Power Saving Mechanism with Optimal Sleep Control in Wireless Sensor Networks

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Abstract

The sensor node in Wireless Sensor Network is with the characteristics of low power consumption, but the sensor node can not be rechargeable. Therefore, the consumed of power is limited. How to effectively control the power of the sensor node and extend the life time of the whole network become a very important issue. In this paper, we proposed an optimal sleep control mechanism. When the sensor nodes are set randomly in the entire network and the sleeping probability is determined through the distance between the sensor node and the sink. The proposed mechanism will effectively reduce the frequency of the transmission of the sensor nodes more close to the sink and reach the loading balance of the whole network. However, the sleeping sensor nodes will process their sleeping schedule according to their own residual power and achieve the effectiveness of saving power.

Key Words: Wireless Sensor Networks, Power Control, Sleep Control, Scheduling

1. Introduction

Advances in the wireless communication and the microelectronic technologies have been expediting the development of wireless sensor networks (WSNs) [1,2]. The WSN has lately attracted considerable attention and is widely used for sensing a variety of environment conditions such as temperature, humidity, and density of air pollutant. The main reasons for its popularity are the low price and the ease to form the network. WSN is defined as a network without manager and central coordinator. Usually Wireless Sensor Networks are used in the environment that humans can not reach. Therefore, sensor devices are distributed randomly and densely in the areas which are about to be observed. The collective information is directly transmitted by a specific protocol to the operating station or some particular sinks.

The researches in Wireless Sensor Networks could be roughly divided into five fields: routing protocol, localization, data collection, tolerant, power consume. In general, sensor nodes are small, low-cost equipments and typically subject to a stringent energy constraint. Hence, energy conservation is a crucial issue for WSNs. How to reserve the power of sensor nodes to increase the effectiveness of entire network is the worthy issue for many researchers [3–8]. The technology of power saving is separated into four study aspects [3]:

1. The schedule between the sleeping and awakening of sensors: achieves the effectiveness of saving power by sleeping mechanism.
2. Power control is used in sensors to adjust the range of sense: generally sensor nodes are set up at the most sensitive range when sensing, but using power control to adjust the sense range will be able to achieve the effectiveness of saving power.
3. Effective routing path to Sink: as wireless sensor nodes adopt the method of Multi Hops, so how to find a shortest path and make the data transmitted to the sink to reach the throughout of power saving is very important.

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4. Reduce the overhead of data: when a sensor node delivers data, other nodes close to it may receive the information that is not transmitted to them. This will cause the consumption of power, so normally the near nodes will be set up to sleep to avoid the happening of overhead.

In this paper, we proposed the "Power Saving Mechanism with Optimal Sleep Control in Wireless Sensor Networks". We reserve the power by the precisely scheduling for the sleep control. The major purposes are: (1) Saving power and increase the time of entire network. (2) Using the optimal sleeping time to avoid the delay of the information. (3) Reducing the delivery frequency of the sensor nodes close to the sink, and therefore the sleeping probability of it will be high.

There are five sections in this paper. The second section will introduce the proposed sleeping mechanisms. In the third section, firstly the relative scheme hypothesis of the primary environment and the formula of power consumption in this paper are introduced. And then we will show the proposed sleep control mechanism. The forth section is the result of simulation and shows the assessment of the sleeping mechanism. Finally, we will indicate the study aspect in the future and make a conclusion in the fifth section.

2. Related Work

There are four kind of the energy consumption in WSNs besides transmitting and sensing [9]. (1) Collision: The collision will occur if there are two nodes want to transfer data to the same node. By this case, the both nodes have to retransmit the data and the energy will be wasted. (2) Sparse: In normal, the nodes are deployed by random. There will be sparse in some areas because of the random deployment. The nodes in these areas will consume more energy for transmitting. (3) Overhead: When nodes transmit data to the other node, the neighbor nodes will receive these redundant data. It will waste the energy for receiving the redundant data. (4) Idle: There are three status for each nodes which are sleep, active and idle. If stay in idle status with long duration, it waste the energy for listening channel.

In the WSNs, how to efficiently use the energy and prolong the entire network lifetime are the major issues. We will introduce the references which saving energy by sleeping control mechanism. There are two categories of sleeping control mechanism, random sleep time and periodic sleep time [10–13]. In sleeping control mechanism, there are two parts for each duty cycle which are active status and sleep status. For active status, sensor nodes could communicate with neighbor nodes. For sleep status, sensor nodes will suspend all communication to save energy.

2.1 Random Sleep Time

As shown in Figure 1, the duration of active and sleep status is unfixed for each duty cycle. In this way, it will decrease the performance for the transmission delay or waste energy for the long active duration with no data transmitting.

2.2 Periodic Sleep Time

In periodic sleep time, we will introduce S-MAC (Sensor Mac) [4] and T-MAC [5]. The periodic sleeping mechanism can avoid the overhead of the sensor node, prevent from the collision, reducing idle time.

2.2.1 S-Mac (Sensor Mac)

S-Mac (Sensor Mac) [4] is a Medium Access Control Protocol whose main purpose is to reserve power. There are four major measurements in S-MAC to reduce the consumption of energy:

- ◆ Make the sensor node enter periodic sleep time: The time of sleeping and awakening of sensor nodes is fixed.
- ◆ Prevent from the happening of collision: When the collision happens, the data have to be resent and this will cause waste.
- ◆ Prevent from the happening of eavesdropping: Makes sensors enter sleeping to avoid receiving any unnecessary information when the target is not itself during the transmission.
- ◆ Message passing: Fragment the long message into many small fragments, and transmit them in burst.

In Figure 2, when sender delivers the package of

Figure 1. Random sleep time.

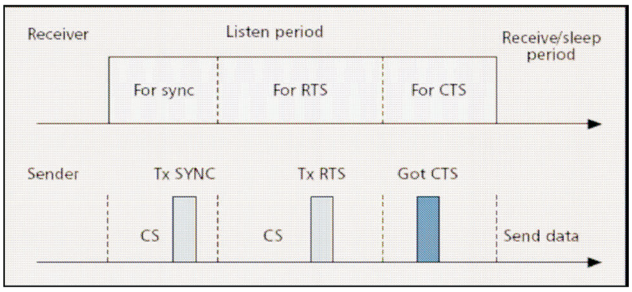

Figure 2. S-Mac package exchange chart.

RTS to Receiver, Receiver will send the package of CTS back to Sender. This means the information can be transmitted mutually and the nearby sensor nodes are unable to delivery any information. The happening of collision will be avoided through the exchange of the package information.

Compared with 802.11 [13], S-MAC can save much energy, but the design of the periodic time is not perfect for the adaptation of network flow. This is because no matter how the environment changes, the sensor transmission protocol won't change the transmission model. A lot of energy will be wasted [11,12] when the operating time of sensors is long, but the flow is few. When the operating time is short, and the flow is high, the transmission ability of the entire network will be limited. This will take much time on the transmission of the information [8,9,12].

2.2.2 Timeout Mac (T-Mac)

The method of T-Mac [5] is very similar to S-Mac. They adopt three kinds of packages of RTS, CTS and ACK. During the active time, if there is no Activation events, sensor nodes will enter the status of sleeping in time TA. TA means the active time in this period, as the sleep time of T-Mac illustrated in Figure 3.

Timeout Mac (T-Mac) solves the problem of power saving by shortening the active time. Both S-Mac and T-Mac adopt the fixed sleep time. Although T-Mac save power by reducing the active time, the active time is shorter, the delay time of the packet is longer. This will lower the throughput of the wireless sensor network.

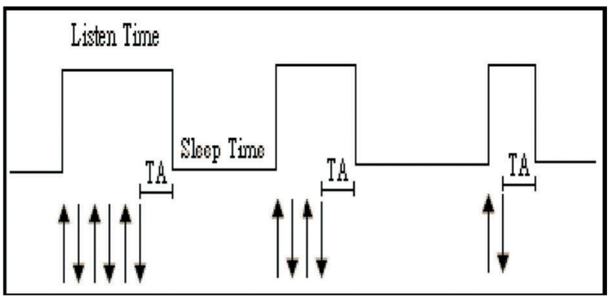

Figure 3. T-Mac sleep time chart.

3. The Optimal Sleep Control for Wireless Sensor Networks (OSC)

In this paper, frequency of relay of the sensor nodes nearest from the sink is reduced through raising the probability of sleeping of the sensors farthest from the sink. The loading of the whole network is balanced. Each sensor node will process sleep and active schedule according to its own residual power and reach the saving of the power of the sensor node.

As shown in Figure 4, the algorithm in this paper is divided into four stages: 1) establish network, 2) set up the probability of sleeping of each sensor node in this level, 3) set up energy table, and 4) arrange the sleep and active of sensor nodes according to the energy table. In the stage of establishing network, sensor nodes are distributed within the range based on the sink as the center of the circle and R as the radius. In this circle, the levels are separated by the method of the concentric circles and each sensor nodes are located in different levels.

After the first stage, the probability of entering sleep-

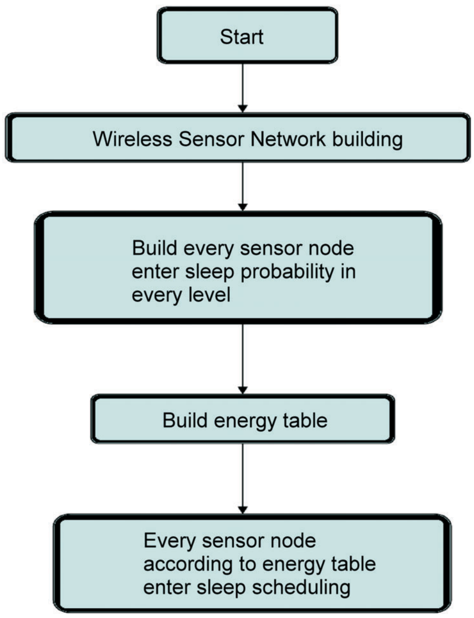

Figure 4. The optimal sleep control chart.

ing of the sensor nodes in each level is established. The probability is figured out via the distributive density of sensor nodes and then sensor nodes in each level will be decided to sleep or awake. The flowchart of the algorithm is revealed as follow:

3.1 Environment

As shown in Figure 5, the structure in this network environment is set up with an active sink in the center of the circle. The difference from general sensor nodes is that it's with sufficient power and stronger ability of compute, and therefore it could receive all the data sensed in the sensor network.

We assume the network is synchronous and then sensor nodes can sense the order of the events and judge the relative mechanism. Below is the assumption of the delivery and sense of each sensor node in network.

- ✧ Sense range: R_s (cm)
- ✧ Transmit range: R_t (cm)
- ✧ Beginning energy: E(J)
- ✧ Packet load: L (bits)

Below is the assumption for the sink:

- ✧ The center in concentric circle A
- ✧ Power is sufficient
- ✧ There is no barrier in the network.

When the sensor nodes are distributed in this area randomly, A will process the action of delaminating and the levels are separated as following figure [14].

What we probe in this paper is the issue of power consumption. The formula and the parameter we refer to the general documents is as follows [14]:

$$E_{TX}(L, d) = L * E_{elec} + L * \varepsilon_{amp} * d^2 \tag{1}$$

$$E_{RX}(L) = L * E_{elec} \tag{2}$$

Formula 1 represents the consume power in the data transmission of sensor nodes. Formula 2 represents the consume power in the data receive of sensor nodes. The parameter of L means the bit of packet load; E_{elec} means the required power of sensor node in a data transmission. When transmitting, the whole wireless power is enlarged, so the consumption of $L * \varepsilon_{amp} * d^r$ is increased. The parameter of d means the distance between the two sensor nodes; parameter of ε_{amp} means the required consume power in enlarging the wireless power.

3.2 Build Sensor Node Enter Sleep Probability

The probability of sleeping of each level in the wireless sensor networks is calculated in below formula [15]. Essentially, the density of the entire wireless sensor networks is figured out and we can know it from following formula:

$$\lambda = N/A \tag{3}$$

N means the number of all sensor nodes; A means the area of the entire wireless sensor networks $A = \pi R^2$; λ means the distributive density. The density will be calculated and can be see from below formula 4:

$$\lambda_i = N_i'/A_i,\ i = 1,2,3 \tag{4}$$

N_i' means the number of active sensor nodes in every level; A_i means the area in each level. $A_i = (2i - 1)\pi r^2$ (r is the radius in each level). Formula 5 is another represent method of λ_i:

$$\lambda_i = (1 - Ps_i)\lambda,\ i = 1, 2, 3 \tag{5}$$

Ps_i means the probability of sleeping of level I;$1 - Ps_i$ means the probability of active sensor nodes in level i,

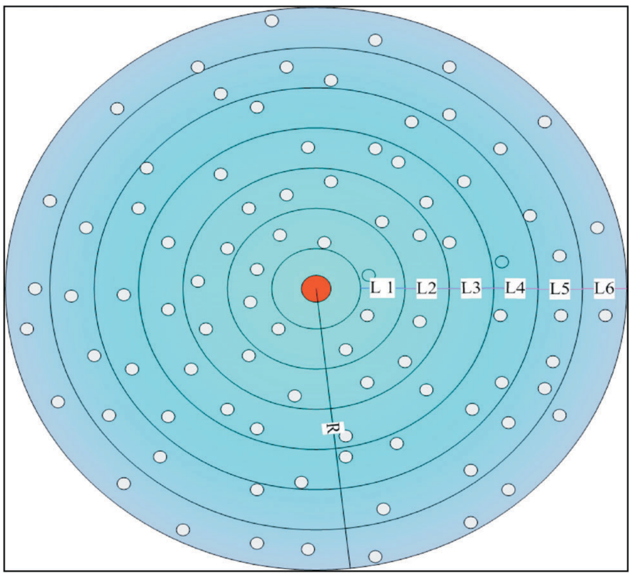

Figure 5. Contructure of Wireless Sensor Network.

formula 5 represents the density of active sensor nodes in level i and it can also show the active probability multiply by the density of whole wireless sensor networks.

According to above formula 4 and formula 5, we can use below formula to stand for the two equations of λ_i:

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

We can know the number of active sensor nodes in level i via formula 7:

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

Therefore, we can combine formula 4 and formula 7 into formula 8:

$$(1 - Ps_i)\lambda A_i = \lambda_i A_i,\ i = 1, 2, 3 \tag{8}$$

$$Ps_i = 1 - (\lambda_i/\lambda) \tag{9}$$

Formula 9 means the probability of sleeping of sensor nodes in each level.

After we calculated the probability of sleeping of each level, we will select which sensor node should sleep and which sensor node should be active. It is showed as formula 10:

$$N_i * Ps_i = S_i \tag{10}$$

N_i means the number of all sensor nodes in the level; S_i means the number of the sleep sensor nodes. After we figure out the number of S_i, we randmoly select the sleep sensor node in this level. The sensor nodes which prepare to sleep will process the sleep schedule according to its residual power and the energy table.

3.3 Build Energy Table

The method of establising the energy table is made by a simulation. At first, there is a specific fixed group and the sleep and active proportion of residual power in each stage is fixed. We make the sleep and active proportion of one stage vary and the optimal combination is made by this measurement. The statement is as follows:

As shown in Table 1, we set up the sleep and active proportion at 50% for the sthages after the 80-90 (%) residual power (i.e. 70-79 (%), 60-69 (%), 50-59 (%), 40-49 (%)…). So, we only make the sleep and active proportion of the 90-100 (%) residual power vary. We can see that the sleep proportion and active proportion is 10% and 90% respectively. From the second stage, we still fix the sleep and active proportion of residual power for other stages; meanwhile, we will change the proportion from 10% and 90% into 20% and 80%, as Table 2 indicates.

Following we keep on fixing the proportion for other stages and make the sleep and active proportion of 90-100 (%) residual power. Refer to Table 3.

Table 1. Power list

E_{ratio} (%)	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

Table 2. Power list

E_{ratio} (%)	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

Table 3. Power list

E_{ratio} (%)	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 proportion for the stage of 90-100 (5) through this simulation. The problem we have to concern is in the actual wireless sensor networks, the sleep and active proportion of each sensor node is not always 50% and 50%. Take the fixed group (10% and 90%) for example, as shown in Table 4.

Through our simulation data such as Figure 6, we evaluate the way to build the future power table, sensor nodes according to their own status, and the remaining amount of electric power based on the table to do sleep with the scheduled action mechanism. It can observe that more remaining power situation, the proportion of sleep will be relatively short, so sensor node is measured more in the electric case, the active cycle will longer to do more with the sensing ability, making the whole wireless sensor network performance boost.

By the average ratio of the fixed group, we could find the best proportion for sleep as shown in Table 5.

3.4 Sensor Node Enter Sleep Scheduling

Before executing the sleep schedule, we will judge the status of sensor nodes according to the power and follow the steps as shown in Figure 7:

- Case 1: $E_{rem} \geqq P_{tx}$: When residual power is much than the power of the transmission of Threshold, the Sleep and Active schedule is used.
- Case 2: $P_{tx} \geqq E_{rem} \geqq P_{rx}$: When the residual power is within the power of the transmission and receive of Threshold, sensor nodes only receive, not transmit.
- Case 3: $P_{rx} \geqq E_{rem}$: When the residual power is little than the power of the receive of Threshold, the sensor node is regarded as a dead node and is without any function of transmission and sense.

As mentioned in 3.3, we calculated the probability of the nodes will be set as sleep status for each level. After that, sink will select the nodes to get into the sleep status randomly. Each node set the sleeping scheduling according to the power list.

4. Analysis and Simulation Results

4.1 Analysis

The proposed sleeping control mechanism takes the dynamic scheduling method. We calculate the sleep probability for each level by the density. The nodes away from the sink will increase the sleep probability to decrease the forward frequency of the nodes near to the sink. In this way, the nodes near to the sink could share the energy consumption and preserve the energy.

For the wireless sensor networks, the sleeping scheduling is very important. If the nodes set into the active status for long duration, it will waste a lot of energy. On the contrary, the transmission will delay if the nodes be with long sleep duration. In this paper, we design a optimal sleeping control mechanism to avoid both of the situations.

4.2 Simulation Results

The environment of wireless sensor networks used in the operation of simulation is as 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.

Table 4. Power list

E_{ratio} (%)	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

E_{ratio} (%)	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

E_{ratio} (%)	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

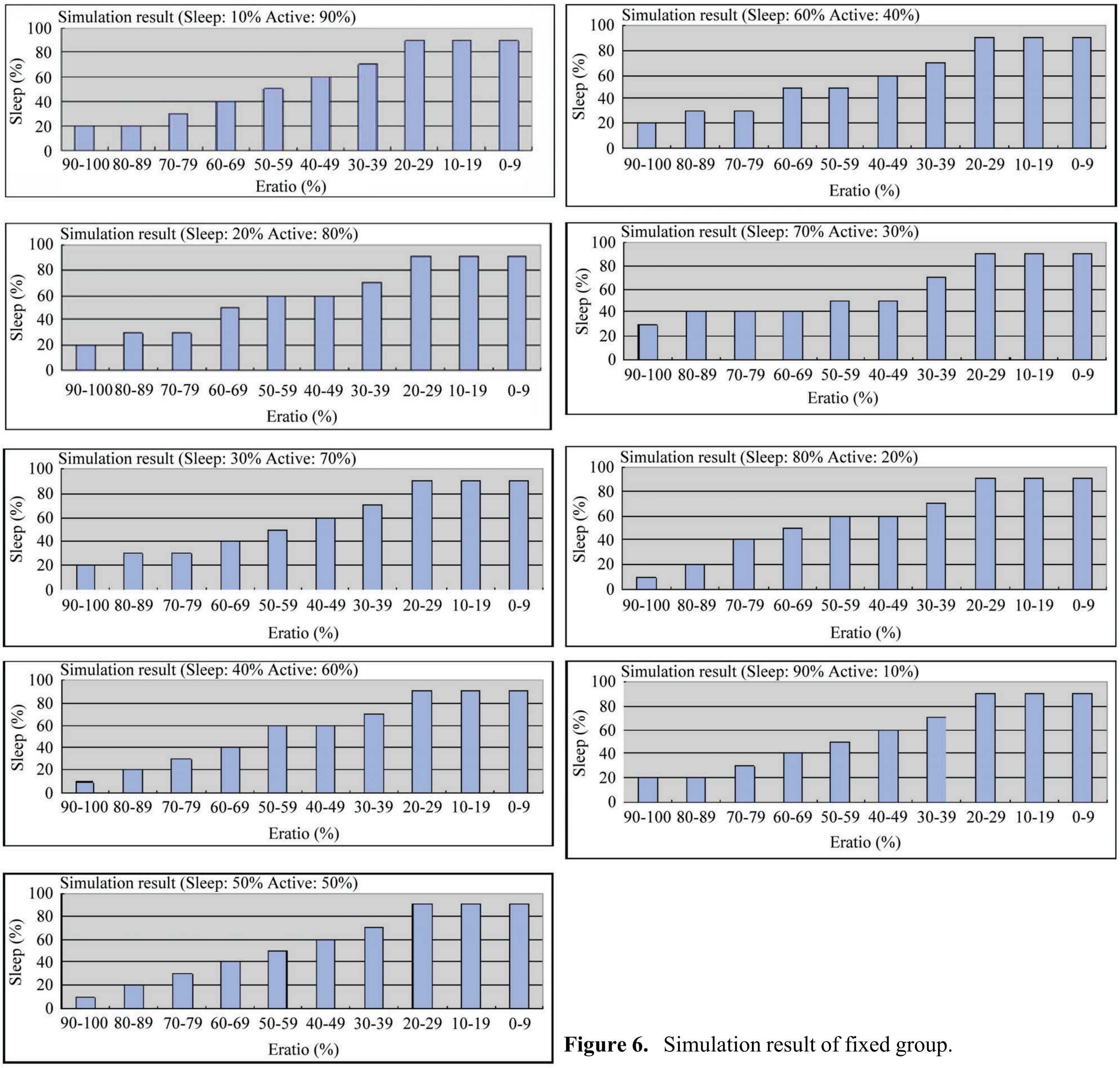

Figure 6. Simulation result of fixed group.

The average remaining energy of the sensor node we observe is as Figure 8 illustrated. For the Normal method, it does not consider the sleep control mechanism, so the energy consumption is unstable. The Random method will cause some sensor nodes sleep for a short time and make the power consume rapidly in this random sleep method. By contrast, the remaining energy of the sensor node that sleep more is much and this will make the network stop operating. As the remaining energy of nodes is huge, we can find the remaining energy of whole network is not even. The load of each sensor node is balanced by using energy table to adjust the sleep and active

Table 5. Optimal power combination

E_{ratio} (%)	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

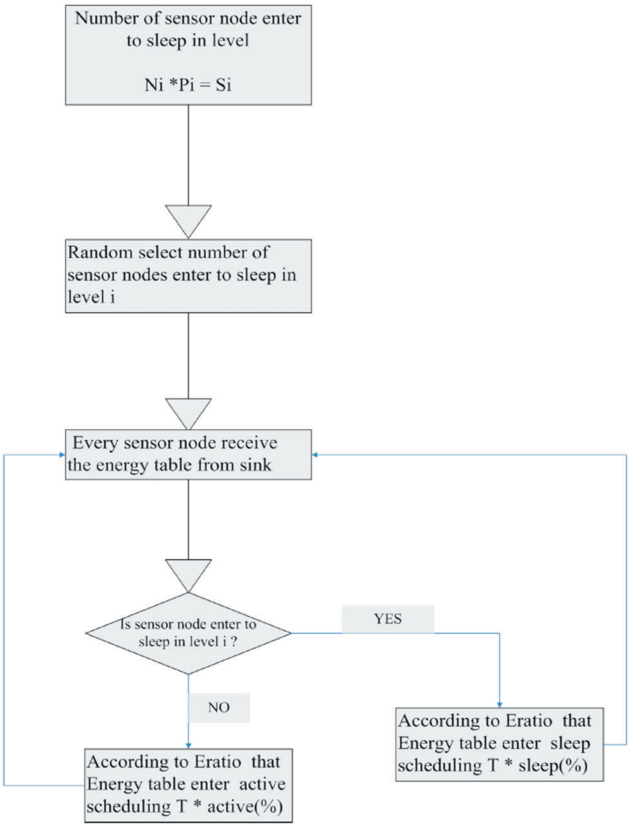

Figure 7. Flowchart of sleep schedule.

time dynamically in the proposed method. For S-Mac, it adopts the periodic sleep method, so the distribution of remain energy is better than random sleep method.

In Figure 9, we can find that the comparison with lifetime of the sensor network. In Normal method, it will cause the node dead because of keeping nodes awake. For the Random method, the energy will be exhausted for the short sleeping duration. In the proposed method, the probability is calculated via the distributive density before the sleep schedule is processed. So, the throughput of the entire wireless sensor networks can make the load of the whole network balance and reduce the frequency of reply of the sensor nodes most close to the sink to extend the lifetime of the whole wireless sensor networks, as figure reveals.

We compare the frequency of transmission packet of sensor node in Figure 10. Regarding the best sleep control set forth in this paper, as the sleep and active time of sensor nodes are adjusted dynamically, the power of sensor nodes can be saved and the frequency of transmission packet is arranged well than other sleep schedules.

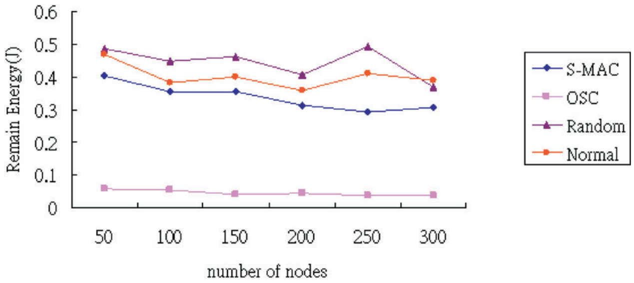

Figure 8. Comparison of the remain energy among sensor nodes.

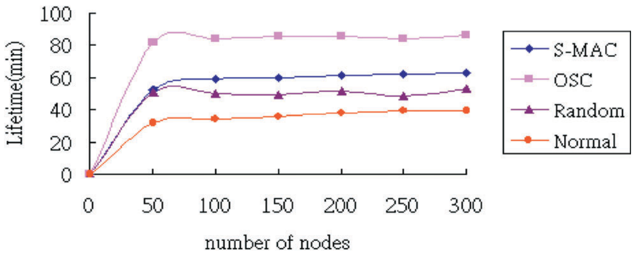

Figure 9. Comparison of sensor node's life time.

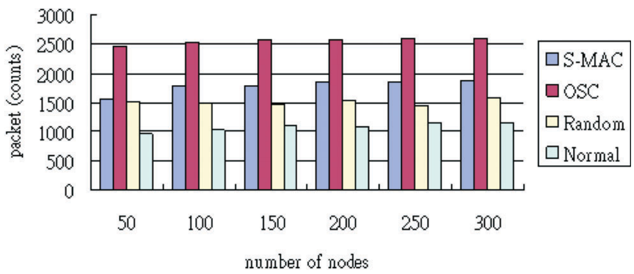

Figure 10. Frequency of transmission packet of sensor node.

5. Conclusion

This paper set forth an effective sleep mechanism to save the energy of sensor nodes. We dynamically adjust the sleep and active time according to the remaining energy of sensor nodes. It will save much power of sensor nodes and make extend the life time of the entire wireless sensor networks. By the simulation results, we can demonstrate that the proposed mechanism could effectively reserve the energy of sensor nodes and prolong the network lifetime.

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