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STUDY ON THE DISCRETE TIME MULTICHANNEL THREE-DIMENSIONAL PROBABILITY CSMA PROTOCOL IN WSN

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Abstract- With the development of the times, in the wireless sensor networks, the increasing amount of information transmission requires more advanced transmission protocols. Especially accompanied by the arrival of the era of Big Data, the conflicts between traditional transport agreement and the sudden or large amount of data are increasingly prominent. The discrete time three-dimensional probability CSMA protocol with multichannel mechanism proposed solves these problems pretty well. By the new MAC protocol to control transmission of information, so that the agreement adapts various contingencies problems in the network better and has more controllable ability. Using simulation tool-MATLAB for the accuracy of the agreement is demonstrated.

Index terms: Wireless Sensor Network, three-dimensional probability, CSMA, multichannel, throughput.

I. INTRODUCTION

Wireless Sensor Network (WSN) is a self-organized network of tiny computing and communication devices or nodes which has been widely used in several un-attended and dangerous environments [1]. With the rapid development and wide application of communication and network technology, people's lives as the society are greatly improved for its convenience. Due to cabling complexity, wired systems are expensive and require great effort for deployment and maintenance. Wireless sensor networks develop fast in wireless network technology in recent years [2].

Wireless sensor networks are a class of wireless Ad Hoc networks, for which the low power consumption is the main requirement. Because sensor nodes may be deployed in remote locations, it is likely that replacing their battery will not be possible. The lifetime of the sensor network is hence limited by the lifetime of the nodes' battery. To be deployable in large quantities, the price of the sensors must be very low [3]. The low cost requirement implies the usage of batteries of modest capacity. The low power consumption is hence a major requirement in the design of communication protocols for sensor networks [4]. Research on WSN is very significant in promoting the application of information technology in national defense， meeting the requirements of some special application field，boosting the transfer of the core technology achievements and finally Popularizing WSN to social life as a new point for economic growth [5].

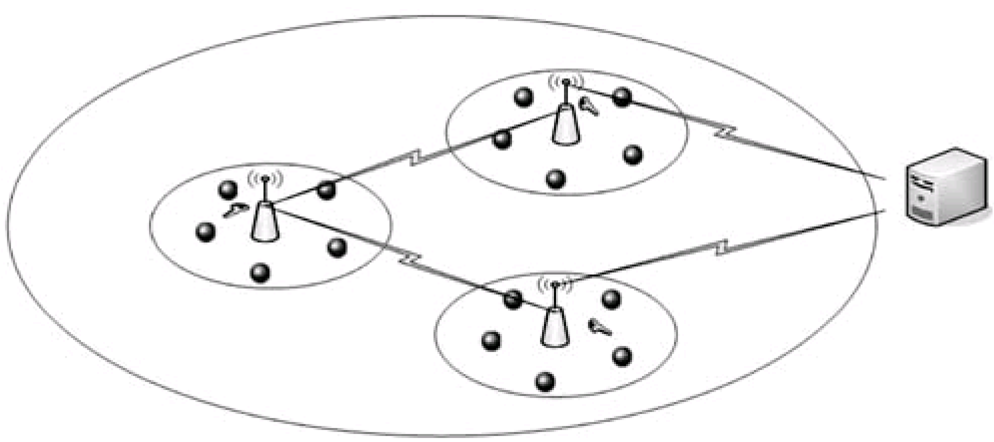

Figure 1. The WSN typical structure

The WSN has many applications, such as:

Process Management: it's not working for cables or wires only sensors in management [6].

Area monitoring: area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored [7]. A military example is the use of sensors detects enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines [8].

Health care monitoring: the medical applications can be of two types: wearable and implanted. Wearable devices are used on the body surface of a human or just at close proximity of the user. The implantable medical devices are those that are inserted inside human body [9]. There are many other applications too e.g. body position measurement and location of the person, overall monitoring of ill patients in hospitals and at homes. Body-area networks can collect information about an individual's health, fitness, and energy expenditure [10].

Environmental/Earth sensing: there are many applications in monitoring environmental parameters, examples of which are given below. They share the extra challenges of harsh environments and reduced power supply [11].

Air pollution monitoring: wireless sensor networks have been deployed in several cities to monitor the concentration of dangerous gases for citizens [12]. These can take advantage of the ad hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas [13].

Forest fire detection: a network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading [14].

Landslide detection: a landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide [15]. Through the data gathered it may be possible to know the occurrence of landslides long before it actually happens [16].

Water quality monitoring: water quality monitoring involves analyzing water properties in dams, rivers, lakes & oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval [17].

Natural disaster prevention: wireless sensor networks can effectively act to prevent the consequences of natural disasters, like floods [18]. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time.

Machine health monitoring: wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality.

Wireless sensors can be placed in locations difficult or impossible to reach with a wired system, such as rotating machinery [19].

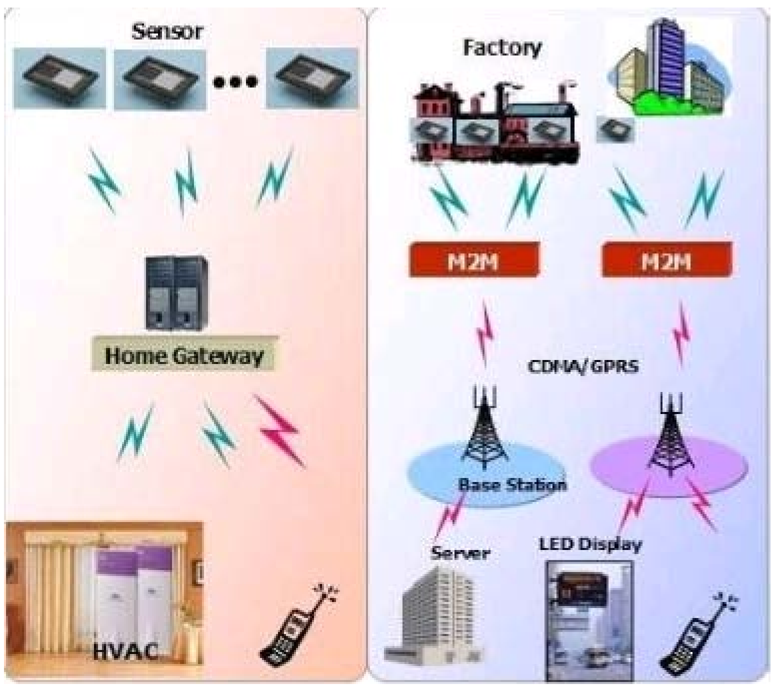

Figure 2. Some applications of WSN

Data logging: wireless sensor networks are also used for the collection of data for monitoring of environmental information; this can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants [20]. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible.

Water/Waste water monitoring: monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country’s water infrastructure for the benefit of both human and animals. It may be used to protect the wastage of water [21].

Structural health monitoring: wireless sensor networks can be used to monitor the condition of civil infrastructure and related geo-physical processes close to real time, and over long periods through data logging, using appropriately interfaced sensors [22].

However, with the rapid development of satellite communications system, wireless packet network and computer communication network presently, random multi-access technology has to be confronted with novel challenge and development [23]. Multi-channel and random multi-access protocols make the network possess many advantages such as reducing time delay, increasing throughput, using enough channels resource and so on.

Thus, the random multi-access mode has broader and broader application in wireless communication network. Medium access control protocol, which can also be called as channel access protocol, is used to decide how to share the finite resource and has an important effect on wireless network [24, 25]. Presently, research on the MAC protocol integrating multiple access technology, multi-service and multi-sever have become the heated topic.

MAC protocol is responsible for allocating limited communication resources among sensor nodes to construct the underlying communication structure of the sensor network system, and therefore is an important aspect of sensor network research.

In this paper, we propose a discrete time multichannel three-dimensional probability CSMA protocol to improve the controllability of the system for WSN. The rest of the paper is structured as follows. After discussing related work covering the above four mentioned aspects in the next section, the model of proposed protocol is elaborated in Section 3. Certain parameters are described and algorithm is elaborated in Section 4. Section 5 presents the simulation setup followed by simulation results and its analysis. Finally Section 6 concludes the paper.

II. RELATED WORK

Shengjie Zhou et al. proposed a three-dimensional probability CSMA (Carrier Sensing Multiple Access) which can change the probabilities according to the network environment, using MATLAB to simulate, simulation results showing much better performance of the system throughput compared with the existing CSMA protocols like 1-persistent CSMA or p-persistent CSMA protocol.

Shengjie Zhou et al. proposed a multichannel three-dimensional probability CSMA protocol which could improve the system performance, such as: system throughput et.al.

a. Getting the precise expression of system throughput

Using the average cycle analysis method, through the rigorous data derived, we get the accurate expression of the system throughput.

b. Reducing the packets dropped

By changing the probabilities, the proposed protocol can adapt the network load more perfect which resolves the congestion when the network load is heavy. Adding the multichannel mechanism, it makes the system utilization of channel resources higher.

c. Increasing the system throughput

Introducing three-dimensional probability and the multichannel mechanism, improves the system controllability. The throughput of the new protocol is also increased by introducing the multichannel mechanism.

d. Improving the system QoS

Multi-channel technology, making the system throughput is improved, meets the needs of different traffic and business. QoS (Quality of Service) of the overall system has been greatly improved.

III. DISCRETE TIME MULTICHANNEL THREE-DIMENSIONAL PROBABILITY CSMA MODEL

In the proposed protocol, there will be three random events: a packet is sent successfully(U events), the packet transmission is sent unsuccessfully(the collision appears, C events), the channel is idle (I events), these three events are forced into: the channel is idle (I events) event, the channel is busy (CU events) and the channel is idle following the CU events (CUI events); the packet is sent successfully or unsuccessfully(combined C events with U event, denoted by CU event); force the CU events and the CUI events into B events. A cycle period is T_n. TP is the transmission period. Use three-dimensional probability: $P1$, $P2$, $P3$ to control the period of I events, CUI events and CU events separately.

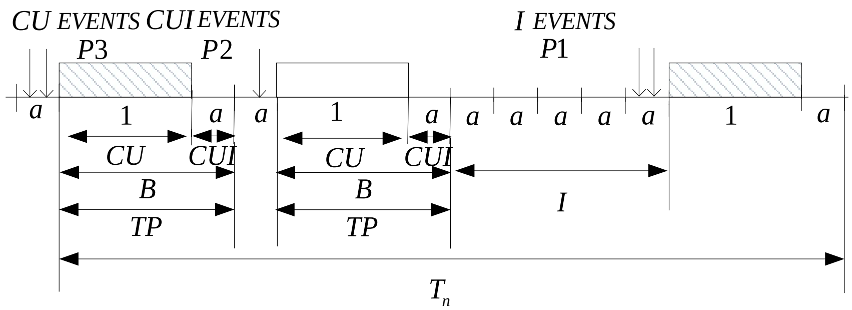

Figure 3. The model of three-dimensional probability CSMA protocol with multichannel mechanism in channel i

Consider the system having N channels and N priorities, the nodes are accessed to the channels randomly by the business priorities of themselves. Assume that the priority sequence is arranged from low to high as priority 1, priority 2… priority N. The service with priority i occupies channel 1 to i (i=1, 2… N), that is the service with priority 1 occupies channel 1, priority 2 occupies channel 1 and channel 2, and the service with priority N occupies channel 1 to channel N.

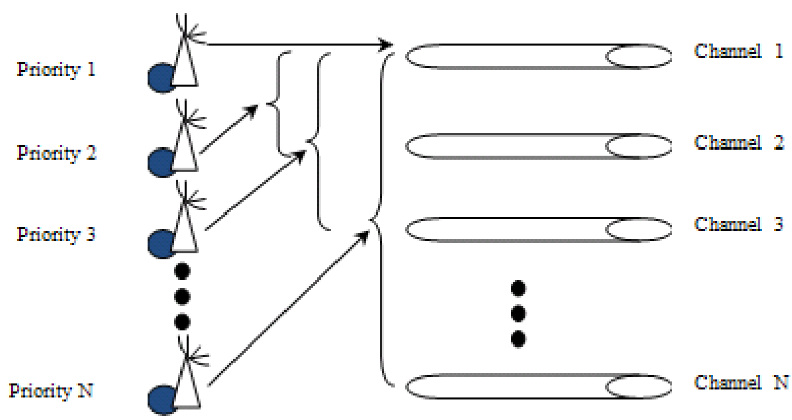

Figure 4. The multichannel mechanism owning N channels

In channel i, if the channel is idle, then the user decides to send an information packet probability $P1$; in the transportation period, if the channel is the first idle following the CU events, then the user listens to the channel at probability $P2$; if the channel is busy, the user listens to the channel at probability $P3$. This control strategy, $P1$, $P2$ and $P3$ by three-dimensional selection enables the system under different load utilization and throughput is guaranteed.

IV. 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 $i\left(i=1,2,...,N\right)$ channel is timeslot p-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 three-dimensional probability 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.

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

$$q_1^0 = e^{-ap_1G_i} \tag{1}$$

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

$$q_1^1 = ap_1G_ie^{-ap_1G_i} \tag{2}$$

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

$$q_3^0 = e^{-(ap_2+p_3)G_i} \tag{3}$$

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

$$q_{1+a}^{1} = (ap_2 + p_3)G_i e^{-(ap_2+p_3)G_i} \tag{4}$$

In a cycle, the possibility of continuous r idle I events and j B events in channel i is:

$$P(N_I = r, N_B = j) = (e^{-ap_1G_i})^{r-1}(1-e^{-ap_1G_i})(1-e^{-(ap_2+p_3)G_i})^{j-1}e^{-(ap_2+p_3)G_i} \tag{5}$$

The possibility of $E(N_I)$, the average number of r continuous I events in channel i in a cycle is:

$$\begin{aligned} E(N_I) &= \sum_{r=1}^{\infty}\sum_{j=1}^{\infty} rP(N_I = r, N_B = j) \\ &= \sum_{r=1}^{\infty}\sum_{j=1}^{\infty} r(e^{-ap_1G_i})^{r-1}(1-e^{-ap_1G_i})(1-e^{-(ap_2+p_3)G_i})^{j-1}e^{-(ap_2+p_3)G_i} \\ &= \frac{1}{1-e^{-ap_1G_i}} \end{aligned} \tag{6}$$

The possibility of $E(N_B)$, the average number of j continuous B events in channel i in a cycle is:

$$\begin{aligned} E(N_B) &= \sum_{r=1}^{\infty}\sum_{j=1}^{\infty} jP(N_I = r, N_B = j) \\ &= \sum_{r=1}^{\infty}\sum_{j=1}^{\infty} j(e^{-ap_1G_i})^{r-1}(1-e^{-ap_1G_i})(1-e^{-(ap_2+p_3)G_i})^{j-1}e^{-(ap_2+p_3)G_i} \\ &= \frac{1}{e^{-(ap_2+p_3)G_i}} \end{aligned} \tag{7}$$

The number of information packet transmitted successfully in channel i in I events is:

$$E(N_{U_1}) = \frac{q_1^1}{1-q_1^0} = \frac{ap_1G_i e^{-ap_1G_i}}{1-e^{-ap_1G_i}} \tag{8}$$

The average length of information packet transmitted successfully in channel i in I events is:

$$E(U_1) = E(N_{U_1}) \times 1 = \frac{ap_1G_i e^{-ap_1G_i}}{1-e^{-ap_1G_i}} \tag{9}$$

In a cycle, the average length of continuous K U events in the TP time in channel i is:

$$
\begin{aligned}
E(U_2) &= \sum_{r=1}^{\infty}\sum_{j=1}^{\infty}\sum_{K=0}^{r-1} KP(N_I = r, N_B = j) \\
&= \sum_{r=1}^{\infty}\sum_{j=1}^{\infty}\sum_{K=0}^{r-1} K(e^{-ap_1G_i})^{r-1}(1-e^{-ap_1G_i})(1-e^{-(ap_2+p_3)G_i})^{j-1}e^{-(ap_2+p_3)G_i} \\
&= (ap_2 + p_3)G_i
\end{aligned} \tag{10}
$$

In a cycle, the average length of time slot that information packet has been successfully sent in channel i in a cycle is:

$$
E(U_i) = E(U_1) + E(U_2) = \frac{ap_1G_ie^{-ap_1G_i}}{1-e^{-ap_1G_i}} + (ap_2 + p_3)G_i \tag{11}
$$

The average length of B event in channel i is:

$$
E(B_i) = E(N_B)\times(1+a) = \frac{1+a}{1-e^{-(ap_2+p_3)G_i}} \tag{12}
$$

where $(1+a)$ represents the length of information packet whether it transmitted successfully or not in channel i in the TP cycle.

The average length of I event in channel i is:

$$
E(I_i) = E(N_I)\times a = \frac{a}{1-e^{-ap_1G_i}} \tag{13}
$$

The throughput of the new protocol in channel i is:

$$
\begin{aligned}
S_i &= \frac{E(U_i)}{E(B_i)+E(I_i)} \\
&= \frac{\dfrac{ap_1G_ie^{-ap_1G_i}}{1-e^{-ap_1G_i}} + (ap_2 + p_3)G_i}{\dfrac{1+a}{1-e^{-(ap_2+p_3)G_i}} + \dfrac{a}{1-e^{-ap_1G_i}}}
\end{aligned} \tag{14}
$$

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:

$$
G_1 = G_2 = G_3 = \cdots = G_i = \cdots = G_N = G \tag{15}
$$

Basing on the above analysis and computational formula of the systemic throughput:

$$S=\sum_{i=1}^{N}\frac{E(U_i)}{E(B_i)+E(I_i)} \tag{16}$$

The systemic throughput of discrete time three-dimensional probability CSMA protocol with multichannel mechanism is:

$$S=NS_i=\frac{\frac{Nap_1G_ie^{-ap_1G_i}}{1-e^{-ap_1G_i}}+N(ap_2+p_3)G_i}{\frac{1+a}{1-e^{-(ap_2+p_3)G_i}}+\frac{a}{1-e^{-ap_1G_i}}} \tag{17}$$

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

$$\lambda_i=\frac{G_i}{N-i+1}(i\le l) \tag{18}$$

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 discrete time three-dimensional probability CSMA protocol with multichannel mechanism with the priority l:

$$S_{pl}=(\sum_{i=1}^{l}\frac{1}{N-i+1})\frac{\frac{ap_1Ge^{-ap_1G}}{1-e^{-ap_1G}}+(ap_2+p_3)G}{\frac{1+a}{1-e^{-(ap_2+p_3)G}}+\frac{a}{1-e^{-ap_1G}}} \tag{19}$$

V. SIMULATION RESULTS AND ANALYSIS

From the above analysis, the expression of the system throughput under the discrete time three-dimensional probability CSMA protocol with multichannel mechanism is got. With the simulation tool-MATLAB R2010a, the simulation results are shown in Figure 5 to Figure 13. If not specified $a=0.1$.

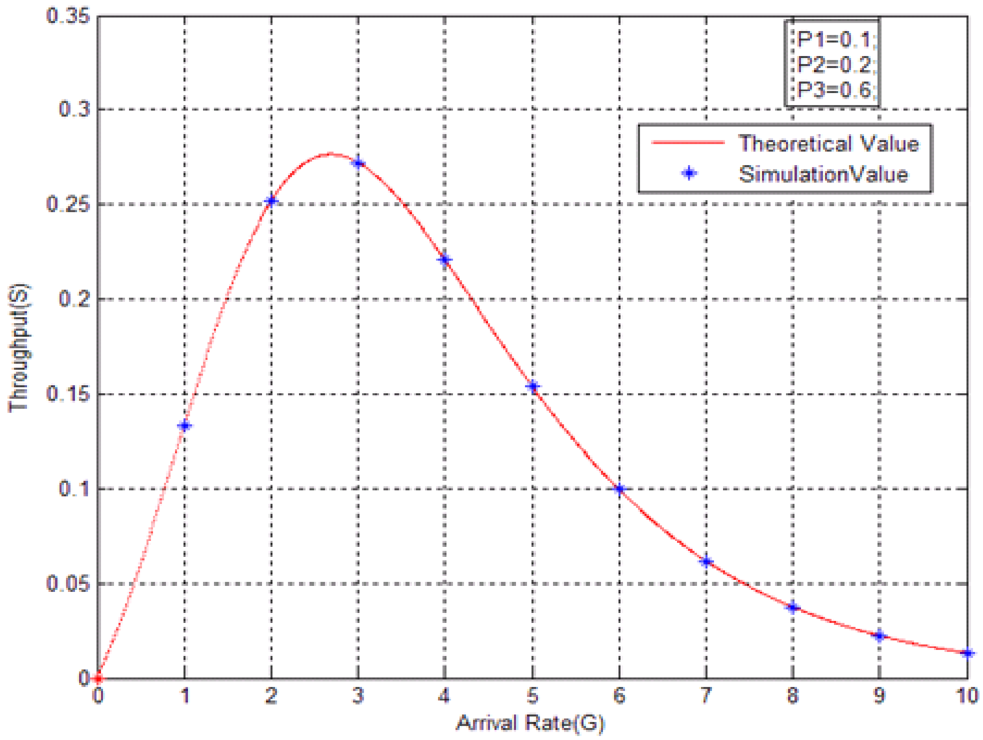

Figure 5. The throughput of the discrete time three-dimensional probability CSMA protocol

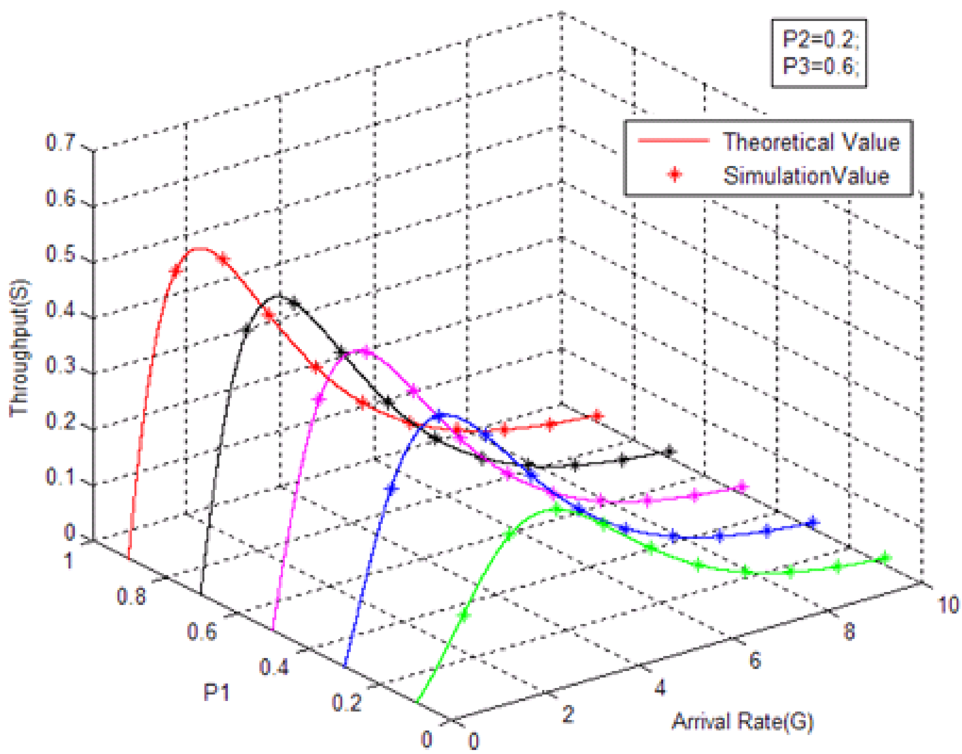

Figure 6. The throughput of the discrete time three-dimensional probability CSMA protocol with variable P1

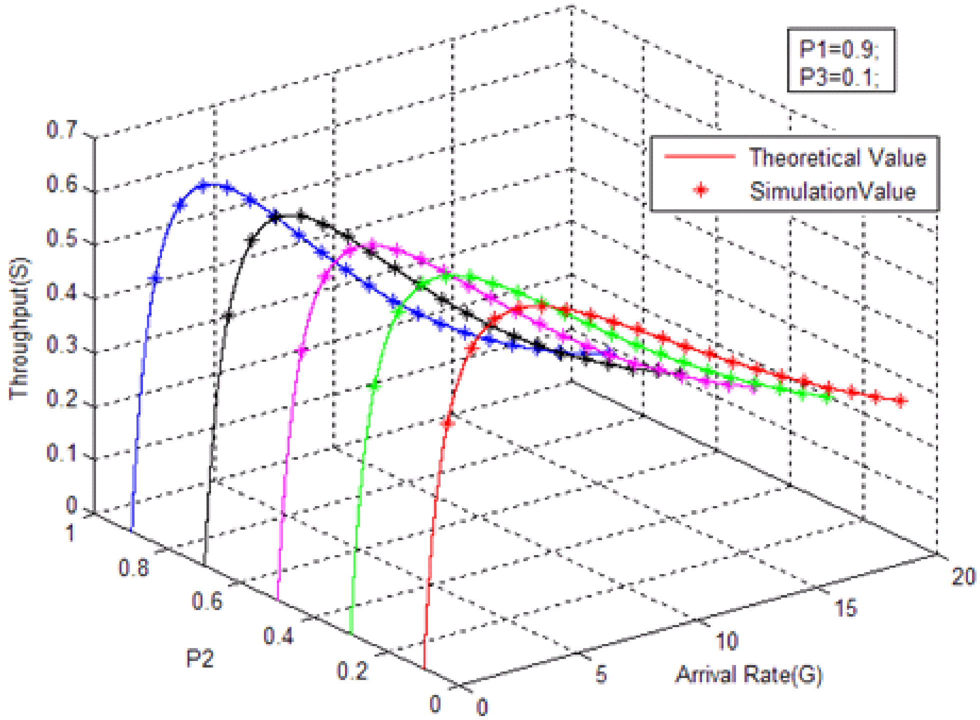

Figure 7. The throughput of the discrete time three-dimensional probability CSMA protocol with variable P2

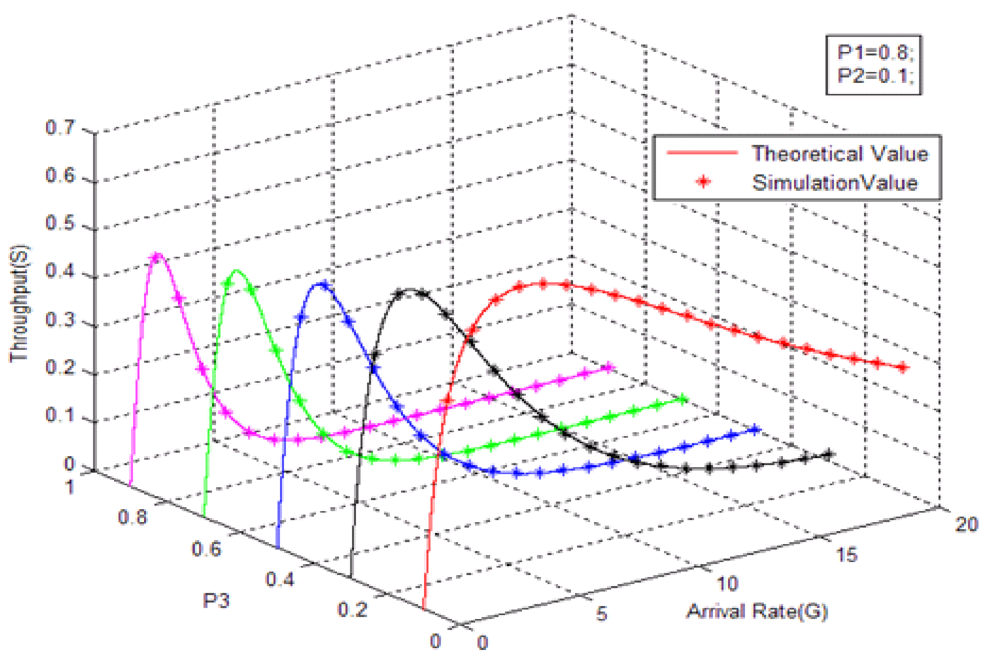

Figure 8. The throughput of the discrete time three-dimensional probability CSMA protocol with variable P3

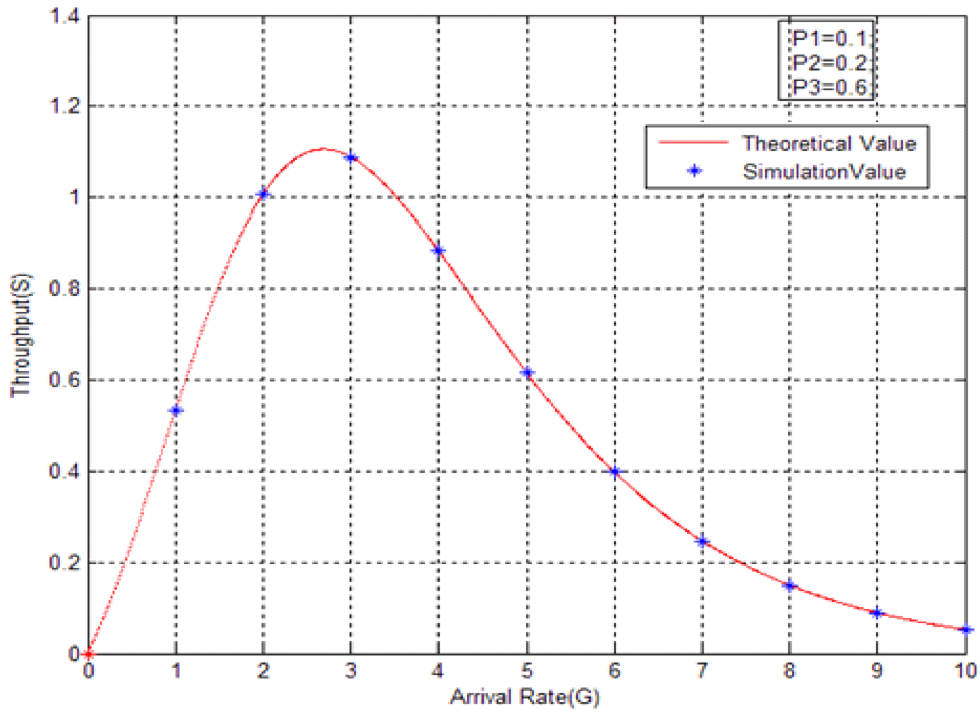

Figure 9. The throughput of the discrete time three-dimensional probability CSMA protocol with 4 channels

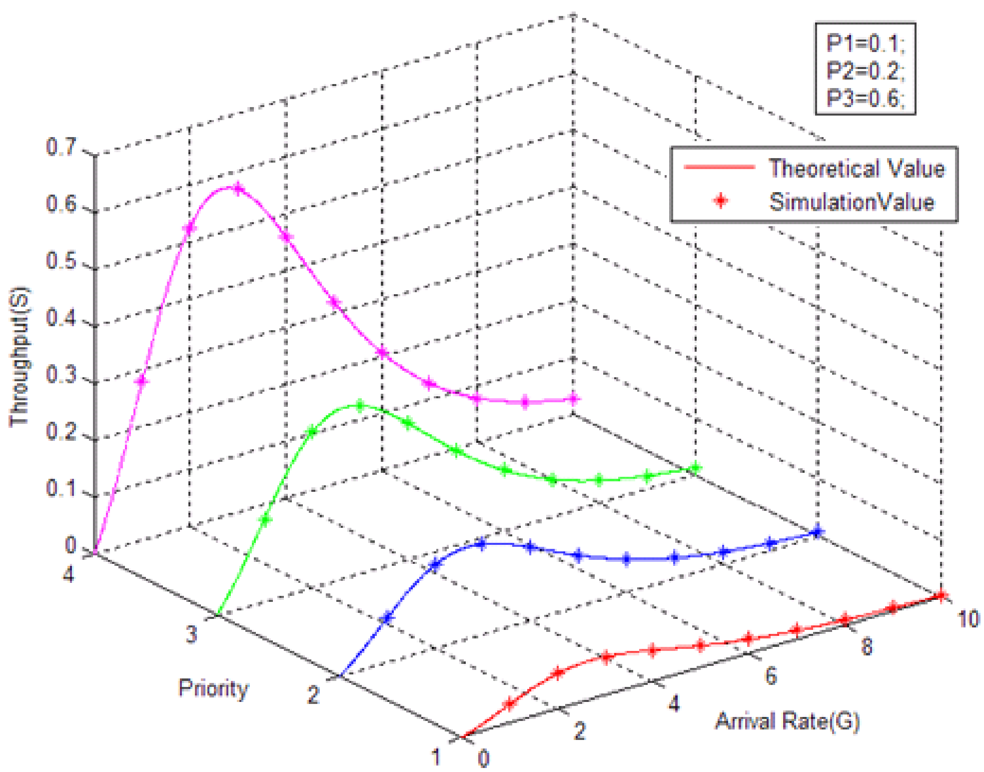

Figure 10. The comparison of 4 channels with different priorities

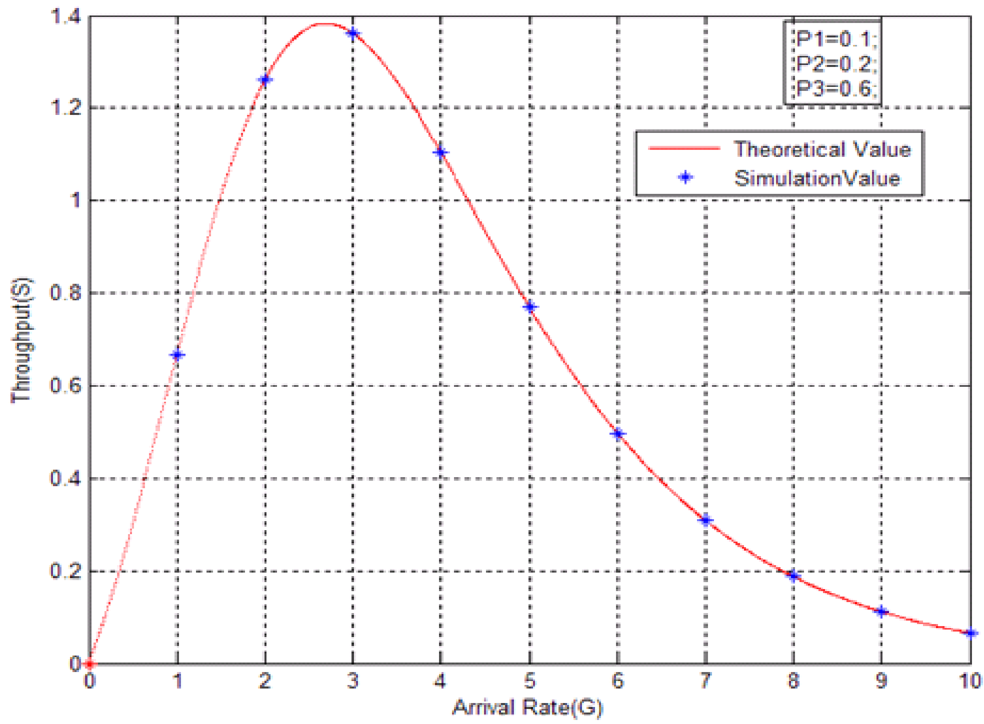

Figure 11. The throughput of the discrete time three-dimensional probability CSMA protocol with 5 channels

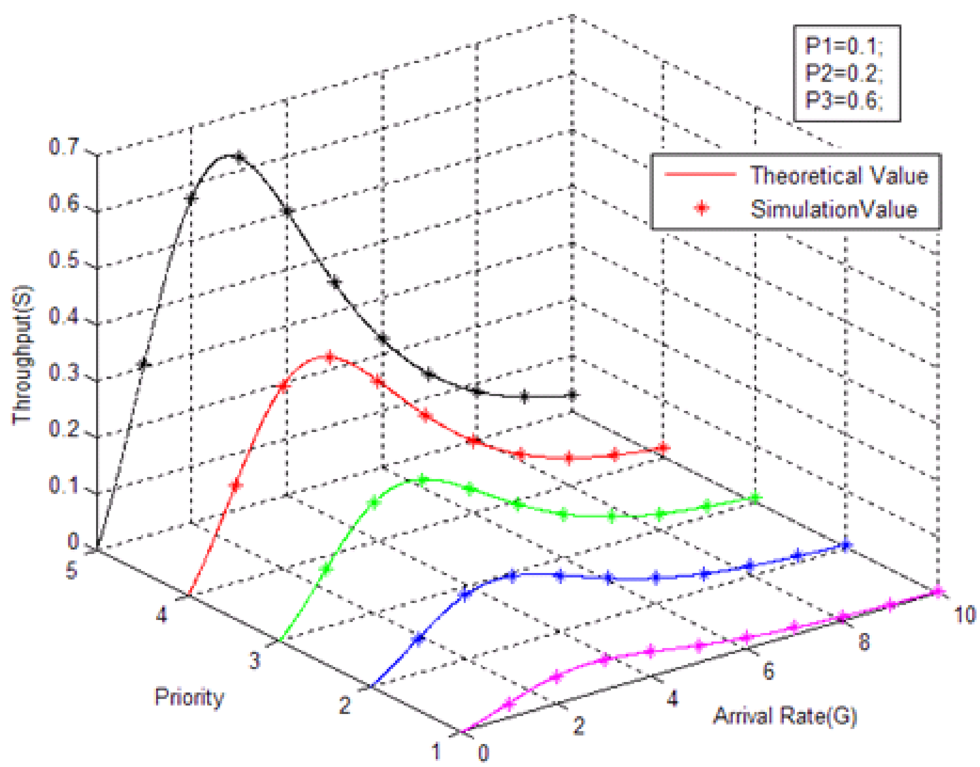

Figure 12. The comparison of 5 channels with different priorities

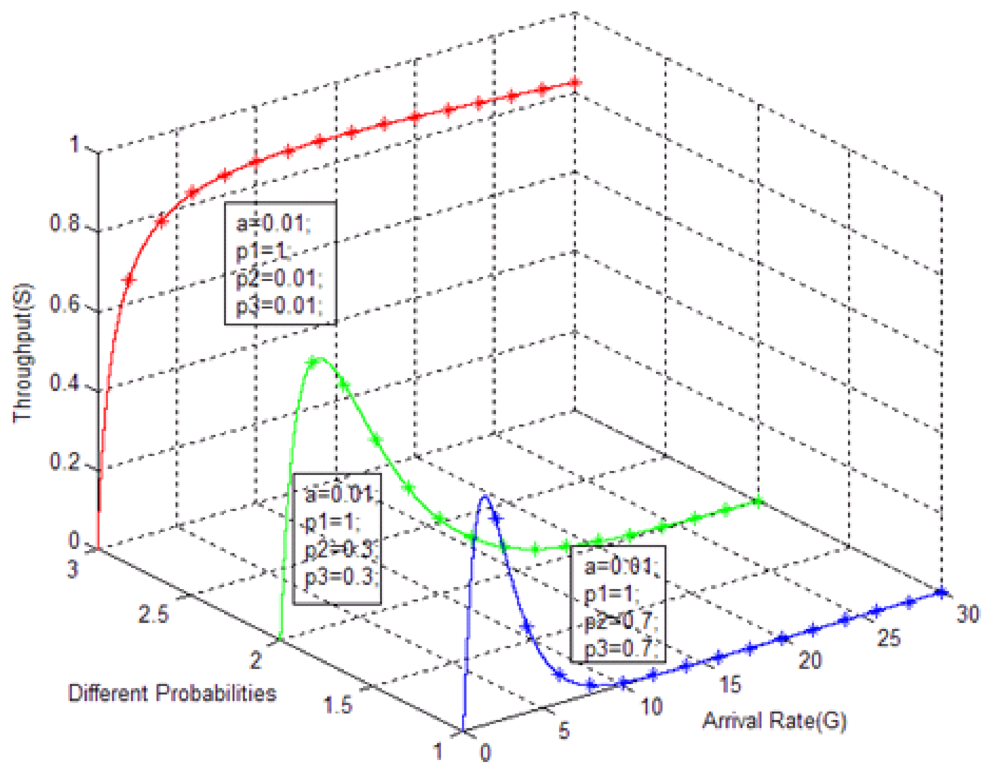

Figure 13. The comparison of system throughput under the new protocol with different probabilities

From Figure 5 to Figure 8, the simulation values of system throughput under the new protocol are consistent with the theoretical ones. First, when $P1$ becoming bigger, the throughput will increase, especially with small value of G_i ; because when the channel is idle, the probability of an information packet sent successfully will increases. But by contrast, when $P3$ becoming bigger, the throughput will decrease; because when the channel is busy sending the packet, the more new arrival information packets the more collisions will be. Third, when $P2$ becoming bigger, the cure of the system throughput will be steeper with subtle changes of its value.

Figure 9 through Figure 12, with the number of channels increases, the value of the new protocol's system throughput also increases; the priority is higher, the corresponding channel can get more network resources; network resources utilization has been greatly improved.

In the Figure 13, when $a = 0.01$ $P1 = 1$ $P2 = P3 = 0.01$, the throughput of the system under new protocol is approaching 1, much bigger than the other probabilities. Thus we can change the probabilities to obtain different system throughput.

VI. CONCLUSIONS

The discrete time three-dimensional probability CSMA protocol with multichannel mechanism, using the average cycle method, gets the precise mathematical expressions of system throughput by rigorous mathematical derivation. The correctness of the theory is verified through the simulation. By three-dimensional probability and the multichannel mechanism, improves the system controllability. The throughput of the new protocol is also increased by introducing the multichannel mechanism and the utilization of network resources has been greatly improved and the system becomes more robust. It's proved that the new protocol is especially designed for the network or equipment testing in the WSN.

ACKNOWLEDGEMENTS

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