A Sensing Resolution-based Energy Efficient Communication Protocol for Wireless Sensor Networks

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Abstract. In this paper, we propose a Sensing Resolution-based Energy Efficient (SREE) communication protocol for wireless sensor networks. SREE is intended for meeting the application's sensing objectives, where sensor nodes are densely deployed and have the determinate accuracy requirement. The primary contribution of this paper is active group head node selection with round-robin procedure, which increases the sensing accuracy and distributes the nodes energy consumption. The second contribution is using energy efficient intermediate node selection by considering both group size and energy consumption. We present the design of SREE and provide simulation results.

Keywords: Wireless Sensor Networks, Network Lifetime, Sensing Resolution, Energy Efficiency, Grouping

1 Introduction

Wireless sensor networks (WSN) are expected to be used in a wide range of applications, especially in the military applications, it is required the network deployed rapid, self-organization, and fault tolerance [1]. This network typically have numerous sensor devices, they work together in an ad hoc multi-hop fashion.

Some common WSN protocols consider the lifetime, scalability and fault tolerance. LEACH [2-3], provides a combined TDMA/CDMA based MAC approach. The entire network is divided into non-overlapping clusters, inside the cluster using the TDMA scheme it allows to let the node directly communicate with the dynamically elected cluster head. The cluster head relays the data to the base station directly using a fixed spreading code and CSMA. For low power, short range sensors, and direct communications are not always practical.

The sensor nodes are usually operated by batteries and left unattended after deployment, so the energy consumption is the crucial factor in sensor network design.

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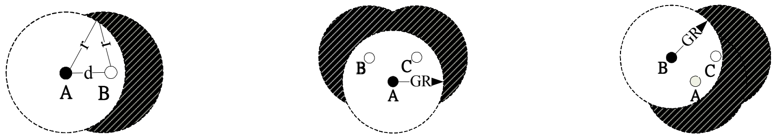
This may lead to sensor network protocols which prioritize energy savings over network throughput and packet latency. We propose a group-based communication protocol that can simultaneously achieve high energy efficiency, high network throughput, low packet latency, and fault tolerance.

The rest of this paper is organized as follows. Section 2 gives the definition of redundant node and sensing region. Section 3 presents the protocol design. Section 4 provides simulation experiment results. Finally, the paper concludes with Section 5.

2 Definitions

Sensor networks are typically consisted of very large number of low cost sensor nodes which collaborate among each other to enable a wide range of applications. In the CSMAC [4], they proposed the concept of the *Sensing Resolution* (SR), which denotes the sensing accuracy desired by an application. In the SR, the redundant nodes are forced to turn off themselves, and the battery power of these redundant nodes can be preserved for future use.



(a) Redundant node (b) Node A is active (c) Node B is active

Fig. 1. Sensing Resolution

In Figure 1-(a), where *d* is distance between node A and B. The *d* is smaller than the *sensing resolution r*. If node A keeps active, then node B is the redundant node, in the CSMAC, node B is the backup node to node A and will decide whether it should take over the node A when it finds the energy level of the node A is bellow certain threshold. The disadvantage of it is that can cause sensing accuracy loss. When node A works, the shadow area is beyond the sensing area of the node A.

From the mathematics we can get the area of the shadow part (sensing accuracy loss), and the proportion to the area of *sensing resolution* decided (πr^2) is:

$$1-\frac{1}{\pi r^2}-\left[4\times\left(\frac{\arccos((d/2r)\times\pi r^2)}{2\pi}+\frac{d}{2}\times\sqrt{r^2-\frac{d^2}{4}}\right)+2\times\left(\frac{d}{2}\times\sqrt{r^2-\frac{d^2}{4}}\right)\right] \qquad (1)$$

After some simplification we obtain:

$$1-\frac{\arccos(d/2r)}{\pi/2}-\frac{d\times\sqrt{r^2-(d^2/4)}}{\pi r^2} \qquad (2)$$

If an application requires r = 2m, d = 1m, the proportion is 31.41%. The value is increasing with the increasing of d, the extreme situation is $d = r$, the proportion can reach 60.89%. This means that if only take the redundant node as the backup node to the active node as CSMAC, the accuracy loss will be a problem in a densely deployed network, because so many backup nodes are inactive all the time before the active node is run out of battery.

We propose a round-robin based grouping method. The group radius (GR) is based on the SR. Nodes within the GR will make a group. At each round the active node is rotated within the group, which will increase the sensing accuracy at some degree, even though this way still can't solve the accuracy loss completely. Figure 1-(b) and (c) shows the sensing resolution extension in accordance with active node rotation. We can also evenly distribute energy consumption inside the group by this way. By changing the active node each round, we can avoid the situation that the sensing accuracy of the node is loss forever when a node is run out of battery.

3 The Proposed SREE Protocol

The proposed SREE protocol is targeted to meet the following requirements. In the densely deployed networks, the node densities may be as high as 20 nodes / m^3 [6], in which there will be existed so many redundant nodes in a network. Energy consumption should be evenly distributed in the sensor networks to extend network life time and to increase the sensing accuracy. We assume that all nodes are normally static nodes and can adjust their transmission power to reach different neighbors.

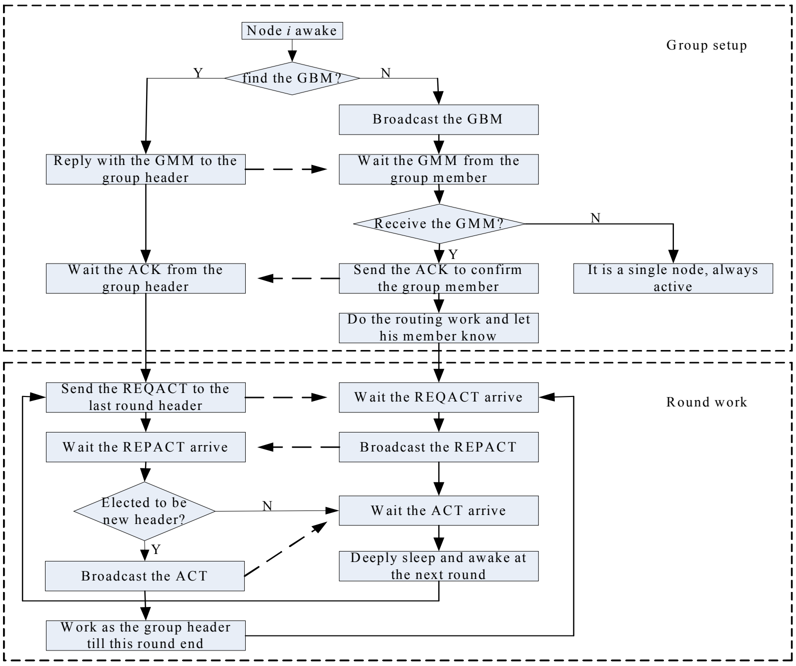


Fig. 2. Flowchart of the SREE at each node

The SREE has 3 procedures: group setup, optimal neighbor selection for packet forwarding, and group header change. Figure 2 shows the group setup and header change flows at each node.

3.1 Group Set up

After the node deployed, the group set up phase is followed. Nodes would randomly awake and sense the channel whether there is a group broadcast message (GBM) or not. If not, it will work as the group header (GH), whose task at this phase is broadcasting the GBM with the small transmitting power (group power, which only covers the pre-determined group radius area). To avoid collision and save energy, all the communications are done with this power at the group set up phase. This message will be broadcasted periodically and continued during a relative long time (T_W) to make sure all nodes in a group radius can successfully join the group. When a node receives the GBM, it replies the group member massage (GMM) and waits the ACK from the GH to make confirm. Figure 3 shows MAC message exchanges for the group set up.

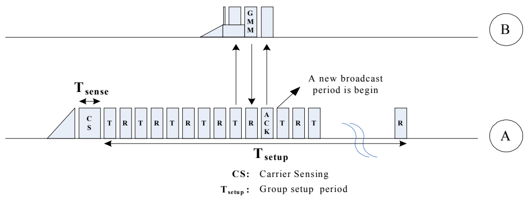


Fig. 3. Message exchanges for group set up procedure

Assuming the distance between node A and B is smaller than the GR, they can hear each other's transmission with the group power. Node A awakes and senses the channel, finds it is idle, it immediately begin the periodically GBM broadcasting, in some time later, node B awakes, receives the GBM and replies a GMM, the node like node B who sent the GMM is called a group member (GM). After A receiving the GMM, it adds B to the group list (GL) and sends back an ACK to let B know that it is in the group. At the same time, the broadcast also needs to continue for that more nodes can join in the group, during T_w period.

If a node in its broadcast period can not receive any GMM, it means that there are no redundant nodes in its GR area. We call it as single node that should be always active. The GMs already confirmed by the GH enter the periodically sleep mode and they become inactive nodes, only group header (or single node) is working. as an active node.

3.2. Optimal Path Selection

In wireless networks, transmission power between two nodes is proportional to d^k, where d is the distance between two nodes and k is the path loss that can vary from 2 to 6. Increasing the distance, required energy to communicate between the nodes is exponentially increased and then through the relay node which uses minimum transmission power between the nodes, it can reduce the consumed energy than direct transmission [7-8].

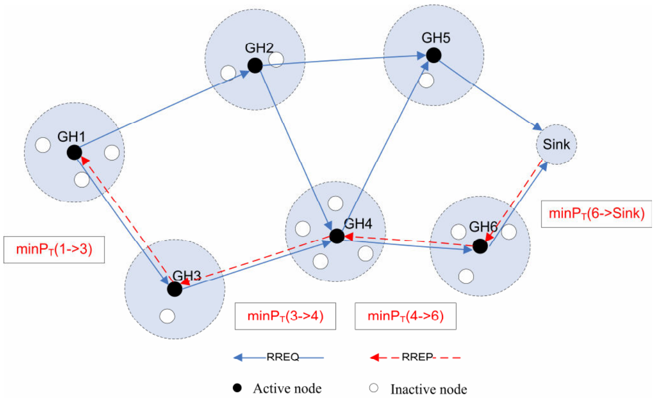


Fig. 4. On-demand routing path establishment

It is needed for a node to make a path to destination to transmit a packet. An ad hoc routing protocol such as AODV [10] uses the hop count as criterion to select a path, and MTE routing [2] selects minimum energy consumed path among various paths. However, considering only either hop count or minimum transmission energy as criterion to select a path, a node would exhaust remain battery and the node **c**an not work anymore. At that situation network partitioning can be happened and sensing accuracy of particular region is also decreased. For solving the problems, based grouping mechanism, we propose the optimal path selection algorithm to reduce transmission energy and make consumed energy evenly for each node in a group.

As shown in figure 4, GH1 that made a sensing event initiates *path discovery* process by broadcasting a RREQ (route request) to neighbor nodes using pre-defined transmission power (maximum power) and limiting the hop count to maximum value to avoid loop problem. Whenever each neighbor node receives a RREQ, it rebroadcasts the RREQ if the node is not sink node and the RREQ is not duplicated. The RREQ contains the following information: 1) Minimum required transmission power from node *i* to *j* ($minP_{T(i\rightarrow j)}$), where node *i* denote current node and node *j* denote previous node, 2) The number of group nodes of group header *j* (G_{Nj}), where $minP_{T(i\rightarrow j)}$ is minimum transmission power of node *i* that node *j* can receive a data from node *i* correctly.

The minimum transmission power, denoted $minP_{T(i\rightarrow j)}$, to be transmitted by node *i* to conserve power while still maintaining required E_b/N_o at the receiver is given by:

$$minP_{T(i\rightarrow j)} = \frac{P_{max}}{P_{Rj}} \times R_{thresh} \qquad \textbf{(3)}$$

where P_{Rj} is the received power by node *j* when node *i* transmits at the maximum power level (P_{max}), and R_{thresh} is minimum required power level, achieving certain E_b/N_o, at the receiver.

The group header node receiving the RREQ can respond by a RREP (route reply) if the node is sink node. Before transmitting a RREP, sink node waits certain time (T_w) to collect enough RREQs which took a different route and then it selects an optimal path. The optimal path is an energy efficient path and determined by:

$$P_{Ck} = \sum \frac{P_{Ti} + P_{Pi}}{G_{Ni}} \qquad \textbf{(4)}$$

where,

P_{Ck} = path cost of path k.

P_{Ti} = minimum transmission power of node *i* on the path *k*

P_{Pi} = processing power of node *i* on the path *k*, processing power includes receiving power, we assume that processing power of each node is the same, so that the P_{Pi} is already known by sink node.

In this paper, we employ a cost function determined by dividing transmitting and receiving power by the number of group nodes of a group as Eq. 4. The group header is changed in a group through round-robin, being bigger group (many nodes are in a group) average consuming energy of each node is decreasing because the nodes share the energy consuming. A group that has a few nodes would exhaust ahead of a group having many nodes, then entirely network life time is decreasing and a region that died node used to cover can not be sensed, which is lowering the sensing accuracy.

Sink node selects the optimal path k^* among all paths using calculated P_{Ck} as Eq. 5 and unicasts a RREP on the selected path.

$$k^* = \arg\min_{\forall k} \{P_{Ck}\} \qquad \textbf{(5)}$$

All nodes, including the sink node, unicast the RREP containing $\min P_{T(i \to j)}$ that is recorded in their power table on the path k^*. Therefore, when a node wants to transmit a data, they can adjust transmit power to minimum as known in power table to reduce energy consumption.

3.3 Group Header Change

At the end of each round, GH waits for the GM periodically awake, after the GM awake they use the CSMA/CA method to transmit the request to active message (REQACT) to the header, in the REQACT has the counter (*n*), which indicates how many times this node has been header, and the node remaining energy (E_{remain}), the round group header needs this information to decide which node to be the header at the next round. After an election time, the header compares the value of *n* in each received REQACT. If it can find a unique node with minimum *n*, the GH broadcast the reply to active message (REPACT), in it has the decision that the node with the minimum *n* will work as a header at the next round. If the minimum is not exclusive, after comparing the node's remaining energy, the node that has maximum residual energy will become the header at next round.

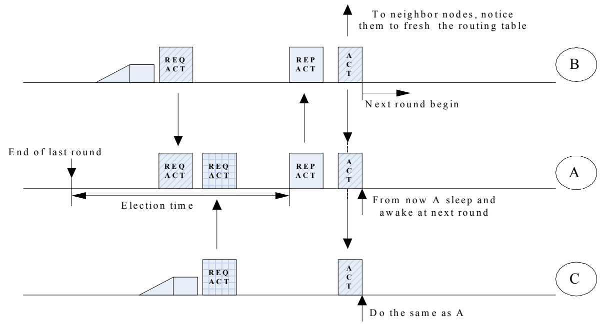


Fig. 5. Group header change

The current round header during the election time may receive the REQACT from all his GM, or can not receive any REQACT. If it receives nothing, it should work as a group header at the next round. And for the consideration of fault tolerance, if group member nodes that send REQACT cannot hear any REPACT from the current group header during the pre-determined rounds (e.g., three rounds), each member node will work as a group header.

The group node that was elected as a group header for the next round broadcasts the active message (ACT) with its biggest transmit power to announce that it will replace the last round header's work. The last round header keeps work until it receives the ACT from the new header, then it enters sleep mode and at the end of the new round it wakes up and sends the REQACT to the new header. The neighbor group headers who receive the ACT will replace the last group header with the new group header in their routing table. Figure 5 shows the proposed group header change procedure.

4. Simulation Experiment Results

In this section, we compare the performance of SREE and MTE (Minimum Transmission Energy) [5-6] by computer simulation. In MTE routing, the path that has the minimum total transmission energy is selected to send sensing data. The number of nodes we used is 100 and 150, where nodes were randomly distributed between (0, 0) and (100, 100) with the BS (base station, sink) at location (50, 175). The group radius increases from 2 m to 7 m. Each node has initial 2J energy and sends 525 bytes packet to the BS at each round. The communication energy consumption model is adopted from [3] with the same parameters.

Table 1. Parameters for energy model

Parameter	Attribute	Values
E_{elec}	Electronics energy	50 nJ/bit
ε_{fs}	Free space transmit amplifier	10 pJ/bit/ m^2
ε_{mp}	Multipath transmit amplifier	0.0013 pJ/bit/ m^4

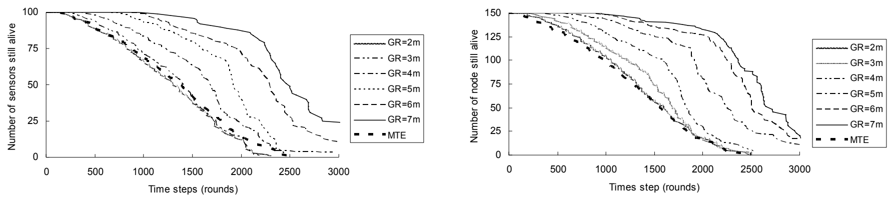
Both the free space (α =2) and the multipath fading (α =4) channel models were used. If the distance is less than a threshold d_0 (we set d_0=1m), the free space (fs) model is used; otherwise, the multipath (mp) model is used. Thus to transmit an l-bit message a distance d, the radio expends

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs} d^2, \; d < d_0; \\ lE_{elec} + l\varepsilon_{mp} d^4, \; d \geq d_0 \end{cases} \quad \textbf{(6)}$$

and to receive this message, the radio expends:

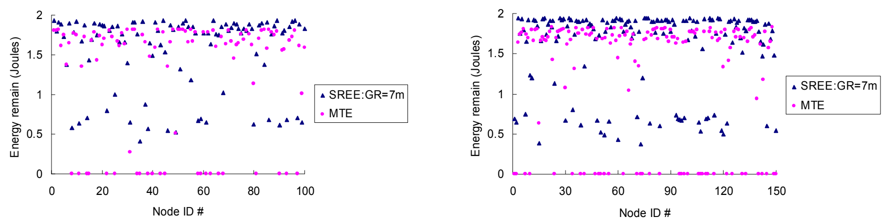
$$E_{RX}(l) = \mathrm{E}_{\text{RX-elec}}(l) = lE_{elec} \quad \textbf{(7)}$$

Figure 6 shows the relationship of system lifetime with GR and the node density. When the node density is fixed, for the bigger GR that means the smaller number of groups, shows the longer network lifetime so that the performance improvement is more significant. When the GR is fixed (e.g., GR=3m), for the higher node density network, we can get the better result as Figure 6-(b). And in the Figure 6-(a) also tells us when the node density is small, and the GR is small like 2-3m, the performance of the SREE is almost same as the MTE, because the number of group nodes is little. When there exist more groups (node density increasing or large value of GR), the performance of the SREE is more outstanding.



(a) 100 nodes random deploy (b) 150 nodes random deploy

Fig. 6. System lifetime using MTE routing and SREE under different GR



(a) 100 nodes random deploy (b) 150 nodes random deploy

Fig. 7. Remain energy level of each node after 800 rounds

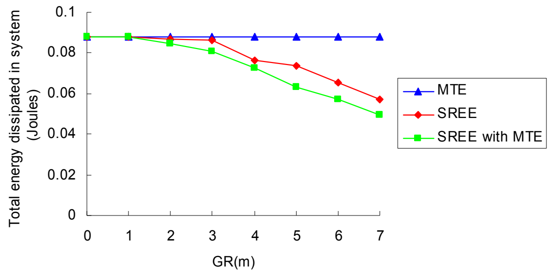


Fig. 8. Total system energy dissipated using MTE, SREE with MTE and original SREE under different GR

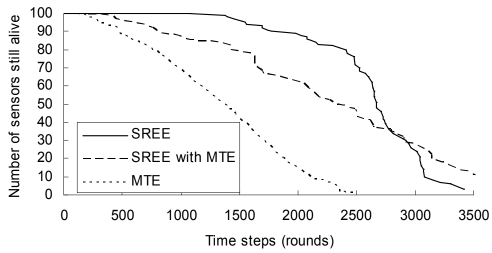


Fig. 9. System lifetime using MTE, SREE with MTE and original SREE under GR=7m

To evaluate how the SREE distributed the energy cost among the network, we choose a big value of GR (7m) and relatively long time (800 rounds) to observe remain energy of each node. Figure 7 shows there are more nodes alive with the SREE than MTE routing. To evaluate the proposed optimum path selection method, we compared three methods:

- MTE: There is no grouping and sensing data is delivered to BS with minimum transmission energy routing.
- SREE with MTE: With the proposed group header selection method, grouping and group header change are performed. But routing path between group headers is determined with MTE.
- SREE: The proposed group header selection and optimal path selection are used.

From Figure 8, 100 nodes are used for this experiment, SREE method needs less energy to send data to BS compared with MTE. And we can see the original SREE consumes a little more energy than the SREE with MTE, because SREE aim to extend the lifetime of the total network. When SREE chooses the intermediate nodes, it uses the cost function that considers not only energy consumption, but also fair energy consumption in the network. As shown Figure 9, the lifetime of the network is better indication of the advantage of SREE, because the SREE through the optimal choosing the intermediate nodes, avoids the single node energy exhausting so early, and also distributes the energy consumption among the network nodes

5. Conclusion

When designing a protocol for wireless sensor networks, it is important to consider the required sensing accuracy, energy consumption, and network lifetime. These features lead us to design SREE, which uses grouping method and lets the redundant nodes into sleep mode to reduce energy consumption for application specific sensing accuracy. Changing group header by round-robin procedure in each round, we could get the result that energy consumption of each nodes is distributed and prolong the network lifetime. Proposed optimal routing algorithm distributed the energy consumption and reduced energy consumption that nodes send to the sink node on the optimal path than sending directly.

The simulation results shows that proposed SREE protocol, many nodes were in a group by increasing either node density or group radius made a good result that nodes can reduce energy consumption and distribute the energy consumption evenly compared with MTE routing.

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