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Sleep Algorithm of Wireless Sensor Network Based on Low Duty Cycle

Yu Shaojun
School of Information Engineering
Kunming University
Yunnan, 650214, China
E-mail: 879527755@qq.com

***Abstract*—WSN is a wireless network composed of a large number of static or mobile sensors in a self-organized and multi-hop way, which sense, collect, process and transmit the information of the perceived objects in the geographical area covered by the network in a cooperative way, and finally send these information to the owner of network. Aiming at the problems of uneven energy consumption and long working time in low duty cycle WSN network, a node adaptive sleep algorithm is proposed in this paper. The algorithm can schedule node sleep time slot and working time slot according to the wireless link condition, so as to ensure the minimum overall energy consumption under the condition of delay constraint. Energy sensing is added to the adaptive sleep mechanism to make no line according to adaptive adjustment of residual energy of the nodes, the energy consumption of each node is balanced and the working time of WSN network is improved. The simulation analysis shows that the algorithm can effectively reduce the working time slot and energy consumption while meeting the transmission delay, so as to improve the working period of the network.**

Keywords-Wireless Sensor Network; Low Duty Cycle; Adaptive Sleep; Energy Sensing; Wireless Node; Sleep Slot; Working Slot

I. INTRODUCTION

A wireless sensor networks, as one of the most influential technologies in the 21st century, has been a research hotspot in the field of wireless communication since its inception because of its wide application, strong academic expansion and wide interdisciplinary. However, many wireless sensor networks, such as handheld device networking in complex natural environment, wildlife behavior observation networking in nature reserves, rapid networking after disasters, etc. The uncertainty of sensor node movement will lead to the decline of network connectivity or even connection interruption, and further performance degradation of the whole network. The reason is that the traditional wireless sensor networks is a wireless network based on the perception of wireless sensor nodes and through self-organized multi-hop communication[1-2].

Due to the limitation of deployment environment, most of the network nodes are powered by batteries, which makes battery energy often become bottleneck of network communication. In low duty cycle (LDC) wireless sensor networks, the duty cycle of wireless sensor nodes is less than 10%, which can effectively extend the life cycle of WSN, but the low duty cycle also makes the communication delay between neighbor nodes larger. In recent years, most of the energy-saving researches focus on the hardware design and power management, and the low duty cycle mode is relatively less. For low duty cycle WSN network, node dormancy mechanism is an effective way to improve network energy consumption. At present, there are few researches on sleep mechanism of nodes in low duty cycle WSN network environment, and the sleep mechanism has little consideration on link quality and data delay, so there is no in-depth and effective research. In this paper, a new method is proposed to solve the problems of link instability and energy consumption imbalance in the low duty cycle WSN. The algorithm can schedule sleep time slot and working time slot according to wireless link condition, so as to ensure the minimum energy consumption of the whole network under delay constraint[3-4].

II. LOW DUTY CYCLE WSN NETWORK MODEL

In WSN, sensor nodes are generally in two states, i.e., working and sleeping. In working state, the nodes need to carry out wireless sensing, completing wireless transmission, routing, and wireless listening in idle time; in sleeping state, only the timing function is reserved. Assuming that T_i represents a working cycle of wireless sensor node *i*, then T_i consists of multiple consecutive working timeslots and sleeping timeslots. Take node *i* as an example, (t_i^j, τ) presents the j[th] working time slot of the node[5], τ represents the number of continuous time slots of node *i* in working state.

In low duty cycle WSN network communication, if the time slot size is fixed, the work schedule of node *i* in a certain period can be expressed as

$$T_i = \left[(t_i^1, \tau), (t_i^2, \tau), \cdots, (t_i^n, \tau)\right] \quad (1)$$

Duty cycle refers to the ratio of all working hours of wireless sensor node to the whole cycle time in a cycle. According to formula (1), the duty cycle of node *i* can be deduced as

$$C_i = \frac{\sum_{j=1}^{n} \tau}{T_i} \quad (2)$$

In WSN network, the node dormancy needs to meet the following conditions: 1) Wireless sensor node determines dormancy scheduling mechanism according to algorithm design before deployment; 2) Neighbor node shares its dormancy scheduling table through broadcast messages; 3)

After the wireless sensor node updates dormancy scheduling table, it will notify the neighbor node in the next round of broadcast. After receiving confirmation reply, the node will adjust in the next round. A new sleep mechanism is used in WSN. When all nodes in the network are in working state, the neighbor nodes can send or receive data at any time. At this time, the wireless transmission delay is generally only in millisecond level. But in WSN with low duty cycle, in addition to the general transmission delay, the sending node needs to wait for the neighbor nodes to be in working state to send wireless data[6-7].

Due to the low duty cycle of WSN, sleep delay is longer than wireless communication delay between wireless nodes, and transmission of wireless data needs to wait longer time and delay. In this paper, the definition of sending node from receiving the data to finding that neighbor node is in the working state and can send information, the duration is the sleep delay.

III. ALGORITHM DESIGN

In the case of unstable link quality in low duty cycle WSN, the adaptive sleep mechanism of nodes is required to reduce energy consumption as much as possible while meeting specific delay requirements, so as to prolong the working cycle of network system. Therefore, the adaptive sleep mechanism of nodes in low duty cycle WSN needs to include two aspects: 1) node sleep scheduling, adjusting the selection of path nodes. Select the probability, increase the working time slot, reduce the energy consumption of nodes in the network on the premise of ensuring the transmission delay. 2) energy sensing. At the same time of node sleep scheduling, the energy sensing of neighbor nodes is carried out, so as to balance the energy consumption of all nodes in the network and improve the working cycle of the system[8].

A. *Adaptive sleep scheduling algorithm*

In order to meet the delay requirements of practical application, sensor node's working time slot is required. The node sleep scheduling mechanism should ensure working time slot increases at least, so that the wireless transmission needs to consume the least energy. The specific steps are shown in Figure 1.

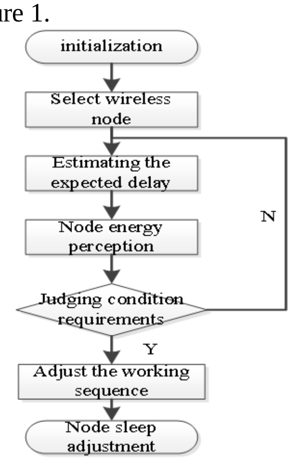

Figure 1. Flow chart of algorithm

In order to quantify the network transmission delay from node *i* to node *j*, suppose node *i* receives wireless data at time *t*, and then needs to send it to node *j*. if *h* working time slots are added to complete the task within the minimum sleep delay, *E [DM, H (I, J, t)]* is used to represent the minimum sleep delay expectation, *m* is the number of hops in the route, h≤m.

Specific steps of the algorithm are described as follows:

1) Initialize the working cycle of the network sensor, and calculate the time delay expectation value *E [DM, H (I, J, t)]* of nodes *i* to *j*. if *E [DM, H (I, J, t)]* ≤ *B* and the real-time delay expectation is less than or equal to the delay index *B* required by the network service, then the working time slot of the network node does not need to be increased; otherwise, skip to step 2).

2) Increase working time slot one by one, as well as calculate and increase the working time slot one by one When the WSN is working, the minimum delay expectation value *E [DM, H (I, J, t)]* of low duty cycle WSN network is until*E [DM, H (I, J, t)] is* ≤ *B* or *h =m*. The value of *h*is the minimum under specified delay range.

3) If the working time slot of node *j* is not increased, transmission delay in the network remains unchanged. In the same working cycle, in creasing working time slot of node *j* can reduce sleep delay between nodes*i*and *j*. And the expected delay between nodes*i*and *j* can be expressed as

$$E[Dm,h(i,j,t)] = \begin{cases} E[D(i,j,t)], & (m=1, h=0) \\ E[D^1(i,j,t)], & (m=1, h=1) \end{cases} \quad (3)$$

B. *Energy perception*

In actual wireless transmission process of WSN network, due to the difference of node distribution, frequency of wireless route passing through the node in the key position is much higher than that of the ordinary node. This makes energy consumption of wireless sensor node in the key position much larger, while the energy of remote node is more retained, and the energy consumption is unbalanced, which makes some nodes in the network run out of energy. The work cycle ends prematurely, or it has a negative impact on subsequent wireless data transmission. In view of these problems, this paper adds the function of energy perception in the adaptive sleep mechanism of nodes. Based on the energy perception of nodes, this mechanism can adjust work time slot of network nodes, for example, limit the work time slot of nodes with less remaining energy in the network, so as to make them sleep as much as possible, in order to achieve the purpose of less energy consumption; at the same time, increase the number of nodes with higher residual energy in the network to wake up, so that they can participate in data transmission process as much as possible. Although energy sensing may increase the delay of data transmission, it can balance the energy consumption of nodes in WSN network, so as to extend the life cycle of WSN network. If Eavg is used to represent the average energy of network, the remaining energy of node j is denoted as E_{res}^{j}, then expected value of delay between nodes i and j can be expressed as

$$\min\begin{cases} E\left[D^{il}(t)\right]\oplus E\left[D^{lj}(m-1,h,t)\right], & (m>0,h>0) \\ E\left[D^{il}(t)\right]\oplus E\left[D^{lj}(m-1,h-1,t)\right], & \left(E_{res}^{j}>aE_{avg}\right) \end{cases} \quad (4)$$

In the formula, α is weight value. Formula (4) first forces the wireless sensor node to compare its residual energy with the average energy of the node by using the energy sensing strategy. When the residual energy of node j is greater than required proportion of average energy, the working time slot can be increased; otherwise, the time slot needs to be arranged according to sleep schedule. Through a large number of experimental analysis, it is found that when α ≈1.2, the cooperative optimization of wireless node sleep schedule and node energy balance can be realized.

IV. Simulation and Analysis

In the experiment, Matlab is used to simulate a circular area with a radius of 50 m, in which 600 wireless sensor nodes are randomly deployed. According to the energy consumption model proposed by Deborah, energy consumption value of nodes in WSN is calculated. In order to effectively simulate simulation environment, each experiment is repeated 50 times, and the average value of 50 experiments is taken, as well as the algorithm in this paper is compared with classical node rest Sleep TOSS algorithm and LDAS algorithm, and the idea of linear node sleep scheduling is used to minimize end-to-end delay.

Figure 2 is the life cycle comparison chart of WSN network with low duty cycle corresponding to three algorithms under different delay conditions. It can be seen from the analysis that the life cycle of the network is shorter when delay requirement is more stringent (no more than 120 s); when the delay requirement is lower (more than 120 s), life cycle of the network will be greatly longer. Because the lower the delay requirement, the more working time slot the network data transmission needs. The more energy the nodes consume, the shorter the life cycle of the low duty cycle WSN network; on the contrary, the less time slots are needed, the more sleep time slots the nodes can get, and the longer the life cycle of network. With the increase of delay times, the algorithm in this paper can better schedule the node sleep, which further highlights the advantage of network life cycle extension.

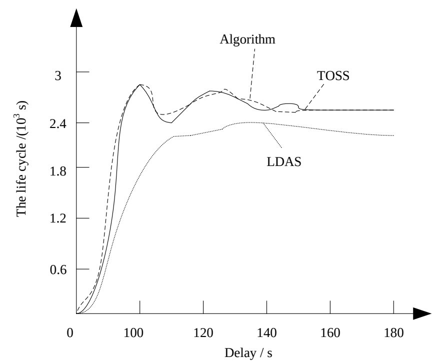

Figure 2. Life cycle comparison chart of WSN network with low duty cycle

V. Conclusion

According to wireless link status, the algorithm can adaptive schedule the sleep time slot and working time slot of nodes to ensure the minimum overall energy consumption of the network under the delay constraint. At the same time, energy sensing is added to the adaptive sleep mechanism, so that the wireless routing can adjust itself according to the residual energy of nodes, balance the energy consumption of each node, and improve work hours of WSN. Through simulation and analysis, it is found that the algorithm can not only meet the transmission delay, but also effectively reduce the working time slot and energy consumption, so as to improve working cycle of the network.

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