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An Efficient Power Saving Mechanism Issues 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 cannot 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.

In this article, efficient power saving scheme and corresponding algorithm must be developed and designed in order to provide reasonable energy consumption and to improve the network lifetime for wireless sensor network systems. The cluster-based technique is one of the approaches to reduce energy consumption in wireless sensor networks. In this article, we propose a saving energy clustering algorithm to provide efficient energy consumption in such networks. The main idea of this article is to reduce data transmission distance of sensor nodes in wireless sensor networks by using the uniform cluster concepts. Simulation results indicate the superior performance of our proposed algorithm to strike the appropriate performance in the energy consumption and network lifetime for the wireless sensor networks.

Keywords: cluster, distance, power consumption, lifetime, sensor networks, Power Control, Sleep Control, Scheduling

I. Introduction

Advances in the wireless communication and the microelectronic technologies have been expediting the development of wireless sensor networks (WSNs) [1,2]. Usually Wireless Sensor Networks are used in the environment that humans cannot 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. 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.

The technology of power saving is separated into four study aspects [3]:

- The schedule between the sleeping and awakening of sensors: achieves the effectiveness of saving power by sleeping mechanism.
- 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.
- 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 throughput of power saving is very important.
- 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.

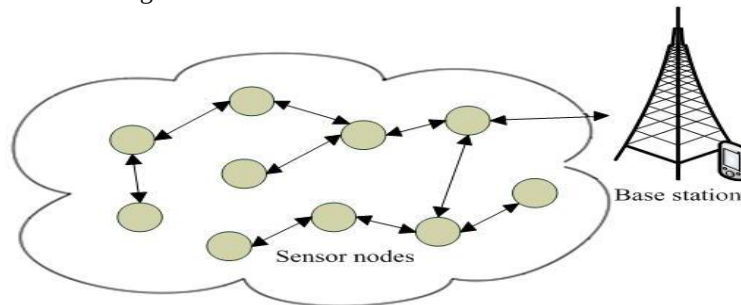
In this paper, we proposed the “Power Saving Mechanism with Optimal Sleep Control in Wireless Sensor Networks”. We reserve the power by the precisely scheduling for the sleep control.

The major purposes are:

- Saving power and increase the time of entire network.
- Using the optimal sleeping time to avoid the delay of the information.
- Reducing the delivery frequency of the sensor nodes close to the sink, and therefore the Sleeping probability of it will be high.

In wireless sensor networks, the main power supply of the sensor node is battery. However, in most application scenarios, users are usually difficult to reach the location of sensor nodes. Due to a large number of sensor nodes, the replacement of batteries might be impossible. Figure 1 shows an infrastructure of wireless sensor networks.

Fig. 1 Infrastructure of wireless sensor networks.



Low Energy Adaptive Clustering Hierarchy (LEACH) is a typical cluster-based protocol using a distributed clustering formation algorithm [5]. In LEACH, the large number of sensor nodes will be divided into several clusters. For each cluster, a sensor node is selected as a cluster head. The selection of cluster head nodes is based on a predetermined probability. Other non-cluster head nodes choose the nearest cluster to join by receiving the strength of the advertisement message from the cluster head nodes. A non-cluster head node can only monitor the environment and send data to its cluster head node. The cluster head node is responsible for collecting the information of non-cluster head nodes in the cluster. Then, it processes data and sends data to the BS. As a non-cluster head node cannot send data directly to the BS, the data transmission distance of the sensor node is shrunk. Therefore, the energy consumption is reduced in the wireless sensor networks.

In this article, we propose a saving energy clustering algorithm (SECA) to provide efficient energy consumption in wireless sensor networks. In order to make an ideal distribution for sensor node clusters, we calculate the average distance between the sensor nodes and take into account the residual energy for selecting the appropriate cluster head nodes. The lifetime of wireless sensor networks is extended by using the uniform cluster location and balancing the network loading among the clusters. The main benefits of proposed scheme are that the energy consumption is reduced and better network lifetime can be carried out.

II. Related Work

There are four kind of the energy consumption in WSNs besides transmitting and sensing [9].

- 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.
- 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.
- 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.
- 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.

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.

A. System model

The system infrastructure is composed of a BS and some sensor nodes. We classify all sensor nodes into non-cluster head nodes and cluster head nodes. The non-cluster head nodes operate in sensing mode to monitor the environment information and transmit data to the cluster head node. Also, the sensor node becomes a cluster head to gather data, compresses it and forwards to the BS in cluster head mode. In this model, to exchange an L-bit message between the two sensor nodes, the energy consumption can be calculated by.

$$ETx(L, d) = E_{elec} \times L + \epsilon_{amp} \times L, \quad (1)$$

$$ERx(L) = E_{elec} \times L, \quad (2)$$

where d is the distance between the two sensor nodes, ETx(L, d) is the transmitter energy consumption, and ERx(L) is the receiver energy consumption. Eelec is the electronics energy consumption per bit in the transmitter and receiver sensor nodes. ϵ_{amp} is the amplifier energy consumption in transmitter sensor nodes, which can be calculated by

$$\epsilon_{amp} = \begin{cases} \epsilon_{fs} * d^2, & \text{when } d \leq d_0 \\ \epsilon_{mp} * d^4, & \text{when } d > d_0 \end{cases} \quad (3)$$

where d_0 is a threshold value. If the distance d is less than d_0 , the free-space propagation model is used. Otherwise, the multipath fading channel model is used. ϵ_{fs} and ϵ_{mp} are communication energy parameters.

B. Proposed methods: SECA

In order to increase energy efficiency and extend the lifetime of the sensor nodes in wireless sensor networks, efficient power saving algorithm must be developed and designed. Based on the centralized clustering architecture, we propose a SECA to provide efficient energy consumption and better network lifetime in the wireless sensor networks. In the proposed scheme, we assume that the BS receives the information of location and residual energy for each sensor node and the average residual energy can be calculated. When the residual energy of sensor node is higher than the average residual energy, the sensor node becomes a candidate of cluster head. We modify k-means algorithm to make an ideal distribution for sensor node clusters by using the information of location and residual energy for all sensor nodes [12]. In this algorithm, the operation includes two phases: set-up and steady-state phases.

▪ Set-up phase

During the set-up phase, the BS collects the information of the position and energy level from all sensor nodes in the networks.

Let C be the center location for all sensor nodes. If there are n sensor nodes in the wireless sensor networks, C can be calculated by

$$C = \frac{\sum_{i=1}^n X_i}{n} \quad (4)$$

where X_i is the coordinate of sensor node i.

Let R be the average distance between C and all sensor nodes, which can be calculated by

$$R = \frac{\sum_{i=1}^n |X_i - C|}{n} \quad (5)$$

According to C and R, the locations of initial mean of point $m_i(mix, miy)$ for the cluster i is calculated by

$$\begin{cases} m_{ix} = R \times \cos\left(\frac{360}{k} \times (i-1) \times \frac{\pi}{180}\right) + C_x \\ m_{iy} = R \times \sin\left(\frac{360}{k} \times (i-1) \times \frac{\pi}{180}\right) + C_y \end{cases} \quad (6)$$

where k is the number of clusters and $i = 1, 2, \dots, k$. k can be calculated by

$$K = \left\lceil \frac{\sqrt{n}}{\sqrt{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \frac{M}{d^2 \text{ to BS}} \right\rceil \quad (7)$$

where M is the side of the given square field. The d to BS is the average distance from the cluster head nodes to the BS which is defined in LEACH-C. If there are k clusters in the system, the k-means function can be expressed by

$$avg \min \sum_{i=1}^K \sum_{j \in S_i} |X_j - m_i|^2 \quad (8)$$

where S_i is the cluster i , X_j is coordinate of sensor node j^2 and m_i is the coordinate of mean of point. If the X_j is the closest to the m_i in the t th execution, the sensor node j will join the cluster i , which can be expressed by

$$S_i^{(t)} = \{X_j : |X_j - m_i^{(t)}|^2 \leq |X_j - m_{ik}^{(t)}|^2 \text{ for all } i^* = 1, \dots, k\} \quad (9)$$

When the classification of all nodes is done, the new mean of point is created which is calculated by

$$m_i^{(t+1)} = \frac{1}{|S_i^{(t)}|} \sum_{j \in S_i^{(t)}} X_j \quad (10)$$

Where $|S_i^{(t)}|$ is the number of sensor nodes in the cluster i . Figure 3 shows the example of the new means of points.

Fig. 2 Example of the initial means of points.

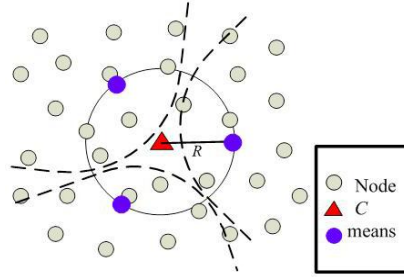
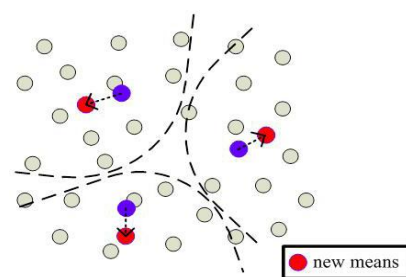


Fig. 3 Example of the new means of points.

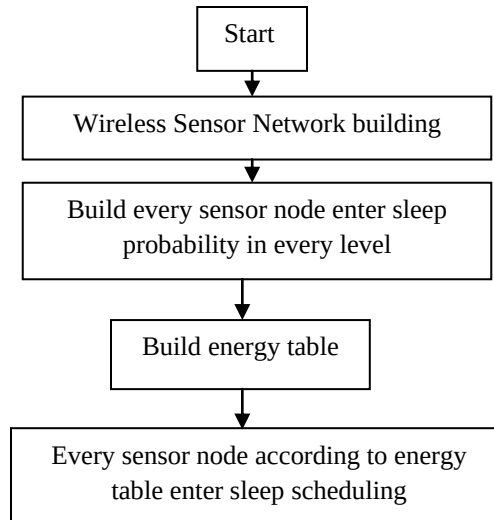


C. The Optimal Sleep Control for Wireless Sensor Networks (OSC)

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 sleeping 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:



▪ Build Sensor Node Enter Sleep Probability

The probability of sleeping of each level in the wireless sensor networks is calculated in below formula. 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 seen from below formula 4:

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

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 :

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

Psi means the probability of sleeping of level i ; $1 - Psi$ 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 :

$$(1-Psi) = N_i/A_i, i = 1, 2, 3 \quad (6)$$

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

$$N_i = (1-Psi)\lambda A_i, i = 1, 2, 3 \quad (7)$$

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

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

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

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:

$$N_i * Psi = S_i \quad (10)$$

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 randomly select the sleep sensor node in this level.

III. 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.

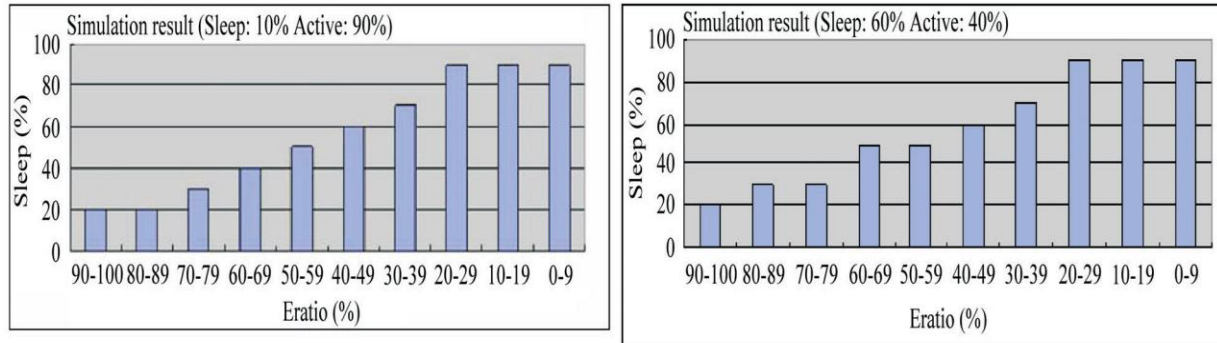


Fig.4 Simulation result of fixed group

In Figure 5, 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 6. 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.

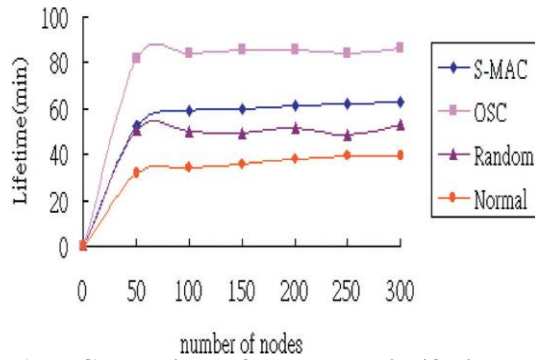


Fig. 5 Comparison of sensor node's life time.

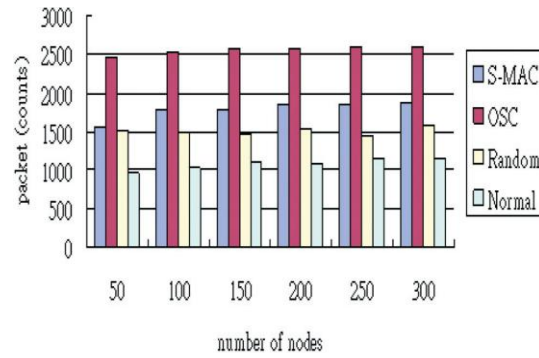


Fig. 6 Frequency of transmission packet of sensor node.

IV. Conclusions

The energy saving is a challenging issue in the wireless sensor networks. To increase energy efficiency and extend the lifetime of sensor node, new and efficient energy saving schemes must be developed. In the proposed scheme, we calculate the average distance between the sensor nodes and take into account the residual energy for selecting the appropriate cluster head nodes. The lifetime of wireless sensor networks is extended by using the uniform cluster location and balancing the network loading among the clusters. Simulation results indicate our proposed algorithm achieves the low energy consumption and better network lifetime in the 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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