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RESEARCH ARTICLE

The Performance Analysis of SPMA Protocol in High Speed Mobile Ad Hoc Network

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ABSTRACT Aiming at the performance analysis of statistical priority-based multiple access (SPMA) protocol, the time slot transmission probability modeling method based on preemptive M/G/1 queue is proposed. The equation of time slot transmission probability is deduced through mathematical modeling, and the solution method under given system parameters is given. Then, the successful reception probability of the message is derived, and the general relationship between the successful reception probability and the duty cycle is established, so as to obtain the threshold setting method of the message with the highest priority. To solve the contradiction between channel utilization maximization and priority scheduling mechanism between nodes, the strategy of minimizing re-served resources among priorities is adopted to set the low priority threshold with the minimum threshold difference, which solves the SPMA protocol threshold setting problem. The simulation scenario of high speed mobile ad hoc network is established. The performance curves of SPMA protocol under typical simulation parameters are obtained, including throughput, probability of successful transmission and end-to-end transmission delay, etc. The effectiveness of the proposed method is verified comprehensively.

INDEX TERMS SPMA protocol, ad hoc network, slot transmission probability, threshold setting.

I. INTRODUCTION

Collins Aerospace's Tactical Targeting Network Technology (TTNT) is a secure and robust IP-based waveform that delivers the fastest ad hoc mesh network to the tactical edge [1].Statistical priority-based multiple access (SPMA) protocol which is adopted for TTNT ensures critical data is sent and received by holding off the transmission of lower priority data until needed [2], [3]. SPMA is required to support for multiple different Classes of Services and provides a much lower latency for packets with high priority [4], [5]. Meanwhile, signal recognition can also be applied to SPMA to improve anti-interference ability [6], [7], [8], [9].

In order to solve the problems of the duty cycle increasing and channel conflict intensifying caused by random access, SPMA adopts random backoff mechanism. SPMA evaluates the duty cycle and backoff when t the duty cycle exceeds the threshold of priority queue. The setting of backoff threshold is the key problem affecting the performance of SPMA protocol. Reference [10] proposes a multi priority single threshold access control protocol, which improves the channel utilization, data transmission success rate and throughput of UAV network. Reference [11] designed a hybrid channel load statistics method, which effectively reduces the channel conflict and ensures the real-time performance of data transmission and the high successful transmission probability. Reference [12] designed a new dynamic backoff algorithm, which effectively improved the network throughput. Reference [13] proposes a dynamic threshold algorithm for SPMA protocol in joint power domain, which reduces the collision probability. Reference [14] proposes a dynamic threshold setting method for SPMA protocol, which dynamically sets the threshold based on the probability of the frame successful transmission, realizes the stability of network throughput, and ensures the access delay of high priority services. However, the above research does not provide a theoretical guidance method for setting the threshold, which can not take into account the contradiction between the channel utilization maximization and priority scheduling mechanism between nodes. By establishing the general relationship between the

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probability of successful message reception and the duty cycle, this paper obtains the method of setting the threshold of the highest priority message, and adopts the strategy of minimizing the reserved resources among the priorities to set the low priority threshold with the minimum threshold difference, so as to ensure the maximization of the channel utilization. The simulation scenario of high speed mobile ad hoc network is established to verify the performance of the proposed algorithm.

The rest of the paper is organized as follows. In Section II, the mathematical modeling of SPMA protocol is presented. In Section III, the key protocol parameters are derived. In Section IV, The method for threshold setting is proposed. In Section V, the simulation scenario of high speed mobile ad hoc network is established and the effectiveness of the proposed method is verified. Finally, a summary of the full work is presented in Section VI.

II. MATHEMATICAL MODELING OF SPMA PROTOCOL

SPMA is a random contention multiple access protocol. The physical layer has the characteristics of low delay and low bit error rate. Among all the multiple access protocols, Aloha has the shortest access delay. However, ALOHA protocol has poor packet delivery performance when the channel load rate is high. For this reason, the SPMA physical layer is called coded ALOHA which adds many functions on the basis of traditional ALOHA, such as message encoding and decoding, random time hopping and frequency hopping and so on. It can ensure the delivery rate of messages at the cost of channel bandwidth and channel utilization, improve the low delay performance of service in multiple access environment, and provide the basis for the operation of SPMA link layer.

It adopts turbo coding. The sender encodes the message as n pulses. After receiving k ($k < n$) pulses, the receiver can decode the message.

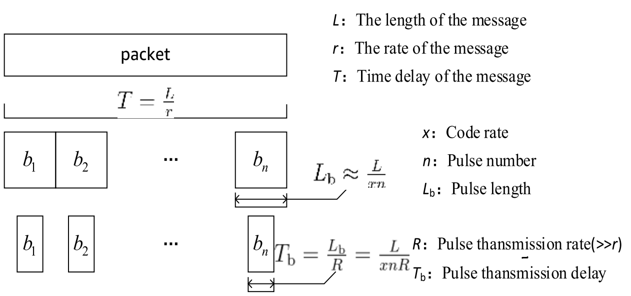

FIGURE 1. Relationship between message and pulse.

The node has multiple working frequency. Without considering the third-party interference, there are two types of pulse reception conflicts. One is half-duplex, when a node sends pulses, it cannot receive pulses from other nodes; the other is multiple access interference, multiple pulses may reach the receiver at the same time, but some of them cannot be received.

When a message is coded and divided into several pulses, it will be sent out in time and frequency domain. If two pulses are transmitted at the same time and the same frequency, the two pulses will collide and conflict, so the information in the two pulses will not be analyzed. SPMA protocol adopts random transmission mechanism, which greatly reduces the probability of pulse collision. When the node receives the message, the channel coding node used in the protocol only needs to receive more than half of the pulses to decode the complete message.

It supports multiple service priorities and provides extremely low access delay for high priority services. SPMA link layer mainly includes channel detection mechanism and multi priority transmission decision mechanism. SPMA evaluates the duty cycle, and backoff when the duty cycle exceeds the threshold. That is, the sending of packets with the priority is suspended. Packets can be sent only when the duty cycle is lower than the threshold.

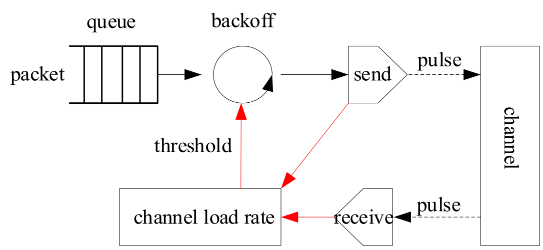

FIGURE 2. Link layer sending mechanism.

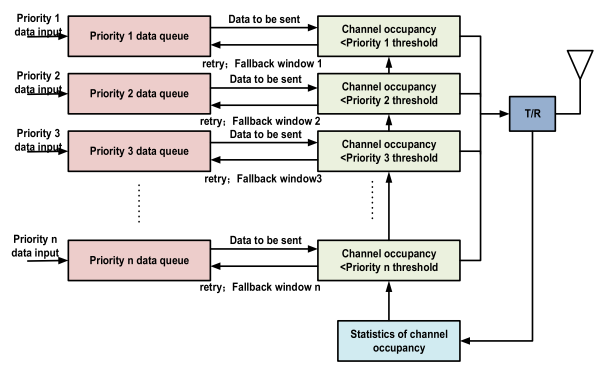

FIGURE 3. Multi-priority transmission decision mechanism.

SPMA is mainly composed of multi-priority queue, random backoff, channel occupancy estimate and other modules. The priority queue is provided, and high priority messages are sent first. The channel occupancy evaluation is provided, which based on the pulse indication provided by coded-Aloha. The backoff mechanism is provided to restrict message sending when the duty cycle is higher than the threshold.

The threshold setting method is very important for SPMA protocol. SPMA sends messages with different priorities for the upper layer. Different priorities have different sending thresholds. When a message needs to be sent, the message will first enter the corresponding sending queue, and then compare the duty cycle with the sending threshold of the queue. When the duty cycle is less than the threshold, the message can be sent normally. When the duty cycle is higher

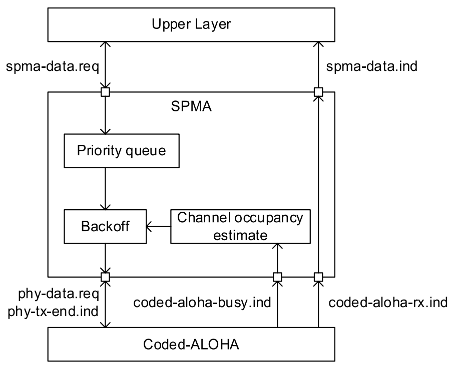

FIGURE 4. SPMA model.

than the threshold, the message will backoff for a period of time, and then detect the channel. Therefore, SPMA sets a high threshold for high priority messages to ensure that high priority messages can be sent preferentially with a shorter waiting delay.

SPMA protocol adopts flow control mechanism. When the system is under high load, its throughput will be relatively stable. At the same time, high-priority packets have a higher probability of sending success and lower access delay. Therefore, the SPMA priority queue is modeled as M/G/1 queue in the range of single hop [15].

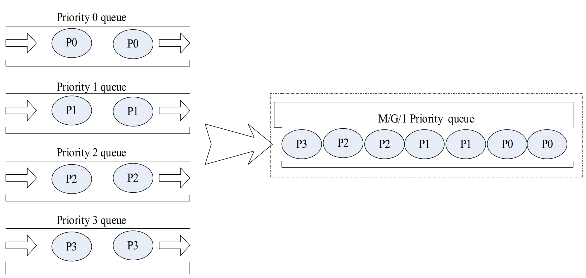

FIGURE 5. The mathematical modeling of SPMA protocol.

In the M/G/1 queue, M means that the arrival process of the message obeys the Poisson distribution, G means that the service time of the message follows the general distribution, and 1 means that there is only one server serving the message, that is, at most one packet is sent at the same time. In Fig. 5, the SPMA sets four priorities, so there are four priority queues. When packets arrive, packets with different priorities are placed in different queues. Of course, the position is determined according to the arrival time.

III. DERIVATION OF KEY PROTOCOL PARAMETERS

A. SLOT TRANSMISSION PROBABILITY

When the input of the system is saturated, its throughput will be at a relatively stable value. At this time, it can be considered that the probability P of sending packets from each node in the system in any slot is a stable value, which is called slot transmission probability (STP).

The main flow of calculating the time slot transmission probability is shown in Fig. 6.

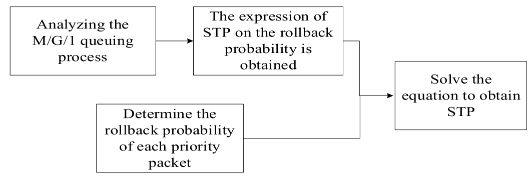

FIGURE 6. Main flow of calculating STP of SPMA system.

The calculation of slot transmission probability of SPMA system based on M/G/1 queue in preemption mode is analyzed below.

Firstly, the expression of STP about backoff probability is calculated. Based on the classical Markov model, the backoff process of each priority packet is analyzed. According to the assumption, the arrival of packets with priority i $(0 \leq i \leq I)$ obeys the Poisson process, and the arrival rate is λ_i. Then, within time segment t, the probability that n packets arrive is:

$$q_i\,(n;\,t) = \frac{e^{-\lambda_i t} \cdot (\lambda_i t)^n}{n!} \tag{1}$$

For the packet with priority i, the probability that no packet with a higher priority arrives is:

$$y_i\,(t) = \prod\nolimits_{j=0}^{i-1} q_j\,(0;\,t) = \prod\nolimits_{j=0}^{i-1} \mathrm{e}^{-\lambda_j t} = \mathrm{e}^{-\sum_{j=0}^{i-1} \lambda_j t} \tag{2}$$

when $i = 0$, $y_i\,(t) = 1$.

Consider the following parameters.

- γ_i: backoff probability of the packet with priority i.

For the convenience of derivation, it is assumed here that when the system is in a steady state, the probability that the packet will backoff again after each backoff is completed is a stable value. The probability of backoff of each priority is the unknown vector to be solved, and is related to the transmission probability.

- K: maximum backoff times.

The actual system does not necessarily have a fixed backoff number limit, but the message is discarded when the queue is full or exceeds the aging constraint. In order to avoid the complexity of modeling, it is assumed that there is a maximum backoff limit, and when the maximum backoff limit is reached, the message is sent instead of discarded.

- δ: the time length of each backoff slot.

Slotting the system and discretizing the system state is an important method to analyze the saturated steady-state performance of the system. The selection of backoff slot length is very important. The backoff time slot is too long, which will increase the access delay. If it is too short, it is not urgent to respond to the change of channel load rate, which is easy to cause a large number of message bursts. In this paper, The length of the backoff time slot is the same as the equivalent transmission time of packets.

- b_k: average number of backoff slots for the k th backoff.

When the k th backoff, the window length is W_k time slots. The number of backoff slots is selected randomly and uniformly within the range of $[1, W_k]$, and the average number of backoff time slots is $(W_k + 1)/2$.

After the previous packet is sent, when preparing to send the current packet, if the channel load rate is lower than the threshold of the current message priority, there is no need to back off and send the current message directly. The probability of this happening is $1-\gamma_i$. Otherwise, backoff.

When the packet is in the backoff stage, a packet with higher priority than it enters the transmission queue, then the packet with higher priority will seize the transmission status of the current packet, and the system will process the transmission of high priority packet first. According to the assumption, the packet will freeze the current backoff process. After all high priority messages are sent, the packet will continue the previous backoff process.

Therefore, for any packet, check the process from the first arrival of the packet at the head of the queue to the final successful transmission, and cut out the time occupied by all other packets, that is, only consider the backoff waiting process when the packet is at the head of the queue, which is called the reduction process. The reduction process exists $K+1$ cases.

When the packet is successfully sent after exactly $k(0 \leq k \leq K)$ times of backoff, exactly k times of backoff occurs in the reduction process. The average number of backoff time slots is:

$$B_k = \sum\nolimits_{c=0}^{k} b_c \tag{3}$$

The probability of such process is:

$$e_i(k) = \gamma_i^k \cdot (1-\gamma_i) \cdot y_i(B_k\delta) \tag{4}$$

where, $\gamma_i^k \cdot (1-\gamma_i)$ indicates the probability of sending a packet after the k th backoff. $y_i(B_k\delta)$ represents the probability that no packet with a higher priority arrive within the time $B_k\delta$.

Therefore, when the packet is at the head of the queue, the probability of the packet being sent is:

$$E_i = \sum\nolimits_{k=0}^{K} e_i(k) \tag{5}$$

If the packet priority is i, when the packet is at the head of the queue, the average number of backoff time slots before successful transmission is:

$$X_i = \sum\nolimits_{k=0}^{K} B_k \cdot e_i(k) \tag{6}$$

The average service time of the packet is:

$$S_i = X_i\delta \tag{7}$$

According to Little's theorem, when the arrival rate of packets with priority i is λ_i and the service time is S_i, the traffic is:

$$\eta_i = \lambda_i S_i \tag{8}$$

The total traffic of the system is:

$$H = \sum\nolimits_{i=0}^{I} \eta_i \tag{9}$$

When observing the system at any time, the probability of the packet with priority i being placed at the head of the queue is:

$$\varphi_i = \frac{\eta_i}{H} \tag{10}$$

Thus, the expression of STP is:

$$P = f_P(\vec{\gamma}) = \sum\nolimits_{i=0}^{I} \varphi_i E_i \tag{11}$$

Secondly, the backoff probability of each priority packet is determined. The packet sending process is independent and identically distributed, and obeys the binomial distribution with probability P. In the channel detection window U, N nodes access the channel at the same time, which is equivalent to $U_N = UN$ slots, and the probability of sending packets in each slot is P. Therefore, the probability of m packets appearing in channel detection window is:

$$\beta_m = C_{U_N}^{m} \cdot P^m \cdot (1-P)^{U_N-m} \tag{12}$$

The threshold of packets with priority i is D_i, that is, when the number of detected packets in the window is greater than D_i, the packet backoff. According to the hypothesis, the node can accurately detect the duty cycle. Therefore, the expression of the backoff probability γ_i is:

$$\gamma_i(P) = 1 - \sum\nolimits_{m=0}^{D_i} \beta_m \tag{13}$$

Substituting (13) into (11), the equation for P is as follows:

$$P = f_\gamma(P) = f_P(\vec{\gamma}(P)) \tag{14}$$

For each given P, the $\vec{\gamma}$ can be obtained through (13), and then $\vec{\gamma}$ can be substituted into (11) to calculate the corresponding $P(\vec{\gamma})$. If P and $P(\vec{\gamma})$ are equal, the value of P is the result to be found.

TABLE 1. **The parameters of slot transmission probability calculation.**

parameter	value
Priority quantity I	8
Packet arrival rate λ (packets/s)	[60 80 100 120 140 160 180 200]
Backoff slot length δ	0.45 ms
Maximum backoff times K	8
Fixed window length W	8
Exponential backoff window length W	[1 2 4 6 8 16 32 64]
Log backoff window length W	[1 2 2 3 3 3 3 4]
Number of nodes accessing the channel N	[5 10 15 20 25 30]
Channel detection window length U	10
Packet quantity threshold of each priority D	[11 10 9 8 7 6 5 4]

The calculation results are as follows.

Fig. 10 shows the numerical solution of STP under different backoff methods and different node numbers. It can be seen that the influence of backoff mode on the STP is very small. The STP is mainly affected by the number of nodes.

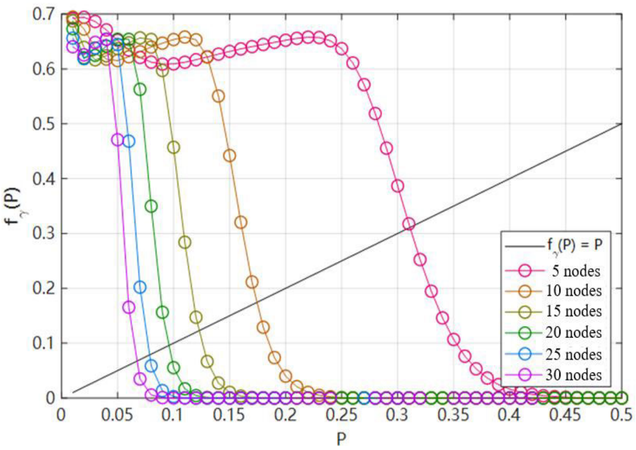

FIGURE 7. Fixed point solution algorithm of STP (fixed backoff window).

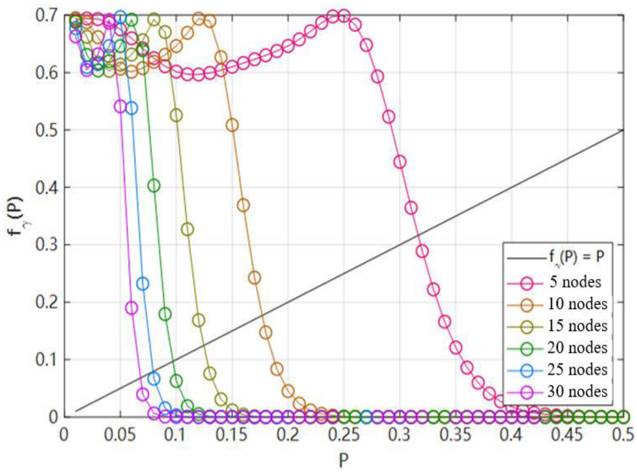

FIGURE 8. Fixed point solution algorithm of STP (exponential backoff window).

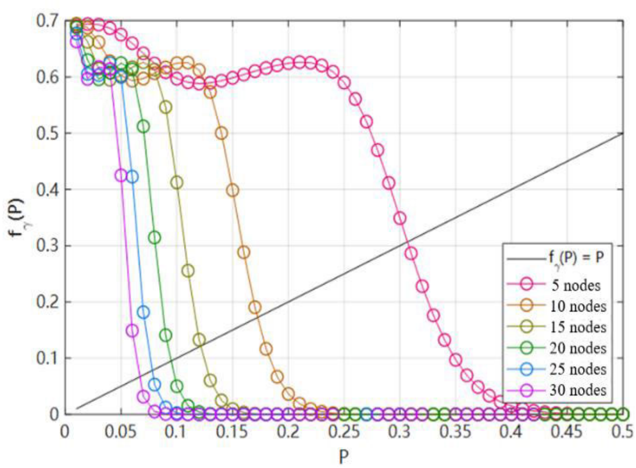

FIGURE 9. Fixed point solution algorithm of STP (logarithmic backoff window).

B. PROBABILITY OF SUCCESSFUL MESSAGE RECEPTION

SPMA protocol selects several frequencies in the whole spectrum and the number of frequencies is N_f. When a packet needs to be sent out in the system, it will be coded, and each packet will be coded as n_b pulses, and the number of nodes in the system is N, the length of a slot is δ. Due to the flow control mechanism of SPMA protocol, when the input of the system is in a saturated state, its throughput will be in a relatively stable state value. The probability that each node in the system will send packets in any slot is P, then in unit time a node can send P/δ packets, or n_bP/δ pulses.

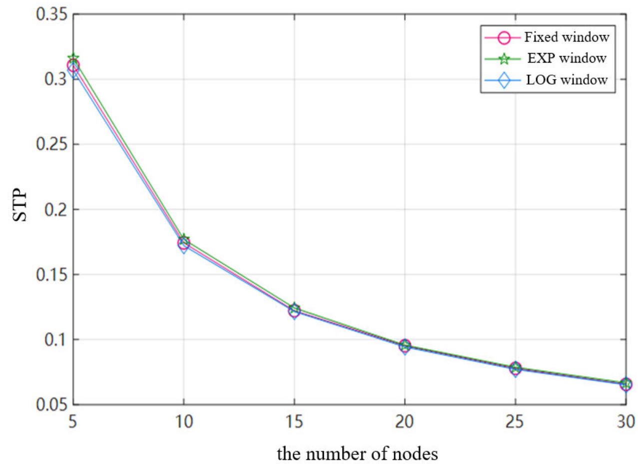

FIGURE 10. The relationship between the number of nodes and the STP.

Thus, the average number of pulses sent by the system per second is:

$$\lambda = \frac{n_b PN}{\delta} \tag{15}$$

each node sends pulses at a rate of $\lambda_1 = \lambda/N$.

According to the performance analysis of traditional single channel ALOHA, the length of pulse collision time is twice that of pulse transmission time T_b. That is, the probability of successful transmission of a single pulse is:

$$P'_{bs} = e^{-2T_b\lambda} \tag{16}$$

There are two kinds of interference in the system. The first interference is that the system works in half duplex mode. When the node is transmitting, it cannot receive pulses. The second kind of interference refers to the interference between pulses when multiple packets are received at the same time. p_P is the probability that the first interference does not occur. p_R is the probability that the second interference does not occur.

$$p_P = e^{-2\lambda_1 T_b} \tag{17}$$

Multi -channel system can distribute the pulse evenly in N_f channels. The total pulse sending rate of all other nodes is $\lambda_{-1} = \lambda(N-1)/N$. In each channel, the generation rate of the pulse is $\lambda'_{-1} = \lambda_{-1}/N_f$.

$$p_R = e^{-2\lambda'_{-1} T_b} \tag{18}$$

Therefore, the successful reception probability of pulse in multi-channel system can be expressed as:

$$\theta = p_P p_R = e^{-2\lambda_1 T_b} e^{-2\lambda'_{-1} T_b} = e^{-2\lambda T_b\left(\frac{1}{N}+\frac{N-1}{NN_f}\right)} \tag{19}$$

When $N \rightarrow +\infty$, the upper bound is:

$$\theta^* = e^{-\frac{2\lambda T_b}{N_f}} \tag{20}$$

In Fig. 11, the red line is the data obtained by simulation, while the blue line is calculated by formula. It can be seen from the figure that as the load in the network increases, the difference between the simulated value and the theoretical value will be greater. At the same time, it can be seen from the figure that when the number of nodes is small in five channels, the theoretical value is still different from the simulation results, but when the number of nodes reaches 20, it is basically the same.

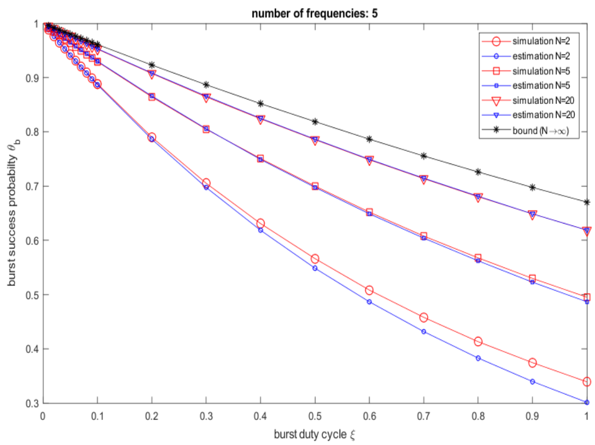

FIGURE 11. Burst successful probability under five channels.

The probability of successful transmission of a single pulse is:

$$P_{bs} = e^{-2\lambda T_b\left(\frac{1}{N}+\frac{N-1}{NN_f}\right)} \tag{21}$$

If the receiver can decode the whole packet successfully, at least k_b ($k_b > n_b/2$) pulses is successfully received, the probability of successful transmission of a packet can be expressed as:

$$P_s = \sum_{i=k_b}^{n_b} C_{n_b}^i \cdot P_{bs}^i \cdot (1-P_{bs})^{n_b-i} \tag{22}$$

If $P_s = 99\%$, the total duty cycle of the system at this time can be calculated through (21) and (22), which is recorded as $\xi_0 = \lambda T_b$. The duty cycle is the product of pulse transmission time T_b and pulse transmission rate λ. When the total channel duty cycle of the system is not higher than ξ_0, it can ensure that the probability of receiving a packet successfully is not less than 99%.

In the actual system, the factors affecting the message receiving probability include the evaluation error of channel load rate, the arrival of service message and pulse transmission do not obey Poisson distribution, which will deviate from the theoretical analysis.

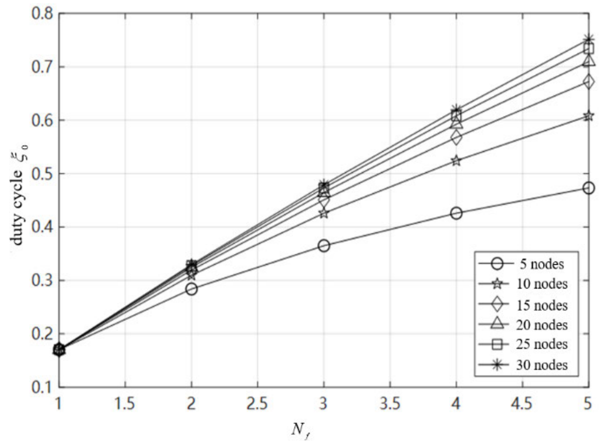

FIGURE 12. The Threshold value of duty cycle at 99% message delivery rate.

C. THRESHOLD OF THE HIGHEST PRIORITY

The SPMA protocol can provide the ability to distinguish multi priority services, and messages of different priority services will set different thresholds. Pre-setting the thresholds of messages with different priorities plays an important role in the performance of the whole system. In the setting process, since the sending of high priority messages will be better than the sending of low priority messages, it is necessary to ensure that the threshold of high priority messages is greater than that of low priority messages. The threshold value of the highest priority message should not be set too high so that the transmission success rate of the highest priority message can reach 99%.

In SPMA protocol, the highest priority message is always sent first, and the sending success rate of this priority message needs to reach 99%, so it is necessary to determine the threshold of the highest priority message. For the threshold value of the highest priority message, when the duty cycle exceeds the threshold value of priority 1. It can be considered that there is only priority 0 business in the system, but no lower priority business. In this case, as the service load of priority 0 increases, the success rate of message reception will gradually decrease. When the success rate of message reception drops to 99%, the average number of messages in the channel detection window can be used as the threshold of the highest priority message.

When the detection window length is U slots, the time length of the detection window is $U\delta$. When the probability of successful reception is 99%, the average number of pulses in the window is $U\delta\lambda$. Therefore, the average number of packet in the window is:

$$D_0 = \frac{U\delta\lambda}{n_b} = \frac{U\delta}{n_b T_b}\xi_0 \tag{23}$$

The threshold D_0 of the highest priority packets can be obtained based on the upper limit ξ_0 of the channel occupancy.

Because the pulse transmission is not an ideal Poisson process, but a piecewise dense transmission, it is different

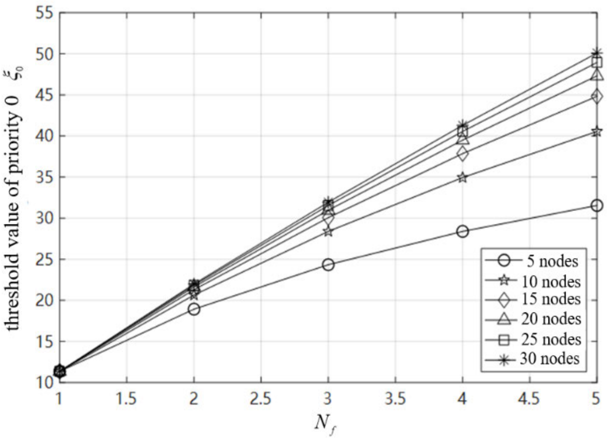

FIGURE 13. The threshold value of priority 0 at 99% message delivery rate.

from the theoretical calculation. Therefore, a correction factor is added to (21).

$$\tilde{P}_{bs} = e^{-\alpha \frac{\lambda^{\beta}}{N^{\gamma}}} \cdot P_{bs} \tag{24}$$

The root mean square error of the corrected pulse delivery rate and the actual value is minimized.

$$\tilde{P}_{bs} = e^{-1.6\lambda} \cdot P_{bs} \tag{25}$$

The scenario with 50∼200 nodes and network load of 2Mbps∼18Mbps is simulated. Fig. 14 shows the evaluation results of pulse success rate. The solid line is the pulse success rate obtained from the actual simulation. The space drawing line is the result calculated by (21). The dotted line is the result calculated by (25).

As can be seen from Fig. 14, the modified curve is highly consistent with the simulation results, and can be used to estimate the pulse success rate outside the simulation parameter points.

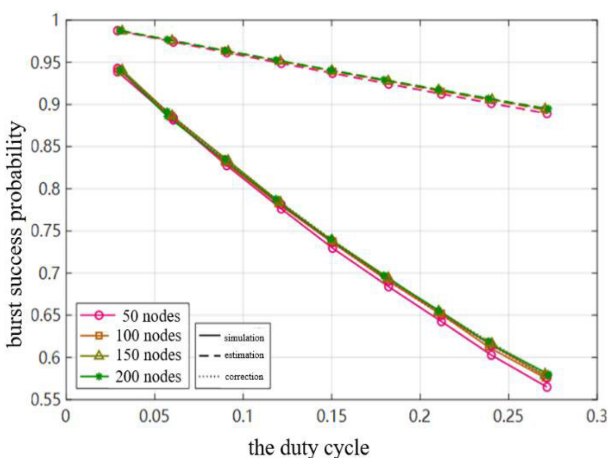

FIGURE 14. The evaluation of burst success probability.

Because the message sending is not an ideal Poisson process, it is different from the theoretical calculation results. Therefore, a correction factor is added on the basis of (22).

$$\tilde{P}_{s} = e^{-\alpha \frac{\lambda^{\beta}}{N^{\gamma}}} \cdot P_{s} \tag{26}$$

The root mean square error between the corrected message delivery rate and the actual value is minimized.

$$\tilde{P}_{bs} = e^{-8 \frac{\lambda^{2.2}}{N^{0.29}}} \cdot P_{bs} \tag{27}$$

As can be seen from Fig. 15, the modified curve is very consistent with the simulation results, and can be used to estimate the message success rate outside the simulation parameter points.

Using the result of (27), the channel load rate threshold can be deduced according to the message delivery rate of 99%.

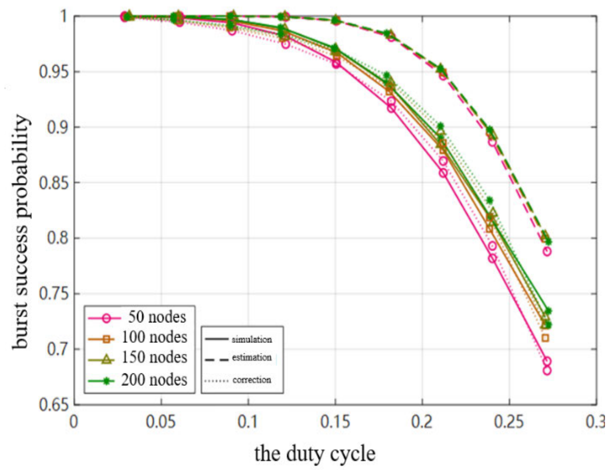

FIGURE 15. The evaluation of burst success probability.

IV. THE METHOD FOR THRESHOLD SETTING

The threshold of each priority queue is the upper limit of the channel load rate when the packets of this priority are sent to the channel. The threshold sets the upper limit of the rate at which packets of this priority can be sent. The total load of each priority should be below the upper limit of the transmission rate as determined by its threshold. The threshold of a high-priority queue should not be lower than that of a low-priority queue. The threshold of the queue with the highest priority is the channel load rate when the packet delivery rate reaches 99%.

Since the low priority service will compete for the channel with the high priority service, if $\lambda_{n-1} = \lambda_n$, the high-priority and low-priority services can be distinguished only within nodes, but cannot be distinguished between nodes. Therefore, the policy must be adopted to ensure that high-priority services have channel access priority between nodes.

In this paper, channel resources are reserved for high-priority services so that the transmission rate of low-priority services is limited between nodes based on the variation of channel load rate. However, if high-priority services do not use the reserved resources, the channel utilization will be decrease. This paper is to minimize the resources reserved between priorities. As shown in Fig. 16, set the threshold of low priority with the minimum threshold difference.

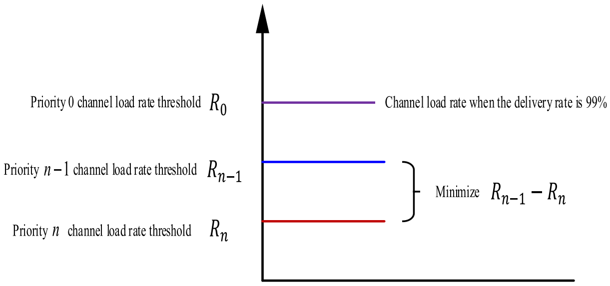

FIGURE 16. Minimize reserved resources between priorities.

The minimum threshold difference is determined by the high priority burst traffic. For example, When the traffic with priority n is sent at rate R_n, the channel load rate remains close to threshold λ_n. At this time, when a higher priority service is generated, the higher priority service will be sent immediately. Due to the delay in the evaluation of channel load rate, the channel should be able to withstand the burst traffic of high priority services in a short time, so resource reservation is required. The additional channel load rate caused by the burst traffic of high priority services is preliminarily estimated as follows.

$r^{+}_{n,\sum} = \sum_{p=0}^{n-1} r_n$ represents the sum of burst traffic of higher priority services. Therefore, the minimum threshold difference can be estimated as:

$$\delta_n = R_{n-1} - R_n = T_e r^{+}_{n,\sum} \tag{28}$$

where, T_e is the evaluation delay of channel load rate. For example, T_e can be 5 times the length of the perceived slot.

When a high priority service burst occurs, because the current channel load rate is lower than the high priority service threshold, the high priority service will be sent immediately and the channel load rate will be raised. There is a certain delay in channel load rate evaluation. When the node sending low priority services perceives that the channel load rate is higher than its threshold, it will limit the transmission rate of low priority services and make the channel load rate fall near the threshold.

Therefore, the threshold difference of different priorities is mainly used to reserve certain channel resources so that high-priority services can burst, and the burst quantity should not cause excessive pulse conflicts. Therefore, the amount of reserved resources, namely the threshold difference, is related to the channel load rate evaluation delay and burst traffic size.

V. SIMULATION VERIFICATION

The simulation scenario is a high speed mobile ad hoc network composed of 20 nodes. The nodes are randomly distributed within the range of 500km×500km and move according to the Random Way Point (RWP) movement model. Each node randomly selects a destination node for service delivery. The point-to-point transmission distance is 200km, so the network is a mobile multi-hop network. In this paper, it is assumed that the network is wireless heterogeneous network with capacity constraints [16].

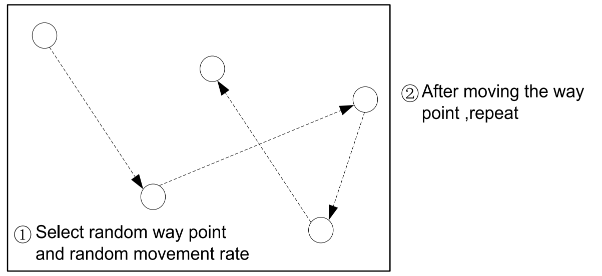

FIGURE 17. The Random Way Point model 1.

The exponentially weighted moving average (EWMA) method is used to evaluate the duty cycle. The duty cycle statistics are based on slot, an every U slots is a statistical window.

The simulation parameters are shown in TABLE 2.

TABLE 2. Simulation parameters of high speed mobile ad hoc network.

Protocol layer	Parameter	Value
	Number of nodes	20
	Moving range	500km×500km
	Moving rate	1~10Mach
App	Network load	2.88Mbps
	Priority quantity	8
	Priority load ratio	1:2:3:4:5:6:7:8
	Message length	900bit
	Business start time	20s
OLSR	Hello interval	1s
	TC interval	1s
	Routing control priority	1
SPMA	Priority threshold	[0.1, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03]
	Priority queue length	Each priority queue is 9000bit
	Physical layer rate	2Mbps
	Channel load rate evaluation	EWMA weight 0.25
	Evaluation slot length	0.45ms = 900bit / 2Mbps
	Backoff window length	2 time slots
	Backoff slot length	0.45ms = 900bit / 2Mbps
Coded-Aloha	Coding rate	1/3
	Pulse length	100bit
	Channel rate	40Mbps
	Number of channels	5
	transmission distance	200km
	Simulation time	200s

The end-to-end performance simulation results of the application layer are as follows.

Eight priorities are set in the simulation system, and SPMA protocol provides eight priority queues to realize the preemptive priority scheduling function. According to

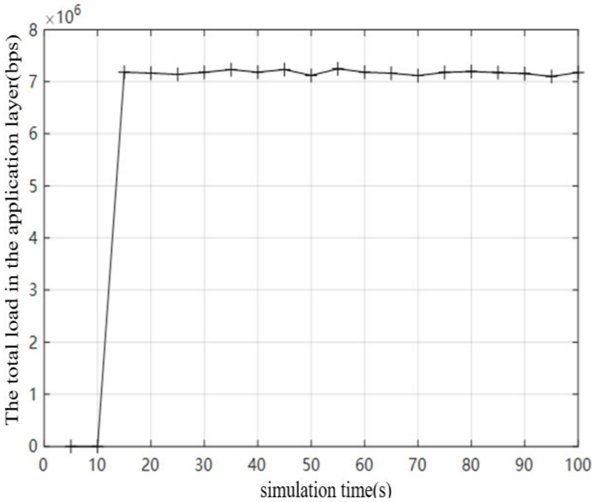

FIGURE 18. The total load in the application layer.

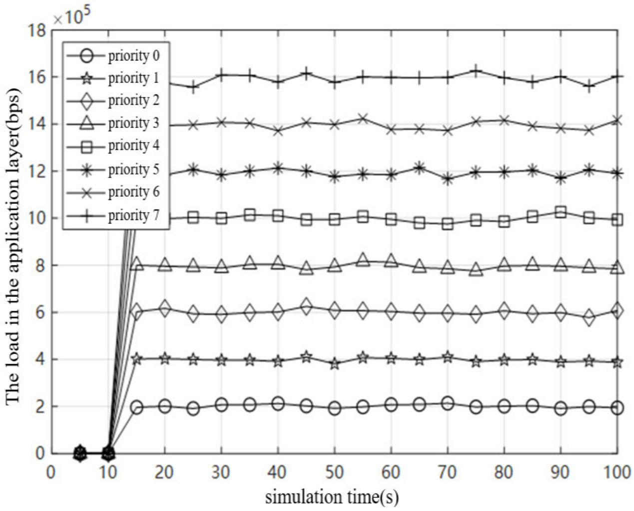

FIGURE 19. The load in the application layer.

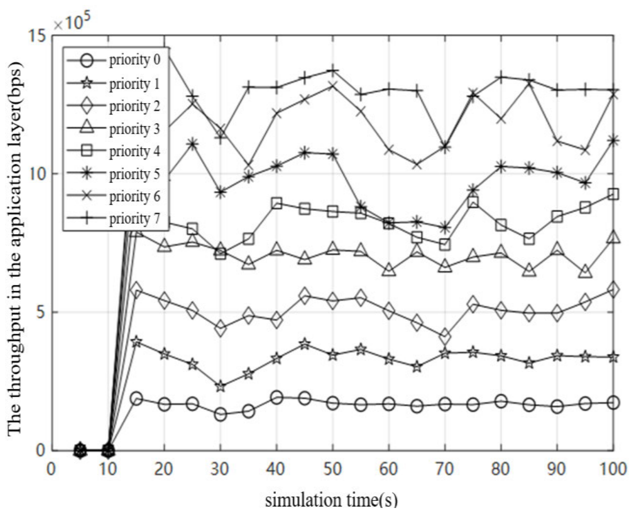

FIGURE 20. The throughput in the application layer.

the requirement that the probability of successful packet transmission is 99%, the threshold of the highest priority is about 0.1 under the given parameters. When low-priority and high-priority services compete for channels, some channel resources are reserved for high-priority services. In this way, when the channel load rate is higher than the threshold, low-priority services cannot be sent. However, in order to ensure maximum channel utilization, the low priority channel load rate is set at the minimum threshold difference. The minimum threshold difference is determined by the high-priority burst traffic. As can be seen from Fig. 18, the total load in the application layer can be stabilized at 7Mbps and the channel utilization is high. As can be seen from Fig. 19, the load in the application layer of all kinds of priority services is relatively stable and consistent with the priority load ratio in simulation parameters. It can be seen from Fig. 20 that the throughput in the application layer of various priority services is lower than the threshold and is stable over time. Fig. 21 shows the probability of successful transmission of various priority services, which can roughly ensure that high-priority services

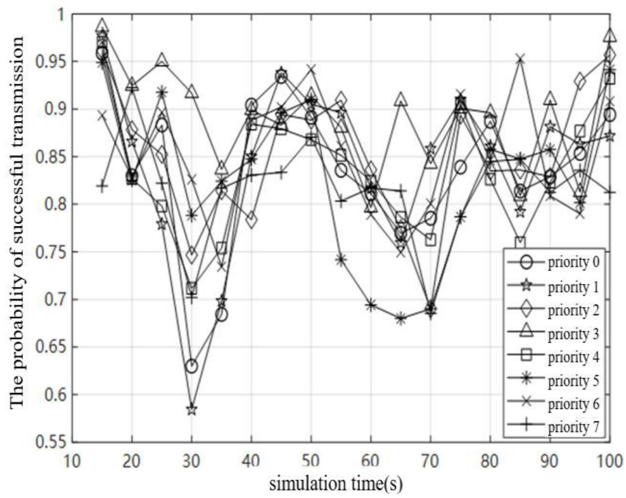

FIGURE 21. The probability of successful transmission in the application layer.

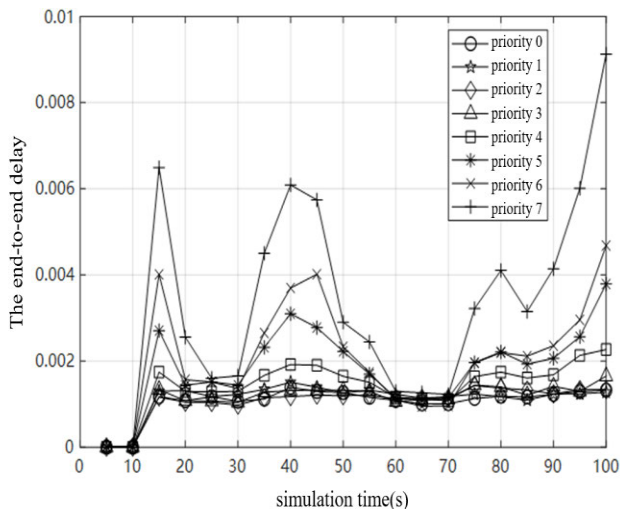

FIGURE 22. The end-to-end delay in the application layer.

correspond to high probability. The errors are mainly caused by the multi-hop environment. Fig. 22 shows the end-to-end delay of various priority services in the application layer, and high-priority services have lower delay.

VI. CONCLUSION

In this paper, the working mechanism and key parameters of SPMA protocol are studied. The priority queue of SPMA protocol is modeled as M/G/1 queue, and the slot transmission probability equation is derived. It is analyzed that the slot transmission probability is mainly affected by the number of nodes. Furthermore, the probability of successful message reception is derived, and the general relationship between the probability of successful message reception and the duty cycle is obtained. When the total channel load of the system is not higher than ξ_0, the probability of successful message reception is not less than 99%, and the threshold of the highest priority can be obtained through the upper limit of ξ_0. In order to ensure that high priority services have channel access priority between nodes, the channel resources are reserved for high-priority services, so that when the duty cycle is higher than the threshold, the transmission of low priority services is limited. At the same time, the strategy of minimizing the reserved resources between priorities is adopted to set threshold of low priority with the minimum threshold difference, so as to ensure the maximization of channel utilization. Aiming at the application scenario of high speed mobile ad hoc network, the SPMA simulation model is established, and the comprehensive performance of SPMA protocol is simulated and analyzed, including throughput, probability of successful transmission and end-to-end transmission delay, etc. The effectiveness of the proposed method is verified comprehensively.

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