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Energy and Cost Efficient Time Synchronization Using a Mobile Agent for Wireless Sensor Network

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***Abstract* — Over the past few years, Wireless Sensor Network is one of the emerging technology which is used in many distributed communication network for variety of powerful application such as environmental monitoring, traffic management, agriculture and defence etc. The basic communication in Wireless Sensor Network (WSN) greatly depends on the time synchronization of the sensor nodes in the Network. Clock synchronization is one of the basic services provided by WSN's that aims at providing a common time scale for local clocks of nodes in the network. Nodes in sensor network have its own local clock which is difficult to time synchronize between due to some internal or external effects. Each sensor nodes have limited processing power and memory which affect the lifespan of it which in turn affect the whole network. Many synchronization protocols have been proposed for synchronizing the WSN. These protocols have their own advantages as well as disadvantages according to the way of deployment of the sensor nodes in the WSN. Clock synchronization has paid a great magnitude of attention in Wireless Sensor Network. The main aim of this paper is to synchronize the wireless sensor network using a powerful mobile agent, thereby saving the energy of the sensor nodes. This helps to increase the lifespan of the sensor nodes. Simulation results show that our proposed scheme is more energy efficient and cost effective.**

***Keywords* — Wireless Sensor Network (WSN), Mobile Agent, Time Synchronization, Energy Efficiency, Synchronization Ratio.**

I. Introduction

A WSN consists of one or more base stations and large numbers of small and battery powered sensor nodes which have limited memory and processing power. These sensors are equipped with data processing and communication capabilities. The sensor nodes sense the data from the environment conditions, such as temperature, sound, pressure etc and to cooperatively pass their data through the network to the base station. The sensing data are reported to the internet users through the base stations along the pre-established routes consisting of multiple wireless hops. The various deployment of WSN was motivated by military application such as battlefield surveillance, environmental monitoring etc. Today such networks are used in many industrial and consumer applications, such as machine health monitoring, industrial process monitoring and control and so on.

Time synchronization is a process of bringing the entire sensor node's local clock time to a common notion of time. The main goal of time synchronization in WSN is to achieve the accuracy of the information collected from the sensor nodes. Time synchronization in WSN is required to know the order of events that has sensed by the sensor nodes and it is also important for data fusion. In modern computer networks, time synchronization is critical because every aspect of securing, managing, planning a network involves determining when actually an event occurs. Since the performance of time synchronization is greatly influence by many factors, the energy conservation is one of the main issues in WSN to increase the lifetime of the network.

Many researchers have come up with various time synchronization schemes to provide efficient time synchronization among the sensor nodes in the network. Many existing synchronization schemes rely on the clock information from GPS (Global positioning system) which requires a relatively high power receiver and it is not cost efficient. Among many protocols that have been used for maintaining synchronization in computer networks, NTP (Network Time Protocol) gives an outstanding performance. However, NTP is not suitable for WSN since WSN has numerous challenges like limited bandwidth, energy, hardware etc.

A Mobile Agent (MA) is a type of software agent which consist of program code and the program execution state with the feature of social ability, learning and most importantly, mobility. A MA can transport its state from one environment to another, with its data intact and capable of performing in new environment.

In this paper we will be using a powerful mobile agent attached with UTC (Coordinated Universal Time) which traverses inside the network to synchronize the sensor's nodes in the network. The sensors nodes will get synchronize with reference to the mobile agent UTC. The mobile agent must cover the whole network in any fashion for proper synchronization of the sensor network and it should be able to synchronize the whole sensor nodes in the network.

The rest of this paper is organized as follows: Section 2 deals with the related work and the drawbacks of the existing time synchronization methods in WSN's. Section 3 presents the sensor network model and describes the proposed Energy and Cost Efficient Time Synchronization method. Simulation and analysis of our proposed method is given in Section 4 Section 5 concludes the work.

II. Related Work

There has been substantial works about time synchronization in various environments of WSN. A lot of research works [1] [2] [3] [4] [5] [6] [7] are available in the field of clock synchronization in distributed systems. However most of the existing methods do not take into account the limited resource available for sensor network. Time synchronization in WSN plays a significant role in reducing the energy consumption within the nodes and thereby increases the lifetime of the network. Many time synchronizations methods in WSN try to reduce the synchronization error along with the energy consumption during the synchronization process. Some of these time synchronization process can be categorised as Sender-Receiver Synchronization (SRS) and Receiver-Receiver Synchronization (RRS).

The receiver-receiver approach introduced with the Reference Broadcast Synchronization (RBS) reduces the time critical path and improves the time synchronization accuracy compared to SRS. RBS uses a sequence of synchronization signals from a dedicated sender which is the reference which make periodical broadcast. However the major drawback of RBS is the need of a fixed reference, which will be an overhead for self organised WSN applications. In RRS, the nodes to be synchronize first receives a beacon packet from the common sender and then compare the receiving times of the beacon packet to compute the relative offsets. It does not require the reference node to exchange timing packet with other sensors, only unsynchronized nodes exchange the timing packets.

SRS follows 2-way message exchange between a pair of nodes. A node initiates a two way message exchange with the reference node when it wants to be synchronized. Examples of SRS are Timing-Sync Protocol (TPSN), Tiny-Sync and Mini-Sync etc. TPSN creates a spanning tree for the sensor network. The root of the tree is usually a base station. Clock synchronization is done by synchronization of the child node to the parent. In TPSN, nodes are synchronized in a pair wise manner. Timing Sync Protocol for wireless sensor network (TPSN) which uses an SRS scheme perform 2-way handshake methodology to reduce uncertainty to half since the mean time difference is used. But TPSN consumes more energy and it performs poorly in sparse network. When nodes of the sensor network get depleted TPSN faces problems of lost of network coverage.

Many methods have been proposed for global clock synchronization in [8] [10] [11]. The idea of “All-Node-Based” method is impractical due to its assumption of finding a single cycle which includes all the nodes at least once. The main disadvantage of this method is that it is applicable only in case of small network. In “Cluster-Based-Method” we need to create and maintain clusters and use the “All-Node-Based” method to synchronize among the cluster nodes. But still “Cluster Based” method is having a great amount of overhead for cluster maintenance which ascertains its limitation to be implements in energy constraint sensor network. In Diffusion based method of clock synchronization, nodes can be synchronized at any time with its neighbour and also adapt the adverse communication channel and node mobility.

Passive Cluster based algorithm for Time Sync (PCTS) performs overhearing in time synchronization phase. In this algorithm there is a need to set the clock continuously which leads in more power consumption. PCTS performs too many transitions to achieve synchronization since the nodes that are member of more than one cluster heads have to calculate the mean clock time of all the cluster heads and send the calculated clocks’ time to them. So this is not energy efficient. Dynamic cluster based algorithm technique for time synchronization is based on exchange and update of clock information locally among the neighbour nodes. Synchronous rate based algorithm exchange clock reading values proportional to their clock difference in a set order. But asynchronous method can synchronize at any time with its

In the Flooding Time Synchronization protocol (FTSP), the sensor nodes participate in a process in which a root node is elected. This election of root node is time consuming thereby reducing the energy of the sensor nodes. The root is the origin of the time synchronization messages of the sensor nodes. If a node does not hear a time synchronization message for a while, it declares itself the new root. So, there is an overhead of new root. The protocol requires that if at a later time the node receives a time synchronization message from a node with a lower id than itself, it gives up its root status. When a node receives a time synchronization message from the root, it adjusts its clock and broadcast its own local clock time to its neighbours. Here the energy of the sensor nodes is wasted in election of the root node in the initial phase as well as the broadcasting of its own local clock time to its neighbours.

Wireless Sensor Network which uses GPS uses Flooding time synchronization protocol and GTPS to perform a simple method of synchronizing the idle clock time and logical sensor network time. The main disadvantage of this is the use of energy hungry equipments like GPS which helps in reducing the synchronization error between the neighbour nodes, but fails to take care of energy consumption of the nodes. Moreover using multiple GPS enabled sensor nodes for the time synchronization process is not a cost efficient. It reduces the lifetime of the Wireless Sensor Network which is not a better choice for WSN. GPS greatly reduces the message overhead when synchronization pairs are being determined. However the performance of the GPS is lots worse than the NPS as many unnecessary PBS are performed when comparing with the NPS (Network-wide Pair Selection Algorithm).

III. Energy and Cost Efficient Time Synchronization Scheme

In our proposed scheme, our work tries to decrease the energy consumption during the time synchronization of the WSN to improve the lifespan of the network using a powerful single mobile agent. The mobile agent traverses inside the network for the synchronization of the sensor nodes.

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Some assumptions have been made for our proposed scheme:

a) A powerful mobile agent which will not fail during the entire synchronization process is use for the synchronization process of the WSN. The mobile agent is having a coverage range of radius 100m, which is able to synchronize the sensor nodes whichever are in its range.
b) The path of the mobile agent covers the entire network in any fashion for proper synchronization of the sensor nodes.
c) Propagation delay between the mobile agent and the sensor nodes which are in its range are very small. This is because the density of the sensor nodes deployed in our network design is very high. When the distance between two sensor nodes is very small, propagation delay between the two becomes a negligible value. So the synchronization error reduces to infinitesimally small value.

Figure 1 depicts a sensor network deployed over a geographical area in which the sensor nodes are randomly placed and static in nature. After deployment, a mobile agent traverses the sensor network broadcasting the timestamp messages to the sensor nodes which are in its coverage range. This is shown in figure 2. The timestamp message contains the timing information of the mobile agent. Any node receiving the timestamp message will synchronize its local clock time with respect to the mobile agent time.

Fig.1. Deployment of sensor nodes in the sensor network.

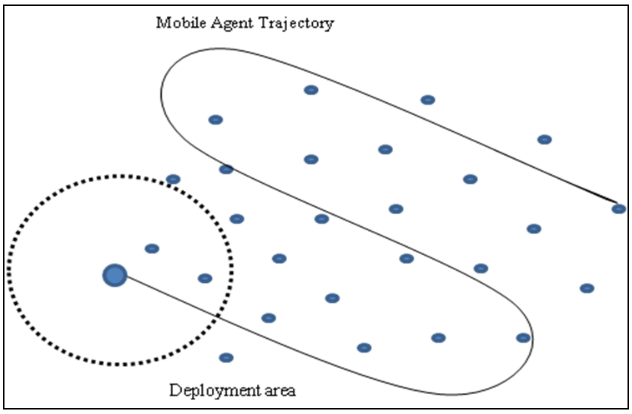

Fig.2. A Mobile agent assisting the synchronization of the sensor nodes.

Every sensor nodes contains a Boolean flag which is set to true when they get synchronized. Once the flag is set to true it will not synchronize again further when they receive the timestamp message. This setting of Boolean flag reduces the number of synchronization process to one. As there is no message exchange between the sensor nodes and the mobile agent the energy of the sensor nodes are preserved to a large extent. The mobile agent will be broadcasting its timestamp messages for every "*t"* secs which is set by the designer of the network according to the coverage range of the mobile agent, size of the network and density of the sensor nodes in the network.

Figure 3 shows the actual synchronization process by the mobile agent when it traverses the sensor network. Once the mobile agent starts broadcasting the timestamp message two sensor nodes receives the timestamp message and they get synchronized according to the timestamp message and set their Boolean flag to true. After some t secs the mobile agent traverses some distance and it again broadcast the timestamp message. In this four sensor nodes receives the timestamp message in which two sensor nodes has already synchronized and the remaining two needs to be synchronize. So in this synchronization phase only two sensor nodes will synchronize according to the time stamp message.

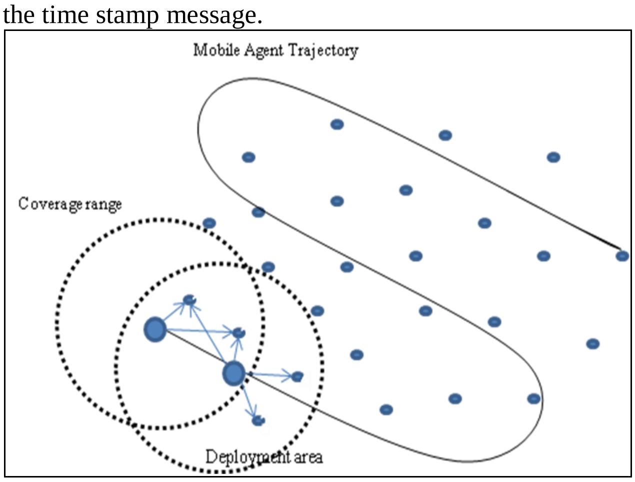

Fig.3. Synchronization process when the mobile agent traverses the network

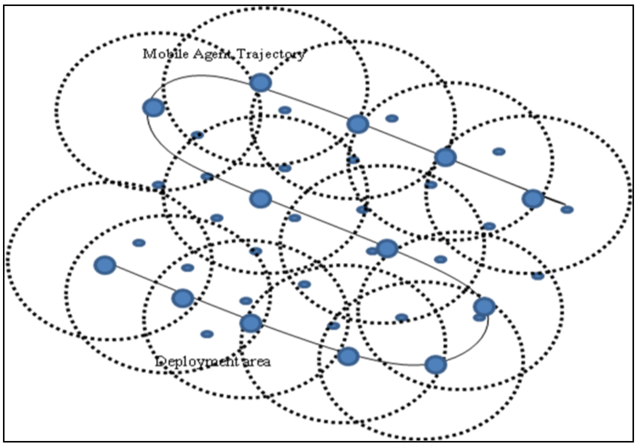

Fig.4. Complete Synchronization process with respect to mobile node.

This synchronization process continues till the mobile agent completely synchronizes the whole sensor nodes in the network. The synchronization process last till the mobile agent completely traverses the whole network. Figure 4 shows the complete synchronization process of the sensor nodes by the mobile agent.

IV. Simulations and Analysis

4.1 Simulation Setup

We simulate the scheme using NS-2 simulator. This work is being simulated taking multiples of 100 nodes into consideration. The initial energy of all sensor nodes is 5 joules. The sensor nodes are deployed over a square sized area of 100m × 100m with adjustable communication range and fixed sensing range. This section compares the performance of proposed algorithm with PBS (Pair Wise Broadcast Synchronization) protocol.

4.2 Performance Metrics

The following performance metrics are used to show the efficiency of the proposed scheme by measuring the average energy consumption, synchronization ratio and convergence time.

Energy Consumption: The total amount of energy used during the synchronization of the whole network by the mobile agent.

Average Energy: Is defined as the ratio of total amount of energy remaining in all sensor nodes by the Total number of sensor nodes synchronized.

Synchronization Ratio (SR): The ratio of total number of nodes synchronized by the total number of nodes deployed.

Convergence Time (CT): The time taken by the sensor nodes to wind up the synchronization.

4.3 Results

In this section the effect of network parameters like network density and the coverage range of the mobile agent are used to compare the performance metrics discussed above. The performance result of our proposed scheme is compared with PBS.

4.3.1 Network density

Network density is defined as the total number of nodes deployed in the network.

Figure 5 illustrates the performance comparison of our proposed scheme with PBS in terms of energy consumption. As shown in figure 4, energy consumption of our proposed scheme is less than that of PBS. As the number of sensor nodes increases the average energy consumption also increases.

Figure 6 illustrates the synchronization ratio graph of our proposed scheme plotting the synchronization ratio on the X-axis and the number of sensor nodes on the Y-axis. For the proper synchronization of all the nodes in the network the synchronization ratio must be equal to 1. As the number of nodes increases in the network the SR also decreases since some sensor nodes are not synchronize. This is shown in the below figure.

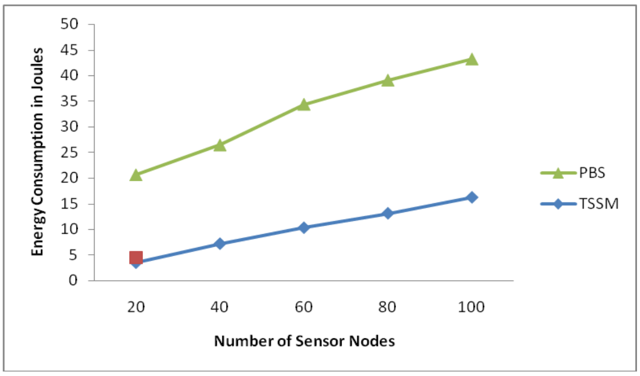

Fig.5. Energy consumption graph

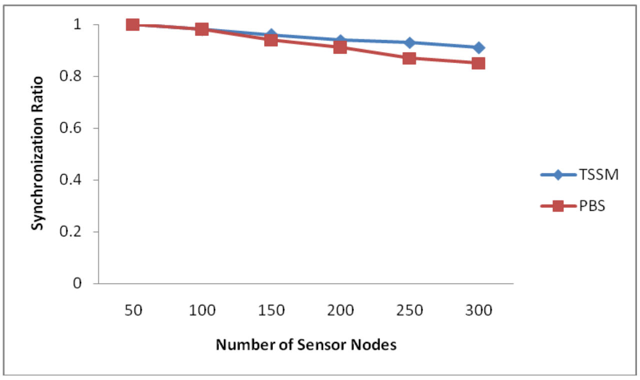

Fig.6. Synchronization Ratio graph

Figure 7 illustrates the Convergence Time of our proposed scheme according to the number of nodes deployed in the network. When 100 sensor nodes are deployed in the network it takes around 9 minutes to wind up the synchronization process. As the number of nodes increases in the network the CT also increases. This is shown in the below figure.

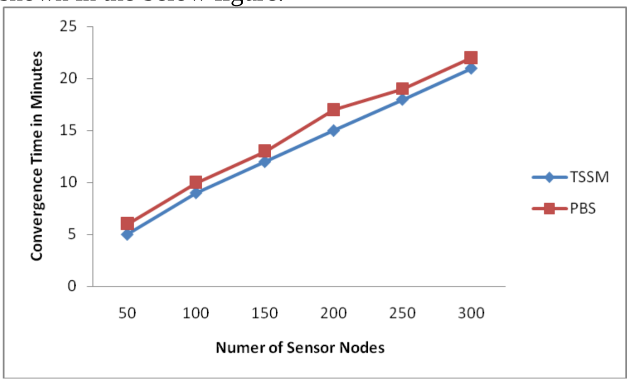

Fig.7. Convergence Time graph

4.3.2 Coverage range of the Mobile Agent (MA)

Initially the coverage range of the MA is 200m i.e. radius is 100m. When we increase the coverage range of the MA, we compare the performance with respect to Synchronization Ratio and Convergence Time.

Figure 8 illustrates the synchronization ratio of our proposed scheme when we increase the coverage range of the MA which is deployed in the network for the synchronization process. Here it clearly shows that more number of sensor nodes can be synchronized when we increase the coverage range of the MA.

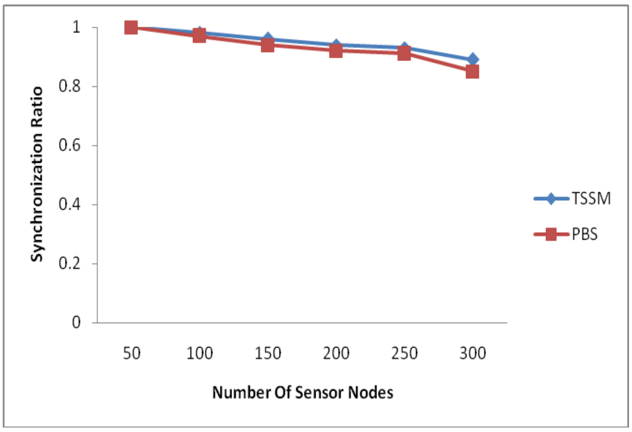

Fig.8. Synchronization Ratio graph when the coverage range of the MA is increased.

Figure 9 illustrates the Convergence Time of our proposed scheme when we increase the coverage range of the MA which is deployed in the network for the synchronization process. Here it clearly shows that CT almost reduces to half when we increase the coverage range of the MA.

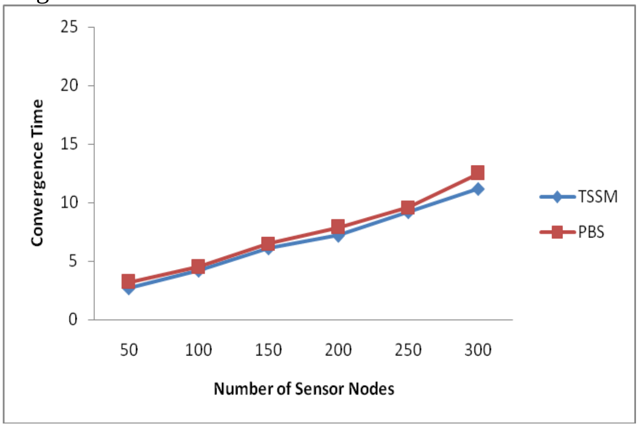

Fig.9. Convergence Time graph when the coverage range of the MA is increased.

4.3.3 Beacon Interval of the Mobile Agent (MA)

Beacon Interval of a mobile agent is time set by the programmer how frequently the mobile agent will be broadcasting the timestamp messages. When we increase the beacon interval of the MA we compare the performance with respect to Synchronization Ratio and Convergence Time.

Figure 10 illustrates the synchronization ratio graph of our proposed scheme when we increase the beacon interval of the mobile agent. Here we can see some decrease in the synchronization ratio when we plot it against the number of sensor nodes deployed in the network.

Figure 11 illustrates the Convergence Time graph of our proposed scheme when we increase the beacon interval of the mobile agent. Here we can see some increase in the Convergence Time when we plot it against the number of sensor nodes deployed in the network.

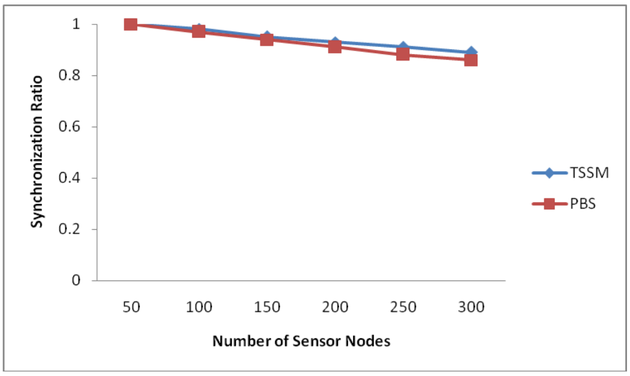

Fig.10. Synchronization Ratio graph when the beacon interval of the MA is increased.

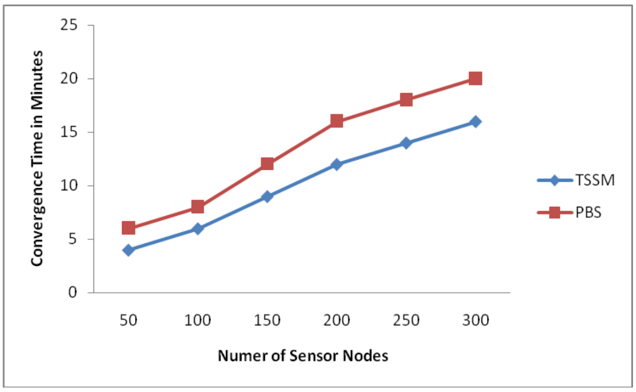

Fig.11. Convergence Time graph when the beacon interval of the MA is increased.

V. Conclusions

In this paper, we had proposed a Time synchronization scheme using a mobile agent which helps us to reduce the energy consumption to a great extent of the sensor nodes by optimizing the required number of transmissions to achieve time synchronization. It also reduces the cost of synchronization which is shown in analysis of the proposed scheme using NS2 simulator. Simulation results depicts that energy efficiency is achieved compared to PBS and synchronization error is reduced. So, we can conclude that our proposed scheme reduces the total amount of energy consumption for the synchronization of the sensor nodes thereby increasing the lifespan of the network.

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