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GRESS: Based on Gradient and Residual Energy of Sleep Scheduling in the Distributed Sensor Networks

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ABSTRACT

The most critical issue is how to increase network lifetime and scalability and balance load on sensor nodes in the Wireless Sensor Networks (WSNs). This study presented a new method for data gathering that maximizes lifetime for distributed sensor networks. It involves the following parts. First, nodes organize themselves into several static clusters by a given clustering algorithm. Second, clusters are formed only once but the role of cluster head is optimally scheduled among the cluster members according the gradient and residual energy. A single cluster head is in active state and non cluster head is in sleep or listen state with different sleep period. Third, after cluster-heads are selected, they form a backbone network to periodically collect, aggregate and forward data to the base station. Comparing with non-sleep and synchronous sleep by the MATLAB, significant lifetime extension is obtained with the use of this method.

Key words: Sleep scheduling, wireless sensor networks, gradient, residual energy, cluster, energy-saving

INTRODUCTION

The WSNs consist of a large number of wireless sensor nodes that are capable of measuring and reporting physical variables related to their environment. The sensor nodes are typically equipped by power-constrained batteries which are often difficult and expensive to be replaced once the nodes are deployed. Therefore, it is a critical consideration on reducing the power consumption in the network design.

Energy conservation in WSNs is critical and has been addressed by substantial research (Raghunathan *et al.*, 2002; Cardei *et al.*, 2005; Idris *et al.*, 2009; Guo *et al.*, 2010; Liu *et al.*, 2010a, b; Wei *et al.*, 2010a, b). We address the global problem of maximizing network lifetime under the joint clustering, routing and coverage constraint. We consider a sensor network that is deployed in a certain area A to monitor some given events. When the network is dense, sensing ranges of neighbor sensors usually overlap. This means that when an event occurs at a certain point P of A, it will be detected and reported by all the sensors whose sensing range encompasses P. This redundant transmission results in useless energy consumption. To save network energy and increase its lifetime we propose to cluster WSNs and switch on only Cluster Heads (CH) that covers a certain area while all non-CH nodes in clusters are periodically turned off (Guo *et al.*, 2009).

Our proposed algorithm is based on Gradient and Residual Energy of Sleep Scheduling (GRESS). GRESS maintains a cost field called gradient (Han *et al.*, 2004) and residual energy that

provides each CH direction to forward data toward the sink. GRESS is particularly suitable for dense WSNs with dynamic channel conditions and unreliable nodes. With the sleeping scheduling mechanism, nodes running GRESS do not need to constantly maintain routing. In the clusters, the CH has been in active state and non-CHs have been sleep. The CHs the time division multiple access (TDMA) MAC protocols and common nodes adopt different sleep period which can directly support low duty cycle operations and has the natural advantages of having no contention-introduced overhead and collisions (Ye *et al.*, 2002). In this study, the non-CH cycles to open the radio for a short time and monitors the CH whether to issue a request to replace it, just carries out conversion of the CH. In WSNs, the routing updates are purely driven by the CH and hence incur little overhead.

Heinzelman *et al.* (2000), Chang and Kuo (2006) and Chen and Wen (2009) are clustering-based protocols that tries to minimize the energy dissipation in sensor networks. Chen and Wen (2009) presented an adaptive sensor management scheme for wireless sensor networks which manages the sensors by utilizing the hierarchical network structure and allocates network resources efficiently. Proposes a TDMA based scheduling scheme that balances energy-saving and end-to-end delay. Pantazis *et al.* (2009) proposed a TDMA based scheduling scheme that balances energy-saving and end-to-end delay. This balance is achieved by an appropriate scheduling of the wakeup intervals, to allow data packets to be delayed by only one sleep interval for the end-to-end transmission from the sensors to the gateway. Guo *et al.* (2009) developed the novel duty cycling which includes two algorithms of the sleep scheduling algorithm and the gradient query algorithm based on sleep periods. Under the proposed design, most of the sensor nodes can be in sleep while still keep the functions of target monitoring and target query in the sensor networks.

GRESS proposes a sleeping scheduling which is different from previous works which makes use of the link cost and residual energy as metrics of nodes state transformation. GRESS will save a lot of energy and balance nodes load.

Gradient is a state representing the direction through which the BS can be reached (Han *et al.*, 2004; Ye *et al.*, 2005). It can be constructed according to different parameters, such as energy consumption, hop count, distance, temperature, illumination and so on. Sensing data are forwarded along the direction of the gradient descending to reach the BS. Information gradients by Lin *et al.* (2008) diffuse information away from source nodes holding desired data to establish information potentials. Hints left on sensor nodes on the existence of data sources will smoothly guide queries or mobile users towards desired sources. Sarkar *et al.* (2008) developed a gradient based routing scheme such that from any query node, the query message follows the signal field gradient or derived quantities and successfully discovers all iso-contours of interest. Guo *et al.* (2009) addressed the gradient based on sleep periods from the node who wants to know the target information to the active state nodes are decreasing. So the node sends the query packet along the sleep periods decreasing route to find active state nodes. The gradient of a node is established based on the minimum energy consumption of transmitting a packet from node to sink (Huang *et al.*, 2009). In the data transmission stage, the forwarder of a routing node is selected among multiple candidate nodes through a distributed contention process. The probability that a candidate node wins the contention depends on the nodes gradient, channel condition and remaining energy.

In most of previous literatures, the gradient as the data forwarding foundation is derived from a parameter in the global network, without taking into account the node load balancing. The novelty of GRESS is that it does not only use the gradient but also makes use of residual energy

in the cluster. GRESS uses the gradient and remaining energy as the condition of the cluster head exchange. What is more, the nodes sleep periods are decided by the gradient. GRESS increases network lifetime and scalability and balances load on sensor nodes.

SENSOR NETWORK SCENARIO AND ASSUMPTIONS

We describe the network scenario and give the following assumptions:

- The network is used as periodic data collection. Sensor nodes are evenly dispersed within a square area. After the deployment is finished, the nodes are no longer moved and the energy can not be replaced
- The BS has no energy limitation. Each sensor has the same initial characteristic, such as energy, processing capacity etc
- we assume that sensors have ideal sensing capabilities and the largest sensing range is far greater than the diameter of the cluster so that ensure the CH can cover the cluster coverage
- The network is high density so that when the partial sensors are active, the monitored area is fully covered. Besides we assume that the sensor network is connected and has been clustered. In a cluster, only the CH is active and the non-CH is sleep
- Only the CHs can perform data routing. Routing over the overlay network composed of CHs can be performed using one of the energy-efficient routing protocols for WSNs proposed in the literature

However, we do not address any specific routing protocol; we only guarantee the existence of a routing topology.

GRESS DESIGN

GRESS is a sleeping scheduling scheme in clustered WSNs where the network is partitioned into a set of clusters with one cluster head in each cluster. Communication between cluster head and BS is direct. Every CH can cover and monitor the whole cluster area, so that the CHs are active to complete monitoring the task and the non-CHs are in sleep state to save energy. During the survival of the network, the CHs are replaced by the gradient and remaining energy of non-CHs, so that balance every sensor nodes load. On-CHs transform their state between sleep state and listen state. In listen state, the node turns on the radio to listen the information from the CH. For easy reference, we summarize the notations in Table1.

Gradient establish: In this study, the gradient is a state representing the direction (toward the working CHs) through which a new cluster head can be elected. It is built according to energy

Table 1: Meanings of the notations

Notation	Meaning
ID	The serial number of the node in the network
$E_{residual}$	The residual energy of node
CH	The cluster head
$Cost_i$	The cost of the i th node
T_a	The back-off time
T_{slot}	The time slot
T_{CH}	The CH's working time

consumption. At each node, the cost field is defined as the minimum total energy consumption to send a packet from itself to the sink. The mentioned cost field forms the global gradient. The global gradient needs to be established only once when the network is initialized. In a cluster, the local cost field is defined as the minimum total energy consumption to send a packet from itself to the CH. The local cost field maintained is purely driven by the cluster head alternation.

The cost field is set up according to the following straight forward way. We assume each node can estimate the cost of sending data to the sink without relay. The sink first advertises HELLO packets to all nodes. The cost at a node is the minimum energy overhead to the sink. The costs of all nodes in the network form the cost field.

SLEEPING SCHEDULING ALGORITHM

We present the design of GRESS in detail in this section. There are two steps to implement GRESS, one is initialization phase and another is state transformation phase. We will introduce these two steps in the following subsections separately.

Initialization: GRESS is designed for sensor networks of periodically monitoring and all the sensor nodes do not need to know their positions. There are three states for nodes: Active state (cluster head) listen state and sleep state. After deployment, all nodes are active state and send a packet from itself to the sink to get its cost field. Network is divided into different clusters. In a cluster, the cluster head is a node with the minimum cost. At the same time, the non-CHs diffuse its ID, cost field and Residual to the CH. The CH queues the nodes in accordance with the cost reduction and builds an interrelated information just as in Table 2 for a certain inter-cluster members. The information table includes ID, $Cost_i$, $E_{residual}$ and state of existence. If the CH receives the information from the non-CHs, the state of existence is alive otherwise, the state of existence is dead. When a node state of existence is dead it is looked as a failure node or moved from network and isn't updated its value. During the initial phase, all nodes are alive. After the information Table is completed, the CH computes the non-CHs sleep period according to its $E_{residual}$. In this study, time slot T_{slot} is determined according to the node processing capacity and state transformation process in advance and used as listen period. The node with ID = 3 own 2 Tslot sleep period and the node with ID = 7 own 22 Tslot sleep period and the node with ID = 2 own 23 Tslot sleep period and the node with ID = 5 own 25 Tslot sleep period. The CH broadcasts the sleep period packet to all nodes in the cluster and the non-CHs receive the packet and pick itself sleep period according to ID and turn to sleep state. The CH collects collect, aggregate and forward data to the BS periodically.

After initial phase is over, the network topology picture is shown in Fig. 1, the red nodes are in active state and the gray nodes are in sleep state respectively, the gray nodes are in sleep state with different sleep period. The red nodes detect the environment and disseminate useful data to the BS periodically.

State transformation: When the sleep period is over, a node turns to listen state. After the 2 Tslot, the node with cost reduction ID order queuing in second place is in listen state in Fig. 2.

Table 2: Members information in the CH during initial phase

ID	$Cost_i$	$E_{residual}$ (J)	State of existence
7	$Cost_7$	40	Alive
2	$Cost_2$	40	Alive
5	$Cost_5$	40	Alive
3	$Cost_3$	40	Alive

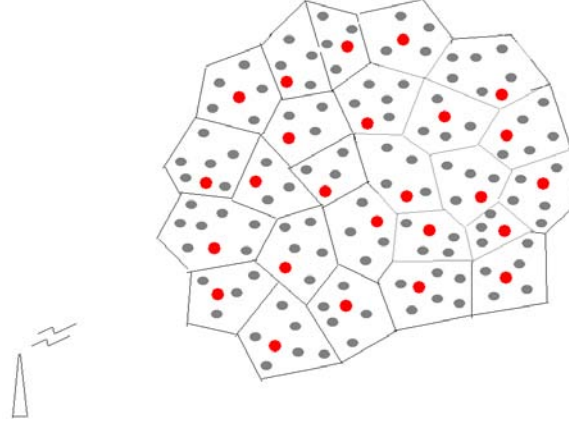


Fig. 1: Initialization phase network topology. Red nodes are in active state and the gray nodes are in sleep state

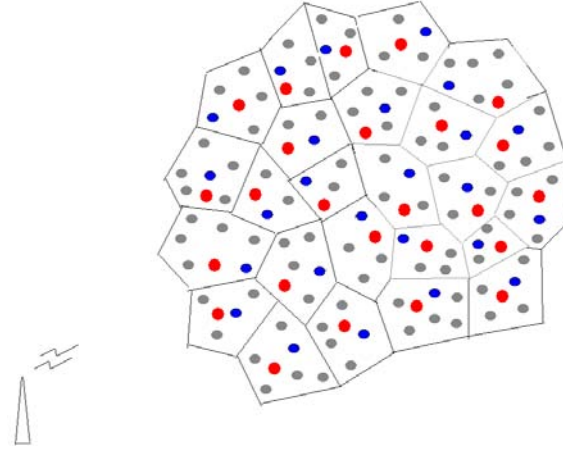


Fig. 2: At $2T_{\text{slot}}$ time network topology, Red nodes are in active state, gray nodes are in sleep state and blue nodes are in listen state

During listen period, if a node does not receive a query packet from the CH, it turns to sleep state again after the listen period. When a node gets a query packet matching to its ID, it turns to active state and soon afterwards becomes a new CH. The old CH turns to sleep state. The CH and non-CH role transformation is drove by a query packet from the CH.

The CH diffuses the data to the BS periodically. When the remaining energy of the CH is $E_{\text{residual}}/2$, the CH changes its role into an ordinary node. In order to avoid the communication interruption, the CH sends a query packet for role transformation to non-CHs in the cluster in advance. The CH's working time is $T_{\text{CH}} = (E_{\text{residual}} - \text{COST}_i) / \text{Cost}_i$. Because the farthest node with the current CH in the cost field direction owns $8T_{\text{slot}}$ sleep period and a T_{slot} listen period, it senses the query to need the time $T_q \geq 9T_{\text{slot}}$. We sets $T_q = 9T_{\text{slot}}$ as back-off time. At the time $T_{\text{CH}} - T_q$, the CH checks the information Table to look over the neighbor row. For example, in Table 2, the CH looks over the node with ID = 7. If the nodes E_{residual} is greater than Cost_7 and its state of existence is alive, the CH has found the new CH and broadcasts the query packet with ID = 7 in the cluster. If the nodes E_{residual} is less than or equal Cost_7 or its state of existence is dead, the CH will check the row with ID = 2 (Table 2).

Assuming the CH finds the node with ID = 7 as the next CH, it spreads a query packet in the cluster. When the node with ID = 7 receives the query, it responses the query. If it does not response to the CH in T_q time, the CH afresh to look over the Table 3 to choose the new CH and set its state of existence is dead. If the node with ID = 7 response to the CH, the CH propagate a query packet again for getting the nodes E_{residual} and update E_{residual} in the Table 3. If the CH does not receive the node E_{residual} response or the nodes E_{residual} is less than or equal Cost_7 in T_q time, the corresponding node state of existence is dead. The CH sets itself information in the last line of the Table 3. At the moment, the table is up to date and the current CH propagates it to the next CH and turns to sleep state. The node with ID = 7 starts to work as a CH.

SIMULATION

We evaluate the performance of GRESS implemented with MATLAB. For simplicity we assume the probability of signal collision and interference in the wireless channel is ignorable and the node in sleep state does not cost energy while in all other states costs one slot energy per sec. Energy consumption per unit of time k is $50 \mu \text{ J sec}^{-1}$. A cluster has four nodes.

We compare the energy cost of GRESS to non-sleep and synchronous sleep with listen period equal to T_{slot} in Fig. 3. The comparison among results indicates that the energy cost of GRESS is much smaller than the schemes of non-sleep and all the nodes synchronous sleep. As you know, the less energy consumption can get the longer network lifetime.

To evaluate the impact of the maximum cluster size on the performance of present algorithm we measured the network lifetime for different cluster sizes of, respectively, 4, 5, 6, 7 and 8 sensors. In Fig. 4, we observe that for all configurations when the cluster size increases, the network lifetime

Table 3: Updated members information

ID	Cost_i	E_{residual} (J)	State of existence
7	Cost_7	38	Alive
2	Cost_2	38.8	Alive
5	Cost_5	39.2	Alive
3	Cost_3	18	Alive

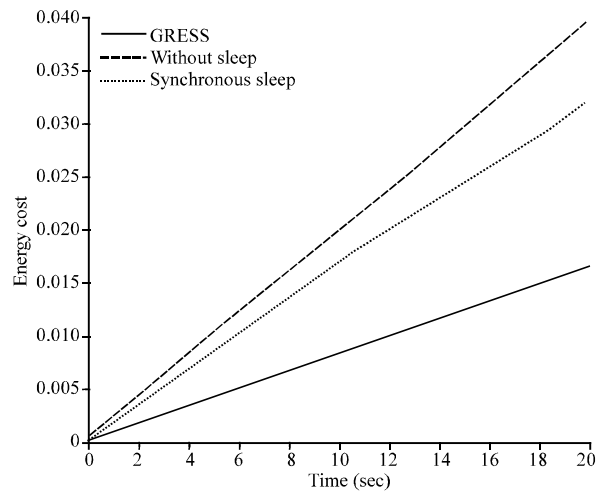


Fig. 3: The energy cost compare of GRESS to without sleep and synchronous sleep

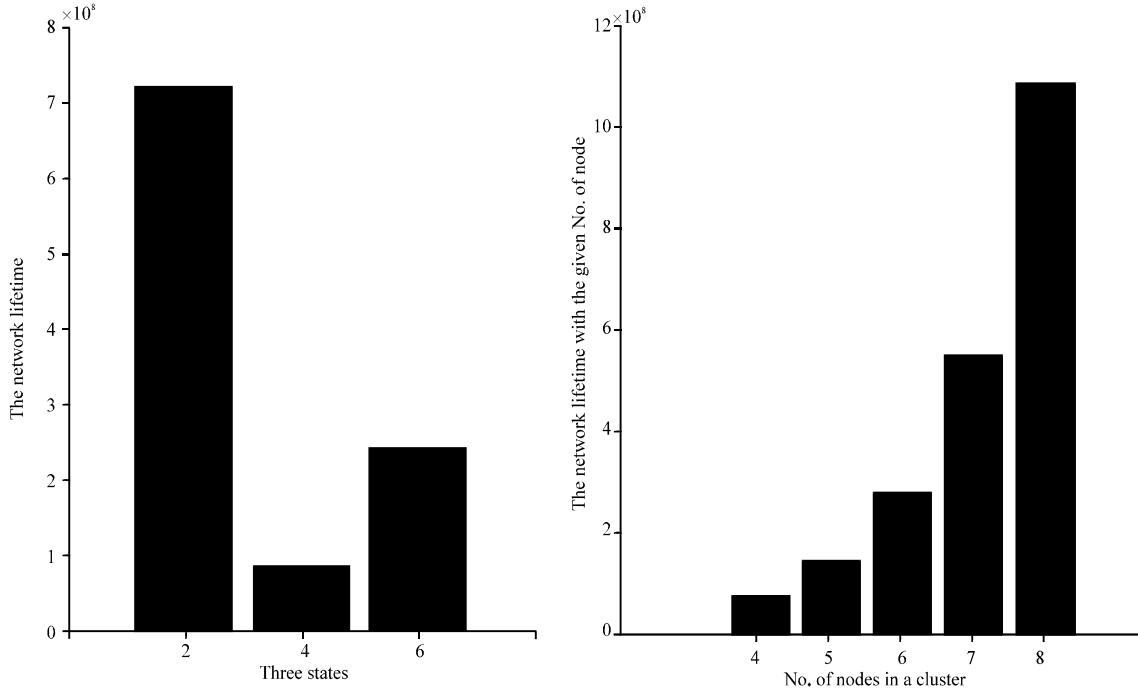


Fig. 4: The network lifetime when the cluster is in GRESS, non-sleep and synchronous sleep

increases as well. This is due to the fact that when the cluster size increases, more non-CHs are put into sleep state with longer sleep period since one single CH can ensure the connectivity of all the sensors that can reach it.

CONCLUSION

In this study, we proposed a novel sleep scheduling mechanism for large-scale cluster-based monitoring wireless sensor networks. Present mechanism is based on the gradient and residual energy that compute a near-optimal CH in a cluster in which a single CH can be active, all non-CHs can be put in sleep mode or promoted as cluster head. Our mechanism maximizes network lifetime while ensuring the full coverage of the monitored area and the connectivity of the obtained configuration. Connectivity is fulfilled through optimally computed clusters connecting the BS. Simulations show that our mechanism provides for acceptable results with respect to the synchronous sleep and without sleep and exhibits low complexity and low computation times making its practical implementation adaptable for large-scale networks. As future research directions we intend to develop a more sophisticated heuristic to improve the network lifetime. Furthermore, we intend to work on distributed algorithms that address energy-efficient clustering under the joint gradient and residual energy.

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