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The P-persistent CSMA Protocol with Monitoring Function in WSN and the Analysis of the Protocol

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Abstract: This paper presents a new p-persistent CSMA wireless sensor network MAC protocol with monitoring function based on random multiple access system, and gets the mathematical expressions of system throughput, system average operating power and the life cycle of terminal nodes of p-persistent CSMA wireless sensor network MAC protocol with monitoring function through complicated mathematical modeling, rigorous mathematical derivation and using average period analysis. The computer simulation results not only confirm the correctness of the theoretical analysis but also show that the p-persistent CSMA with monitoring for WSNs MAC protocol due to join the monitoring signals, resulting in the decrease of systemic throughput, but reduce the collision probability. Meanwhile, the p-persistent CSMA wireless sensor network MAC protocol with monitoring function this paper presents can effectively reduce energy consumption. *Copyright © 2013 IFSA.*

Keywords: Random multiple access system, Throughput, Average operating power, Life cycle, Monitoring function, and Average period analysis.

1. Introduction

Wireless sensor network [1, 2] is composed of a large number of tiny nodes distributed randomly, which integrate with sensor, data processing unit and communication module, the nodes make up a network themselves, and is distribution system which is large, unattended and resources restrict limited, with self-organization, autonomy and adaptive dynamic characteristics [3, 4], and has a large applications in military, medical, explosion and many other fields. The new research direction of wireless sensor network protocol is to reduce the collision rate of information packets, improve the throughput and reduce the energy consumption, so to solve the problems such as the carry limited energy of the sensor terminal nodes, the difficult to supply or replace battery.

The paper presents a new Wireless sensor network MAC protocol [8-10], p-persistent CSMA control protocol with monitoring function based on random multiple access system [5-7]. By adding a monitoring signal ACK behind the system delay to increase the controllability of the system, reduce the collision probability and improve the channel utilization. We get some important system parameter such as the throughput, average power and life cycle of nodes by using the average cycle analysis method [5-7] on the bases of the increasing controllability. Computer simulation results verify the correctness of the theory.

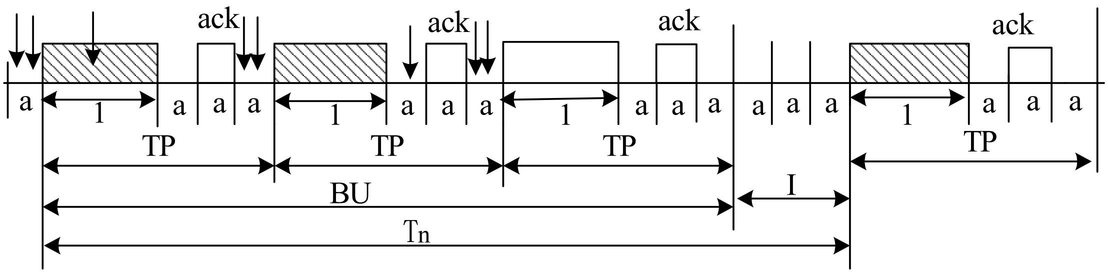

Fig. 1. The model of p-persistent CSMA wireless sensor network MAC protocol.

2. P-persistent CSMA Protocol with Monitoring Function

The model of p-persistent CSMA wireless sensor network MAC protocol with monitoring function this paper presents is shown in Fig. 1. In the wireless communication system using p-persistent CSMA protocol with monitoring function, the first thing when a terminal user wants to send information packets is to listen to the channel state. The user will send the information packets with probability p and give up sending with probability (1-p) if the channel is idle; but if the channel is busy, the user listen to the channel persistently until the channel is idle, then the user will send the information packets in the next slot with probability p, and give up transmitting with probability (1-p). Thus, the number of packets accumulated in the end of a TP equals to the number of packets listened continuously within (1+3a), if it is greater than or equal to 1, the next TP is still busy period, but if it is 0, then the busy period end.

The channel is divided into the following three events [12] based on the situation of the information packet transmission in the channel.

1) The event that information packet sent successfully (U);

2) The event that information packet conflict in the channel (B);

3) The event that the channel is idle, that is there is no packets in the channel (I).

From the Fig. 1, the successful event U, collision event B and idle event I can be grouped into two categories in nature, one is the idle event I, the other is the busy event BU, and these two events alternating cycles occur on the timeline, the time period is T_n.

2.1. Analysis of System Throughput

1. Before analyze the system performance, do the assumptions on the system as follows:

1) The channel is an idle channel without noise and interference;

2) The maximum transmission delay of the channel is a, and the TS length is also a, the information packet length is unit length 1, an integer multiple of a;

3) The time axis of the channel is divided by a, packets arrived within any a will be sent in the begin of next slot;

4) The time generated an acknowledge signal (monitoring signal) ACK is a, then the length of a transmission period TP is 1+3a;

5) The channel access way is slotted p-persistent CSMA protocol, information packets arrived on the channel follows Poisson Distribution with independent parameter G;

6) The information packets needed to be sent in the first slot (delay a) of a TP can always detected the channel state at the last time;

7) The impacted packets will be resend in the following slots, and the re-transmitted information packet does not affect the process of the packets arriving in the channel.

2. According to the above control principle of the p-persistent CSMA protocol with monitoring function, we can get the following expressions.

The probability there are n information packets at time t in the channel is

$$p(n) = \frac{(Gt)^n}{n!} e^{-Gt}, \tag{1}$$

The probability there are m information packets to be sent with probability p in which has n information packets arrive at time t is

$$p(m) = \frac{(Gpt)^m}{m!} e^{-Gpt}, \tag{2}$$

The probability there is no packet in an idle slot is

$$q_a^0 = p(m=0) = e^{-Gpa}, \tag{3}$$

The probability that has only one packet to transmit in an idle slot a is

$$q_a^1 = p(m=1) = Gpae^{-Gpa}, \quad (4)$$

The probability there are i idle events continuous in the channel is

$$p\{N_I = i] = (e^{-Gpa})^{i-1}(1-e^{-Gpa}), \quad (5)$$

The probability there is no packet in a TP is

$$q_{1+3a}^0 = p(n=0) = e^{-G(1+3a)}, \quad (6)$$

The probability there is only one packet in a TP is

$$q_{1+3a}^1 = p(n=1) = G(1+3a)e^{-G(1+3a)}, \quad (7)$$

The probability there are j busy events BU continuous in the channel is

$$p\{N_{BU} = j] = (1-e^{-Gp(1+3a)})^{j-1}e^{-Gp(1+3a)}, \quad (8)$$

We can get the joint probability [11] of the p-persistent CSMA wireless sensor network MAC protocol with monitoring function is

$$\begin{aligned} &p\{N_I = i, N_{BU} = j] = \\ &= (e^{-Gpa})^{i-1}(1-e^{-Gpa})(1-e^{-G(1+3a)})^{j-1}e^{-G(1+3a)}, \end{aligned} \quad (9)$$

The average timeslots of idle state based on the joint probability in a period is

$$E(N_I) = \frac{1}{1-e^{-Gpa}}, \quad (10)$$

The average timeslots of busy state in a period is

$$E(N_{BU}) = \frac{1}{e^{-G(1+3a)}}, \quad (11)$$

Defined as follows:

U_1 : There is only one packet to be sent with probability p among all the packets arrived at the last slot in the idle time, and the packet will be sent successfully in the next timeslot.

U_2 : There is only one packet is sent with probability p among all the packets arrived in the busy time, and the packet will be sent successfully in the next slot.

Then we have

$$E(N_{U1}) = \frac{Gpae^{-Gpa}}{1-e^{-Gpa}}, \quad (12)$$

$$E(N_{U2}) = G(1+3a), \quad (13)$$

The average number of timeslots that the packet transmitted successfully in a cycle time is

$$E(N_U) = E(N_{U1}) + E(N_{U2)}) = \frac{Gpae^{-Gpa}}{1-e^{-Gpa}} + G(1+3a), \quad (14)$$

The average length of the successful packets in a cycle time is

$$E(U) = \frac{Gpae^{-Gpa}}{1-e^{-Gpa}} + G(1+3a), \quad (15)$$

The average length of the busy time in a cycle time is

$$E(BU) = \frac{1+3a}{e^{-G(1+3a)}}, \quad (16)$$

The average length of the idle state in a cycle time is

$$E(I) = \frac{a}{1-e^{-Gpa}}, \quad (17)$$

From the definition of system throughput [13], we get the throughput of the p-persistent CSMA protocol with monitoring function is

$$S = \frac{e^{-G(1+3a)}[Gpae^{-Gpa} + G(1+3a)(1-e^{-Gpa})]}{(1+3a)(1-e^{-Gpa}) + ae^{-G(1+3a)}}, \quad (18)$$

From the literature [7], the throughput of traditional p-persistent CSMA protocol is

$$S = \frac{Ge^{-G(1+a)}[(1+a) + ape^{-Gpa} - (1+a)e^{-Gpa}]}{ae^{-G(1+a)} + (1+a)(1-e^{-Gpa})}, \quad (19)$$

2.2. The Efficiency Analysis of System Energy

The p-persistent CSMA with monitoring for WSNs MAC protocol this paper presents can effectively reduce energy consumption. The control principle is shown in Fig. 2. The first thing when a terminal user wants to send information packets is to listen to the channel state. The user will send the information packets with probability p and give up with probability (1-p) if the channel is idle; but if the channel is busy, the user listen to the channel persistently until the channel is idle, then the user will send the information packets in the next slot with probability p, and give up transmitting with probability (1-p). Thus, the number of packets accumulated in the end of a TP equals to the number of packets listened continuously within (1+3a), if it is greater than or equal to 1, the next TP is still busy period, but if it is 0, then the busy period end and enter into sleep.

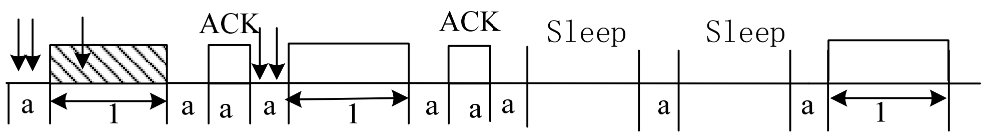

Fig. 2. Working schematic diagram for node.

The efficiency analysis of the system this paper used is based on the battery model of literatures [15] [16], we make the following definitions:

$P_T = 1.8mW$ refers to the power of service nodes which are in transmission;

$P_R = 2.5mW$ refers to the power of service nodes which are in accepting state;

$P_D = 0.5mW$ refers to the power of the channel which is in detecting state;

Assuming the leakage power of battery is 10 % of the total energy E (unit: Wh), then the discoverable power of the year is

$$P_{lk} = \frac{0.1E}{24 \times 365}, \tag{20}$$

If the node does not work, then the battery will run out in a decade, when the average power of the sensor node is P_n, then we can know the node's life cycle when the battery run out.

$$T = \frac{E}{P_n + P_{lk}} = \frac{E}{24 \times 365 \times P_n + 0.1E}(\text{year}), \tag{21}$$

For the p-persistent CSMA control protocol with monitoring function, we have

$$E(B) = E(BU) - E(U)(1+3a), \tag{22}$$

Refer to the battery model, in a transmission period TP on the channel, we have

1) Energy consumption of transmitting.

For the busy time of the channel (BU), the number of the packets arrived in a TP (1+3a) listen to the channel persistently and will be sent at the start time of the next TP when listen to the channel is idle is $G(1+3a)$.

For the idle period I, the average number of packets which will be sent in the first of the next TP is Gpa.

The energy consumption of sending in a T_n is

$$W_t = P_T G(1+3a)\left[\frac{E(BU)}{1+3a} - 1\right] + P_T Gpa, \tag{23}$$

2) Energy consumption of receiving.

The energy consumption of receiving in a T_n is

$$W_{rec} = E(U)P_R, \tag{24}$$

3) Energy consumption of detecting.

For the compound event BU, the total duration that the nodes which needed to send information packets in a TP detecting the channel is

$$G(2a + \frac{a}{2} + 0.5), \tag{25}$$

The number of TP in the busy time is

$$\frac{E(BU)}{1+3a}, \tag{26}$$

So, the total detecting duration of all the service nodes in the channel is

$$t_d(BU) = \frac{E(BU)}{1+3a} G(2a + \frac{a}{2} + 0.5), \tag{27}$$

The energy consumption of detecting in a T_n is

$$W_d = t_d(BU)P_D, \tag{28}$$

The average operating power of the channel is

$$P_n = \frac{W_t + W_{rec} + W_d}{E(BU) + E(I)}, \tag{29}$$

The life cycle of the node is

$$T = \frac{E}{24 \times 365 \times P_n + 0.1E}, \tag{30}$$

3. The Computer Simulation Experiment and Result Analysis

The simulation [14] of the p-persistent CSMA wireless sensor network MAC protocol with monitoring function is based on the previous analysis. And we use the Matlab to simulate, and compare the simulation results with the theoretical results.

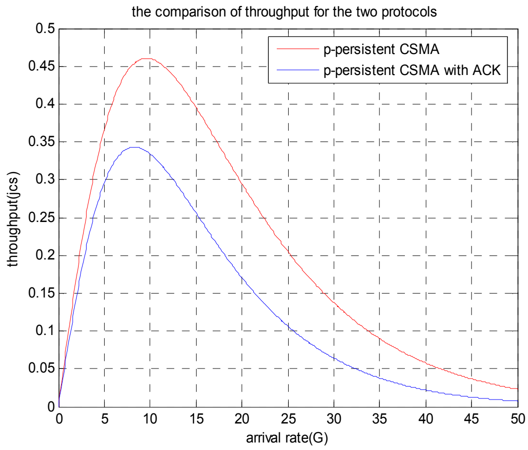

Fig. 3. The comparison of throughput for p-persistent CSMA with ACK and no ACK.

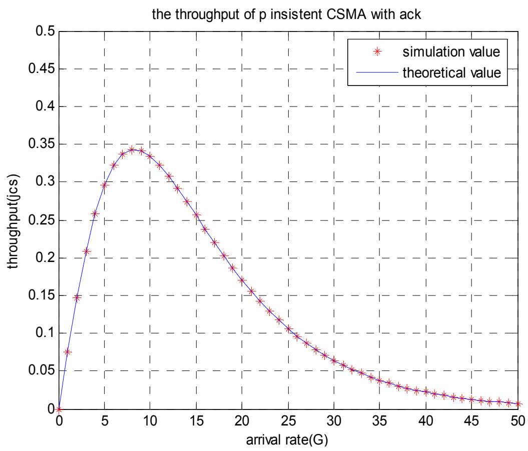

Fig. 4. The throughput of p-persistent CSMA with ACK when $a = 0.1, p = 0.1$.

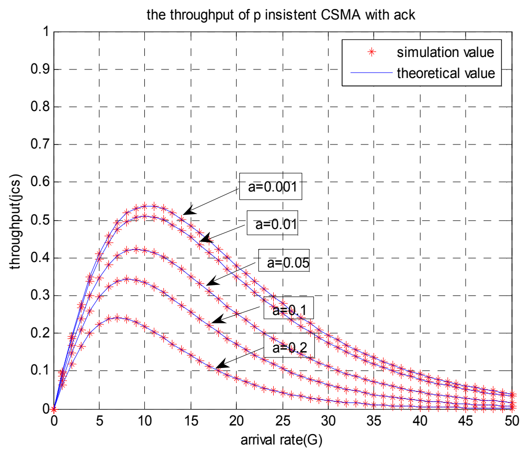

Fig. 5. The throughput of p-persistent CSMA with ACK when $p = 0.1$.

From the foregoing figures, we can have the following results:

1) In the Fig. 3, we can see that the p-persistent CSMA wireless sensor network MAC protocol with monitoring function has a lower throughput than the single the p-persistent CSMA wireless sensor network MAC protocol. This is because when the system function is increased, such as increasing the monitoring function, the system needs to keep stability by reducing the throughput.

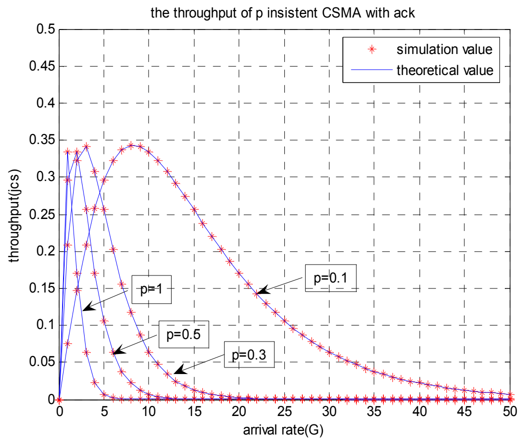

Fig. 6. The throughput of p-persistent CSMA with ACK when $a = 0.1$.

2) Fig. 4 is the comparison of the theoretical value and the simulation value for the p-persistent CSMA wireless sensor network MAC protocol with monitoring function when $a = 0.1$ and $p = 0.1$. As can been seen from the figure, the theoretical values is well agree with the simulation values so that proved the correctness of the theoretical analysis. And under the control of the protocol, the system has a higher throughput and utilization rate in the light load, avoiding the waste of channel resources. But when the system load increases, the system throughput will decrease with the creasing of the collision probability. This is because the number of arrived packets increases when the load increase, then the number of the packets will be sent in the next slot will also increase, thus, the packets will conflict in the channel as a result of the number of packets want to be sent in the channel increases, then the system throughput will on the decline.

3) Fig. 5 shows the change of the throughput S over the arriving rate G with different system delay a when $p = 0.1$.The smaller system delay, the greater system throughput in the same arriving rate, the reason is that when system delay is small, the number of packets which can know the channel is in idle state in a transmission delay is relatively small, then the number of packets decide to be transmitted in the next slot is also reduced, which also reduce the collision probability of information packets, the system throughput will rise. That is to say, the increase of system loads has a little effect on the system throughput when system delay has a smaller value.

4) Fig. 6 shows the comparison of the throughput when using different transmission probability and

system delay $a = 0.1$. As can be seen from the figure, the increasing of transmission probability p will lead to a decline in the overall system throughput, because when the transmission probability increases, the number of packets want to be transmitted when the channel is idle increases, which also makes the information packet collision increases, resulting in the decrease of throughput.

4. Conclusions

The paper presents a new p-persistent CSMA wireless sensor network MAC protocol with monitoring function based on random multiple access system, and gets the mathematical expressions of system throughput, system average operating power and the life cycle of terminal nodes of p-persistent CSMA wireless sensor network MAC protocol with monitoring function through a complicated mathematical modelling and rigorous mathematical derivation. The computer simulation results not only confirm the correctness of the theoretical analysis but also show that the p-persistent CSMA with monitoring for WSNs MAC protocol due to join the monitoring signals, resulting in the decrease of systemic throughput, but reduces the collision probability. Meanwhile, the p-persistent CSMA wireless sensor network MAC protocol with monitoring function this paper presents can effectively reduce energy consumption.

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