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Research Article

ANALYSIS OF DOUBLE CLOCKS MULTI-CHANNEL TWO-DIMENSIONAL PROBABILITY CSMA BASED ON BINARY TREE CONFLICT RESOLUTION MECHANISM

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ABSTRACT

With the rapid development of the communication technology, the increase of the users, more and more multi-task requirements will be presented by users who want to take advantage of the wireless access. It proposed new requirements and challenges for multi-users to share limited spectrum resources and ensure the Quality of Service (QoS) of wireless communication network. Based on the successful application of double clocks control to ALOHA, we try to apply this theory to the CSMA protocols. Meanwhile, we set the probability of sending packet and the probability of sensing channel to improve system performance. But in the CSMA protocol, the conflict between packets is inevitable. Then we introduce binary tree conflict resolution mechanism which could resolve the conflict and resent the information packets in conflict. Based on the above two considerations, we proposed a double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism which improves the controllability of the system, the channel utilization, system security, and reliability of packet transmission, meets the different priority of different QoS requirements. By modeling analysis, the analytical results and simulation results show that the theoretical analysis are consistent with the simulation experiments and has a better performance in many aspects.

INTRODUCTION

In simple terms, a number of nodes located in the same geographic area do not rely on a fixed network structure, Ad hoc network is formed by a combination of clustering. Ad hoc network has a network in the form of a very flexible and powerful network self-healing capacity, and low cost of network building, so applications are very wide [Zhao Dongfeng, 1999]. Ad hoc network routing forwarding and network distribution channel of information through the network belonging to each cluster head node implementation. Hierarchical thinking to be used in the Ad hoc network, and therefore at a higher level in the network cluster structure can be considered to be a separate Ad hoc network, and the formation of a whole group of nodes connected by a hierarchical cluster head [Hongwei Ding et al., 2015]. Since the introduction of the concept of hierarchical, even if the end of the network topology changes, it will not affect the higher-level network topology, so the Ad hoc network has better stability and scalability. Ad hoc networks achieve interoperability by radio station in form of spread dispersed geographically; this is the biggest difference compared with the conventional mobile communication network [Shengjie Zhou, 2015]. Ad hoc networks' non-fixed network can be considered as a distributed network, there is no centralized control of its central site, and each radio equipment is undertaken tasks for forming the network. Since the introduction of hierarchical thinking, Ad hoc networks using a multi-hop shared channel mode, and the traditional MAC layer protocol applies only to single-hop shared channel network. Coupled with network radio device will often in the fast-moving situation, leading to the communication link between the networks will also change rapidly [Zhao Dongfeng et al., 1997]. Therefore, the improved traditional network characteristics of random multiple access technology can be well applied to Ad hoc networks, ensuring Ad hoc network to obtain better system performance. The competition is based on random multiple access scheme most significant features. We had to compete with other sites to transmit data for the wireless channel. So the conflict between packets is inevitable. In this paper, we proposed a double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism, set the probability of sending packet and the probability of sensing channel, improves the controllability of the system, the channel utilization, system security, and reliability of packet transmission, meets the different priority of different QoS requirements.

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By modeling analysis, the analytical results and simulation results show that the theoretical analysis are consistent with the simulation experiments and has a better performance in many aspects. In this paper, using the averaging cycle period conduct analytical and simulation experiment with the control strategy mentioned above.

THE MODEL

When we introduce the multichannel mechanism, 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 [Yi Shang and Hongchi Shi, 2007]. Priority i of business occupied the channel 1 to channel i. 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 $G_i = G(i = 1, 2, ..., N)$ [Liu Binbin, 2006].

The model of multichannel three-dimensional probability CSMA protocol with function of monitoring based on binary tree conflict resolution in channel i is showed as Fig. (**1**).

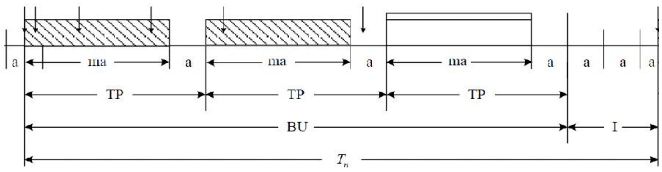

Fig. (1). The model of double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism in channel i.

In the proposed protocol, there will be three random events:

- U events: Event that information packets are sent successfully.
- C events: Event that information packets collide with each other (the collision appears).
- I events: Event that there is no information packets in the channel arrive, the channel is idle.
- Set the probability P_1 of sending packet and the probability P_2 of sensing channel.

ANALYSIS OF THE MODEL

The Analysis of System Throughput

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 three-dimensional probability 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 [Ma Zuchang, 2004];
- The channel using the new protocol, 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

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

In Equation (1), $P(n)$ is the event of n packets arriving during time of a.

First, solve the average length $E(U_i)$ of i-th channel packet successfully sent in the event of U.

Packet successfully sent into the following two cases:

(1) If packets arrive during the last slot of idle period, namely packet arrives at the continuous clock control, and in the next slot time, no one but it adhere to send it, then it is sent successfully, the record for the event is Ui_1.

The average length of Ui_1 in channel i is:

$$E(Ui_1) = E(N_{Ui_1}) \times 1 = \frac{ap_1 G_i e^{-ap_1 G_i}}{1 - e^{-ap_1 G_i}} \quad (2)$$

(2) If the packet arrives at the busy period, and the packet is the only packet adhere to sent at the current TP period, then the packet will be successfully transmitted within the next TP period, referred to as an event of Ui_2.

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

$$q_0 = e^{-p_1 p_2 G_i (1+a)} \quad (3)$$

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

$$q_1 = p_1 p_2 G_i (1+a) e^{-p_1 p_2 G_i (1+a)} \quad (4)$$

In a cycle, the average length of information packets transmitted successfully at the Ui_2 in channel i is:

$$E(Ui_2) = \frac{q_1}{q_0} = p_1 p_2 G_i (1+a) \quad (5)$$

Then the average length $E(U_i)$ is:

$$E(U_i) = E(Ui_1) + E(Ui_2) = \frac{p_1 G_i a e^{-p_1 G_i a}}{1 - e^{-p_1 G_i a}} + p_1 p_2 G_i (1+a) \quad (6)$$

Secondly, solving average length $E(B_i)$ during the busy period at the i-th channel.

$$E(B_i) = E(N_{B_i})(1+a) = \frac{1}{q_0}(1+a) = \frac{1+a}{e^{-p_1 p_2 G_i (1+a)}} \quad (7)$$

Finally, solving average length $E(I_i)$ during the idle period of the i-th channel.

Since the number of idle slots I within the geometric distribution with the mean: $E[N] = \frac{1}{1 - e^{-G_i p_1 a}}$, an information packet arrive in a time slot with normalized probability: $p_{I1} = \frac{G_i p_1 a e^{-G_i p_1 a}}{1 - e^{-G_i p_1 a}}$, more than an information packet arrives in a time slot with the normalized probability: $p_{I2} = \frac{1 - G_i p_1 a e^{-G_i p_1 a} - e^{-G_i p_1 a}}{1 - e^{-G_i p_1 a}}$.

Then we get:

$$E(I_i) = \left(\frac{1}{1 - e^{-G_i p_1 a}} - 1\right)a + \frac{G_i p_1 a^2 e^{-G_i p_1 a}}{2(1 - e^{-G_i p_1 a})} + \frac{(1 - G_i p_1 a e^{-G_i p_1 a} - e^{-G_i p_1 a})a}{1 - e^{-G_i p_1 a}} \quad (8)$$

The throughput of the new protocol in channel i is:

$$\begin{aligned} S_i &= \frac{E(U_i)}{E(B_i) + E(I_i)} \\ &= \left[\frac{p_1 G_i a e^{-p_1 G_i a}}{1 - e^{-p_1 G_i a}} + p_1 p_2 G_i (1+a)\right] \\ &\quad / \left[\frac{1+a}{e^{-p_1 p_2 G_i (1+a)}} + \left(\frac{1}{1 - e^{-G_i p_1 a}} - 1\right)a + \frac{G_i p_1 a^2 e^{-G_i p_1 a}}{2(1 - e^{-G_i p_1 a})} \right. \\ &\quad \left. + \frac{(1 - G_i p_1 a e^{-G_i p_1 a} - e^{-G_i p_1 a})a}{1 - e^{-G_i p_1 a}}\right] \end{aligned} \quad (9)$$

When there's more than one packet arrive, the collision will happen and the conflict will be resolved at the next time slot according to the modified binary tree conflict resolution mechanism. When there are some packets arrive in the conflict resolution, they will

be transmitted according to the non-persist CSMA protocol. After the resolution is done, the new packets will be transmitted according to the new protocol.
In a cycle, for channel i, the average effective length that collision packets have been successfully divided and retransmitted is:

$$E(N_{Bx_i})=\sum_{x=2}^{\infty}\frac{[p_1p_2G_i(1+a)]^x e^{-p_1p_2G_i(1+a)}}{x!(1-e^{-ap_1G_i})e^{-ap_1G_i}} \tag{10}$$

$$\begin{aligned}E(U_{Bx_i})&=E(N_{Bx_i})\times x\\&=\sum_{x=2}^{\infty}\frac{x[p_1p_2G_i(1+a)]^x e^{-p_1p_2G_i(1+a)}}{x!(1-e^{-ap_1G_i})e^{-ap_1G_i}}\end{aligned} \tag{11}$$

The average length $E(U_i^*)$ is:

$$\begin{aligned}E(U_i^*)&=E(N_{U_i})\times(1+a)\\&=\frac{q_1}{q_0(1-q_0)}\times(1+a)\\&=\frac{(1+a)p_1p_2G_i(1+a)e^{-p_1p_2G_i(1+a)}}{e^{-p_1G_ia}(1-e^{-p_1G_ia})}\end{aligned} \tag{12}$$

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.

$$p_{ij}=p_{ij}^{'}+p_{ji}^{'} \tag{13}$$

$$p_{i(x-i)}=2!C_x^iC_{x-i}^{x-i}p^x=2!C_x^ip^x \tag{14}$$

In Equation (14), x is the odd number, $i=0,1,...,[N/2]$.

$$p_{(x/2)(x/2)}=C_x^{x/2}p^x \tag{15}$$

In the Equation (15), x is the even number. The average length of successfully resolve the x collision packets are:

$$\begin{aligned}E(L_x)&=p_{0x}[1+E(L_x)]+p_{1(x-1)}^{'}[1+E(L_{x-1})]\\&\quad+p_{(x-1)1}^{'}[2+E(L_{x-1})]+\sum_{i=2}^{[x/2]}p_{i(x-i)}[1+E(L_i)+E(L_{x-i})]\\&=\frac{p_{0N}+p_{1(x-1)}^{'}[3+2E(L_{x-1})]}{1-p_{0x}}+\frac{\sum_{i=2}^{[x/2]}p_{i(x-i)}[1+E(L_i)+E(L_{x-i})]}{1-p_{0x}}\end{aligned} \tag{16}$$

$$\begin{aligned}E(Bx_i)&=E(N_{Bx_i})(1+a)\times(x+E(L_x))\\&=\sum_{x=2}^{\infty}\frac{[p_1p_2G_i(1+a)]^x e^{-p_1p_2G_i(1+a)}(1+a)}{x!(1-e^{-ap_1G_i})e^{-ap_1G_i}}\bullet(x+E(L_x))\end{aligned} \tag{17}$$

The throughput of double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism for channel i, is:

$$S_i^{'}=\frac{E(U_i)+E(U_{Bx_i})}{E(U_i^*)+E(I_i)+E(Bx_i)} \tag{18}$$

In the N channels of wireless communication system, because this channel model is a load equilibrium model, so the arrival probabilities of each channel are the same, that is to say:

$$G_1=G_2=G_3=\cdots=G_i=\cdots=G_N=G \tag{19}$$

Basing on the above analysis and computational formula of the systemic throughput.
The systemic throughput of double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism is:

$$S = NS_i^{'} \tag{20}$$

The arrival probability of the business with the priority l in channel i is

$$\lambda_i = \frac{G_i}{N-i+1}(i \le l) \tag{21}$$

Assuming that the length of information packet sent by the business with priority l successfully in the average cycle period of channel i is: $E(U_i^{(pl)})(i \le l)$.

Then according to the above analysis, we can get the throughput of the double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism with the priority l:

$$S_{pl} = (\sum_{i=1}^{l} \frac{1}{N-i+1})S_i^{'} \tag{22}$$

The Analysis of System Delay

First do the following assumptions before analyze the system delay: the monitoring signal can always being transmitted correctly; the time generating monitoring signal can be ignored; R is the average delay of a packet to be transmitted twice, then R is formed by four parts: the time that information packet transmitted 1, round-trip propagation delay a, and the average retransmission delay δ [Huang Jiancheng et al., 1983]. R is the average delay of a packet to be transmitted twice, then $R = 1 + a + \tau_A + \delta$.
$(\frac{G}{S} - 1)$ is the average number of information packets be retransmitted [Zhao Dongfeng, 1999].

The average delay of information packets for the three-dimensional probability CSMA protocol is:

$$D = (\frac{\frac{p_1 G_i a e^{-p_1 G_i a}}{1-e^{-p_1 G_i a}} + p_1 p_2 G_i (1+a)}{\frac{1+a}{e^{-p_1 G_i (1+a)}} + (\frac{1}{1-e^{-G_i p_1 a}} - 1)a + \frac{G_i p_1 a^2 e^{-G_i p_1 a}}{2(1-e^{-G_i p_1 a})} + \frac{(1 - G_i p_1 a e^{-G_i p_1 a} - e^{-G_i p_1 a})a}{1-e^{-G_i p_1 a}}} - 1)R + 1 + \tau_A \tag{23}$$

The Analysis of Energy Efficiency

Assuming the transmitting power of sensor node is P_{tx}, receiving power is P_{rx}, the power of detection channel is P_{dd}.
1)Energy consumption analysis (1) Sending consumption: during the busy time, the average number of the information packets which arrived within a transmission period $(1+\tau_A)$, to be sent at the starting time of next transmission period in the idle state is $GP_1P_2(1+\tau_A)$; the average number of information packets arrived within a which decide to transmit when detecting the channel is idle is GP_1P_2a, then there is $(\frac{E(B)}{1+a+\tau_A} - 1)$ transmission periods in a channel period [Zhao Dongfeng, 1997].
The number of information packets which arrived at the last slot of idle period and be transmitted successfully in the transmission period is GP_1a, and then the sending consumption in the transmission period is

$$W_t = P_{Tx} GP_1P_2(a+1+\tau_A)(\frac{E(B)}{1+a+\tau_A} - 1) + P_{Tx} GP_1 a \tag{24}$$

(2) Receiving consumption: the receiving consumption in the next transmission period is: $W_{rec} = E(U)P_{Rx}$.

(3) Sensing consumption: for the busy period, the detecting total duration in a transmission period $(1+\tau_A)$ that the information packet who wants to be sent within need is $(a + 0.5 + 0.5\tau_A)GP_1P_2(1+\tau_A)$, the total duration that the information packets want to send after detecting the channel is idle need to be sent in the time a is $GP_1P_2a^2$, the number of TP in busy time is $\frac{E(B)}{1+a+\tau_A}$, then the sensing duration of all service nodes in the busy time is:

$$t_d(B) = \frac{E(B)}{1+a+\tau_A} P_1 P_2 G[a^2 + (1+\tau_A)(a+0.5+0.5\tau_A)] \quad (25)$$

The detecting duration of all service nodes in the idle time is:

$$t_d(I) = \frac{a^2}{2} GE(I) \frac{a}{1-e^{-GP_1 a}} \quad (26)$$

Then the sensing consumption in the next T_i is:

$$W_d = (t_d(B) + t_d(I))\ P_{lsm} \quad (27)$$

Therefore, the average operating power of channel *i* is:

$$P(S) = \frac{W_t + W_{rec} + W_d}{E(B) + E(I)} \quad (28)$$

The life cycle of node

For the terminal nodes, assuming it sleeps 1 at a time, then it sleeps *a* within time *a*, the average power of the node which priority is *l* in the N nodes is:

$$P_d = \frac{W_t + W_d}{E(B) + E(I) + [q_0 + q^0_{\tau_A} \tau_A + a e^{-ap_1 G_i}] \frac{E(B)}{1+a+\tau_A}} \quad (29)$$

Where, $q^0_{\tau_A}$ is the definition of the probability that there is no packet to be sent within time τ_A in a transmission period, $q^0_{\tau_A} = e^{-GP_1P_2\tau_A}$.

For the aggregation nodes, the average power is:

$$P_s = \frac{W_{rec} + P_{lsm} \frac{E(I)+E(B)}{T_s} a}{2E(B) + E(I) + \frac{E(I)}{a}} \quad (30)$$

Since the energy consumption is constant in the transmission process, therefore, for the terminal, the lifecycle T_d is:

$$T_d = \frac{E}{24 \times 365 \times P_d + 0.1E} \quad (31)$$

For the aggregation node, the lifecycle T_s is:

$$T_s = \frac{E}{24 \times 365 \times P_s + 0.1E} \quad (32)$$

SIMULATION

From the above analysis, the expression of the system throughput under the double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism is got. Based on the above analysis, with the use of simulation tool: MATLAB R2010a, the simulation results are shown as following. During the simulation, transmission delay time: $a = 0.01$. In Fig. (**2**) and Fig. (**3**), the simulation values of system throughput under the new protocol are consistent with the theoretical ones, verified the correctness of mathematical derivation done before. We can see that we are able to control the system throughput by change the probability of sending packet or the probability of sensing channel. Also we can change both of them at the same time too. By the introduction of binary trees conflict resolution, even if when G_i increase greatly, the system throughput still holds a value stably. The new protocol can adapt many kinds of network environments, even the heavy network load in particular. So the new protocol can perform better than other protocols when the channel arrival rate G_i is great while the other common CSMA protocol's system throughput will get to zero when the arrival rate of packets reaches a certain number.

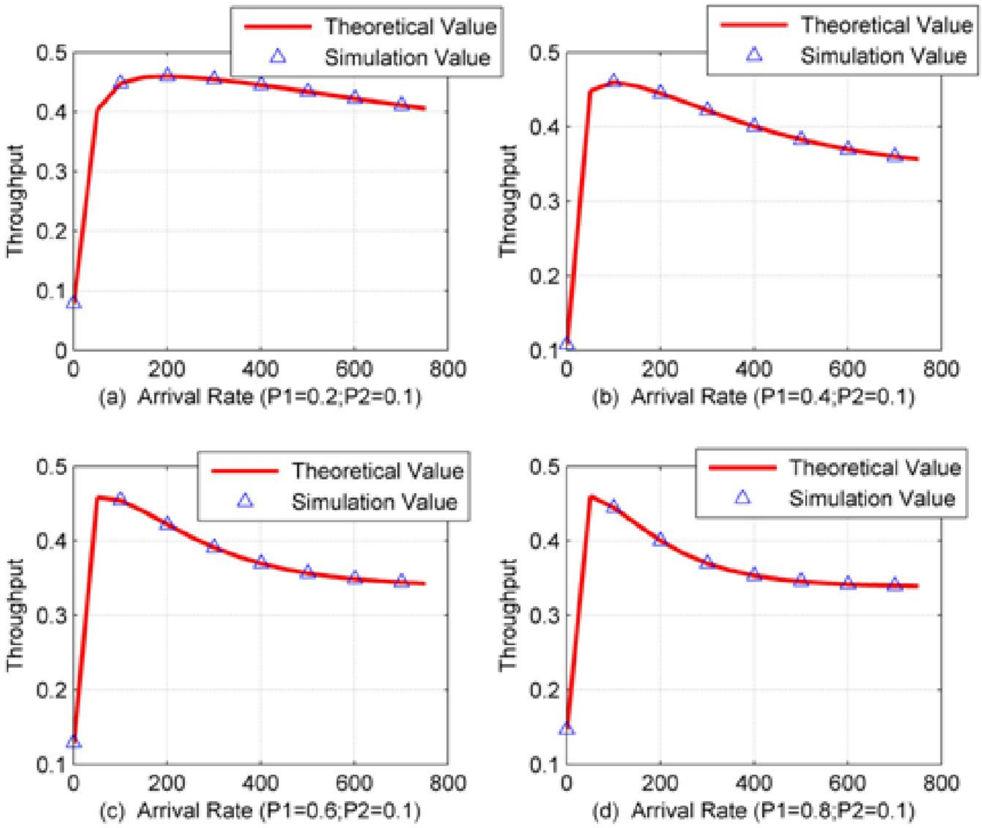

Fig. (2). The throughput of the new protocol with different P1 for channel i .

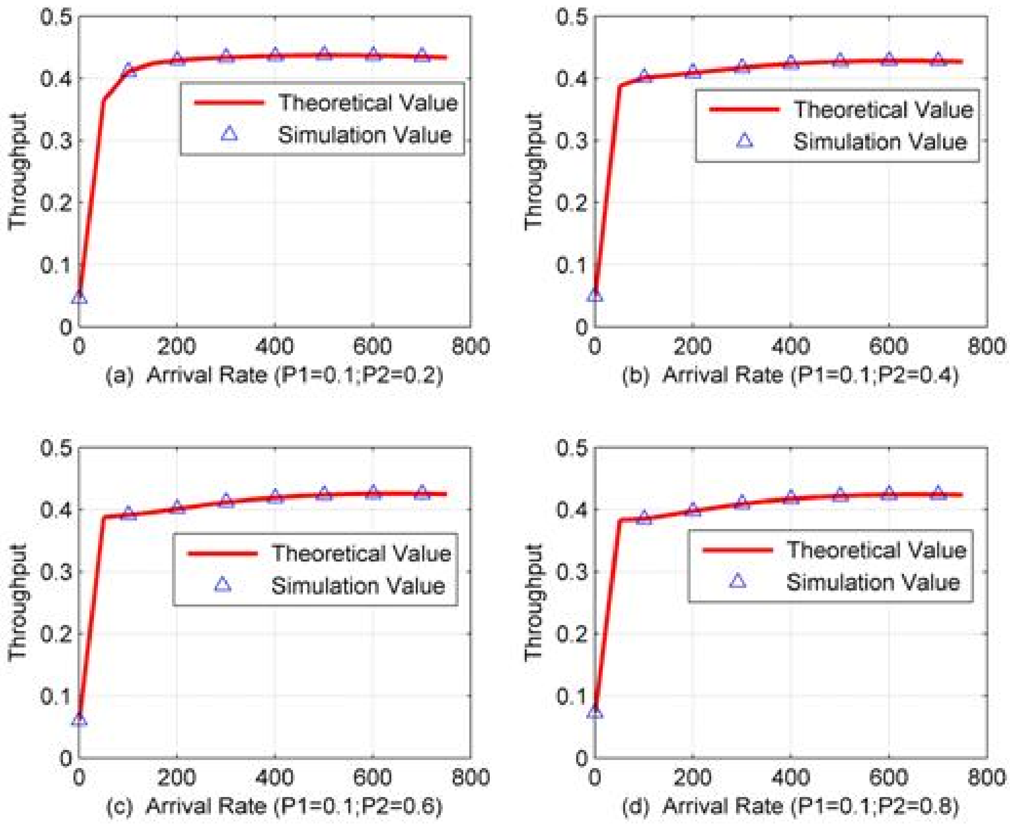

Fig. (3). The throughput of the new protocol with different P2 for channel i .

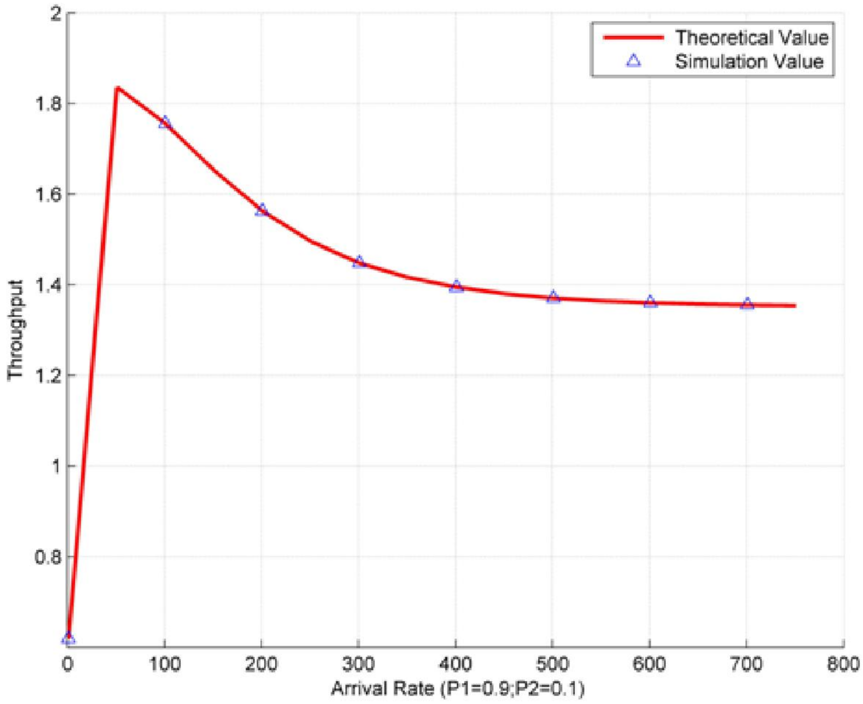

Fig. (4). The throughput of the new protocol with 4 channels

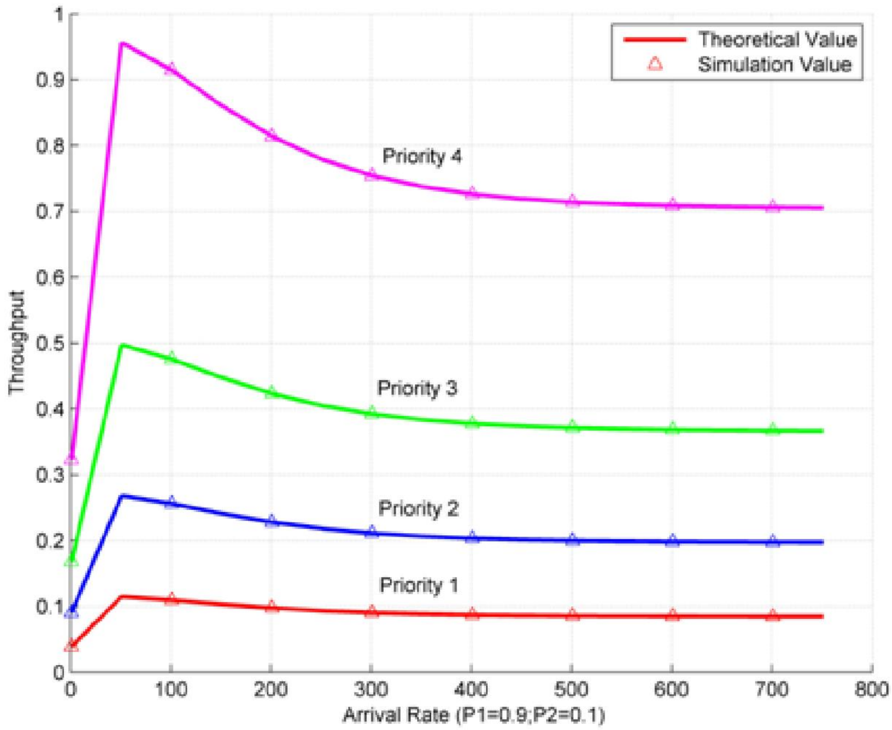

Fig. (5). The comparison of 4 channels with different priorities

From the Fig. (**4**) to the Fig. (**7**), we know the simulation values of system throughput under the new protocol are consistent with the theoretical ones, verified the correctness of mathematical derivation done before.

By the adoption of the multi-channel mechanism, with the number of channels increases from 4 to 5, the new protocol's total system throughput increases too. And by the mechanism of multi-channel, the higher priority channel is the more network resources it gets. More importantly, our assumptions are realized, we can distribute the channel resources to users according to their priority separately, improves the channel utilization, reliability of packet transmission, and meets the different priority of different QoS requirements.

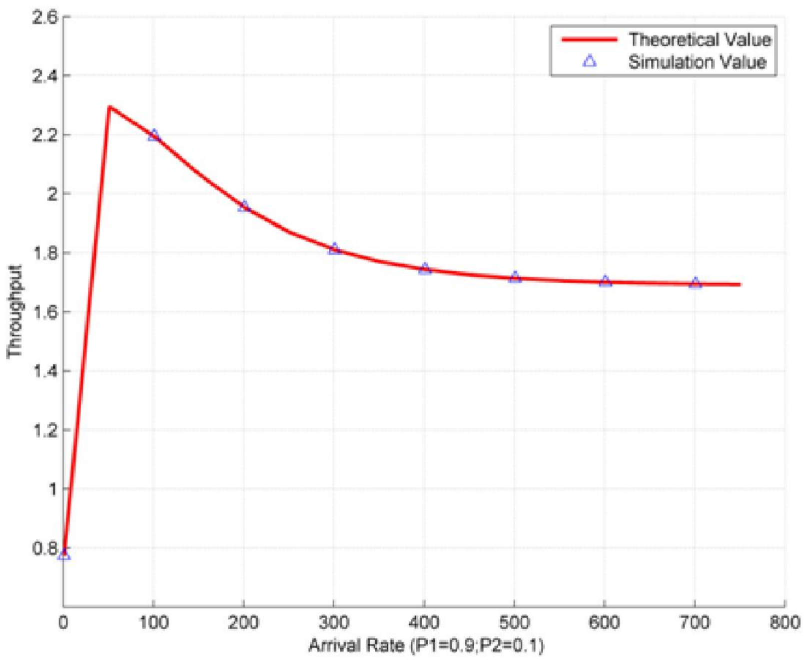

Fig. (6). The throughput of the new protocol with 5channels

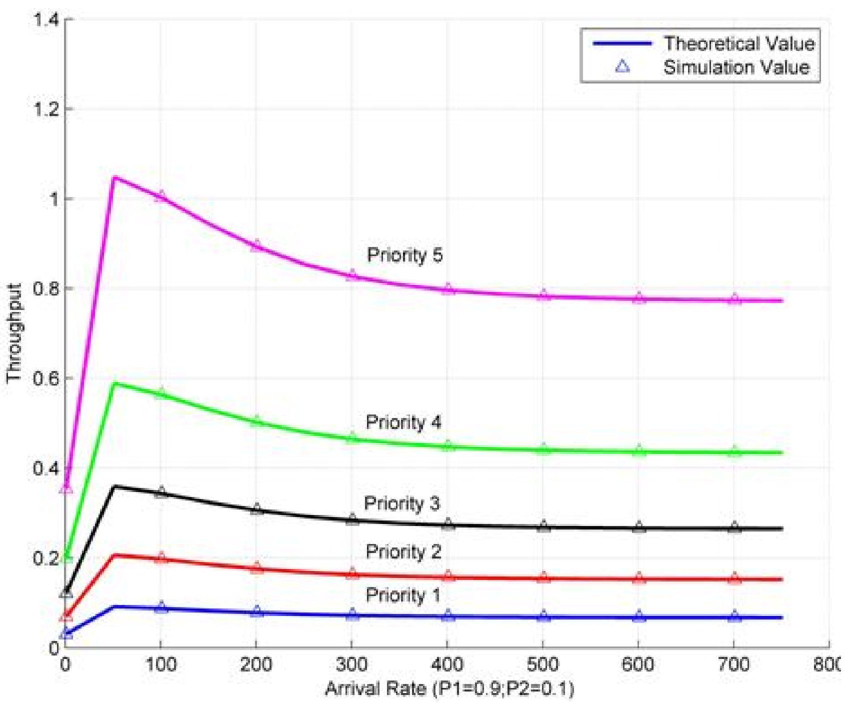

Fig. (7). The comparison of 5channels with different priorities

Conclusion

With new requirements and challenges for multi-users to share limited spectrum resources and ensure the Quality of Service of wireless communication network. Based on the successful application of double clocks control to ALOHA, we try to apply this theory to the CSMA protocols. We set the probability of sending packet and the probability of sensing channel to improve system performance. We introduce binary tree conflict resolution mechanism which could resolve the conflict and resent the information packets in conflict which is inevitable in the CSMA protocol. Based on the above two considerations, we proposed a double clocks multi-channel two-dimensional probability CSMA based on binary tree conflict resolution mechanism which improves the controllability of the system, the channel utilization, system security, and reliability of packet transmission, meets the different priority of different QoS requirements.

Using the averaging cycle period conduct analytical and simulation experiment with the control strategy mentioned above. By modeling analysis, the analytical results and simulation results show that the theoretical analysis are consistent with the simulation experiments and has a better performance than the common CSMA protocols.

Conflict of Interest

The author confirms that this article content has no conflict of interest.

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