Bandwidth Efficient Hybrid Synchronization for Wireless Sensor Network

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Abstract— **Data collection and transmission are the fundamental operations of Wireless Sensor Networks (WSNs). A key challenge in effective data collection and transmission is to schedule and synchronize the activities of the nodes with the global clock. This paper proposes the Bandwidth Efficient Hybrid Synchronization Data Aggregation Algorithm (BESDA) using spanning tree mechanism (SPT). It uses static sink and mobile nodes in the network. BESDA considers the synchronization of a local clock of node with global clock of the network. In the initial stage algorithm established the hierarchical structure in the network and then perform the pair-wise synchronization. With the mobility of node, the structure frequently changes causing an increase in energy consumption. To mitigate the problem BESDA aggregate data with the notion of a global timescale throughout the network and schedule based time-division multiple accesses (TDMA) techniques as MAC layer protocol. It reduces the collision of packets. Simulation results show that BESDA is energy efficient, with increased throughput, and has less delay as compared with state-of-the-art.**

Keywords— Aggregation; Delay; Energy; Scheduling; Synchronization;

I. INTRODUCTION

Synchronization algorithms are required to co-ordinate the time scale of node and network, and scheduling algorithms are required to allocate the collision-free time slots to reduce the energy consumptions in the WSN[1,2]. For instance, if the nodes used in the sensing and collection of data is not synchronized with global clock, it takes more time to send the packet to sink and hence consume more energy. Also, if the activities of the nodes are provided with different schedules according to the local clock and not synchronized with global clock, then end result will be different and uneven. In this paper, a hybrid approach is proposed, which takes care of synchronizing a local clock with global clock of network and schedules the activities based on the present and next state of the channel. With mobility of node, it is difficult to integrate and interpret the information sensed by the nodes without synchronization. The unusable network conditions and scare resources of WSN makes essential to develop a time synchronized protocols. Also, mobility of a node causes topological variations in the network architectures, and low bandwidth restricts the multi-hopping. Hence, to deal with these challenges hybrid protocol needs to be designed which takes care of scheduling and clock synchronization in WSN. In a hierarchical structure, the potential sources of energy consumption and delay are the collisions. These occur due to improper scheduling and synchronization of the packets generated from the lower layer to the upper layer. Also, retransmission delay is caused due to improper balancing of slot allocation during scheduling and difference in the local clock of the node and global clock of the network. In order to reduce the retransmission delay, an efficient scheduling medium-access protocol is required, which manages the time slots of cluster head (CH) and nodes. The nodes and network are synchronized with the global clock that avoids the mismatch of the packets from root nodes to the upper layer. The data propagation from node to CH and CH to the base station (BS) may be at one hop or multi-hop depending on the depth of the spanning tree. Timing-Synch Protocol for Sensor Networks (TPSN) [2], considers the traditional approach of two-way message exchange between sender-receiver synchronization with increase in sync errors and energy consumption.

The paper focuses on a hybrid approach to minimize the energy consumption with increased throughput, hence bandwidth utilization. It considers clustered architecture with the spanning tree in the presence of non-ideal clocks. The result shows that application of spanning tree algorithm for synchronization performs better than structured as compared to scheduled-based algorithms. The BESDA algorithm is compared with TPSN, which is an efficient synchronization algorithm.

The remaining part of the paper progress with different sections as; Section II focuses on the present work related to synchronization and scheduling algorithms. Section III presents the required assumptions and network model. Section IV details about the proposed mechanism used for the BESDA, Section V discusses simulation setup and results, and Section VI conclusion along with the future scope.

II. RELATED WORKS

This section explores the idea how one can use TDMA technique for scheduling and synchronization techniques to improve the QoS. Ref. [3] proposes the hybrid approach for scheduling the activities of mobile nodes, and slots are allocated using TDMA for improving energy consumption. The mobility of node restructures the cluster and increases the energy consumption. In [4], nodes are organized in tree structure and energy consumption is calculated according to the different states of the radio. The TDMA protocol helps assigning the time slot and reduce the state transitions, hence energy consumption. The sleep period of the node is adjusted and triggers are given by short duration pulses by maintaining the number of transmission and receptions fixed. Ref [5] considers the spanning tree mechanism to improve the energy consumption as compared with TPSN. It shows the reduced sync errors. [6] Considers the delay-sensitive approach to achieve low packet delay and high throughput by considering cycle based sync scheduling. The proposed hybrid approach helps in reducing the delay but has a limitation of overhead with increased network size and synchronization error. Ref [7] proposes algorithm for reducing memory and computational overheads. The clock of each node is synchronized with reference clock based on feedbacks i.e. value tracking time sync protocol. In ref [8], clock of each node is synchronized with the clock of reference node so that clock skew is minimized, but at the same time the energy consumption is increased, since time required for network wide synchronization increases. Ref [9] considers the clock adjusting protocol that works during node failure to minimize the clock adjustment time. [10] Presents the scheme for data aggregation under distributed algorithms with an asynchronous and synchronous time model. Sensor clocks are synchronized up to a small drift that balances the delay. It uses competitive analysis to assess the quality of the algorithms. It lacks in the proper balance of data to be transmitted from nodes to sink with an increase in cost. Ref [11] considers the data aggregation tree based on collection and time synchronization is achieved eventually during the establishment. Relative time drift and phase offset are the metrics of calculation. In [12] Clustered Time Synchronization algorithm and energy model is presented that conserves the energy beside accuracy while synchronizing the WSNs. Green Conflict Free (GCF) [13,14] algorithm uses conflict-free schedule for the three hop neighbors. It improves the minimum slot sharing for reducing the energy consumption and delay. [15] Addresses the issue of adopting the mobility and space division multiple accesses techniques to collect the data. Author minimized the data gathering time by moving the mobile data collector through optimal route. The errors are increased due to improper balancing of data flows. Ref [16], proposes the distributed clustering algorithm for grouping the mobile nodes into the clusters. Mobility of node frequently changes the structures and accordingly not suitable to use spanning tree.

The different algorithms used in the section are either work on the scheduling or synchronization technique to improve the QoS parameters. During scheduling slot allocation is the major concern to avoid the collision, when number of aggregated packets are increased. During synchronization, if global clock of network is not synchronized with local clock of node, results in sync errors. To minimize the energy loss and errors an innovative technique of combining the two approaches (synchronization and scheduling) is presented, which works level by level.

III. Proposed Network Model

A. Assumptions

- Nodes deployment is random and organized in the cluster.
- The network is divided into the clusters. Each cluster consists of CH, which acts as a parent node for collection of data from different levels within the cluster.
- The stable sink node is equipped with GPS capabilities to synchronize their time with global time, and act as the parent node in the network.
- Communication inside the network is considered as bi-directional.
- All the CHs are scheduled in TDMA as MAC layer protocol.

B. Network Model

Consider a network tree T (V, E), where 'V' denotes the set of 'n' wireless nodes and 'E' denotes the set of wireless links. The network T (V, E) is divided into many sub-trees T1, T2, T3,…,Tn called as a cluster. Every sub-tree has one CH, which acts as root for each sub-tree. There is one base station (sink) in the network located at the root of the tree and collects data from all CHs. All CHs collects information from each sensor node in the network. Each node uses its clock for maintaining the time stamp which is synchronized with global clock of the network for collection of data. The collected data will be forwarded to CH and then to sink with minimum errors and, reduces transmission time per forwarding. The network should use min, max, average functions for aggregations. All the aggregated packets from CH are scheduled in such a way that minimum collision occurs.

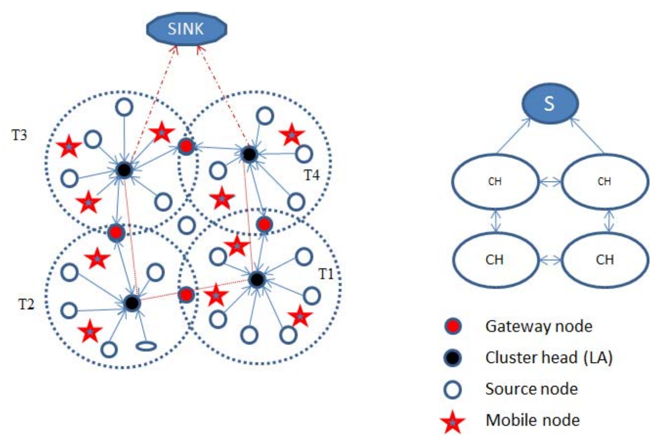

Fig. 1. Cluster-based Network Model

The network assumes a time-slotted approach with error free channels. At each time slot T_s, the clock of a node is synchronized with global clock and then the aggregated data is communicated either in intra-cluster or inter-cluster stage. The overall system operation is described as follows. Assume that a measurement event occurs at time t_m, each node senses its environment and generates data, which is denoted by the message 'm'. All messages from sensor nodes have to be delivered to the CH and then to the sink. During the first time slot, each message 'm'generated by nodes within cluster after forming tree is combined into packet with time stamp and forwarded to parent node (CH). At the second level, all the CH is scheduled in TDMA for allocation of slot with collision-free transmission of data to sink.

IV. PROPOSED MECHANISM

The main objective of proposed hybrid approach is to minimize the energy consumption with increase in throughput. The steps in development of algorithm are as follows

- Formation of spanning tree of each cluster and the whole network
- Allocation of collision-free scheduling slots and
- Synchronize local clock of nodes with global clock to reduce the energy consumption and increase the throughput

A. Spanning tree formation (SPT)

In the present case WSN is considered as a connected, undirected graph G (V, E), the work considers the conversion of the graph into a minimum spanning tree. The minimum spanning tree of graph G (V, E) is formed by using the Kruskal algorithm. It considers number of nodes in set A as a forest with the weight of each as one-hop. The working of spanning tree formation mechanism is shown in Fig2.

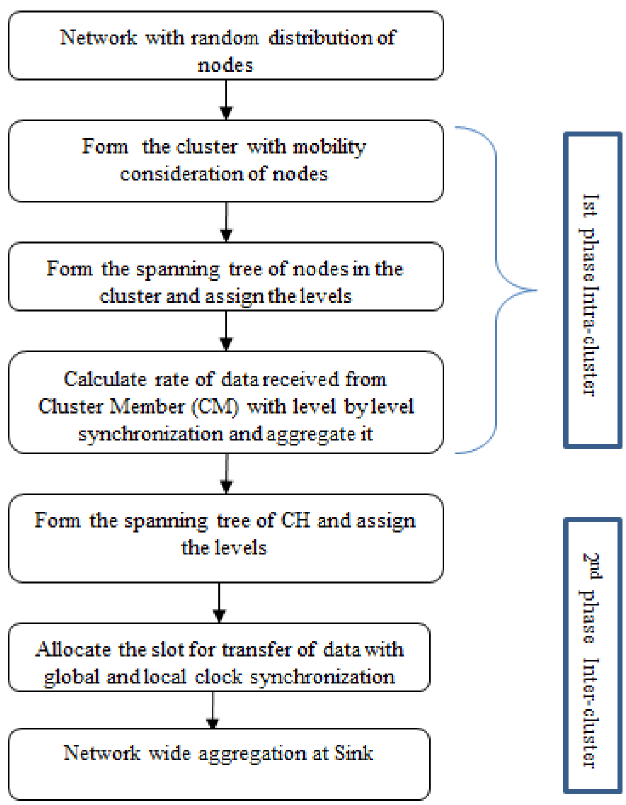

Fig. 2. Flow of BESDA

First, The mobile nodes are grouped into clusters at time interval 't' then the spanning tree will be formed in the individual cluster i.e. intra-cluster spanning tree. In one cluster, CH will be assumed to have level 0. The CH will broadcast message to all neighbors. The neighbors who will receive the message will be added to forest A, only the edges that are forming a loop will be discarded. The spanning tree of individual cluster follows the same algorithm. The major constraint in the formation of tree is the mobility of node. Here, the work considers the time duration for settling the nodes and then they are grouped to from the intra-cluster tree.

The second step is to form a spanning tree for inter-cluster. All the CH nodes with level 0 will be grouped, and graph G(*v*,*l*) will be formed, where *v* is CH and *l* is an edge in between CH to CH or CH to sink node. Here, the same step like intra-cluster formation is repeated, only difference is that all the CH are static. The sink node will be assigned to level 0, and it will transfer the neighbor finding message, the CH who will receive the message will form the spanning tree with sink node as parent node. After connecting first level CH to sink node, the first level CH forwards the neighbor finding message to a next CH and connect it to the spanning tree as shown in Fig3.

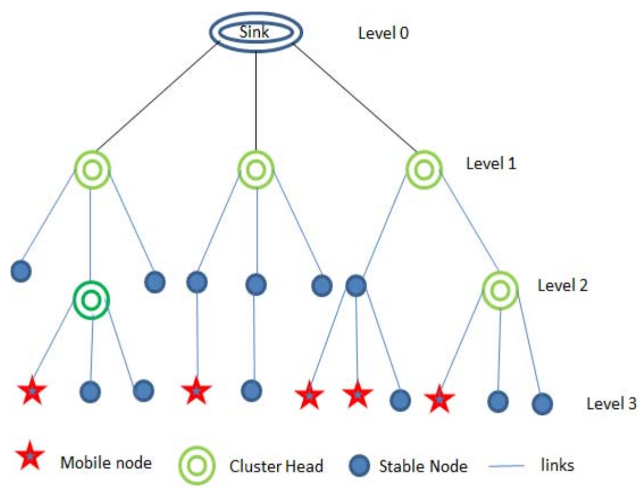

Fig. 3. Structure of Proposed Spanning Tree Mechanism

B. Synchronization of nodes:

The spanning tree formation will maintain the different levels of nodes, the sink node will be given as level 0, the CH directly connected to the sink node will be at level 1 of spanning tree, the next level CH will get level 2 and all other nodes under CH will be assigned the next levels. Here, the sink node is the parent node of all nodes in the network, and it maintain the global notion of time. The aim of the synchronization mechanism is to synchronize the clocks of all nodes with sink node. The CH connected to sink or to other CH will act as parent in any level to nodes. The sink node, which is parent node, send clock estimation message to the direct child. The direct child is a child, who is one level distance from the parent as shown in Fig.3.

The TPSN mechanism tries to apply global time-scale across the network at one time. Here, every node has to synchronize with global time, which is maintained by one particular node. The major reason for better performance of proposed BESDA is level-by-level synchronization and application of proper time slots to forward the data to sink. Here, the sink maintains the global time, only the CH at next level of sink will take global time scale from sink node, other nodes or CHs takes a global time scale from previous level

CHs. The level-by-level mechanism reduces the overheads to maintain equal time scale among all nodes at one time. It leads to increase in synchronization errors and also require more energy to keep it.

C. Scheduling the slot:

In this part of the algorithm, all slots are allocated based on TDMA for transfer of packets received from the CH to sink. In the intra-cluster communication, information is collected within the current state (myopic scheduling) of sensor nodes, and then it is aggregated at CH. While non-myopic schedule is applied to inter-cluster communication with less number of nodes. The decision is taken based on current and future state of a channel that helps to avoid the conflicts with increase in throughput.

V. SIMULATION RESULTS

A. Simulation Details

The simulation of the algorithm is performed using NS-2 (ns-2.34). The nodes are placed randomly in a given area. The parameters considered for simulation are shown in Table I. The results are obtained by applying the spanning tree mechanism and time synchronization (TPSN) [2] on the GCF[13] as scheduling algorithm and BESDA as hybrid synchronization algorithm.

TABLE I. SIMULATION AND NODE PARAMETERS

Parameters	Value
Number of nodes	25,50,75 and 100
Number of sources	24, 49, 74 and 99
Number of sinks	1
Placement of source and sink	Random and sink at center
Initial energy	100J
Idle power	14.4mW
Receive power	14.4mW
Transmit power	36.0mW
Runs of each simulation	20
Node mobility	20 mtrs /sec

B. Results and Discussions

Fig. 4 and 5 shows the result of synchronization errors and average energy consumption required for synchronization of local and global clock used by varying number of mobile nodes with TPSN and spanning tree synchronization mechanisms. It is seen that the performance in case of spanning tree mechanism is better than TPSN. The major reason for better performance is level-by-level synchronization performed by the proposed mechanism. Here, the sink maintains the global time, only the CH at next level of sink will take a global time scale from the sink node, other nodes or CHs takes global time scale from previous level CHs. The level-by-level mechanism reduces the overheads by maintaining equal time scale among all nodes at one time. Uneven time stampings of TPSN leads to increase in synchronization errors and also require more energy to keep it.

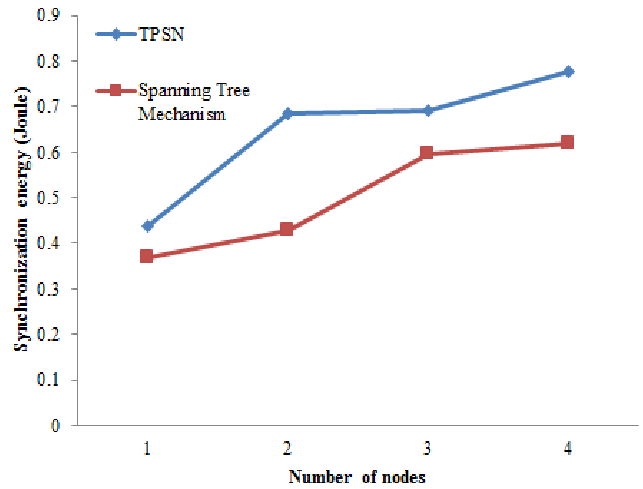

Fig. 4. Comparison of Sync Energy Consumption

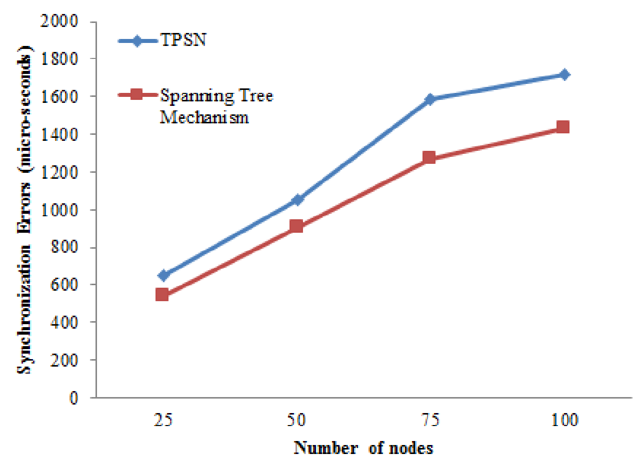

Fig. 5. Comparison of Sync Errors

Fig.6 shows the average energy consumption of two different scheduling mechanisms GCF, and BESDA after applying TPSN and spanning tree synchronization technique. The average energy consumption by using TPSN is more than that of SPT-based synchronization mechanism because TPSN tries to apply global time-scale across the network at one-time, while the SPT-based synchronization mechanism apply it level by level. The distribution of global time scale across whole network require larger amount of energy, and it leads to larger time drift in between global time and actual time. It leads to higher resultant energy consumption in such cases, as nodes have to give their larger share of energy to synchronization. At other side SPT mechanism apply global time scale level-by-level, which gives less overhead and leads to reduced energy consumption.

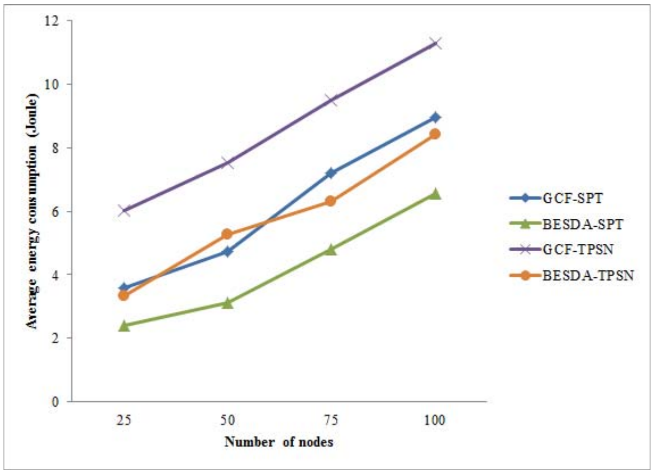

Fig. 6. Comparison of Energy Consumption

Fig. 7 shows the average throughput of hybrid mechanism applied on the two scheduling algorithms GCF and BESDA under two different synchronization techniques. With an increase in the number of nodes, throughput increases by 4.59% and 5.29% in case of SPT as compared to TPSN. This improvement in the result is due to the effect of mobility and addition of number of nodes in the cluster with one hop weight. If global state-of information is considered in TPSN, it will change every time the nodes go mobile and need to update the global state in whole network, hence reduced throughput.

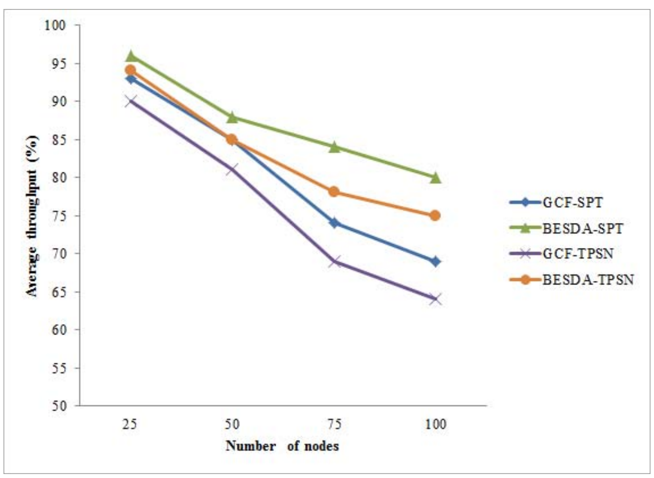

Fig. 7. Comparison of Throughput

Fig. 8 shows the average delay of hybrid mechanism. With introduction of controlled mobility to nodes, an Avg delay in matching the local and global clock is reduced by 17.21% and 6.33% with SPT as compared to TPSN. The larger time drift introduced in TPSN takes large time to take decision on schedule as compared to SPT. In SPT level by level synchronization distribute the tasks among different levels, each level gets synchronization information from the previous level and propagates among all nodes in the network. The process of exchanging a global state of information increases the overhead in the network, which leads to increased delay and reduced throughput in case of TPSN.

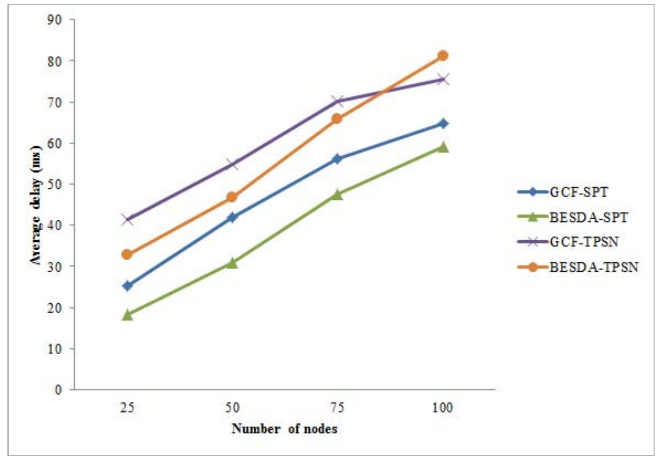

Fig. 8. Comparison of Average Delay

VI. Conclusions and Future Work

The proposed hybrid synchronization and scheduling algorithm with spanning tree mechanism shows improvement in delay, throughput and has reduced energy consumption as compared with TPSN. Synchronization with the local and global clock increases the lifetime of the network along with variation in the throughput, which correlates the bandwidth utilization. A synchronization error that occurs due to improper balancing of clocks is minimized by 17.30% and improves the energy consumption by 22.32%. With the introduction of node mobility, the performance of the synchronized algorithm is improved by a factor of 3%. The work can be extended by considering the heterogeneity of nodes and sink mobility in the network.

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