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Intra and Inter Cluster Synchronization Scheme for Cluster Based Sensor Network

V. Shunmuga Sundari[1], N. Mymoon Zuviria[2]

[1]Student, [2]Asisstant Professor, Computer Science and Engineering, National College of Engineering, Tirunelveli, Tamil Nadu, India

Abstract **- Cluster based wireless sensor network (CWSN) is one of the approaches to reduce the energy consumption of wireless sensor network. In this network communications are categorized into two types that are intra cluster communication among sensors in the same cluster of the network and inter cluster communication among different cluster of the network. If these two communications are not handled properly, communication efficiency and network performance will be degraded. In this paper, intra and inter cluster synchronization scheme for cluster based sensor network is proposed which has two scheduling approaches that synchronize both intra- and inter cluster communication. In the first approach an efficient Cycle-Based synchronous Scheduling (CBS) is proposed to achieve low average packet delay and high throughput by optimizing the cycle length and transmission order. In the second approach, a Relay-Based asynchronous Scheduling (RBS) is developed to eliminate the necessity of communication synchronization so that packets are transmitted with no synchronization delay, yielding very low end-to-end packet delay. This synchronization scheme integrates both CBS and RBS without any interruption on data gathering during switching, which allows the network to utilize the benefits of both approaches to meet the stringent requirement of delay sensitive applications.**

Keyword **–Clustering, Synchronization, Data gathering, Scheduling approaches, Wireless Sensor Network.**

I. Introduction

In Wireless Sensor Networks (WSN), clustering is a good candidate to increase scalability, improve energy efficiency and provide QOS guarantees. In CWSN, Sensors elect themselves to be local cluster-heads at any given time with a certain probability. These cluster head nodes broadcast their status to the other sensors in the network.

Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except during its transmit time, thus minimizing the energy dissipated in the individual sensors. Once the cluster-head has all the data from the nodes in its cluster, the cluster-head node aggregates the data and then transmits the compressed data to the base station.

Sensors' energy cannot support long haul communication to reach a data sink and thus requires many levels of hops or a gateway to forward the data on behalf of the sensor. These gateways, group sensors to form distinct clusters in the system and manage the network in the cluster, perform data fusion to correlate sensor report and organize the sensors by load balancing technique have been suggested in the literature[2].

To reduce the cost and improve the scalability, introducing two layered network helps to reduce the power consumption of the sensors. In [5], we focus on finding fast collision- free polling schedules. We then introduced Cluster Head selection metric that accounts for both residual energy of node, link qualities in its neighborhood or node degree [3, 4, 7, 9].

In general, Intra- cluster communication in each cluster is usually controlled by the Cluster Head (CH) with Time Division Multiple Access (TDMA) based protocol to avoid transmission collisions. For inter-cluster communication, CHs can be considered to form a smaller relay network where either TDMA or Carrier Sense Multiple Access (CSMA) based protocols can be utilized. To avoid the interference between intra- and inter- cluster communications, different channels are used in [8] and scheduling approaches are developed in [1, 10].

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Sink mobility in many scenarios allows different communication between the sensors and sink, opening up many problems in delay sensitive application [6, 8], many communication protocols in cluster- based sensor network adopt hybrid approaches that utilize both TDMA and CSMA.

In this paper, we propose hybrid scheme to synchronize the cluster based sensor network communication which is used to achieve high throughput and higher energy efficiency. Our scheme supports delay sensitive applications and to solve the synchronization problem. The rest of the paper is organized as follows. Section 2 and Section 3 describe system model and methodologies respectively. Section 4 presents the experimental results for the proposed approaches. Finally, section 5 gives conclusion.

II. System Model

The system architecture for the synchronization scheme is shown in Fig 1. There are three kinds of nodes in the system; cluster member node, Cluster Head (CH), relay node. These nodes are assumed to be of the same kind and have same properties respectively. All communication is over wireless links. A wireless link is established between two nodes only if they are in range of each other. Cluster Head and relay nodes are capable of long-haul communication compared to the cluster member. Communication between nodes is over a single shared channel. Current implementation supports TDMA and CSMA.

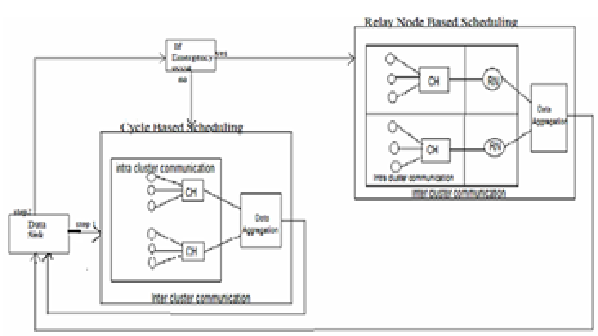

Fig 1 System for synchronization scheme

In this paper we assume that all the nodes and data sink are stationary. Initially Data sink follows Cycle Based synchronous scheduling (CBS) for data gathering. In this approach, data collected by cluster members are first sent to CHs, which in turn deliver the data to the data sink either by direct communication or through relays on intermediate CHs. Each node is assigned a single interval for transmission so that the synchronization overhead between the transmission pair is minimized. Relay node Based asynchronous Scheduling (RBS) is switched over, when the emergency or severe channel interference is detected by the sink through the analysis of the received data. During relay node based asynchronous scheduling (RBS), while cluster members still send sensing packets to the corresponding CH, the CH sends the aggregated packet to the relay node of its own cluster instead. Upon receiving the packets, the relay node further combines them with its own sensing packets and forwards the packets to the next-hop relay node until the packets reach the sink. When the sink decides that the network can return to regular monitoring, cycle based synchronous scheduling is switched over to increase energy efficiency.

III. Methodologies

In this section, we discuss Cycle Based synchronous Scheduling (CBS), Relay node Based Asynchronous Scheduling (RBS) and integration of both CBS and RBS.

3.1 Cycle Based Synchronous Scheduling (CBS)

We first propose a TDMA based synchronous scheduling approach, CBS schedules communications in consecutive cycles and each node is assigned some fixed conflict-free intervals to transmit and receive packets in each cycle. Nodes only wake up in the assigned intervals and otherwise it switches to sleep mode for energy consumption. Each node is assigned a single interval for transmission so that the synchronization overhead between the transmission pair is minimized. The goal of the scheduling is to minimize the average end-to-end packet delay.

Intra cluster communication includes all transmissions from cluster member to cluster head. Since different radio channels are assigned to adjacent clusters which are used to avoid interferences from other cluster.

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Cluster head doesn't need to switch between intra and inter cluster communications because we limit all communications for a cycle in a consecutive period. We consider TDMA scheme for the intra- cluster period. The whole period is divided into multiple identical time slots whose length '*l*' is equal to time required for packet transmission. Packets are sent in these time slots directly from cluster members to the cluster head. Each node is assigned the't' time slots for necessary control packets. Assume the cluster has *'n'* modes, the duration of the intra-cluster period is thus $n \cdot t \cdot l$.

Inter–cluster communication includes transmissions in the relay network, which consists of CHs and the sink. Within a cycle, each CH is assigned an interval to send all packets, including packets collected by itself and packets received from other CHs, to its parent. The practical length of this interval should be slightly longer than the transmission time of all packets to accommodate the necessary control packets such as ACK and potential synchronization errors. However, since we are focusing on the cycle scheduling, we set the length equal to the transmission time of all packets for simplicity.

The idea is to first determine a tentative cycle length and then try to schedule all the intervals within this cycle. Then it starts to schedule the intervals from the nodes that are closer to the sink. For assistance, two node sets V_n and V_c are constructed. Let

$$\mathbf{V_n = \{ i \mid I(i)=0, I(p_i)=1, I \in V' \}} \qquad \ldots(1)$$

To assume $I(V_s) = 1$ so that V_n includes all nodes that directly send packets to the sink. Clearly, these intervals cannot be overlapped. In addition, their conflicting intervals cannot be overlapped with these intervals either. For that , the set V_c is construct

$$\mathbf{V_c = V_n \cup \{ j \mid (i,j) \in E, I(j) = 0, i \in V_n \}} \quad \ldots(2)$$

Then schedule V_c with the basic scheduling algorithm with no range requirement and obtain the tentative cycle length. For other nodes that are not scheduled, since nodes are not in the current V_c, it is guaranteed that their scheduled intervals can be overlapped with intervals for nodes in V_n. Thus the rest of nodes from the beginning of the cycle is scheduled. Thus V_n and V_c according to current schedule are updated and repeat the basic scheduling algorithm.

Since nodes that are closer to the sink have longer intervals, in most cases the updated V_c can be scheduled at the beginning part of the cycle, leaving the rest part of the cycle available for further scheduling then schedule the rest of nodes to fill in the available part of the cycle to avoid queuing delays. This process is repeated until all nodes are scheduled. The finiteness of this process is guaranteed by the construction of V_n, which guarantees that all children of already scheduled nodes will be scheduled in the next iteration.

3.2 Relay Node Based Asynchronous Scheduling (RBS)

We develop second scheduling approach, which adopts an asynchronous approach that essentially avoids the synchronization problem. RBS adopts the TDMA protocol for intra cluster communications and CSMA protocol for inter cluster communications. Major task for RBS is that CHs need to switch between intra- and inter cluster state periodically. Since there is no synchronization required among different CHs, the state switching.

To determine the inter-cluster duration of a CH stays in inter- cluster state. When a Cluster Head switches to inter-cluster state, it cannot transmit a packet immediately. The protection from CTS/RTS handshake fails as they were not received by the CH who was in intra- cluster state then we call the period in which such collisions may occur the blind period and its duration equals the transmission time of a packet of a maximum allowable packet length. After this blind period, the cluster head sends the aggregated packets to the next- hop relay node. Once the transmission are completed switch back to intra-cluster state to continue data collection.

To determine the intra-cluster duration of a CH stays in intra- cluster state. We use fixed collection duration, denoted as T_c. The required time slots for member in a intra- cluster period is $k = [\lambda (T_c + T_o)]$, where T_o represents the duration of the last inter-cluster period. For energy efficiency, we organize the intra-cluster period into time frames with each consisting 'm' time slot, allowing each node to send a packet in a time frame.

3.3 Integration CBS and RBS

CBS is more energy efficient due to the nature of TDMA. RBS yields lower end to end delay.

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Our hybrid scheme integrates both the CBS and RBS can meet the network requirements of both achieving low latency when necessary and preserving a long life time. The major task is switching between the adoptions of CBS and RBS which we discuss in this section.

A. Switching from CBS to RBS

The switching from CBS to RBS occurs when the CH is overloaded or severe channel interference is detected by the data sink through the analysis of the received data. There are two major tasks: RBS structure formation and switching notification.

1) RBS Structure Formation: To select the current Cluster Head as the relay node that minimizes the inter-cluster communication overhead. We then select the node with highest residual energy from the remaining nodes as the new CH.

2) Switching Notification: Data sink initiates this process which sends the switching notification to direct children called CH and the CHs sent that information to other CHs or its own children.

B. Switching from RBS to CBS

The switching from RBS to CBS occurs when the sink decides that network can return to regular monitoring. This switching task can be divided into two major tasks: CBS structure formation and switching notification.

1) CBS Structure Formation: The relay node and the current CH in RBS consumes much more energy so we select the CH based on some energy efficient cluster head selection algorithm

The algorithm can be described as follows. At first, each node sends the position of itself in the network to its neighbors. If it is in active state then it calculates its chance parameter using fuzzy logic based on energy, density and centrality. Each node that has more chance than its neighbors, introduce itself as cluster Head candidate to the data sink.

Data sink determines the main cluster Heads and inform this information to all nodes in the network. Then cluster member will join to the nearest CH and uses TDMA schedule. After all data has been received, the CH performs data fusion function by removing redundant data and compresses the data into a single packet then transmit it to the Data sink. After the head selection process ends, the cluster formation process starts. This algorithm improves performance of cluster head and reduces the cluster head overload.

2) Switching Notification: The sink spreads switching notification to relay node. Each relay node notifies the selected CH then performs switching.

IV. Performance Evaluation

In this section, we evaluate the performance of our hybrid scheme via simulations in the following aspects. At first we examine the network lifetime, the main objective of our proposed and most previous scheme is to prolong network lifetime. The network lifetime also depends on the energy efficiency of data collection, if the role of cluster heads is rotated among all nodes. Therefore, we will evaluate the energy efficiency of the cluster head selection algorithms in terms of energy consumption of all nodes in a single round of data collection.

In the following subsection, we evaluate the proposed algorithm for large WSNs in terms of network lifetime, total energy consumption in one round of data collection, Packet generation ratio and End to End delay.

4.1 Comparison with optimal clustering

We obtain the network lifetime of optimal clustering in CWSNs and compare with the network lifetime of our energy efficient cluster head selection algorithm, the HEED and LEACH algorithm.

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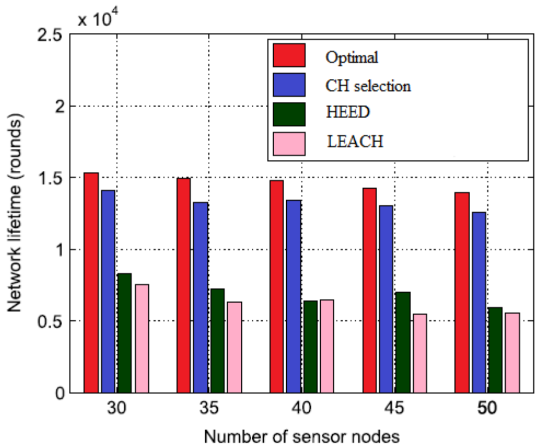

Fig 2 Performance of energy efficient cluster head selection algorithm compared with optimal results.

We consider a WSN where all nodes are randomly deployed in a 50 × 50 m2 field and the transmitting power level of each node is −5 dB. The network lifetime for each clustering scheme is given in Fig. 5, where the number of sensor nodes increases from 30 to 50. We can see that the network lifetime of our energy efficient cluster head selection algorithm is very close to the optimal result, regardless of the number of sensor nodes. On the contrary, both LEACH and HEED algorithms have a much shorter network lifetime. Specifically, the network lifetime of LEACH and HEED algorithms is 52% and 61% less than the optimal result, when there are 45 nodes in the network. This indicates that the energy efficiency of intra- and inter cluster communications in CWSNs may be significantly improved by taking the reliability of links into consideration when forming clusters. For large-scale WSNs, due to the NP-hardness of them problem, it is infeasible to obtain optimal solutions. Thus, we will evaluate the proposed algorithms mainly based on simulations in the following subsections.

4.2 Experiment results

The table 1 shows the measurement of packet delivery ratio and send to end delay for set of nodes.

TABLE 1
PACKET DELIVERY RATIO AND END TO END DELAY

Number of nodes.	Packet delivery ratio.	End to end delay(seconds)
30	0.9823	0.76
40	0.9887	1.07
50	0.9932	1.34

For simplicity, we consider over network with 30, 40, 50 nodes. The sink is stationary sensor and the cluster size ranges from 5 to 8. Sensing packets have a uniform length of 30 B and the transmission bandwidth is set to 1 MBPS. The performance metric evaluated are packet delivery ratio, energy consumption and end to end delay. Packet delivery Ratio is defined as no of packet received to num of packet sent. End to end delay is defined as the average time taken by a data packet to reach the destination. It also includes the delay caused by route discovery process and the queue in data packet transmission.

The evaluation time is set to 100 seconds to obtain the network performance at the stable state. Each experiment is repeated to 10 times to obtain the average value.

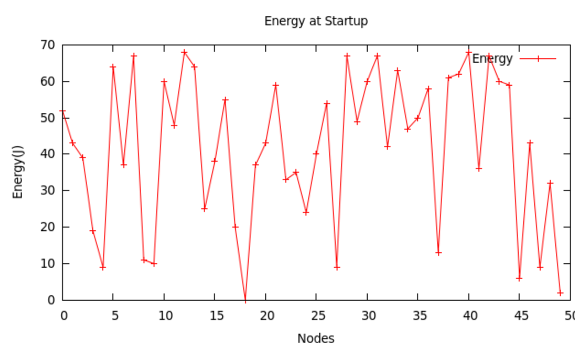

Fig 3 Energy level of various nodes in the WSN before the transmission

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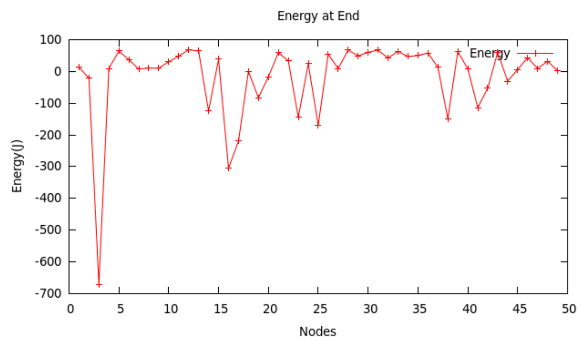

Fig 4 Energy level of various nodes in the WSN after the transmission

Fig 6-8 depicts an energy level of various nodes in WSN before and after the transmission and system energy consumption. Figure 9 shows End to end delay of four scheduling approaches under different packet generation rate. Fig 9 shows the end to end delay of four approaches with allowable packet generation rates. We can observe the RBS yields the shortest packet delay. Due to the introduction of relay nodes, packets are transmitted without any extra delay caused by state switching. Global Frame (GF) scheduling yields long end to end delay and the synchronization of the intra- and inter-cluster communication incurs many concurrent packet transmissions with high contentions, eventually resulting in long delay.

The performance comparison is that GF exhibits poor performance compare to other scheduling approaches. While RBS shows the shortest delay, we observe that CBS obtains a higher performance gain compared to 802.15.4, whose delay is nearly twice of CBS. This contrast indicates that CBS scheduling utilize the benefits in large-scale wireless sensor network.

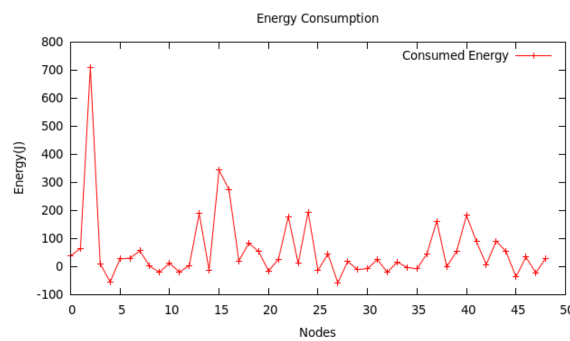

Fig 5 System Energy consumption for 50 nodes.

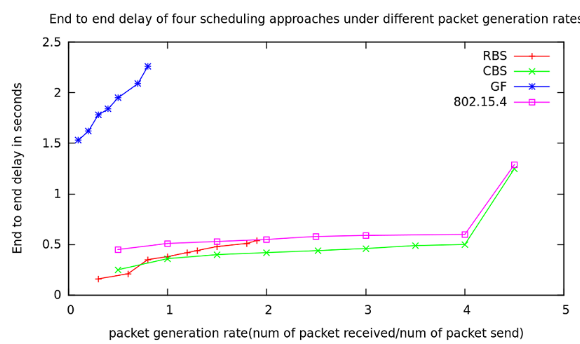

Fig 6 End-to-end delay of four scheduling approaches under different packet generation rates

V. CONCLUSION

In this paper, we proposed hybrid scheme that integrates two communication scheduling approaches CBS and RBS to enable cluster-based WSNs to serve as network infrastructure for information collection. In CBS, TDMA based schedule is constructed that minimize the packet delay and allows continuous packet forwarding from the source to the sink.

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In RBS, novel clustering structure is introduced that minimize the end to end delay and achieve high throughput. Our simulation results shows that proposed approach exhibit better performance compare to scheduling approaches in terms of packet delivery ratio and end to end delay. The hybrid scheme integrates CBS and RBS that allows the network to utilize the benefits of both approaches to meet the wireless sensor network requirements.

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