Energy-Efficient Sensor Node Control Based on Sensed Data and Energy Monitoring

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Abstract. This paper proposes an energy-efficient sensor node control mechanism to prolong sensor networks' lifespan by minimizing and equalizing energy consumption of sensor nodes. The proposed scheme newly defines three operational modes of a sensor node, which are normal, power-saving, and inactive. When the remaining energy of a sensor node is lower than the average remaining energy of all sensor nodes in the same network or cluster, it operates in the power-saving or inactive mode. This makes it possible to minimize and equalize energy consumption of each sensor node. The proposed mechanism additionally includes another scheme to prevent a sensor node transmitting duplicate sensed data. When a sensor node takes sensed data, it compares them with pre-sensed data to decide their duplicity. This makes it possible to avoid unnecessary energy consumption caused by transmitting duplicate sensed data. We implemented and simulated the proposed schemes with TinyOS and NS-2, respectively. The simulation results show that the proposed mechanism can efficiently reduce and equalize energy consumption, and therefore prolong sensor networks' lifespan.

Keywords: energy-efficient, sensor node control, remaining energy, normal, power-saving, inactive, duplicity.

1 Introduction

In wireless sensor networks, it is very important to minimize and equalize energy consumption of each sensor node to prolong sensor networks' lifespan, because the only energy source for a wireless sensor node is a battery. The energy is mainly consumed during the process of sensing, processing, and transmission [1-2]. In particular, RF transmission and reception of data is the major cause of the energy consumption. So, many researches are being made to minimize energy consumption of sensor nodes by reducing packet size or the number of transmission and reception of sensor data [3-7]. Plus, it is also important to equalize energy consumption of each sensor node to prolong sensor networks' lifespan, especially when sensor nodes are widely distributed.

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This paper proposes an energy-effective sensor node control mechanism based on sensed data and power monitoring to improve energy efficiency and sensor networks' lifespan.

2 Sensor Node Control Based on Sensed Data and Energy Monitoring

The proposed mechanism newly defines three operational modes of a sensor node, which are normal, power-saving, and inactive. A sensor node operates in one of the three operational modes, which are decided by a monitoring entity (e.g., network management system) connected to a sink node. Every sensor node reports its remaining energy with its sensed data to the monitoring entity. And then the monitoring entity decides each sensor node's operational mode and sends a control command to each sensor mode to make it operate in the mode.

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if (E_SN ≥ E_avg)
        mode ← normal
else if (E_th < E_SN < E_avg)
        mode ← power_saving
else
        mode ← inactive
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Fig. 1. Operational mode decision algorithm

Fig. 1 shows the operational mode decision algorithm used by the monitoring entity. The operational mode decision is made by comparing the remaining energy of a sensor node with the average remaining energy of all sensor nodes in the same network or cluster. A sensor node operates in normal mode when its remaining energy (E_{SN}) is higher than the average remaining energy of all sensor nodes (E_{avg}), whereas a sensor node operates in power-saving mode when its E_{SN} is lower than the E_{avg}. **As** the sensor node keeps consuming its battery capacity and its E_{SN} is lower than the pre-defined threshold E_{th}, the sensor node operates in inactive mode until the E_{avg} reaches the threshold E_{th}.

Table 1 shows the comparison between three operational modes. A sensor node operating in normal mode senses and transmits data with a normal period (T) which

Table 1. Operational modes of a sensor node

Operational modes	Period of Sensing and Transmission
Normal	T
Power-saving	$3 \times T$
Inactive	not applicable

can be set and adjusted by the monitoring entity. In power-saving mode, the sensing and RF transmission period is longer than *T*, so energy consumption from sensing and data transmission is reduced. In our implementation and simulation, the period in power-saving mode is three times longer than *T*. A sensor node operating in inactive mode not only stops sensing and transmitting data but also makes its MCU operate in sleep mode. So, energy consumption of a sensor node can be minimized during the node stays in the inactive mode.

The proposed mechanism includes another scheme to prevent a sensor node transmitting its duplicate sensed data to additionally reduce energy consumption of the sensor node. When a sensor node senses data, it compares them with pre-sensed data to decide their duplicity. If they are identical, the sensor node does not send the duplicate sensed data.

Fig. 2 shows the system architecture for the proposed mechanism with the flow of data and control messages. Each sensor node periodically sends to the sink node its remaining energy value with its sensed data such as temperature, humidity, luminance, etc. by RF transmission. The kind(s) of sensed data can be specified by the monitoring entity. The sink node delivers the data to the monitoring system by serial communication. After receiving the data from the sink node, the monitoring entity processes the data and decides each sensor node's operational mode by using the algorithm shown in Fig. 1. The monitoring system sends a control command specifying an operational mode to each sensor node via the sink node. When a sensor node receives the control command, it operates in one of three operational modes.

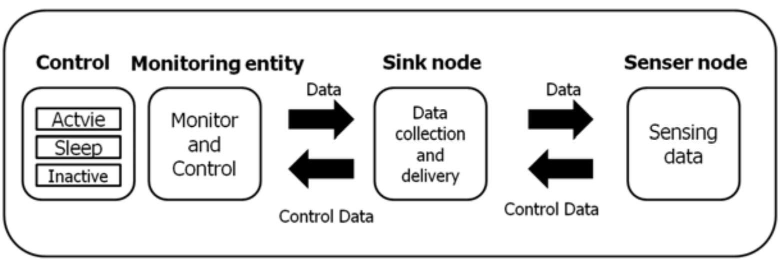

Fig. 2. System architecture of the proposed mechanism

Fig. 3 and 4 show the algorithms of a sensor node and the monitoring entity, respectively. As shown in Fig. 3, the operational mode of a sensor node can be changed only when it receives a control command from the monitoring entity. A sensor node operating in inactive mode stops sensing and transmitting data until it receives a new control command specifying a different operational mode. When a sensor node receives a control command specifying power-saving mode, it increases its sensing period to three times longer period to reduce its energy consumption. If there is no duplication between current and old sensed data, a sensor node sends the current sensed data to the sink node by RF transmission. Yet, if there is a duplication

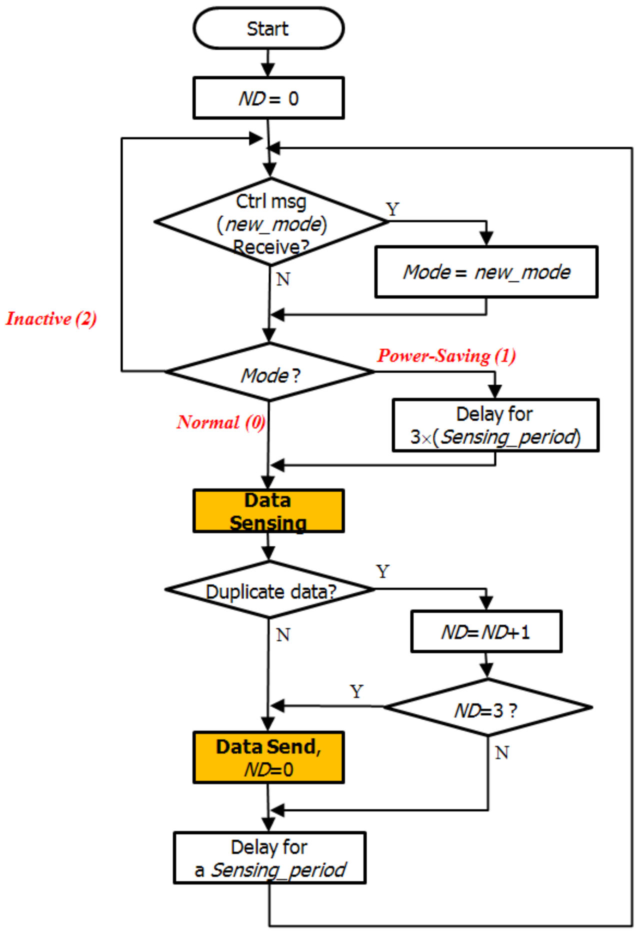

Fig. 3. Sensor node algorithm

between them, the sensor node delays sensing and transmitting the data for a sensing period. In the proposed scheme, we define the maximum number of delays as 3 to prevent the monitoring entity from misunderstanding the data duplicity as the end of sensor nodes' lifespan. If the data duplication continuously happens three times in power-saving mode, the RF transmission will be made in 9 times longer period than the normal period *T*.

As shown in Fig. 4, the monitoring entity decides the operational mode of each sensor node and it sends a control message to the sensor node to make it operate in the decided operational mode. The entity also has the function of data monitoring and processing.

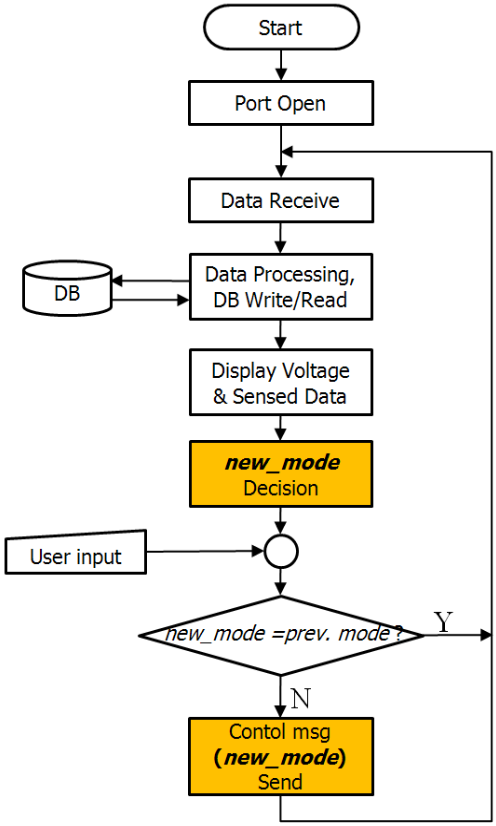

Fig. 4. Monitoring entity algorithm

3 Performance Evaluation

This section evaluates the performance of the proposed mechanism by simulation using NS-2. Table 2 and Fig. 5 show the parameters and topology of the simulation, respectively. We compare the performance of the proposed mechanism with that of IEEE 802.15.4. Two critical performance criteria are average remaining energy and standard deviation of remaining energy. We assume that 30% of sensed data are duplicated once, the other 30% are duplicated twice, and the remainder 40% are not duplicated with pre-sensed data.

Fig. 6 and 7 show the average remaining energy and standard deviation of remaining energy, respectively. As shown in Fig. 6, the average remaining energy of the proposed mechanism is higher than that of IEEE 802.15.4, which means that energy consumption can be reduced very much by the proposed mechanism. As shown in Fig. 7, standard deviation of the proposed mechanism is much lower than that of IEEE 802.15.4, because energy consumption of all sensor nodes is equalized by the proposed mechanism.

Table 2. Simulation parameters

Parameters	Values
MAC	IEEE 802.15.4
Routing protocol	AODV
Network size	50 m × 50 m
Number of sensor nodes	20
Normal sensing period (*T*)	3 sec
Packet size	30 bytes
Simulation time	60 sec
Initial energy	0.5 Joules
TxPower	0.4 W
RxPower	0.3 W

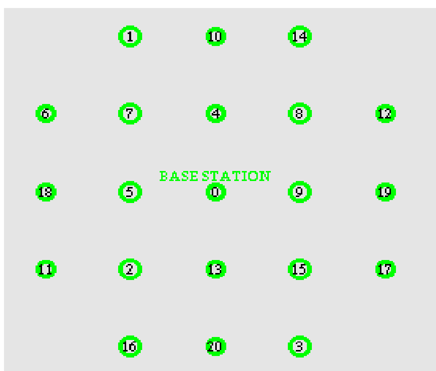

Fig. 5. Simulation topology

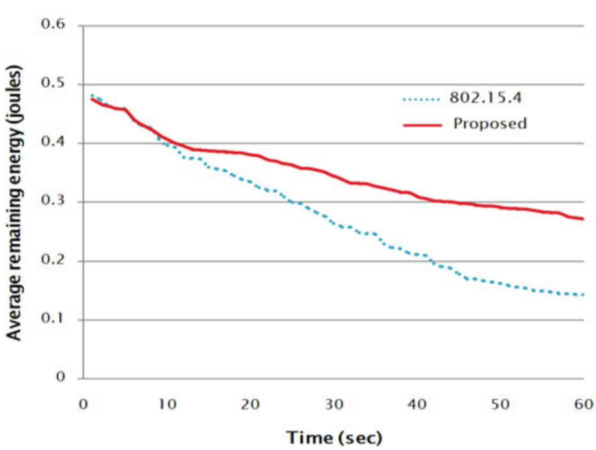

Fig. 6. Average remaining energy

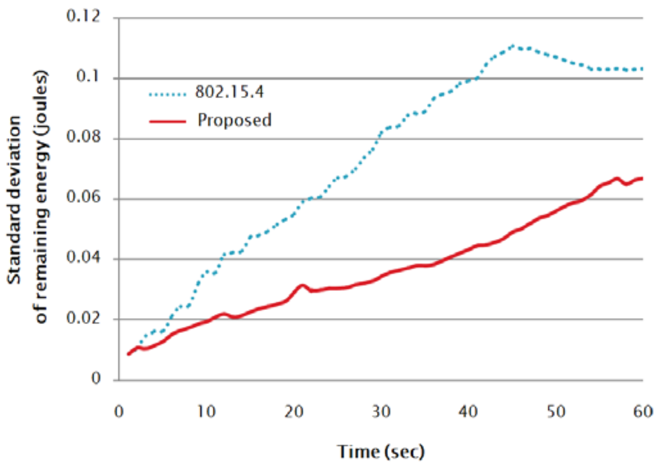

Fig. 7. Standard deviation of remaining energy

4 Conclusions

This paper proposes an energy-efficient sensor node control mechanism to prolong sensor network's lifespan. The monitoring entity defines one of three operational modes for each sensor node based on the remaining energy to reduce and equalize energy consumption of each sensor node. Plus, the proposed mechanism can make it possible to additionally reduce energy consumption by preventing a sensor node from transmitting duplicate sensed data. The simulation results show that the proposed mechanism can prolong sensor networks' lifespan by minimizing and equalizing energy consumption of a sensor node.

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