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Time Synchronization in Wireless Sensor Networks: CCTS

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Abstract: **A time synchronization algorithm which is new for wireless sensor networks have been proposed in this paper named clustered consensus time synchronization (CCTS). On the basis of the distributed consensus time synchronization (DCTS) algorithm, this CCTS is developed. The clustering technique is incorporated into the algorithm in order to maintain the faster convergence of node's clock synchronization and better energy efficiency. The CCTS can have mainly two stages: intra cluster and inter cluster time synchronization. The improved DCTS is applied in the intra cluster time synchronization and for exchanging messages within the cluster, the responsibility will be given to the cluster head only. Cluster heads exchange messages via gateway nodes in the case of inter cluster time synchronization. The proposed algorithm's simulation results shows that it reduces the communication traffic compared to DCTS algorithm, and improves the convergence rate due to the combination of clustering topologies.**

Keywords: **skew, offset, cluster, CCTS, time synchronization.**

I. INTRODUCTION

Spatially distributed autonomous sensors are the wireless sensor networks (WSNs) for monitoring physical or environmental conditions and through the network; they can cooperatively pass their data to a main location. The bi-directional modern networks also enable the control of sensor activity. The wireless sensor networks development was motivated by applications such as military and such networks are used in many applications such as industrial monitoring and control of processes, health monitoring, and so on.

Large numbers of nodes are deployed in wireless sensor networks and from the environment; these nodes sense the data and communicate those data with the sink or base station. The nodes need to be synchronized with global clock for identifying the correct event time. Therefore in WSNs, time synchronization is a significant feature.

Various factors will influence the performance of time synchronization such as Precision, Size of network, Complexity, Convergence time and Consumption of energy. The drawback of the wireless sensor networks are the limited energy resources. The power consumption of nodes must be reduced, the nodes must turn their transceiver on and off at appropriate time, in order to save the energy an accurate timing is required between the nodes. Very tiny instruments are the sensor nodes and they are running with a limited energy, so to synchronize nodes effectively is not easy because of the consumption of energy.

In this paper, it takes a hybrid approach and the clustering technique is incorporated into distributed consensus algorithms, and proposes this Clustered Consensus Time Synchronization (CCTS) algorithm. Here the network is divided into overlapping clusters and the time synchronization process can be divided into two stages such as intra-cluster time synchronization and inter-cluster time synchronization.

II. RELATED WORK

In the most applications of sensor networks without time and space information of an event, the sensed data are meaningless and useless. In many circumstances of network applications, it requires accurate time synchronization. For an instance, TDMA needs accurate time information for media access control, so that the interference of transmissions does not occur. Also, the nodes of sleep scheduling needs to sleep and wake up at the same time. Along with this, synchronization is applicable for some special applications such as mobile target localization and event detection.

In the related works based on different applications, a variety of protocols and algorithms for centralized and distributed synchronization have been proposed. Reference-Broadcast Synchronization (RBS), Timing-sync Protocol for Sensor Networks (TPSN), and Flooding Time Synchronization Protocol (FTSP) are the centralized synchronization protocols. For the whole network, these protocols need a reference node or root node for providing a reference time. These protocols can have a faster convergence rate and little synchronization error. Time-Diffusion Synchronization Protocol (TDP), Average Time Sync (ATS), and Consensus Clock Synchronization (CCS) are the distributed synchronization protocols. In order to achieve the whole network synchronization, they can use local information.

In Reference- Broadcast Synchronization (RBS), nodes send reference beacons to their neighbours. A time stamp does not included in the reference beacon and the receiving nodes used its time of arrival as a reference point for comparing clocks. In Timing-sync Protocol for Sensor Networks (TPSN), the working of protocol involves two phases: level discovery phase and synchronization phase. The first phase is used in the network for creating a hierarchical topology, in which a level is assigned for each node. The root node is assigned level 0. Nodes in the level i synchronize to a node of level i – 1 in the second phase. To the root node, all nodes are synchronized at the end of the synchronization phase and the synchronization of network is achieved. In Flooding Time Synchronization Protocol (FTSP) in order to synchronize multiple receivers, it utilizes the radio broadcast message. The senders' time stamp can be included in this message and then obtain the corresponding local time by the receivers. So the disadvantages of centralized synchronization protocols are their design involves complexity logic with high computational complexity, poor robustness, and the energy consumption is high. Other disadvantages include their cumulative errors and the network synchronization accuracy is unbalanced.

In Time-Diffusion Synchronization Protocol (TDP), from equilibrium, it maintains a small time deviation and allows reaching an equilibrium time. In Average Time Sync (ATS), in order to achieve a global agreement, it averages the local information. In Consensus Clock Synchronization (CCS), an internal synchronization will be provided to a virtual consensus clock. This type of protocols convergence rate which relies on the network topology is very low as compared to the centralized synchronization protocols. But they can easily adapt to a WSN's dynamic topology because they are not hierarchical nodes. This paper chooses a distributed synchronization protocols for achieving time synchronization of WSN.

One kind of distributed time synchronization algorithm is the Distributed Consensus Time Synchronization (DCTS) algorithm including ATS, CCS, Global Clock Synchronization (GCS), Distributed Time Synchronization Protocol (DTSP), Gradient Time Synchronization Protocol (GTSP), Energy-Efficient Gradient Time Synchronization Protocol (EGTSP), and Second Order Distributed Consensus Time Synchronization (SO-DCTS). Such algorithms can have good scalability and robustness in order to maintain a consensus virtual time because in the network, it does not require reference nodes and nodes. The disadvantages of DCTS include high communication traffic and slower convergence rate than that of centralized synchronization protocol.

In WSNs, Clustering algorithms have been widely used. The network is divided into several clusters on the basis of clustering topology. Each cluster can have a cluster-head and a large number of cluster member nodes. The election of the cluster-head is based on certain mechanisms and it can have the following responsibility includes collection of information, integration of data, and the inter-cluster communication. The communication traffic between the nodes will reduce this clustering topology and thus the energy consumption will be reduced and the network lifetime will prolongs.

III. PROPOSED SYSTEM

The proposed architecture takes a hybrid approach in which the clustering technique is incorporated into the distributed consensus algorithm and Clustered Consensus Time Synchronization (CCTS) algorithm will be proposed. Here the network can be divided into overlapping clusters and the time synchronization process can be divided into intra-cluster and inter-cluster time synchronization.

By Low-energy Adaptive Clustering Hierarchy (LEACH), randomly distributed Sensor nodes within the target area form cluster-based network protocol architecture for small sensor networks. Distributed cluster formation technique can be included in LEACH that enables large numbers of nodes self-organization, and includes algorithms for clusters adaptation and the election of rotating cluster-head for distributing the energy load between all the nodes.

In LEACH, it randomly selects cluster heads from the nodes and periodic reselection will be performed. So that the cluster-heads dissipation of high energy experienced will communicate with the base station is spread across the networks nodes. Cluster-heads each iteration is called a round and the LEACH operation can be divided in to two phases including set-up and steady phases. Each sensor node chooses a random number between 0 and 1 in the set-up phase. The sensor node becomes a cluster-head if this is lower than the threshold for node n, T (n).The threshold T (n) can be calculated as

$$T(n) = \begin{cases} \frac{p}{1-p[r \times mod(1/p)]}, & if\ n \in G \\ 0, & otherwise \end{cases}$$

Where P is the nodes desired percentage in which they are cluster-heads, current round r, and G is the nodes set in the past rounds that has not been cluster heads. In order to minimize the cluster formations overhead, longer duration of steady phase will occurs. Based on TDMA schedule, data transmission takes place during the steady phase and through local computation data aggregation/fusion will be performed by the cluster-heads. From the cluster-heads, the base station receives only aggregated data and leading to conservation of energy. Through the set-up phase, the cluster-heads are selected again after a certain period of time in the steady phase.

Through the power control, the clusters overlap each other only after the cluster-heads are elected. Overlap-nodes are the nodes in the overlapping region. From the overlap-nodes, the gateway nodes are elected which are responsible for the message exchange between clusters.

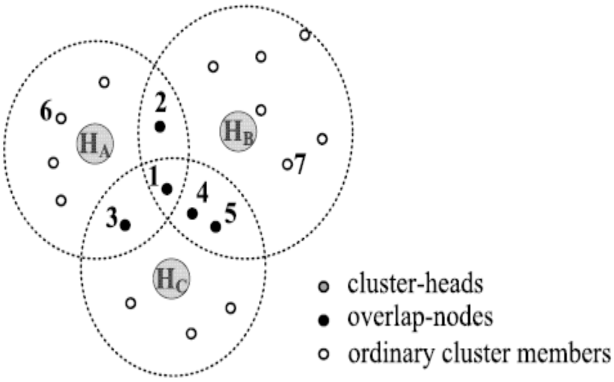

Fig 1: Schematic illustration of the local topology of a network

The fig above schematically represents the local topology of the network. A, B, and C clusters mutually overlap one to another, and closed circles represent overlap-nodes which is represented by nodes 1 to 5. Shade circles and small open circles represent the cluster-heads (H) and ordinary cluster member nodes respectively. B and C clusters are the neighbouring clusters, and 1, 4, and 5 nodes are their overlap-nodes. Assuming that 1, 4, and 5 overlap-nodes received the message from cluster-head B, then after the message from cluster-head C received, they will respond to C a message containing the ID number of the cluster-head B a.

If the node 4 message is first to arrive, then between cluster B and C node 4 is elected as the gateway node, and ignore the messages from node 1 and 5 by cluster-head C. For responding to the loss of message if it does not receive the synchronization messages in one period, then the cluster-head will receive a message from an ordinary cluster member node. The ordinary cluster member node will announce itself be a new cluster-head if there is no response message from cluster-head, and its neighbour nodes will get message in the next synchronous period.

The working of the proposed system includes the following:

A. Cluster formation:

When the network is deployed, this algorithm phase occurs. For identification, each node is assigned with an ID number. After the network is formed, in order to notice them the identity of their cluster heads, the cluster-heads broadcast a message containing their own ID numbers to their cluster member nodes. Then receiving the messages and recording the

ID numbers can be done by the cluster member nodes. Ordinary cluster member nodes record only one ID number whereas the overlapping region nodes record more than one ID numbers. Cluster member nodes respond with a message containing their own ID numbers and the ID numbers of their cluster-heads which they can communicate with only after receiving the message from the cluster-head.

Cluster-heads check the ID numbers of other cluster-heads with who communicate through overlap-nodes and mark them as the neighbouring cluster-heads only after receiving the response messages, , and then from these overlap-nodes the gateway nodes are elected. The overlap-node whose message arrives first is elected as the gateway node only if different overlap-nodes can communicate with the same neighbouring cluster-head.

B. Time Synchronization:

At the root node, the synchronization phase begins and it propagates through the network. Intra-cluster time synchronization is the first stage of the algorithm. The average values of intra-cluster virtual clocks skew compensation parameters within their clusters and the average values of nodes intra-cluster virtual clocks will be calculated by the cluster-heads and then the clock compensation parameters of intra-cluster virtual clocks will be updated and simultaneously broadcast them to the neighbouring nodes. The messages will be received by the Cluster member nodes and then the clock compensation parameters of local intra-cluster virtual clock will be updated in order to achieve the intra-cluster virtual clocks synchronization.

The inter-cluster time synchronization is the second stage of the algorithm. Through gateway nodes, the exchanging of their intra-cluster virtual clocks and their clock compensation parameters will be done by cluster heads. According to the size of each cluster, the received messages are given corresponding weights. Then the network virtual clocks skew and offset compensation parameters will be updated by the cluster-heads in order to achieve the network virtual clocks synchronization.

The synchronization process of intra cluster will be started by the cluster-heads. The synchronization message send by the cluster-head contains its own ID number, the local clock, the intra-cluster virtual clock, and the skew compensation parameter to the cluster member nodes and records the sending time stamping of local clock. After receiving this synchronization message, cluster member nodes record the receiving time stamping of local clock, intra-cluster virtual clock, and skew compensation parameters and the cluster-head will get the response back.

C. Information Interchange:

Synchronization which is pair wise is performed in this phase along the hierarchical structure edges established in the earlier phase. For doing this handshake between a pair of nodes, the classical approach of sender-receiver synchronization is used. Between nodes ‘A’ and ‘B, a message-exchange is performed. Time measured by local clock of ‘A is represented by T1 and T4. Similarly, time measured by local clock of ‘B is represented by T2 and T3. ‘A’ sends a synchronization pulse packet to ‘B’ at time T1. The level number of ‘A’ and the value of T1 is included in this synchronization pulse packet. At T2, node B receives this packet where T2 is equal to T1 + D + d. The clock drift between the two nodes and propagation delay will be represented by D and d respectively. ‘B’ sends back an acknowledgement packet to ‘A’ at time T3. The level number of ‘B’ and the values of T1, T2 and T3 are included in this acknowledgement packet. At T4, node A receives the packet. Assuming that in this small span of time, the clock drift and the propagation delay do not change. ‘A’ can calculate the clock drift and propagation delay:

$$\Delta = \frac{(T1-T2)-(T4-T3)}{2}; \; d = \frac{(T2-T1)+(T4-T3)}{2}.$$

D. Energy Reservation:

The message delivery delay sources can be analyzed by calculating the following time:

• Send Time: The time for constructing the message at the sender. Protocol processing of kernel and the operating system variable delays is included.

• Access Time: Before actual transmission, each packet at the MAC (Medium Access Control) layer faces some delay. The MAC protocol in use can have this delay which is specific to that protocol also.

- Propagation Time: Between the network interfaces of the sender and the receiver, it is the time spent in propagation of the message. This delay is very small when the sender and receiver share access to the same physical media (e.g., ad-hoc wireless networks neighbors, or on a LAN), as it is simply the physical propagation time of the message through the media.
- Receive Time: To receive the message from the channel and notify the arrival of host, this is the processing time required for the receiver's network interface.
- Transmission Time: To transmit the message, this is the time it takes for the sender. Depending on the message length and the radio speed, this time is in the order of tens of milliseconds.

IV. CONCLUSION

In this paper, a new algorithm for time synchronization of WSNs was proposed. It is incorporated with the clustering technique and this algorithm is based on the consensus algorithms. To use local information to achieve a global agreement is the basic idea of CCTS. Compared to the DCTS, the proposed algorithm reduces the communication traffic and improves the convergence rate due to the incorporation of topology of clusters.

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