The Optimal Sleep Control for 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't 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.

This paper sets forth "The Optimal Sleep Control For Wireless Sensor Networks". 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.

This method 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.

Keywords: power consumption, sensor network, sleep control

1. Introduction

Wireless Sensor Networks (WSNs) [1-2], formed with many tiny sensitive devices, is the production combined with three techniques of communication, compute and sense. Recently with the improvement of the technology of miniature manufacture, communication and battery, sensors are widely applied to all aspects, like military,
medicine, commerce, environment protect…and etc.

The study in Wireless Sensor Networks are roughly divided into five fields: routing protocol、localization、data collection、tolerant、power consume. In which, power consumption is the most important issue. This is because sensor is with the characteristic of low power consumption, but it can't be charged and the power will be exhausted. So, how to save the power of sensor to increase the effectiveness of entire network is the proceeding topic for many researchers. The technology of power saving is separated into four study aspects [7]:

"The Optimal Sleep Control" in this paper is to use the optimal sleeping time control to save the power of sensor. The main design concept is as follows:

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.

This paper includes five sections; the second section will introduce the sleeping mechanism. Following the purpose of this paper, which uses the method of reducing the delivery frequency of the sensor nodes close to the sink is indicated. The core is set forth in the third section. The forth section is the result of simulation and shows the assessment of the sleeping mechanism. Finally the fifth section will indicate the study aspect in the future and make a conclusion.

2. Related work

In the research of Wireless Sensor Network, the issue about power consumption and how to effectively make

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the power reach the optimal use to extend the life time of whole sensor network is one of the most significant studies.

In the sleeping mechanism, there are random sleep time and peridoc sleep time [9-12]. The single period is divided into two parts: Active Time and Sleep Time. During the active period, sensors can communicate with other nearby sensors; during the sleep period, sensors stop any communication.

The power consumption is commanded by controlling the ups and downs of the active time.

We will introduce the scheme and method of S-MAC (sensor mac) regarding the peridoc sleep time later.

2.1 Random Sleep Time

In random sleep time, because the sleeping and awakening time of each sensor is not peridoc, some transmission of information may be delayed for a long time and reduce the effectiveness of entire network. Besides, the sensors may awake, but don't deliver any information. The power is wasted. As the 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 Peridoc Sleep Time

In peridoc sleep time, we will introduce S-MAC (Sensor Mac) [9]. The peridoc periodic sleeping mechanism can avoid the overhead of the sensor node, prevent from the collision, reduce idle time. This is the first method to apply the sleeping mechanism to wireless network.

2.2.1 S-Mac(Sensor Mac)

S-Mac(Sensor Mac) [9] is a Medium Access Control Protocol whose main purpose is to save power. There are four major measurements in S-MAC to reduce the consumption of energy:

1) Make the sensor node enter peridoc sleep time: The time of sleeping and awakening of sensor nodes is fixed. Refer to the below figure 2:

Figure 2 Peridoc Sleep Time

2) Prevent from the happening of collision: in the competitive environment, the collision among data usually happens. When the collision happens, the data have to be resent and this will cause waste. The method of 802.11 applied in S-Mac use Virtual and Physical Carrier Sense and the package exchange of RTS/CTS [13]。

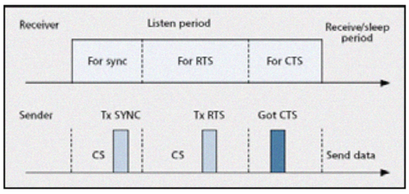

Figure 3. S-Mac Package Exchange Chart

3) Prevent from the happening of eavesdropping: Wireless electric waves are transited in the air. No matter if the data is delivered to which node, the information will be received by any sensors. This action will waste energy on receiving unnecessary information. So, S-MAC makes sensors enter sleeping to avoid receiving any unnecessary information when the target is not itself during the transmission.

Compared with 802.11 [14], S-MAC can save much energy, but the design of the peridoc 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 [15-16] 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. [17-19]

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

The algorithm in this paper is divided into four stages: establish network, set up the probability of sleeping of each sensor in this level, set up energy table, and arrange the sleep and active of sensor nodes according to the energy table. In the stage of establishing network, sensor noses 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.

T flowchart of the algorithm is revealed as follow:

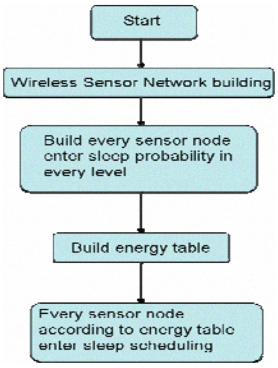

Figure 5: The Optimal Sleep Control Flow Chart

3.1 Environment

We assume the time of the network is synchronous and then sensors can sense the order of the events and judge the relative mechanism.

Below is the hypothesize of the delivery and sense of each sensor in network.

- ✧ Sense range： rs(cm)
- ✧ Transit range： rt(cm)
- ✧ Beginning energy： E(J)
- ✧ Packet load : L(bits)

Below is the hypothesize for the sink:

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

When the sensors are distributed in this area randomly, A will process the action of delaminating and the levels are separated as following figure 6.

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: [15]

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

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

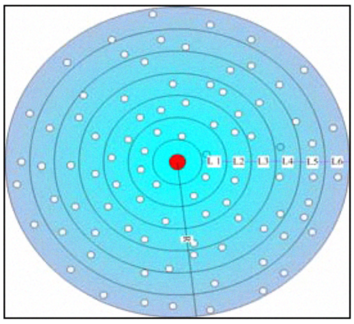

Figure 6: Contructure of Wireless Sensor Network

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 transiting, the whole wireless power is enlarged, so the consumption of $L*\varepsilon_{amp}*d^r$ is added. 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 sensor node 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:

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

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:

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

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

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

Ps_i means the probability of sleeping of level I;$1-Ps_i$ means the probability of active sensor nodes in level i， 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... (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... (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... (8)

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

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

After we 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 :

$N_i * Ps_i = S_i$ (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 selsct 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 we set up.

3.3 Build energy table

At first, there is a specific fixed group and the sleep and active proportion of residual power in every 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 :

From 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, the sleep proportion and active proportion is 10% and 90% respectively.

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	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	[illegible]	[illegible]
80-89	[illegible]	[illegible]
70-79	[illegible]	[illegible]
60-69	[illegible]	[illegible]
50-59	[illegible]	[illegible]
40-49	[illegible]	[illegible]
30-39	[illegible]	[illegible]
20-29	[illegible]	[illegible]
10-19	[illegible]	[illegible]

E_{ratio}(%)	Sleep(%)	Active(%)
90-100	30	70
80-89	[illegible]	[illegible]
70-79	[illegible]	[illegible]
60-69	[illegible]	[illegible]
50-59	[illegible]	[illegible]
40-49	[illegible]	[illegible]
30-39	[illegible]	[illegible]
20-29	[illegible]	[illegible]
10-19	[illegible]	[illegible]

From table 2, we can find the best proportion for 10 % and 90%, because this is we average the optimal proportion of the fixed group and get the following best proportion for sleep.

Table 3 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

3.4 Sensor Node Enter Sleep Scheduling

Before proceeding the sleep schedule, we judge the status of sensor nodes according to the power:

- Case1: $E_{rem} \geqq P_{tx}$:When residual power is much than the power of the transmission of Threshold, the Sleep and Active schedule is used.
- Case2: $P_{tx} \geqq E_{rem} \geqq P_{rx}$:When the residual power is within the power of the transmission and receive of Threshold, sensor nodes only receive, not transit.

- Case3: $P_{rx} \geqq E_{rem}$: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.

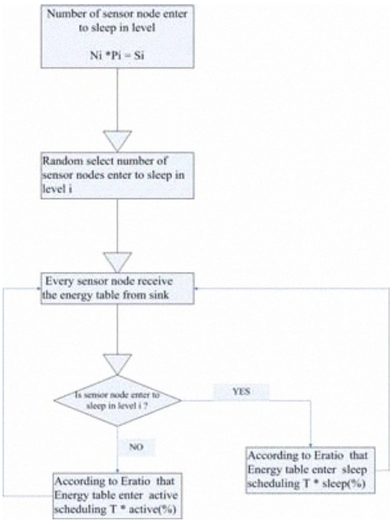

Figure 6 Sleep Schedule Flowchart

4. Simulation Result

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

- Environment area:25m*25m*π
- Sensor nodes : distribute 300pcs 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。

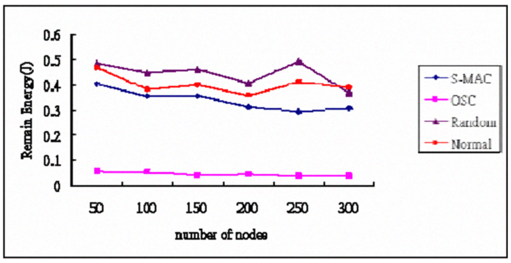

Figure 7：Comparison of the remain energy among sensor nodes

Firstly we observe all kinds of methods to compare the remaining energy of entire network, when the energy of any sensor node in the network is below 10%. The average remaining energy of the sensor node we observe is as figure 7 illustrates. We can know the traits from above chart: The inconsistent sleep time of the sensor nodes 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. The load of each sensor node is balanced by using energy table to adjust the sleep and active time dynamically.

S-Mac adopts the periodic sleep method, so the distribution of remain energy is better than random sleep method.

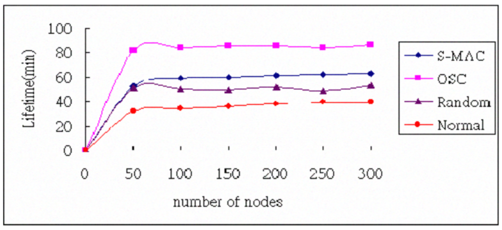

Figure 8 Comparison of sensor node's life time

Before the sleep schedule is processed, the probability is figure out via the distributive density. 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.

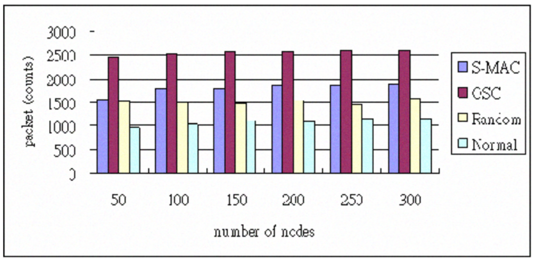

Figure 9: Frequency of transmission packet of sensor node

We compare the frequency of transmission packet of sensor node in figure 9. 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 better than other sleep schedules.

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 remain energy of sensor nodes. This will save much power of sensor nodes and make extend the life time of the entire wireless sensor networks.

6. Reference

[1] I.F.Akyildiz, W.Su,Y. Sankarasubramaniam, E. Cayirci,"Wireless sensor networks: a survey," IEEE Communications Magazine , March 2002, Volume 38, Issue 4, pp.393-422.

[2] J.L. Hill, D.E. Culler, "Mica: a wireless platform for deeply embedded networks," Micro , IEEE, Nov/Dec. 2002 Volume 22, Issue 6, pp.12-24

[3] Mihaela Cardei My T. Thai, Yingshu Li, Weili Wu,"Energy -Efficient Target Coverage in Wireless Sensor Networks"Proceedings of IEEE 24th Annual Joint Conference of the IEEEComputer and Communications Societies, INFOCOM 2005 ,. March 2005,Volume 3, pp.1976 – 1984

[4] Deborah Estrin, John Heidemann, and Wei Ye, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks," Proceeding of IEEE 21th Annual Joint Conference of the IEEE Computer and Communications Societies. INFOCOM 2002Nov 2002,Volume. 3, pp.1567 – 1576

[5] Koen Langendoen and Tijs van Dam, "An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks," Proceeding of The First ACM Conference on Embedded Networked Sensor Systems ,2003, pp. 171-180

[6] Eric Hsiao-Kuang Wu, Gen-Huey Chen, Hung-Wei Tseng, and Shin-Hsien Yang, "Utilization Based Duty Cycle Tuning MAC Protocol for Wireless Sensor Networks," Proceedings of Global Telecommunications Conference , 2005, Volume 6, pp. 3258 – 3262

[7] Chunming Qiaoand, Peng Lin, and Xin Wang, "Medium Access Control With A Dynamic Duty Cycle For Sensor Networks," Proceedings of IEEE Wireless Communications and Networking Conference, WCNC 2004, March 2004,Volume 3, pp.1534 – 1539

[8] Wen - Hwa Liao, Hsiao-Hsien Wang, Wan-Chi Wu," An Adaptive MAC Protocol for Wireless Sensor Networks " Proceedings of Personal Indoor and Mobile Radio Communications, (PIMRC),2003,pp171-180.

[9] LAN MAN Standards Committee of the IEEE Computer Society, " IEEE Std 802.11-1999, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications," IEEE , 1999

[10] V. Rajendran, K. Obraczka, and J. J. Garcia Luna-Aceves,"Energy-Efficient MAC: Energy-Efficient Collision-Free Medium Access Control for Wireless Sensor Networks," Proceedings of ACM Conference On Embedded Networked Sensor Systems , Feb 2006 , Volume 12, pp 63-78

[11] Q. Ren and Q. Liang, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks," IEEE Global Telecommunications Conference , 2005.

[12] X. Yang and N. H. Vaidya, "A Wakeup Scheme for Sensor Networks: Achieving Balance Between Energy Saving and End-To-End Delay," Real-Time and Embedded Technology and Applications Symposium, 2004. Proceedings. RTAS 2004. 10th IEEE , May 2004 , pp 19-26

[13] M. J. Miller, C. Sengul, and I. Gupta, "Exploring the Energy-Latency Trade-Off for Broadcasts in Energy- Saving Sensor Networks," IEEE International Conference Distributed Computing Systems (ICDCS), 2005, pp 17-26

[14] C. Suh and Y. B. Ko, "A Traffic Aware Energy Efficient MAC Protocol for

Wireless Sensor Networks," IEEE International Symposium on Circuits and Systems Circuits and Systems (ISCAS), May 2005,Volume 3 , pp 2975-2978

[15] Yun Wang Demin Wang Wei huang Fu Dharma P. Agrawal " Hops-based Sleep Scheduling Algorithm for Enhancing Lifetime of Wireless Sensor Networks " Mobile Ad hoc and Sensor Systems (MASS), Oct 2006 ,pp 709-714