The Sleep Control Strategy for Wireless Sensor Networks

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Abstract

The sensor node in a wireless sensor network has the characteristics of low power consumption and a non-rechargeable sensor node. Therefore, power consumption is limited. Effectively controlling the power of the sensor node and extending the life time of the whole network become very important issues. In this paper, we offer the optimal sleep control for wireless sensor networks: randomly setting the sensor nodes in the entire network and determining the sleeping probability by the distance between the sensor node and sink. This method reduces the transmission frequency of the sensor nodes that are closer to the sink and effectively reaches the network's loading balance. However, the sensor nodes process their sleeping schedules according to their own residual power to save energy.

Keywords: *WSNs, Sleep Control, Zigbee, Energy-Efficient*

1. Introduction

A Wireless Sensor Networks (WSNs) [1-3, 18] formed with many tiny sensitive devices is a product combining the three techniques of communication, computation and sense. Because of improvements in miniature manufacturing, particularly in communication and batteries, sensors have become widely applied to many fields, including military, medicine, commerce, and environmental protection. Wireless Sensor Networks are usually used in environments that humans cannot reach. Therefore, sensor devices are distributed randomly and densely to observe and sense something in the target areas. The information is transmitted by a specific protocol directly to the operating station or particular sinks.

WSN studies are divided into five areas: routing protocol, localization, data collection, fault tolerance and power consumption. Of these, power consumption is the most important issue because a sensor cannot be charged if the power will be exhausted. Sensor power saving to increase the effectiveness of an entire network is a primary focus for many researchers. Power saving technology is separated into four study aspects [4]: 1) Scheduling between sensor sleeping and waking. 2) Power control in sensors adjusts the sense range: sensors are generally set up at the most sensitive range when sensing, but using power control to adjust the sense range can save energy. 3) Effective routing paths: finding a shortest path and transiting data to a sink to save power are important. 4) Reducing data overhead: when a sensor delivers data, other nodes that close it may receive information that is not transited to them. This situation causes power consumption, so the near nodes are normally set up to sleep to avoid the overhead. The sleep control strategy in this paper utilizes the optimal sleeping time control to save sensor power. The main design concept includes saving power and increasing the lifetime of the entire network. We use the optimal sleep control to avoid data transmission latency and reduce the delivery frequency and have high sleeping probabilities for the sensor nodes near the sink.

The rest of the paper is organized as follows. Section 2 introduces the sleeping mechanism and related work, following the method in this paper, which reduces the delivery frequency of the sensor nodes near the sink. Section 3 describes the optimal sleep control strategy for WSNs, introducing the relative scheme hypothesis of the primary environment and the power consumption formula. The sleeping probability for each sensor node is calculated after establishing the power list. Each sensor node implements the scheduling of sleeping and awakening according to its residual power. Section 4 shows the simulation results. Finally, we indicate future work and our conclusions.

2. Related work

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Issues regarding power consumption and making power optimization effectively extend the lifetime of whole sensor network are significant WSNs studies [17, 19]. Most people adopt the power consumption method to determine whether the sensor node should sleep. Therefore, in this section, we introduce related research that uses a sleeping mechanism to save sensor node power. There are random and periodic sleep times [5-8] in the sleeping mechanism. The single period contains two parts: active and sleep time. During the active period, sensors can communicate with other nearby sensors; during the sleep period, sensors stop any communication. We can control the power consumption by handling the active period. We introduce the S-MAC (sensor mac) scheme and method regarding periodic sleep time below.

2.1 Random Sleep Time

The sleeping and awakening time for each sensor is not periodic in random sleep time: some message transmissions may be delayed for a long time and reduce the efficiency of entire network. Moreover, the power is wasted when the sensors are awake but do not deliver any messages. As Figure 1 reveals, in a specific duty cycle (sleep time + active time = T), the time of sleeping and awakening is randomly decided.

Figure 1. Random Sleep Time

2.2 Periodic Sleep Time

In periodic sleep time, we introduce S-MAC (Sensor Mac) [5, 9]. The periodic sleeping mechanism by Wei Ye et al [12] can avoid overhead in the sensor node, prevent collisions and reduce idle time. This is the first method to apply the sleeping mechanism to wireless networks.

2.2.1 S-Mac(Sensor Mac)

S-Mac is a medium access control protocol whose main purpose is to save power. S-MAC has four major measurements to reduce energy consumption.

1) Make the sensor node enter periodic sleep time: Sensor node sleeping and awakening times are fixed, as in Figure 2.

Figure 2. Periodic Sleep Time

2) Prevent collision: In the competitive environment, data collisions usually occur. When a collision happens, the data must be retransmitted. The 802.11 method applied in S-MAC uses virtual and physical carrier senses and the RTS/CTS package exchange [20].

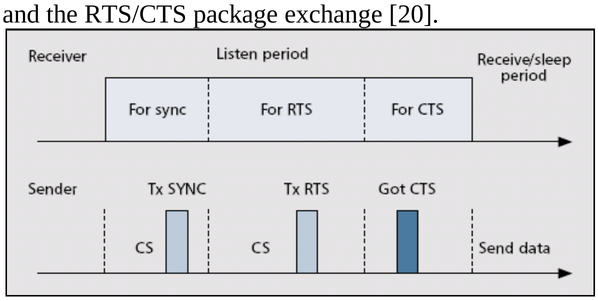

Figure 3. S-Mac Package Exchange Chart

In Figure 3, when the sender delivers an RTS package to a receiver, the receiver returns a CTS package to the sender. This means the message can be mutually transited, and the nearby sensor nodes cannot deliver any message. The collision is thus avoided.

3) Prevent eavesdropping: Wireless electric waves are transited in the air. Any sensor can receive the information, regardless of the node to which the data is delivered. This action wastes energy on

receiving unnecessary message. S-MAC thus makes sensors enter sleeping mode to avoid receiving unnecessary messages when not the transmission target.

Compared with 802.11 [10], S-MAC can save energy but does not save it well for variant network flows. Regardless of environmental changes, the sensor transmission protocols do not change the transmission model. Much energy is wasted [11, 12] when the sensor operating time is long with low network flow. When the operating time is short and network flow is high, the transmission capacity of the entire network is limited. Message transmissions thus require much time [13-15].

2.2.2 Timeout MAC (T-MAC)

The T-MAC [6] method is similar to S-MAC. Both apply three kinds of packages: RTS, CTS and ACK. During the active time, if no activation events occur in time TA, sensors enter sleeping status. TA means the active time in this period, as Figure 4 illustrates the T-MAC sleep time.

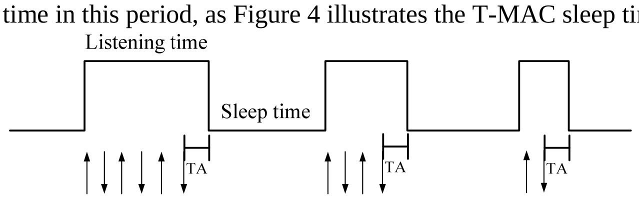

Figure 4. T-Mac Sleep Time Chart

T-MAC solves the power saving problem by shortening the active time. Both S-MAC and T-MAC adopt the fixed sleep time. Though T-MAC saves power by reducing the active time, it causes lower throughput in the wireless sensor network.

3. The Optimal Sleep Control (OSC) Strategy

In this paper, the relay frequency of the sensors nearest to the sink is reduced by raising the sleeping probability of the sensors farthest from the sink. The loading of the whole network is thus balanced. Each sensor processes sleep and active schedules according to its own residual power and reaches the sensor node power saving. The algorithm in this paper contains four stages: establish a network, set up the sleeping probability for each sensor in this level, set up an energy table, and arrange the sleep and active modes for sensor nodes according to the energy table. When establishing a network, sensor nodes are distributed within the range, using the sink as the center of the circle and R as the radius. In this circle, levels are separated by concentric circles, and sensor nodes are located in different levels. After the first stage, the probability of sensor nodes in every level entering sleep is established. The probability is determined using the sensor node distributive densities, and sensor nodes in each level decide whether to sleep or wake. A flowchart of the algorithm follows. We introduce the environment and hypotheses of a wireless sensor network in this section.

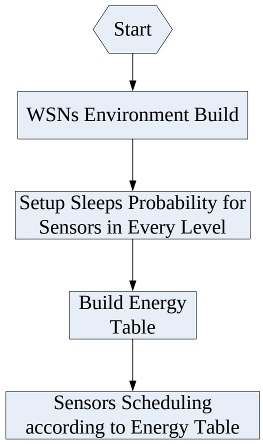

Figure 5. The Sleep Control Chart

3.1 Environment

The structure in this network environment is set up with an active sink at the center of the circle. The sink differs from general sensor nodes in that it contains sufficient power and stronger computational abilities and can therefore receive all data in the sensor network. We assume the network time is synchronous. Other environment parameters affect setup, as observed in the following.

For sensor nodes:

- Sense range： r_s(cm)
- Transit range： r_t(cm)
- Beginning energy： E(J)
- Packet load: *L*(bits)

For the sink:

- The center in concentric circle *A*.
- Sufficient power.
- No barrier in the network.

When the sensors are randomly distributed in this area, the levels are separated as follows in Figure 6. [16]

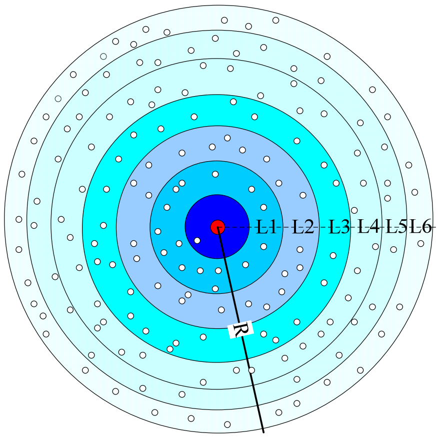

Figure 6. Build the Wireless Sensor Network

For power consumption, we refer to the general documents as follows [16]:

$$ETX(L,d)=L*Eelec+L*\varepsilon amp *d^2 \quad (1)$$

$$ERX(L) = L* Eelec \quad (2)$$

Equation (1) represents power consumption in the sensor node data transmissions. Equation (2) represents power consumption in the data received by sensor nodes. The parameter of *L* indicates the packet load bit; *Eelec* means the required power for a sensor node in a data transmission. When transiting, the wireless power enlarges, and the consumption of $L*\varepsilon$ amp*d^2 increases. The parameter *d* shows the distance between the two sensor nodes; ε amp denotes the power consumption required for increasing the wireless power.

3.2 Setup Sleep Probability for Sensors

The sleeping probability in each level is calculated in a formula below [16]. Essentially, the density of the entire wireless sensor networks is calculated, as derived from Equation (3).

$$\lambda = N/A \quad (3)$$

N means the number of sensor nodes; *A* means the area of the entire wireless sensor network. *A* equals πR^2; λ means the distributive density. The density is calculated and follows Equation (4).

$$\lambda_i=N_{i'}/A_i,\ i=1,2,3... \quad (4)$$

$N_{i'}$ means the number of active sensor nodes in each level; A_i means the area in each level. A_i equals $(2i-1)\pi r^2$ (*r* is the radius of each level). Equation (5) is another representative method of λ_i.

$$\lambda_i = (1 - Ps_i)\lambda, \ i = 1,2,3... \quad (5)$$

Ps_i means the probability of sleeping of level i. 1-Ps_i indicates the probability of active sensor nodes in level i. Equation (5) represents the density of active sensor nodes in level i and also shows the active probability multiplied by the density of the entire wireless sensor network.

According to Equations (4) and (5), we use the formula below to stand for the two equations of λ_i:

$$(1-Ps_i)\lambda = N_{i'}/A_i, \ i=1,2,3... \ (6)$$

We know the number of active sensor nodes in level i via Equation (7):

$$N_{i'} = (1-Ps_i)\lambda A_i, \ i=1,2,3... \ (7)$$

Therefore, we can combine Equation (4), (7) and (8):

$$(1- Ps_i)\lambda A_i = \lambda_i A_i, \ i=1,2,3... \quad (8)$$

$$Ps_i = 1-(\lambda_i / \lambda) \quad (9)$$

Equation (9) indicates the sleeping probability of sensor nodes in each level.

After calculating the sleeping probability in each level, we select which sensor nodes should sleep and which should remain active, as shown in Equation (10):

$$N_i * Ps_i = S_i \ (10)$$

N_i means the number of sensor nodes in the level; S_i means the number of sleep sensor nodes. After determining S_i, we randomly select the sleep sensor node in this level. The sensor nodes that prepare to sleep process the sleep schedule according to their residual power levels and the energy table.

3.3 Build energy table

Establishing the energy table is performed with a simulation. At first, there is a specific fixed group, and the sleep and active residual power proportions in every stage are fixed. We vary the sleep and active proportions in one stage, creating the optimal combination. The statement follows in Table 1:

Table 1. Power list

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	10	90
80-89	50	50
70-79	50	50
60-69	50	50
50-59	50	50
40-49	50	50
30-39	50	50
20-29	50	50
10-19	50	50

From the above table, we established the sleep and active proportion at 50% for stages after 80-90(%) residual power (i.e., 70-79(%), 60-69(%), 50-59(%), 40-49(%)…). We only vary the sleep and active proportions of the 90-100(%) residual power. We see that the sleep and active proportions are 10% and 90%, respectively. From the second stage, we fix the sleep and active residual power proportions for other stages; meanwhile, we change the proportions from 10% and 90% into 20% and 80%, as Table 2 indicates:

Table 2. Power list

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	20	80
80-89	50	50
70-79	50	50
60-69	50	50
50-59	50	50
40-49	50	50
30-39	50	50

20-29	50	50
10-19	50	50

We continue to fix the proportion for other stages and make the sleep and active proportion of 90-100(%) residual power. Refer to Table 3.

Table 3. Power list

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	30	70
80-89	50	50
70-79	50	50
60-69	50	50
50-59	50	50
40-49	50	50
30-39	50	50
20-29	50	50
10-19	50	50

We make the optimal sleep and active proportions for the 90-100(%) stages using this simulation. However, in the actual wireless sensor networks, the sleep and active sensor node proportions is not always 50% and 50%. Take the fixed group (10% and 90%) as an example. From Table 4, we find the best proportions for 10% and 90% because we average the optimal proportion for the fixed group and obtain the following best sleep proportions, as shown in Table 5.

Table 4. Power list

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	10	90
80-89	10	90
70-79	10	90
60-69	10	90
50-59	10	90
40-49	10	90
30-39	10	90
20-29	10	90
10-19	10	90

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	20	80
80-89	10	90
70-79	10	90
60-69	10	90
50-59	10	90
40-49	10	90
30-39	10	90
20-29	10	90
10-19	10	90

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	30	70
80-89	10	90
70-79	10	90
60-69	10	90
50-59	10	90
40-49	10	90
30-39	10	90
20-29	10	90
10-19	10	90

Table 5. Optimal Power Combination

Eratio (%)	*Sleep (%)*	*Active (%)*
90-100	17	83
80-89	25	75
70-79	32	68
60-69	43	57
50-59	55	45
40-49	58	42
30-39	70	30
20-29	90	10
10-19	90	10

3.4 Sensor Nodes Enter Sleep Scheduling

Figure 7 describes the sleep schedule flowchart for sensor nodes. Before sleep scheduling, we judge the status of sensor nodes according to power:

Case1: $E_{rem} \geqq P_{tx}$: When residual power is greater than the threshold transmission power, the sleep and active schedules are used.

Case2: $P_{tx} \geqq E_{rem} \geqq P_{rx}$: When the residual power is between the threshold transmission and receiving powers, sensor nodes only receive, not transit.

Case3: $P_{rx} \geqq E_{rem}$: When the residual power is less than the receiving power threshold, the sensor node is a dead node and lacks any transmission or sense functions.

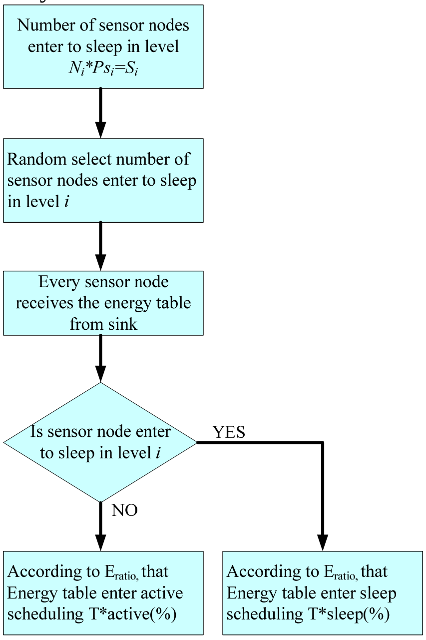

Figure 7. Sleep Schedule Flowchart

4. Simulation Result

The wireless sensor network environment used in the simulation follows:

- Environment area: 25 m*25 m*π
- Sensor nodes: distribute 300 pcs randomly
- Packet load: 40000 bits
- Initial power: 2J
- Sensor node sensing power: $5*10^{-8}$ J
- Transmission range: 2 m
- Duty Cycle T: 20 time slots

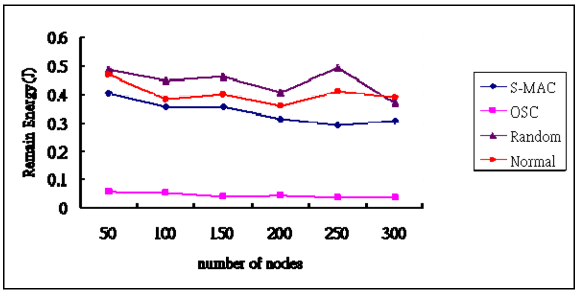

Figure 8. Comparison of the remaining energy among sensor nodes

We observe many methods to compare the remaining network energy, when the energy of any sensor node in the network is less than 10%. Figure 8 illustrates the average observed remaining sensor node energy. The inconsistent sensor node sleep times cause some sensor nodes to sleep for a short time and rapidly consume power in the random sleep method. Conversely, sensor nodes with sufficient remaining energy sleep too long, which stops the network. These nodes are still sufficient. We find that the remaining network energy is not balanced. The load of each sensor node is balanced using the energy table to dynamically adjust the sleep and active times in our method. Furthermore, S-Mac adopts the periodic sleep method, so the remaining energy distribution is better than in the random sleep method.

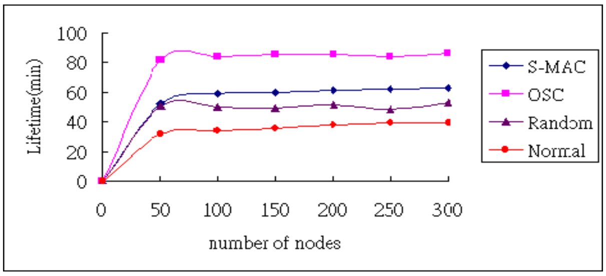

Figure 9. Comparison of sensor node's life time

Before sleep scheduling, the probability was determined using the distributive density. The throughput of the wireless sensor network balances the load of the entire network and reduces the reply frequency of the sensor nodes closest to the sink to extend the lifetime of the wireless sensor network, as Figure 9 reveals.

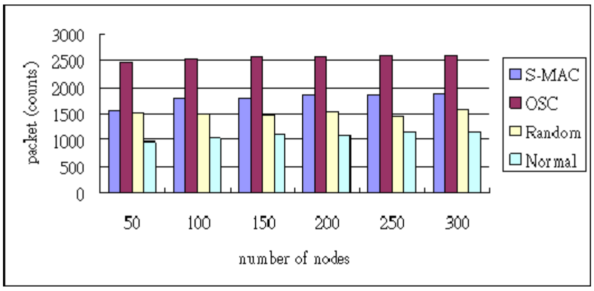

Figure 10. Frequency of the transmission packet of sensor nodes

We compare packet transmission frequencies in sensor nodes in Figure 10. Regarding the best sleep control, sensor node sleep and active times are adjusted dynamically. Sensor node power can be saved, and packet transmission frequency is arranged more effectively than in other sleep scheduling methods.

5. Conclusions

This paper offers an effective sleep control mechanism to save sensor node energy. We dynamically adjust the sleep and active times according to remaining sensor node energy. This saves power in sensor nodes and extends the lifetime of wireless sensor networks.

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