International Journal of Future Generation Communication and Networking
Vol. 9, No. 1 (2016), pp. 223-232
http://dx.doi.org/10.14257/ijfgcn.2016.9.1.20

The One-persistent Multichannel CSMA Protocol with Monitoring Functions Based on Conflict Resolution Algorithm in WSN

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Abstract

In the Wireless Sensor Network, a new MAC protocol: one-persistent CSMA protocol with monitoring functions and multichannel mechanism for Wireless Sensor Network based on conflict resolution algorithm is proposed. Protocol from the system throughput, collision rate, better service quality for higher priority and other aspects improve the traditional CSMA system to perfect the controllability of the system, making the system more stable for the big data, better adapted to different business. The average cycle method is used to derive rigorous mathematical expressions of specific relevant parameters. Using MATLAB simulation tool for the accuracy of the agreement is demonstrated.

Keywords: *Wireless Sensor Network, big data, binary tree conflict resolution, one-persistent CSMA, monitoring function, multichannel, throughput*

1. Introduction

Wireless sensor networks (Wireless Sensor Networks, WSN) is a distributed sensor network, its tip is to check the outside world by sensors [1]. WSN sensors communicate wirelessly, so the network configuration flexibility, it can change the location of the device at any time, can also be connected to a wired or wireless mode with the Internet. It can form into ad hoc networks by wireless communication.

Wireless Sensor Network generates large data (Big Data), large data boosts the WSN. Wireless Sensor Network makes the articles and the Internet linked up to exchange information and communicate, realizing intelligent identification, positioning, tracking, monitoring and management of the process [2]; large amounts of data generated is also affecting electricity, health care, transportation, security, logistics re-formation of environmental protection and other areas of the business model. Wireless Sensor Network handshake with Big Data, are gradually showing great commercial value [3].

Big Data era quietly coming, the explosive growth of data is beyond people's imagination. At the same time, along with WSN, rapid development of mobile intelligent terminals and mobile Internet, the growth rate of mobile network data traffic is also very high. Expected to start from 2014, global mobile data traffic growth rate will remain above 50 percents and will be in a stable growth trend [4]. By 2016, global mobile data traffic will reach 18 times the global mobile data traffic in 2014, reaching 129.6 EBs. With the crazy growth of data, making adaptation and response to the data growth has become the focus of the whole society.

The proposed protocol is mainly the improved of typical one-persistent CSMA protocol. First, based on the original protocol, the new protocol adds the functions of monitoring (ACK) control mechanism, reduces the possibility of conflict, improves the utilization of the channel resources and enhances the safety and reliability of packet

ISSN: 2233-7857 IJFGCN

transmission simply and conveniently. Secondly, the introduction of multi-channel mechanism through service priority division, making the implementation of the Wireless Sensor Network in a variety of business network load balancing effectively; different priorities make the QoS meet the needs of Wireless Sensor Network and Big Data, in both efficiency and the principle of fairness [5]. Finally, the modified binary tree conflict resolution algorithm is applied to the one-persistent CSMA Protocol with three-way handshake and multichannel mechanism, in a certain extent, eases the congestion caused by the crazy growth of data and improves system performance.

2. The Model

There are different service requirements nodes have different priorities in the wireless sensor network. The system has N channels to transmit packets, the nodes occupied of channel resources randomly according to their different business requirements. Each priority has no limit on the number of users, the order of priority from high to low be priority N, priority N-1... priority 1. Priority i of business occupied the channel 1 to channel i, as shown in Figure1. The arrival Information packets on the channel i obey *Poisson* distribution with arriving rate is G_i, the arrival process of priority r on the channel i obedience the process with arrival rate $\lambda_i = G_i / (N - i + 1)$. Such system is a load balancing system, the same arrival rates for each channel is $G_i = G(i = 1, 2, ..., N)$. Different quality of service according to different requirements, the multi-channel CSMA protocol realized different services of different QoS prioritization requirements by prioritizing.

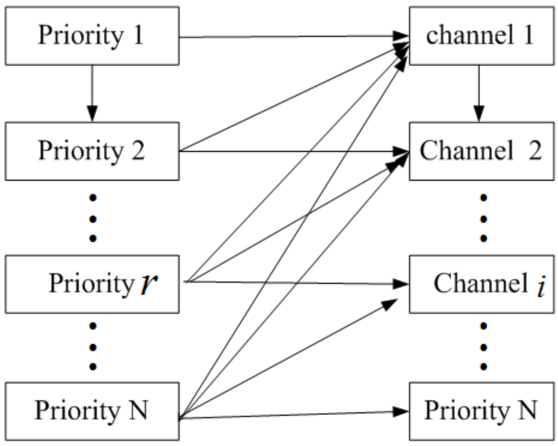

Figure 1. The Model of Multichannel Mechanism

The one-persistent CSMA Protocol with monitoring functions and multichannel mechanism works as followed: the node listens to the channel state before sending information packet, if the channel is idle, then immediately sends the message packet. If the channel is busy, the user listens to the channel consistently, once the channel is idle, repeat the former process. The nodes conducted a short frame data exchange according to the new protocol, confirmed whether the data is received or collision. Length of the transmission period is: $1 + 3a$ [6].

Under the agreement control, there will be three random events: successfully sent a packet (U), collision incident (B) and the channel is idle (I). These three kinds of random events reclassified as: I and BU (information packet sent successfully or collision) [7]. When the collision happens, the system model does not follow the mechanism of random back-off for some time slots after the first re-transmission of the recovery, but detects the channel state. The conflict is resolved by the improved binary tree conflict decomposition mechanisms once a first idle immediately found, in this process the channel detected in a non-persistent CSMA protocol. After the packet is recovered, the model returns to normal after the transmission.

The model of the i channel $(i=1,2,...,N)$ is showed as follow:

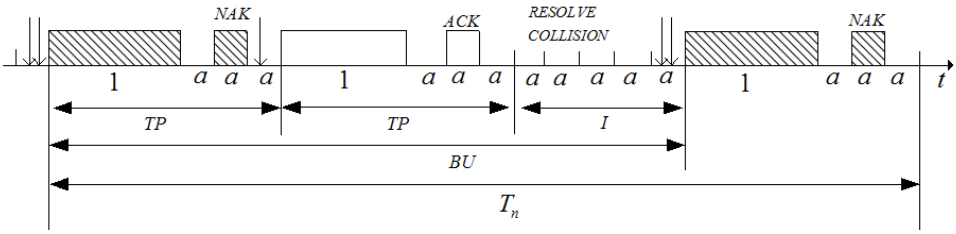

Figure 2. The Model of the One-Persistent Multichannel CSMA Protocol with Monitoring Functions Based on Conflict Resolution Algorithm in WSN

3. Analysis of the Model

Before analyze the system performance, first do the following assumptions:

- The channel is ideal with no noise and interference;
- The basic unit of the system control clock is a, the information packets arrived at time a will transmit at the starting time of the next slot;
- The channel propagation delay is a ,the packet length is unit length and is an integral multiple of a ;
- The access method of number $i(i=1,2,...,N)$ channel is timeslot one-persistent CSMA protocol, and the arrival process of number i channel satisfy the Poisson process whose independent parameter is G_i , each arrival process on the channel is independent of each other;
- The channel using one-persistent CSMA protocol with multichannel mechanism, the information packets need to be sent at the first slot in the transmission period can always detecting the state of the channel at last moment;
- During the transmission of information packets, the phenomenon of packet collisions occur inevitably, and continues to be sent after a random time delay, it sends will not produce any adverse effects on the arrival process channel.

The arrival process of channel satisfies the Poisson process：

$$P(n)=\frac{(aG)^n e^{-aG}}{n!} \quad (1)$$

In I events, at idle time slot a, if there is no information packets to be sent in channel i, its possibility is:

$$q_1^0=e^{-aG_i} \quad (2)$$

In I events, at idle time slot a, if there is only one information packet to be sent in channel i, its possibility is:

$$q_1^1 = aG_i e^{-aG_i} \quad (3)$$

At the transmission period, if there is no information packets to be sent in channel i, its possibility is:

$$q_2^0 = e^{-(3a+1)G_i} \quad (4)$$

In the transmission period $(1+3a)$, if there is only one information packet to be sent in channel i, its possibility is:

$$q_2^1 = (3a+1)G_i e^{-(3a+1)G_i} \quad (5)$$

In a cycle period T_n, the average length of time slot the channel i occupies when it's idle is:

$$\begin{aligned} E(N_I) &= \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} ip(N_I = i; N_{BU} = j) = \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} i\left(1-e^{-G_i a}\right)\left(1-e^{-G_i(1+3a)}\right)^{i-1} e^{-G_i(1+3a)}\left(e^{-G_i a}\right)^{j-1} \\ &= \frac{1}{1-e^{-G_i a}} = \frac{q_1^0}{q_1^0(1-q_1^0)} \end{aligned} \quad (6)$$

The number of time slot that the channel i has successfully sent information packets in a cycle period T_n is:

$$E(N_U) = \frac{q_2^1}{q_1^0\left(1-q_1^0\right)} \quad (7)$$

The average length of time slot that channel i has x collisions in a cycle period T_n is:

$$E(N_{Bx}) = \frac{p_x}{q_1^0\left(1-q_1^0\right)} \quad (8)$$

In (8), $P_x = \frac{\left[G_i\left(1+3a\right)\right]^x e^{-G_i(1+3a)}}{x!}$ represents the probability of x information packets have been successfully resolve and retransmitted during a cycle period T_n.

The average length of time slot that I event has occupied in a cycle period T_n is:

$$E(I) = E(N_I)a = \frac{aq_1^0}{q_1^0(1-q_1^0)} = \frac{ae^{-G_i a}}{q_1^0(1-q_1^0)} \quad (9)$$

The average length of time slot that the channel i has successfully sent information packets in a cycle period $T_n s$ is:

$$E(U) = E(N_U)\times 1 = \frac{q_2^1}{q_1^0\left(1-q_1^0\right)} = \frac{G_i\left(1+3a\right)e^{-G_i(1+3a)}}{q_1^0\left(1-q_1^0\right)} \quad (10)$$

$$E(U^*) = E(N_U) \times (1+3a) = \frac{G_i \left(1+3a\right)^2 e^{-G_i(1+3a)}}{q_1^0 \left(1-q_1^0\right)} \tag{11}$$

The average length of time slot that collisions have occupied in a cycle period T_n is:

$$E(B_x) = E(N_{Bx})x = \frac{\left[G_i \left(1+3a\right)\right]^x e^{-G_i(1+3a)}}{(x-1)!\, q_1^0 \left(1-q_1^0\right)} \tag{12}$$

In a cycle, the average effective length that $x(x >= 2)$ collision packets have been successfully divided and retransmitted is:

$$E(N_{Bx}) = \sum_{x=2}^{\infty} \frac{[G_i(1+3a)]^x e^{-G_i(1+3a)}}{x!(1-e^{-G_i a})} \tag{13}$$

The process of the binary tree conflict resolution is:

If there are x collision packets, they will choose the right or left time slot separately and randomly. Assuming its probability is p_{ij}. $p_{ij}^{'}$ is the probability that i packets come to the left time slot and j packets come to the right time slot. $p_{ji}^{'}$ is the probability that j packets come to the left time slot and i packets come to the right time slot.

$$p_{ij} = p_{ij}^{'} + p_{ji}^{'} \tag{14}$$

$$p_{i(x-i)} = 2!C_x^i C_{x-i}^{x-i} p^x = 2!C_x^i p^x, i = 0,1,...,[N/2] \quad x \text{ is the odd number} \tag{15}$$

$$p_{(x/2)(x/2)} = C_x^{x/2} p^x \quad x \text{ is the even number} \tag{16}$$

The average length of successfully resolve the x collision packets is:

$$\overline{L_x} = \frac{p_{0N} + p_{1(x-1)}^{'}[3+2E(L_{x-1})] + \sum_{i=2}^{[x/2]} p_{i(x-i)}[1+E(L_i)+E(L_{x-i})]}{1-p_{0x}} \tag{17}$$

$$E(B_x^*) = E(N_{Bx})(1+3a)(1+\overline{L_x}) = \frac{\left[G_i \left(1+3a\right)\right]^x e^{-G_i(1+3a)}}{x!\, q_a^0 \left(1-q_a^0\right)} (1+3a)(1+\overline{L_x}) \tag{18}$$

In (18), $\overline{L_x}$ is average length of time slot that successfully decomposing x collisions by the improved binary tree conflict resolution algorithm is needed [8].

From the formula of throughput: $S = \dfrac{E(U) + \sum_{x=2}^{\infty} E(B_x)}{E(U^*) + E(I) + \sum_{x=2}^{\infty} E(B_x^*)}$ [9], then the throughput of the i channel by the one-persistent CSMA Protocol with three-way handshake based on binary tree conflict resolution mechanism is:

$$S_i = \frac{\dfrac{G_i(1+3a)e^{-G_i(1+3a)}}{e^{-aG_i}\left(1-e^{-aG_i}\right)} + \displaystyle\sum_{x=2}^{\infty}\frac{\left[G_i(1+3a)\right]^x e^{-G_i(1+3a)}}{(x-1)!e^{-aG_i}\left(1-e^{-aG_i}\right)}}{\dfrac{G_i(1+3a)^2 e^{-G_i(1+3a)}}{e^{-aG_i}\left(1-e^{-aG_i}\right)} + \dfrac{ae^{-aG_i}}{e^{-aG_i}(1-e^{-aG_i})} + \displaystyle\sum_{x=2}^{\infty}\frac{\left[G_i(1+3a)\right]^x e^{-G_i(1+3a)}}{x!e^{-aG_i}\left(1-e^{-aG_i}\right)}(1+3a)(1+\overline{L_x})}$$

$$= \frac{\dfrac{G_i(1+3a)e^{-G_i(1+2a)}}{\left(1-e^{-aG_i}\right)} + \displaystyle\sum_{x=2}^{\infty}\frac{\left[G_i(1+3a)\right]^x e^{-G_i(1+2a)}}{(x-1)!\left(1-e^{-aG_i}\right)}}{\dfrac{G_i(1+3a)^2 e^{-G_i(1+2a)}}{\left(1-e^{-aG_i}\right)} + \dfrac{a}{(1-e^{-aG_i})} + \displaystyle\sum_{x=2}^{\infty}\frac{\left[G_i(1+3a)\right]^x e^{-G_i(1+2a)}}{x!\left(1-e^{-aG_i}\right)}(1+3a)(1+\overline{L_x})} \quad (19)$$

Similar to the analyses of the one-persistent CSMA protocol with three-way handshake and monitoring function, in the N channels of wireless communication system, using load balancing technology, then $G_1 = G_2 = G_3 = ... = G_i = ... = G_N$ [10].

The above analysis and system throughput formula: $S = \sum_{i=1}^{N}\frac{E[U_i]}{E[U_i^*]+E[B_i]+E[I_i]}$, then the system throughput of the new protocol is:

$$S = NS_i \quad (20)$$

Reference to the multi-channel model and system performance parameters, according to the analysis, under the protocol, the system throughput of the l priority business is:

$$S_{pl} = \sum_{i=1}^{l}\frac{1}{N-i+1}S_i \quad (21)$$

4. Simulation

From the above analysis, the expression of the system throughput under the one-persistent CSMA protocol with monitoring functions and multichannel mechanism for Ad Hoc network based on conflict resolution algorithm is got. With the simulation tool MATLAB R2010a, system simulation and theoretical analysis are under the same working conditions. The simulation results are shown in Figure 3 to Figure 6. If not specified, the default simulation conditions is: $a = 0.01$.

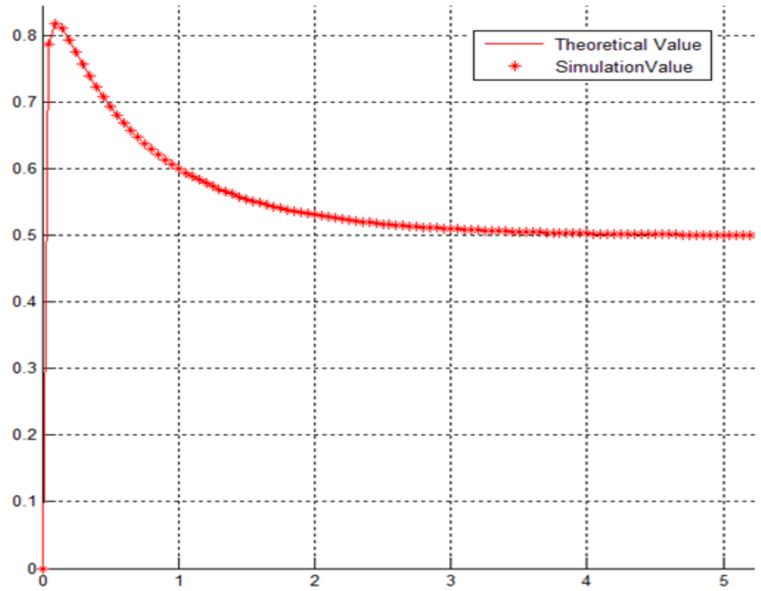

Figure 3. The Comparison of the Theoretical and Simulation Value under the New Protocol

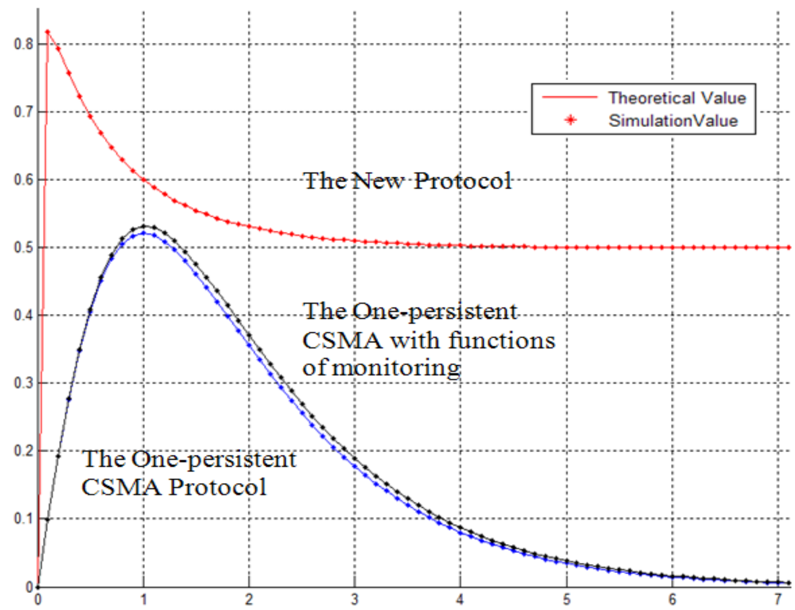

Figure 4. The Comparison between the New Protocol, the Protocol with Functions of Monitoring and the Typical One-Persistent CSMA Protocol

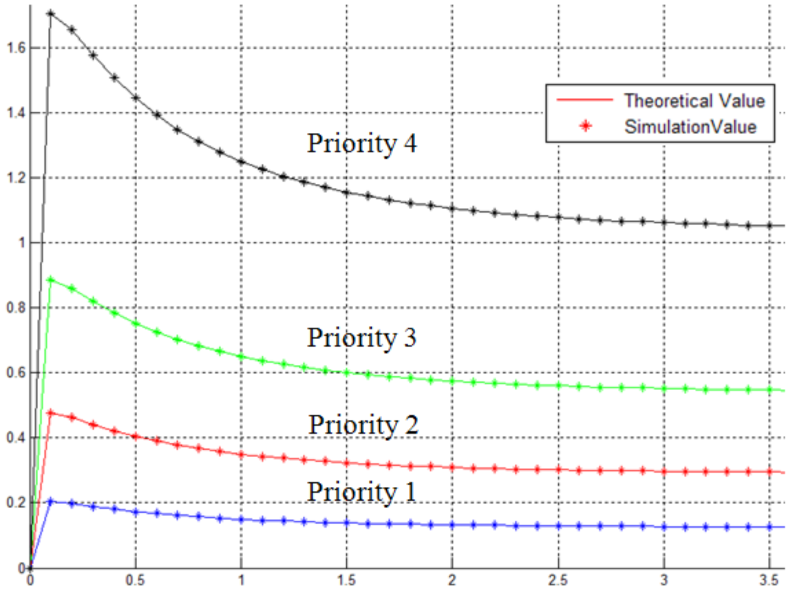

Figure 5. The Comparison of the Theoretical and Simulation Value under the New Protocol with Four Priorities

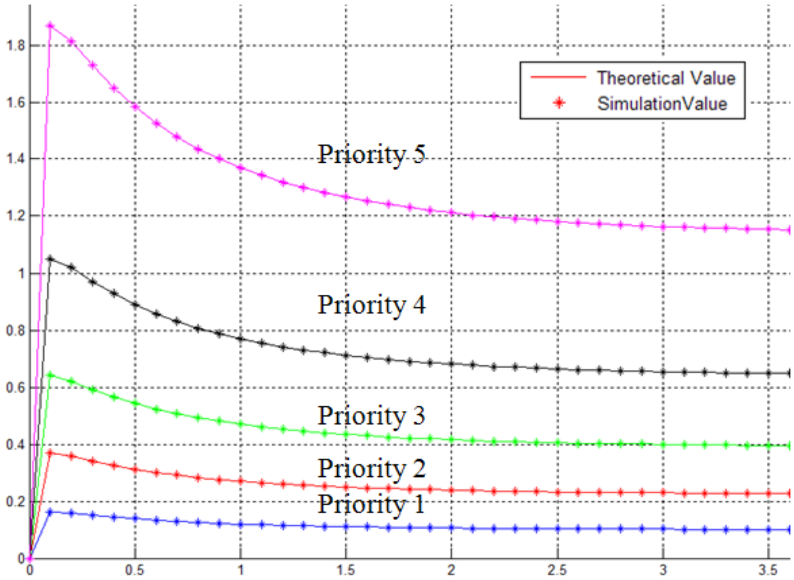

Figure 6. The Comparison of the Theoretical and Simulation Value under the New Protocol with Five Priorities

From the MATLAB simulation, under the one-persistent CSMA protocol with monitoring functions and multichannel mechanism for Ad Hoc network based on conflict resolution algorithm, the characteristics of the new protocol is:

The theoretical and simulation value is highly consistent and the theoretical analysis is proved to be correct. When the number of information packets transmitted is small, under the control of the protocol, the system can quickly perform packet processing. However, with the number of the arrival packet increasing to a certain extent, the decomposition rate of binary tree conflict resolution mechanism will reach the saturation point; the system throughput remains stable. Compared with the one-persistent CSMA protocol with functions of monitoring and the typical one-persistent CSMA protocol, the throughput has been greatly improved and more suitable for Big Data.

With the priority algorithm, the channel resources could be assigned by needs. The higher priority traffic can get more channel resources, while lower priority channel gains less access to resources but does not lose effectiveness, resource acquisition still able to meet its communications needs, ensuring the fairness principle of resource allocation. This system design through balancing load, distinguishing priority services, making transmission to meet the growing communication needs better.

5. Conclusion

Under the one-persistent CSMA protocol with monitoring functions and multichannel mechanism for Ad Hoc network based on conflict resolution algorithm, the theoretical and simulation value is highly consistent and the theoretical analysis is proved to be correct. The higher priority traffic can get more channel resources, while lower priority channel gains less access to resources, ensuring the fairness of resource allocation principles; the access is still able to meet its communication needs even the arrival rate of the node is high in the network. With the flexible controllability, the system could meet the different business better; the system is more robust in Big Data or Wireless Sensor Network.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (61461053, 61461054, 61072079); Natural Science Foundation of Yunnan Province (2010CD023); The financial support of Yunnan University (No. XT412004).

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