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Effective Integration Scheme for Synchronization of Cluster Based Sensor Network

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Abstract **- Cluster based wireless sensor network is one of the approaches to reduce the energy consumption of wireless sensor network. However, in such networks, frequent interactions between the intra-cluster communication and the inter-cluster communication are inevitable, which may severely downgrade the communication efficiency and hence the network performance if not handled properly.Proper synchronization among these two types of communications is required. In this paper, we propose intra and inter cluster synchronization scheme for cluster based sensor networks, which has two scheduling approaches.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 introduced 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 CBS and RBS without any interruption on data gathering during switching, allows the network to enjoy the benefits of both approaches to meet the stringent requirement for delay sensitive applications.**

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

I. Introduction

A wireless sensor network is composed of a large number of sensor nodes and one or more sink nodes (base stations). The sensor nodes are deployed inside the area of interest to collect useful information from the surrounding environment and report it to a base station located generally at the extremity of the area of interest. For example, the sensor nodes can monitor and report certain events like the movement of objects. The role of the base station is to gather the information sent by the sensor nodes and send it back to the user (control node), and eventually send queries to the sensor nodes. Generally, the base station is much more powerful in terms of resources than the sensor nodes.

When the sensor nodes communicate directly with the base station, the sensor nodes located farther away from the base station will have a higher energy load due to the long range communication. When the sensor nodes use a multi-hop communication to reach the base station, the sensor nodes located close to the base station will have a higher energy load because they relay the packets of other nodes.

The clustering-based communication mode is considered as the most suitable communication mode for the wireless sensor networks. Clustering consists in selecting a set of cluster-heads from the set of sensor nodes and then regrouping the remaining sensor nodes around the cluster-heads. The cluster-members send the data to the cluster-head that sends it back to the base station. Clustering gives better results, it reduces and balances the energy consumption and improves the lifetime and scalability of the wireless sensor network. Clustering is often used with a data aggregation technique. Thus, the number of sent messages and transmission ranges can be reduced.

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. Links between two cluster members are considered bidirectional while links between a Cluster Head (CH) and cluster member can be unidirectional depending on the range of the sensor. Cluster Head and relay nodes are capable of long-haul communication compared to the cluster member and all gateways are assumed to be in communication range with one another. Communication between nodes is over a single shared channel. Current implementation supports TDMA and CSMA.

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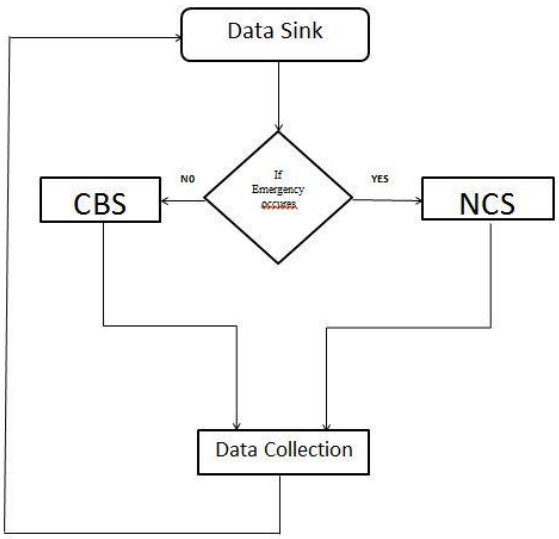

Figure1. System for synchronization scheme

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.

A. *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 switch 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. 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.

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To obtain an efficient interval schedule, we first present an analytical model for the problem then we will propose our scheduling approach.

1) Mathematical Model: The network is represented by a graph $G = (V,E)$. V is the set of nodes, including the sink, the CHs and the corresponding intra nodes. Denote p_i as the parent of node i in the routing tree and (i, j) as a transmission link between node i and node j, then

$E = \{(i, p_i)|i \in V\}$. Since every node has a fixed parent, it is easy to see $|V| = |E|+1$.

To model the interference of transmissions, we construct a conflict graph $G' = (V',E')$. V' represents all the transmission links in E. For simplicity, we use i to represent link (i, p_i) such that $V' = V \setminus \{v_s\}$, where v_s represents the sink. E' is constructed such that if $(i, j) \in E'$, nodes i and j cannot transmit at the same time due to that the distance between any two of nodes i, j, p_i and p_j is within the transmission radius. Such construction is valid if we assume that the receiver may send ACK packets and transmissions will not only be affected by the sender, but also by the receiver. For an intra node i, there is only one conflict edge (i, p_i) corresponding to the fact that the CH cannot send packets during the transmission of its corresponding intra node. The interval scheduling problem is to find a feasible time interval (s_i, f_i) for each node i in V', where s_i and f_i are the starting and finishing time instant with $0 \le s_i \le f_i$. The cycle length is then set as $t = \max_{i \in V'} f_i$. Here we normalize the cycle to time slots with length $l \cdot t$ so that the actual cycle length $T = l \cdot \tau \cdot t$. Since the interval equals the transmission time of all packets, we have $f_i = s_i + n_i$, where n_i is the maximum number of packets node i sends in a cycle. For an interval of node i to be feasible, its transmission link should not conflict with any other transmission links, thus $\forall (i, j) \in E\_$, $s_i \ge f_j$ or $s_j \ge f_i$.

The end-to-end packet delay can be broken down into transmission delay and queueing delay. The transmission delay from an intra node to the corresponding CH is simply the collection delay in the intra-cluster period while the transmission delay from CH i to its parent p_i is n_i. The queueing delay, defined as the waiting time of a packet at a node before it is sent out , will be $(s_{p_i} - f_i + t) \bmod t$ for a parent p_i. Thus, we will design a heuristic algorithm for the problem. Before that, we examine an example to reveal some interesting property in the scheduling problem.

2)Algorithm: The idea is to first determine a tentative cycle length and then try to schedule all the intervals within this cycle. Then it start to schedule the intervals from the nodes that are closer to the sink. For assistance, two node sets Vn and Vc are constructed. Let

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

To assume I(vs) = 1 so that Vn 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 vc is construct

$$\mathbf{Vc = Vn \cup \{ j \mid (i,j) \in E, I(j) = 0, i \in Vn \}}$$

Then schedule Vc 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 Vc, it is guaranteed that their scheduled intervals can be overlapped with intervals for nodes in Vn. Thus the rest of nodes from the beginning of the cycle is scheduled. Thus Vn and Vc according to current schedule are updated and repeat the basic scheduling algorithm.

TABLE 1
CBS ALGORITHM

Input: graph $G = (V,E)$ and conflict graph $G\_ = (V\_, E\_)$.
Output: interval schedules for nodes in $V\_$
$t = 0$
construct V_n, V_c
while $V_c\,! = \varnothing$
schedule V_c with range $[0, \infty)$
$t_c = \max_{i \in V_c} f_i$
if $t_c < t$
$V_u = \{i \mid i \in V\_, I(i) = 0\}$
schedule V_u with range $[t_c, t]$
end if
$t = \max(t, t_c)$
update V_n, V_c
end while

B. Relay Node Based Asynchronous Scheduling (RBS)

We develop second scheduling approach, which adopts an asynchronous approach that essentially avoids the synchronization problem by introducing a novel clustering structure

1) Novel Clustering Structure: The new clustering structure is illustrated in Fig. 2, in which a cluster contains a CH node, a relay node and multiple cluster members.

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The relay nodes always stay in o-state and only participate in inter-cluster communications. During data gathering, while cluster members still send sensing packets to the corresponding CH, the CH no longer sends the aggregated packet to the next-hop CH but sends 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. With such communication pattern, the communication synchronization is greatly simplified. CHs can continue intra-cluster data collection immediately after sending out the aggregated packet, reducing the data collection delay. In the meanwhile, inter-cluster communication can be performed without any restrictions, incurring no waiting delays for synchronization. The wireless channel thus can be better utilized and lower packet delay can be achieved.

2)RBS Scheduling: 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.

C. Integration CBS And RBS

CBS is more energy efficient due to the nature of TDMA. RBS yields lower end to end delay. 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 overload 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 calculates its selection weight and locally broadcasts the weight to all the neighbors. The duration of the head selection process is pre-defined. In the first time slot, each node decides to be a cluster head and broadcasts a declaration message to its neighbors; such a node is called as volunteer cluster head. Volunteer cluster heads keep silent afterward and wait for the time-out of the head selection process. Otherwise, if a node does not satisfy the head selection rule, it does nothing in this time slot.

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In the second time slot, each node except for volunteer cluster heads responds in a message-driven fashion as follows. If a node hears a declaration message, it broadcasts an acknowledgment message to its neighbors, indicating that it has been covered by some cluster head. If the node hears more than one declaration messages from its neighbors, however, it only broadcasts the acknowledge message once and puts all the nodes that have broadcast declaration messages into its final cluster head list F . If a node has not heard any declaration messages but heard acknowledgment messages, which implies that there is no volunteer cluster head in its neighborhood, it keeps silent and removes the neighboring nodes that have sent the acknowledgment messages from its tentative cluster head list T. If a node does not hear any message, it keeps silent and does nothing. In the third time slot, silent nodes in the second time slot run the initial time slot process again.

TABLE 2
CH SELECTION ALGORITHM

Input: receive(i, declaration), receive(i, acknowledge);
//receive a message from node i
Output:
broadcast(u,declaration),broadcast(u,acknowledge);
//broadcast a message to one-hop neighbors
Pre-Process:
calculate and broadcast the selection weight;
create a set T containing all one-hop neighbors and itself;
create an empty set F ;
Cluster Head Selection Process:
if u has the minimum weight among all nodes in T
broadcast(u, declaration);
wait till cluster head selection process time out;
end
do
if receive(i, declaration)
F = F
□
{i};
if the first declaration message is received
broadcast(u, acknowledge);
end
end
if receive(i, acknowledge)
T = T \ {i};
end
if u has the minimum weight in T
broadcast(u, declaration) and wait until time out;
end
until time out;
CBS Formation Process:
if u is not a cluster head
if receive(i, declaration)
F = F U {i};
end
if F ≠ ϕ
associate with cluster head u ∈ F that has the minimum weighted link;
else
broadcast(u, declaration);
end
end

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 EVALUATIONS

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 subsections, we first compare the network lifetime of our proposed CH selection algorithm with the optimal results. We then evaluate the proposed algorithms 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.

A. Experiment results

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.

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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 table 3 shows the measurement of packet delivery ratio and send to end delay for set of nodes.

TABLE 3

num of nodes.	Packet delivery ratio.	End to end delay(seconds)
30	0.9823	0.74
40	0.9887	1.31
50	0.9932	1.378

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

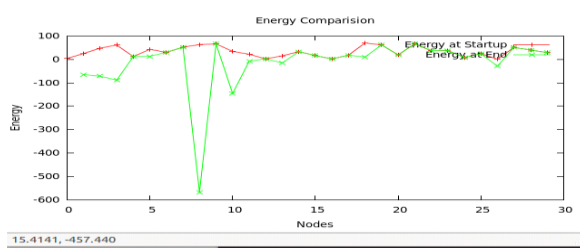

Fig.2. Energy parameter perfomance

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. 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.

This contrast indicates that CBS scheduling utilize the benefits in large-scale wireless sensor network.

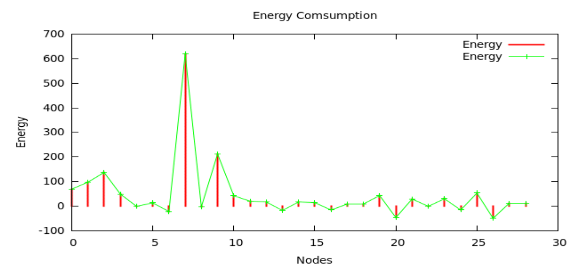

Fig 3 Energy parameter perfomance

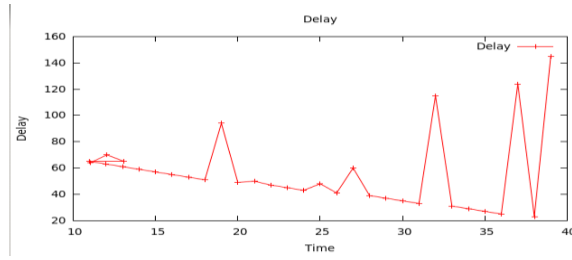

Fig.4. End-to-end delay of time Slot

V. CONCULSION

In this paper, we have presented a hybrid scheme that integrates two communication scheduling approaches CBS and RBS to enable cluster-based WSNs to serve as network infrastructure of information collection for delay sensitive application. In CBS, a cycle based schedule for each CH is constructed based on the pre-determined routing tree. CBS minimizes the cycle length while maintaining the node order in the routing tree, which minimizes the intra-cluster collection delay and allows continuous packet forwarding from the source to the sink. In RBS, a CH-relay-member structure is proposed to replace the conventional CH-member structure. The introduction of relay nodes releases the CHs from the heavy burden of packet relaying so that the intra- and inter-cluster communications can be performed more efficiently. Our simulation results have shown that the proposed approaches exhibit much better performance than existing scheduling approaches in terms of packet delay and throughput. The hybrid scheme integrates CBS and RBS without any interruption on data gathering during switching, allows the network to enjoy the benefits of both approaches to meet the stringent requirement of delay sensitiveapplication

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