the energy utilized. To optimize energy consumption, this paper focuses on the time synchronization between nodes and the cluster head within the cluster, to reduce the relative drift of clocks between two different nodes at two different times thus reducing the synchronization error. We prove the minimization of the relative drift of clocks through a mathematical model with few assumptions on applications. The output of the mathematical model, based on the assumptions, clearly prove that the relative drift of clocks between two different nodes drops to an infinitesimally small value, which is better than many of the existing time synchronization schemes for WSNs.

Keywords
Wireless Sensor Network, Energy Efficiency, Time Synchronization, Relative Clock Drift, Synchronization error.

1. INTRODUCTION
The tasks of sensing, processing and wireless communication have been brought into low power embedded system in the form of sensor nodes, only because of the advancements in micro electro mechanical systems [1]. A sensing and communication network consisting of large number of battery powered sensor nodes is the need of the hour in War Zones.

Since the major application of Wireless Sensor Networks is monitoring of strategic environments, the accuracy of information collected plays a vital role. Information accuracy is highly dependent on time [1]. Hence the time synchronization among nodes in WSNs plays a major role for both accurate information collection and energy conservation in nodes. Legacy time synchronization protocols are not suitable for sensor networks due to obvious reasons. GPS and radio ranging technologies have found extensive usage in the synchronization of global networks. Wireless Sensor Networks are characterized by huge densities of nodes deployed in the remote monitoring area, which require scalable and energy efficient time synchronization algorithm for accurate information. This makes energy hungry equipments like GPS, for time synchronization in WSN as a poor choice. Further for military applications such as enemy motion tracking, time synchronization requirements are more stringent, requiring synchronization of the order of nanoseconds among the nodes involved in communication. Our time synchronization algorithm proposed in this paper outperforms all the other related schemes, in the sense that it requires only lesser number of transmissions to achieve synchronization and mathematically reduces the relative drift of clocks between two different nodes to a nearly zero value. This reduced relative drift of clocks contributes to better synchronization among nodes in mission critical military applications.

We have organized our paper as follows: Section 2 deals with the related works and the drawbacks of the existing time synchronization schemes. Section 3 provides an overview of the organization of nodes and sink, specific to a military application. Section 4 focuses on the various assumptions we have made and justifications for the same in order to develop a mathematical model of the proposed time synchronization algorithm. Section 5 deals with an insight into the mathematical approach of the proposed time synchronization algorithm with necessary equations. Conclusions and future work and references are dealt in section 6 and 7 respectively..

2. RELATED WORKS
Time synchronization in Wireless Sensor Networks plays a significant role in reducing energy consumption within the nodes and hence increases the lifetime of the network. Related works, in the field of Time synchronization in WSN try to reduce synchronization error along with reducing the energy consumption only by a nominal amount. Most of these works can be categorized either as Sender-Receiver Synchronization (SRS) or Receiver-Receiver Synchronization (RRS) [1]. SRS operate on the legacy model of 2-way message exchanges between a pair of nodes. In RRS, the nodes to be synchronized first receive a beacon packet from a common sender and then compare the receiving times of the beacon packet to compute the relative clock offsets.

Reference Broadcast Synchronization (RBS) algorithm synchronizes a set of child nodes that receive the beacon messages from the common sender (a reference or parent node) [2]. RBS synchronizes each set of receivers with each other as against many legacy algorithms that synchronize receivers with senders, through three major events such as Flooding, Recording, and Exchange. The major issue with RBS is that it scales poorly with dense networks where there are many receivers for each transmitter. Moreover, in cases of nodes losing power, RBS does not take into account for lost network coverage. When a sender is depleted of its energy, all the receivers belonging to that sender will be dropped from the network.

Timing Sync Protocol for Sensor Networks (TPSN), an SRS scheme, uses a 2-way handshake methodology to reduce uncertainty to half since the mean of the time differences is used [3]. TPSN's accuracy places it on top of RBS. But considering energy consumption, TPSN performs poorly in sparse networks. Also, TPSN shares a common problem with RBS with respect to lost network coverage, when nodes are out of power due to energy depletion.

Lightweight Time Synchronization (LTS) forms a low depth spanning tree composed of nodes in the network [4]. LTS utilizes pair wise synchronization algorithm for each one of the two nodes on the same edge of the tree. Moreover, LTS utilizes Breadth-First-Search algorithm (BFS) which consists of higher communication overhead compared to other tree construction algorithms. The execution of BFS in distributed systems is considered to be difficult.

Clustering Technique and adjustable radio ranges of nodes are two methodologies adopted by Cluster based Hierarchical Time Synchronization (CHTS) [5]. In CHTS, cluster heads are elected from high performance nodes. The various sub phases of CHTS scheme are cluster head tree construction, cluster member tree construction and the synchronization algorithm. CHTS suffers from the drawbacks of too many assumptions to elect cluster heads and poor scalability.

Passive Cluster based algorithm for Time Sync (PCTS) consists of over hearing in time synchronization phase [6]. This algorithm sets clock continuously which results in more power consumption. Since nodes, that are members of more than one cluster, have to calculate the mean clock time of all their cluster heads and send the calculated clock to them, PCTS consists of too many transmissions to achieve time synchronization which is not energy efficient.

GTSP [7], reduces synchronization error between neighbor nodes, but fails to take care of energy consumption of nodes at the same time.

Precise time synchronization for Wireless Sensor Network using the GPS [8], utilizes Flooding time synchronization protocol [9] and GTSP to deliver a simple and cheap method of synchronizing wall clock time and logical sensor network time. The major drawback of [8] is the use of energy hungry equipments like GPS , which is not a better choice for WSNs.

Our work tries to reduce the synchronization error by minimizing the energy expended from a node due to minimum number of transmissions required to achieve synchronization. This can be categorized as special class of synchronization algorithms and can be called as Node Request-Cluster Head Broadcast algorithm (can also be classified under slave controlled schemes of Time Synchronization).

3. ORGANIZATION OF NODES IN WAR ZONES TO DEMONSTRATE OUR TIME SYNCHRONIZATION SCHEME:

Fig.1 below shows the random placement of nodes in a sensor network grouped into three different clusters within a war zone. Each node within a cluster designates a particular node as cluster head (CH). Each cluster head can communicate with other cluster heads and within the nodes of the same cluster.

Cluster 1 represents our authorized area of operation. Border between Cluster 1 and Cluster 2, Cluster 3 represents line of control. Nodes on either side of line of control transmit and receive messages to their respective cluster heads. Cluster head of cluster 1 also acts as sink which shall be connected to a computer for appropriate human intervention. SN1 and SN2 represent sensor nodes in the cluster 1. Our time synchronization scheme proposes the methodology to achieve synchronization between SN1, SN2 and CH1, which shall be extended further in a similar manner.

4. ASSUMPTION

1. Propagation delay between a sensor node and cluster head, within a cluster and vice versa are very small.

Justification: The density of sensor nodes in the war zone is normally very high. As a result of this, the number of clusters that are formed in the war zone is huge which makes the distance between any sensor node and its corresponding cluster head small. When the distance between two nodes is very small, propagation delay between the two also becomes a negligible value.

2. Difference between propagation delays of any two nodes and the cluster head within a cluster is negligibly small.

Justification: Based on first assumption.

3. At any point of time, only a sensor node initiates time synchronization request to the cluster head.

Justification: Since a sensor node initiates communication to report an event to a cluster head and in turn to a sink, it is assumed that sensor node initiates time synchronization request.

4.All local node timestamps are denoted by uppercase letters (T), and ideal clock timestamps by lowercase letters (t).

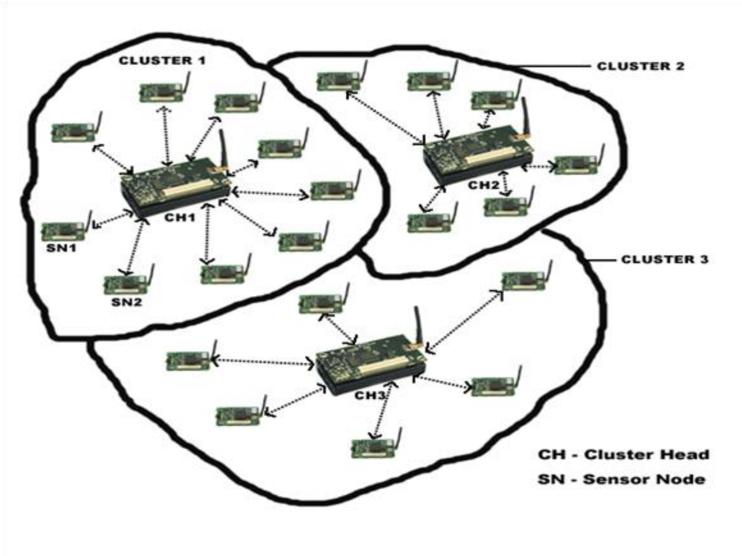

Fig 1: Clusters where Sensor Nodes are Deployed

5. SLAVE CONTROLLED TIME SYNCHRONIZATION SCHEME: MATHEMATICAL PROCEDURE

The below mentioned procedure takes Fig.1 above, as reference.

Sensor Node (SN1) initiates a synchronization request by sending a sync_req packet, time stamped at its MAC layer to its cluster head(CH1).

T1 is sync_req packet and is time stamped in SN1.

When the time stamped - sync_req packet reaches cluster head1(CH1) at time T2, the various delays associated with the request packet that may be taken into account are:

Access time and Transmission time at Sensor Node1 (S_{SN1}).

Propagation delay ($P_{SN1->CH1}$).

Reception time at CH1 (neglecting the receive time since the packet is time stamped at MAC layer), (R_{CH1}).

Drift between sensor node1 and cluster head1 at time t1. ($D_{t1}^{SN1\to CH1}$)

$$T2=T1+S_{SN1}+P_{SN1->CH1}+R_{CH1}+ D_{t1}^{SN1\to CH1} \quad .... (1)$$

Where t1 corresponds to ideal clock time for local node time T1.

CH1 now sends the sync_res packet time-stamped at T3, in its MAC layer to SN1.If the packet, sync_res, reaches SN1 at T4, then, for accurate time synchronization,

$$T4=T3+S_{CH1}+P_{CH1->SN1}+R_{SN1}+ D_{t3}^{CH1\to SN1} \quad .... (2)$$

$$D_{t3}^{CH1\to SN1} = T4-T3- S_{CH1}-P_{CH1->SN1}-R_{SN1} \quad .... (3)$$

This algorithm differs from other implemented time synchronization in a way that, time-stamped sync_res packet shall be broadcasted by CH1 to all the nodes within the cluster. Let sensor node2 (SN2) receive the sync_res broadcast packet at T5. In order to calculate the synchronization error, at SN2, we decompose T5 as

$$T5=T3+S_{CH1}+P_{CH1->SN2}+R_{SN2}+ D_{t3}^{CH1\to SN1} \quad ....(4)$$

To calculate the drift between clocks of CH1 and SN2, we use equation 4, to obtain,

$$D_{t3}^{CH1\to SN1} = T5- T3-S_{CH1}-P_{CH1->SN2}-R_{SN2} \quad ....(5)$$

The same method of computation is followed at each node to perform time synchronization and calculate synchronization error within the cluster. To achieve time synchronization, our algorithm uses only a total of two transmissions namely,

Transmitting the sensor node initiated , sync_req packet to cluster head and

Broadcasting sync_res packet by the cluster head to the entire sensor nodes within the cluster.

The algorithm takes care of the behaviour of nodes with respect to the reception sync_res broadcast packet by including R_{SN1}, R_{SN2},...in the clock drift calculation of sensor node1, sensor node2, ... respectively.

The clocks of sensor nodes are crystal based and those crystal are easily susceptible to huge drifts from the ideal clock. Hence in the process of time synchronization, though the objective is to reduce the synchronization error or drift of the clock in the nodes, all we care about is just the relative drift between the clocks of two different nodes at two different times.

Let the relative drift between two nodes i.e., cluster head1 (CH1) and Sensor Node2 (SN2), between times t3 and t5, be denoted by $RD_{t3 \to t5}^{CH1 \to SN2}$.

$$RD_{t3 \to t5}^{CH1 \to SN2} = D_{t3}^{CH1 \to SN2} \sim D_{t5}^{CH1 \to SN2} \quad \text{............. (6)}$$

Based on assumption 1, it can be written that,

$$D_{t3}^{CH1 \to SN2} \approx D_{t5}^{CH1 \to SN2} \quad \text{................ (7)}$$

Using (7) in (6), we obtain,

$$RD_{t3 \to t5}^{CH1 \to SN2} \approx 0. \quad \text{................. (8)}$$

From eqn.(8), it is clearly evident that our scheme of time synchronization reduces relative drift of clocks between two different nodes to an infinitesimally small value which is better than many of the existing time synchronization schemes for WSNs.

6. CONCLUSION AND FUTURE WORK

Time synchronization in Wireless Sensor Networks provides an efficient base to collect accurate information from the network. In this paper, we have proposed a new class of time synchronization technique called as Node Request-Cluster Head Broadcast algorithm for optimal operation of network clusters. Also, we have identified the drawbacks of existing and most commonly used time synchronization techniques in WSNs. The synchronization error in time synchronization operation shall be reduced drastically, due to the reduction of relative clock drift between two different nodes to a near zero value is transparent from the proposed mathematical model. Our assumptions also make the proposed technique suitable for sensor networks with high node densities such as in monitoring of strategic environments (War Zones). The Node Request-Cluster Head Broadcast Algorithm reduces energy consumption in the battery of nodes, by optimizing the required number of transmissions to achieve time synchronization to two. Moreover, the number of transmissions required for time synchronization cannot be reduced any further as, we shall not achieve time synchronization with a single transmission. From the above referred observations, it is evident that the proposed time synchronization scheme outperforms other existing schemes in the major dimensions of Synchronization Error and Efficient Energy Management .

With the help of the mathematical model of the proposed time synchronization scheme, we shall verify the efficacy of the technique through simulation and real time implementation in a functional sensor network test bed. In future, we shall apply the principle of non linear regression analysis to reduce the clock drift between two nodes within a cluster at any given point of time

7. REFERENCES

[1] Erchin Serpedin, Qasim M.Chaudhari, Synchronization in Wireless Sensor Networks : Parameter Estimation, Performance Benchmarks and Protocols, Cambridge University Press, 2009

[2] Elson J., Girod L., Estrin D.: Fine Grained Network Time Synchronization Using Reference Broadcasts, in 5th Symposium on Operating Systems Design and Implementation, vol.36, pp.147-163, ACM, 2002

[3] S.Ganeriwal, R.Kumar and M.Srivastava, Timing Sync Protocol for Sensor Networks, in Proceedings of 1st International Conference on Embedded Network Sensor Systems, Los Angeles, CA, USA, pp.138-149, ACM, 2005

[4] Van Greunen Jan Rabaey, J.: Lightweight Time Synchronization for Sensor Networks in 2nd ACM International Workshop on Wireless Sensor Networks and Applications, pp.11-19, 2003

[5] Kim H., Kim D., Yoo S.: Cluster based Hierarchical Time Synchronization for Multi-hop Wireless Sensor Networks in 20th International Conference on Advanced Information Networking and Applications, pp.318-322, 2006

[6] Mamun-Or-Rashid Md., Hong C.S., Chi-Hyung,: Passive cluster based Clock Synchronization in Sensor Network in Advanced Industrial Conference on Telecommunications, pp.340-345,2005

[7] Philip Sommer, Rogen Wattenhofer: Gradient Clock Synchronization in Wireless Sensor Networks in 8th ACM/IEEE International Conference on Information Processing in Sensor Networks, San Francisco, USA, April 2009

[8] Miklos Maroti, Branislav Kusy, Gyula Simon, Akos Ledeczi: The Flooding Time Synchronization Protocol in SenSys'04, pp.39-49, New York, NY, USA, 2004

[9] Michael Meier: Precise Time Synchronization for Wireless Sensor Networks using the Global Positioning System, Semester Thesis, Swiss Federal Institute of Technology, Zurich, 2010.