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The Probability Detection CSMA Protocol with Monitoring Function in WSNs and Energy Efficiency Analysis

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Abstract: The paper presents a new WLAN (wireless local area network) MAC protocol, probability detection CSMA with monitoring for WSNs MAC protocol. Analyzes and builds the corresponding mathematical model using average cycle method, and get the mathematical expressions of systemic throughput and the life cycle of terminal nodes of the probability detection CSMA with monitoring for WSNs MAC protocol through a rigorous mathematical derivation. Simulation results show that the probability detection CSMA with monitoring for WSNs MAC protocol due to join the monitoring signal, resulting in the decrease of systemic throughput, but reduces the collision probability. Meanwhile, under the control of the protocol, the systemic throughput and utilization rate has a higher value in the light loads, then avoid the waste of channel resources. Therefore, the probability detection CSMA with monitoring for WSNs MAC protocol has a better performance in the WLAN. *Copyright © 2013 IFSA.*

Keywords: Wireless local area network, Average cycle method, Throughput, Life cycle, Monitoring signal.

1. Introduction

WSNs (Wireless Sensor Networks) [1-3] is a new sensor network, but also a cross of multidisciplinary fields, is composed of a plurality of micro sensor terminal nodes having sensing capability power, computing power and communication capability using IEEE 802.11 protocol standard, compose a network system with multi-hop and self-configuration, with the aim of collecting information and send the collected information to processing center in the way of wireless communication through terminal sensor nodes within the network coverage area. It has a wide range of application in the military, medical, explosion, industrial, disaster relief, and many other fields.

Wireless sensor network is a comprehensive intelligent information system [4, 5] which collected information collection, information processing and information transmission. The network performance (throughput, delay, etc.) depends on the access protocol of MAC (Media Access Control) sub-layer. Thus, the development of appropriate MAC sub-layer

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rulers, allocating channel resources according to the characteristics of network traffic, improving the service efficiency of radio resources, improving system capacity and transmission quality has always been an important research topic. Therefore, in order to better improve the system throughput, increase the security of information transmission, but also to solve the hidden terminal problem, the paper presents a new wireless local area network MAC protocol [6-8], the probability detection CSMA (Carrier Sense Multiple Access) with monitoring for wireless sensor networks MAC protocol, which add ACK after delay a to ensure the channel state, this will help to reduce the collision probability when channel is busy sending information packet and improve protocol performance.

This paper analyzes the probability detection CSMA with monitoring for WSNs MAC protocol seriously, Analyzes and builds mathematical model using average cycle method [9], and get the mathematical analytic expression of systemic throughput [9-11] and the life cycle of terminal nodes [12, 13] and other performance indicators of the probability detection CSMA with monitoring for WSNs MAC protocol through a rigorous mathematical derivation. The simulation results verified the correctness of the theoretical derivation, improved throughput, and prolonged life cycle of nodes.

2. The Probability Detection CSMA Protocol with Monitoring for WSNs MAC Protocol

In this paper, the model of the probability detection CSMA with monitoring for WSNs MAC protocol is shown in Fig. 1. When a terminal user is sending information packets, if the packets arrived in a transmission period (TP) will listen to the channel is busy, then continue to listen to the channel with probability p until the channel is idle; if the packets will listen to the channel is idle, transmit the packet. 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.

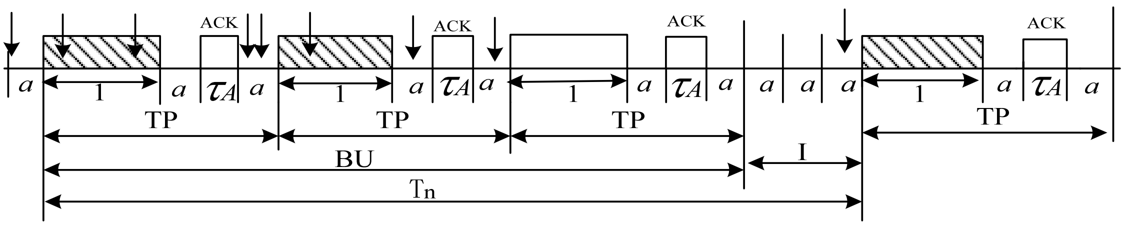

Fig. 1. The model of the probability detection CSMA protocol with monitoring.

As can be seen from the figure, there are three random events [14] on the channel. The event that information packet sent successfully U, the event that information packet impacted on the channel B and the event that the channel is idle I. These three random events can be divided into two events, an idle event I and a compound 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 protocol, the system needs to be defined as follows:

- The channel is an idle channel without noise and interference;
- 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;
- The time axis of the channel is divided by a, packets arrived within any a will be sent in the begin of next slot;
- The time generated an acknowledge signal (monitoring signal) ACK is a, then the length of a transmission period TP is 1+3a;
- The channel access way is slotted p-detection CSMA protocol, information packets arrived on the channel follows Poisson Distribution with independent parameter G;
- 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;
- 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 describe of the control principle of the probability detection CSMA protocol with monitoring function, we know:

The probability that has n information packets arrive at time t is

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

The probability that has m information packets continue listening channel state with probability p in which has n information packets arrive at time t is

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

The probability that has no packet to transmit in an idle slot a is

$$q_a^0 = p(n=0) = e^{-Ga} \quad (3)$$

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

$$q_a^1 = p(n=1) = Gae^{-Ga} \quad (4)$$

The probability that has no packet to transmit in a transmission period 1+3a is

$$q_{1+3a}^0 = p(m=0) = e^{-Gp(1+3a)} \quad (5)$$

The probability that has only one packet to transmit in a transmission period 1+3a is

$$q_{1+3a}^1 = p(m=1) = Gp(1+3a)e^{-Gp(1+3a)} \quad (6)$$

The probability that has i consecutive idle events is

$$p\{N_I = i] = (e^{-Ga})^{i-1}(1-e^{-Ga}) \quad (7)$$

The probability that has j consecutive BU is

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

From (7), (8), we obtain the joint probability of the probability detection CSMA with monitoring for WSNs MAC protocol is

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

The average number of timeslot that the channel is idle in a cycle time is

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

The average number of timeslot that the channel is busy in a cycle time is

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

Defined U_2 as follows:

U_1 : There is only one packet arrives and wants to transmit at the last one slot in idle time, the packet will be sent successfully in the next timeslot.

U_2 : There is some information packets arrive in busy time, but only one packet detects the channel state with probability p, the packet will be sent successfully when the channel is idle.

$$E(N_{U1}) = \frac{Gae^{-Ga}}{1-e^{-Ga}} \quad (12)$$

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

Then the average number of timeslot that the packet transmitted successfully in a cycle time is

$$\begin{aligned} E(N1_U) &= E(N_{U1}) + E(N_{U2)}) \\ &= \frac{Gae^{-Ga}}{1-e^{-Ga}} + Gp(1+3a) \end{aligned} \quad (14)$$

The average length that the packet transmitted successfully in a cycle time is

$$E(U1) = \frac{Gae^{-Ga}}{1-e^{-Ga}} + Gp(1+3a) \quad (15)$$

The average length that the channel is busy in a cycle time is

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

The average length that the channel is idle in a cycle time is

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

From the definition of system throughput [9]

$$S = \frac{E[U]}{E[BU]+E[I]} \quad (18)$$

Combine the expressions (15), (16), and (17), we can get the throughput of the joint probability of the probability detection CSMA with monitoring for WSNs MAC protocol is

$$S1 = \frac{e^{-Gp(1+3a)}[Gae^{-Ga} + Gp(1+3a)(1-e^{-Ga})]}{ae^{-Gp(1+3a)} + (1+3a)(1-e^{-Ga})} \quad (19)$$

Defined U_2 as follow another:

U_2: The information packets arrived at time t a in the TP using non-persistent method access to the channel give up detecting, but only one information packet arrived at transmission time 1 in TP listen to the channel continuous, then the packet will be transmitted successfully in the next transmission period TP.

$$E(N_{U2)}) = Gp \tag{20}$$

$$E(N2_U) = E(N_{U1}) + E(N_{U2)}) = \frac{Gae^{-Ga}}{1-e^{-Ga}} + Gp \tag{21}$$

The average length that the packet transmitted successfully in a cycle time is

$$E(U2) = \frac{Gae^{-Ga}}{1-e^{-Ga}} + Gp \quad (22$$

From the definition of system throughput, combine the expressions (22), (16), and (17), we can get the throughput of the protocol is

$$S2 = \frac{e^{-Gp(1+3a)}[Gae^{-Ga} + Gp(1-e^{-Ga})]}{ae^{-Gp(1+3a)} + (1+3a)(1-e^{-Ga})} \tag{23}$$

2.2. The Efficiency Analysis of System Energy

The probability detection CSMA with monitoring for WSNs MAC protocol this paper presents can effectively reduce energy consumption. The control principle is shown in Fig. 2. When a terminal user want to send information packets, if the packets arrived in a transmission period (TP) will detected the channel is busy, then listen to the channel with probability p until the channel is idle; if it detects the channel is idle, and then transmit the packet immediately. 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 enters to the period of dormancy until the next transmission period TP start. The channel first listens to itself after it is idle, then holding time a, and it enters into dormancy state again if there is no any nodes want to send information packets, the sleep time is 1, so that we can effectively reduce energy consumption.

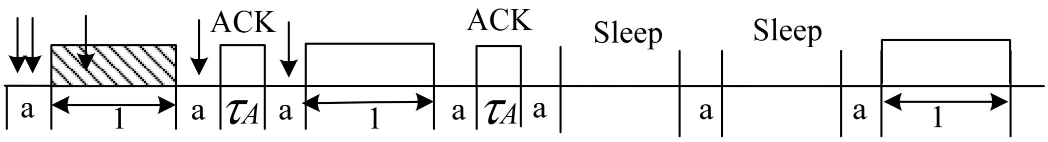

Fig. 2. Working schematic diagram for node.

In this paper, we use the battery model of literature [15] to analyze the system capacity, and also introduce the concept of channel detection power, then having the following definitions: $P_T = 1.8mW$ refers to the power of service nodes which are in transmission; $P_R = 9mW$ 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; $B = 24Kbps$ refers to the data transmission rate.

From the above analysis, the different definitions of U_2 have different average length of the impacted packet:

$$E(B1) = E(BU) - E(N1_U)(1+3a) = \frac{1+3a}{e^{-Gp(1+3a)}} - \frac{Gae^{-Ga}(1+3a)}{1-e^{-Ga}} - Gp(1+3a)^2 \tag{24}$$

$$E(B2) = E(BU) - E(N2_U)(1+3a) = \frac{1+3a}{e^{-Gp(1+3a)}} - \frac{Gae^{-Ga}(1+3a)}{1-e^{-Ga}} - Gp(1+3a) \tag{25}$$

Assuming that the total energy of a system is E (unit: Wh), the effective energy is 90 % of the total, then the loss energy of a system whose total energy equals E in a year is

$$P_{lk} = \frac{0.1E}{24\times 365} \tag{26}$$

Define the average power of service nodes is P_n, then the average power of the probability detection CSMA with monitoring for WSNs MAC protocol is

$$P_{n1} = \frac{[1.8E(U1) + 9E(B1) + 0.5E(I)]\times 10^{-3}}{E(BU)(1+3a) + aE(I)} \tag{27}$$

$$P_{n2} = \frac{[1.8E(U2) + 9E(B2) + 0.5E(I)] \times 10^{-3}}{(1+3a)E(BU) + aE(I)} \quad (28)$$

Thus the life cycle of the protocol is

$$T1 = \frac{E}{24 \times 365 \times P_{n1} + 0.1E} \quad (29)$$

$$T2 = \frac{E}{24 \times 365 \times P_{n2} + 0.1E} \quad (30)$$

3. Experiment Analysis

According to the above analysis, we simulate the probability detection CSMA with monitoring for WSNs MAC protocol, but before simulate the protocol, the simulation environment is assumed as following:

1. The channel is ideal without noise and interference.
2. The channel arriving rate is G
3. The length of each packet equals to unit length.
4. We use the Matlab to simulate, and compare the simulation results with the theoretical results, Fig. 3-7.

From the above simulation figures, we can get the following conclusions:

1) From Fig. 3, we can see that the probability detection CSMA with monitoring for WSNs MAC protocol has a lower throughput than the traditional p-detection CSMA protocol. This is because when the system function increases, such as adding monitoring function, or using the ACK message, the system performance will be affected in a certain extent, to maintain system stability by reducing system throughput.

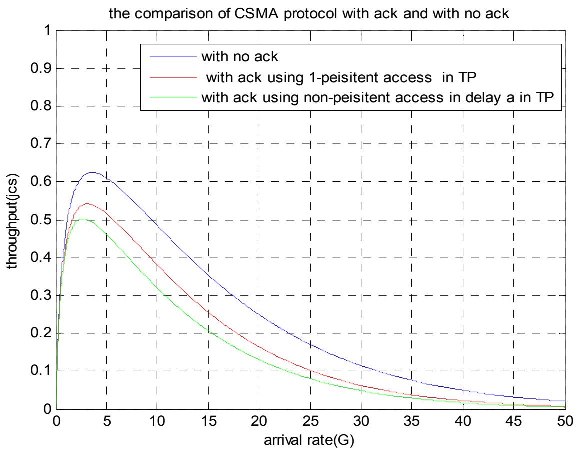

Fig. 3. The comparison of CSMA protocol with ACK and no ACK when $a = 0.1, p = 0.1$.

2) From Fig. 4, we know that the theoretical value of the system throughput is highly coincide with the simulation value for the probability detection CSMA with monitoring for WSNs MAC protocol, proved the correctness of 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.

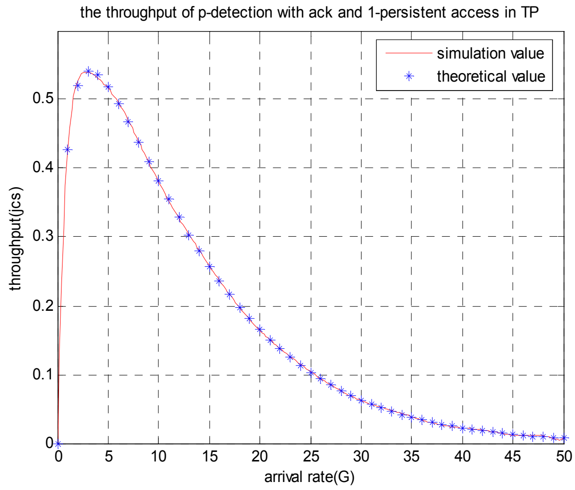

Fig. 4. The throughput of p-detection with ACK when $a = 0.1, p = 0.1$.

3. From Fig. 5 and Fig. 6, we can see that under a same arrival rate, with the detection probability p decreases, the system throughput is increased, and the stable value also becomes large when the system delay remain unchanged ($a = 0.1$). But when p decreases to a certain value, the stable value of system throughput will not increases with the decrease of p. That is because when the detection probability p continue to decrease, that is to say, the probability that the channel give up detecting increase, the channel is wasted.

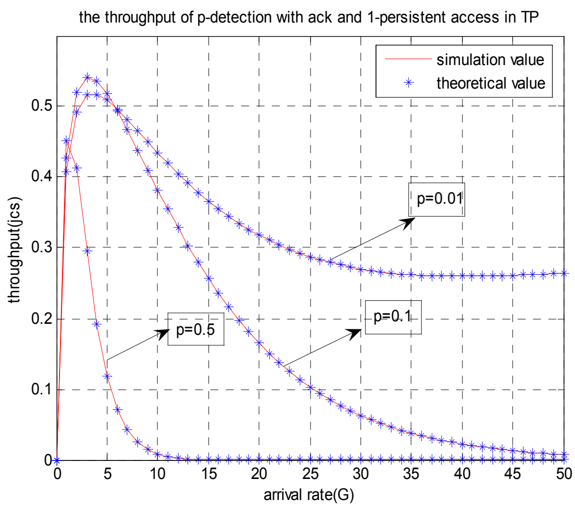

Fig. 5. The throughput of p-detection with ACK when $a = 0.1$.

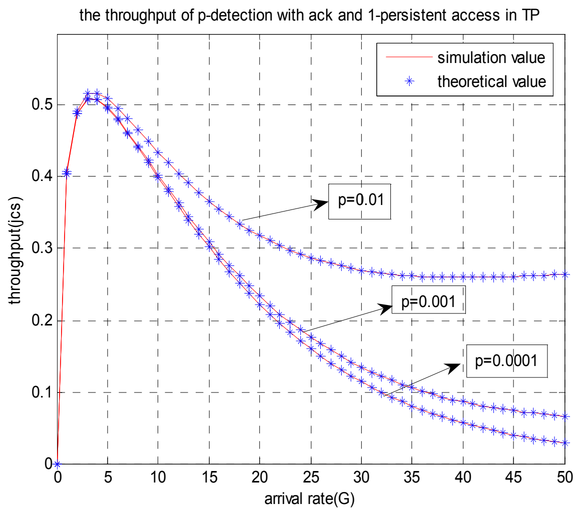

Fig. 6. The throughput of p-detection with ACK when $a = 0.1$.

4. From Fig. 7, we see that the system throughput will change with different maximum transmission delay on the whole when the detection probability remains unchanged ($p = 0.01$), and the system throughput increases with the decrease of the system maximum transmission delay because the system transmission period is an integer multiple of maximum transmission delay a, the small the system delay, the less number of information packets can listen to the channel is busy in TP, then the less number of information packets continue to detect the channel state, so that the less number of information packets will be sent in the idle time, which also reduce the collision probability and increase the throughput.

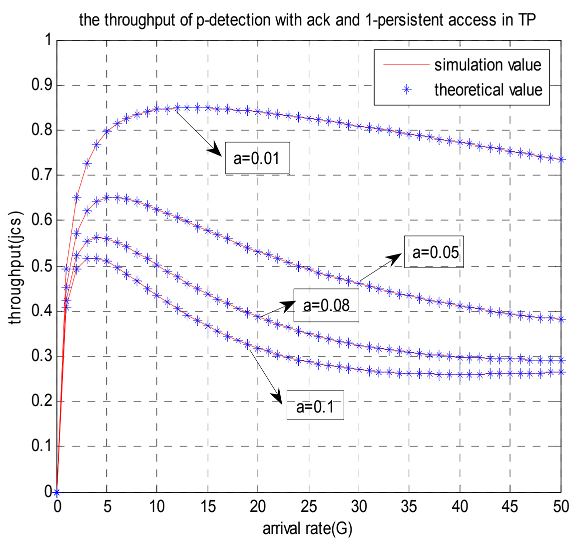

Fig. 7. The throughput of p-detection with ACK when $p = 0.01$.

4. Conclusions

The paper presents a new probability detection CSMA protocol with monitoring for WSNs MAC based on WLAN (wireless local area network), and gets the mathematical expressions of systemic throughput and the life cycle of terminal nodes of the probability detection CSMA with monitoring for WSNs MAC protocol through a rigorous mathematical derivation. The simulation results show that the probability detection CSMA with monitoring for WSNs MAC protocol due to join the monitoring signal, resulting in the decrease of systemic throughput, but reduces the collision probability. Meanwhile, under the control of the protocol, the systemic throughput and utilization rate has a higher value in the light loads, then avoid wasting the channel resources. However, to the channel which can be in higher loads long-term, the probability detection CSMA with monitoring for WSNs MAC protocol increase the loads to some extent, but it can reduce the collision probability and overhead required channel arbitrated effectively, and improve the channel utilization rate of WLAN. Therefore, the probability detection CSMA with monitoring for WSNs MAC protocol is a better WLAN MAC protocol.

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