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STUDY OF MODIFIED PRMA-HS PROTOCOL BASED ON TRANSMIT PERMISSION PROBABILITY CHANGED DYNAMICALLY

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Abstract. *Based on the large traffic user terminal's access requirement to the LEO satellite system and the fixed transmit permission probability's impact to the user terminal, this paper proposes DPRMA-HS protocol which modifies the PRMA-HS protocol by dynamically changing the transmit permission probability. In view of the foundation of Markov chain, the protocol establishes a system model which changes the transmit permission probability dynamically according to the contending numbers of user terminals, and analyzes the data by equilibrium point analysis method. Both theoretical analysis and simulation results show that, compared with PRMA-HS protocol, DPRMA-HS protocol controls the bistable behavior and reduces the packet drop probability effectively. Besides the system throughput rate, the system capacity increases by more than 15% respectively over both the ideal channel and the random packet error channel. To sum it up, the mechanism which changes the transmit permission probability dynamically can be used in PRMA-HS's modified versions to enhance system performance.*
Keywords: User terminals, PRMA-HS, Transmit permission probability, Packet drop probability, Throughput rate

1. **Introduction.** Low earth orbit (LEO) satellite communication system is able to achieve global seamless coverage, which provides high-quality and full range communication service for ground voice and data terminals. Compared with the terrestrial-based communication system, LEO satellite communication system still has obvious delay problem, and the increasing ground terminals traffic put forward higher requirements for it. Multiple access technology is one of the key technologies of satellite communications, and its characteristic directly affects bandwidth utilization, system capacity, and communication service quality [1-4]. Due to the limitation of power and frequency, LEO satellite communication system needs the high-efficiency and high-throughput multiple access protocol. The usual multiple access protocol is based on the competitive mechanism, which has many limitations, such as fix channel allocation in communication process, inefficiency under the condition of burst data services, and low throughput when encountering a large number of terminals competition. PRMA-HS (Packet Reservation Multiple Access with Hindering State) as improved PRMA protocol, which was proposed in 1999 by E. D. Re et al. [1], was one of the most suitable multiple access protocols for LEO satellite communication systems. PRMA-HS protocol adds the Hindering Status in order to overcome the problem of transmission round trip delay.

Owing to PRMA-HS protocol's broad application prospects in LEO satellite communication system, domestic and foreign scholars have done a lot of research on it in recent years. Sharifi and Abed proposed the method of increasing system capacity by power capture [2], which is based on the hypothesis that the power capture model is perfect. However, when the power is almost the same, the model cannot reflect its advantages. Sharifi and Abed also proposed control strategies through state estimation [3], and investigated its applications to LEO satellite communication system, but the round trip delay's impact on PRMA was not taken into account. Xiao et al. calculated the transmit permission probability, which was the only parameter affecting the system throughput [4], but the probability extreme points were obtained by derivation which did not possess generality. Xiao et al. also proposed the conflict weakened MPRMA-HS protocol [5]. In his research, the time slot was divided into the mini-time slot in order to reduce the congestion of the system, but the time slot thinning led to system poor stability. Zhuo et al. introduced a kind of access control mechanism to reduce channel competition and improve communication service quality [6]. In his paper, this mechanism needs to distinguish different terminals according to the different demands of channel resources at different communication stages, which undoubtedly increases the system burden.

The bistable behavior is one of important phenomena that reduce the system capacity. Competition conflict is aggravated along with the increase number of system terminals, which leads to the sharp decline of system throughput. The user terminal that has been competitive success still has the same probability participation in the next competition in the hindering state. At the same time, the delay seriously affects other terminals normal access, which was unfair to the other pending access terminals. Therefore, based on the deficiencies and limitations of the literature 2-6, DPRMA-HS (Dynamically change transmit permission probability of the PRMA-HS) protocol is proposed in this paper. This protocol gives consideration to the requirement of the long round trip delay and high traffic of the LEO satellite communication system. DPRMA-HS provides communication service for ground voice and data terminals and controls the bistable behavior effectively. Under the premise of reducing the system packet drop probability, it increases system capacity and throughput, and allows more user terminals to share the communication medium.

2. **System Model.** In this paper, the DPRMA-HS system model includes voice terminals and data terminals. Due to real-time characteristic, voice terminals are much more complex than the data terminals [3,4], and the following model assumes terminals as voice terminals. We assume that the number of voice terminals is M and the length of slot is τ. During a talkspurt, the voice terminals produce speech information at the rate of R_s bit/s. Channel transmitting rate is R_c bit/s, and the head length of packet is H bytes. Therefore, when the $N = \lfloor R_c T/(R_s^T + H) \rfloor$ packets/frame, the voice terminals have $T = N\tau$ seconds speech information. Settings t_1 and t_2 represent the time interval of voice activation period and silence period respectively, and assume that both of them are greater than τ. σ_ν is the probability of leaving silent state, which obeys the exponential distribution $\sigma_\nu = 1 - \exp(-T/Nt_2)$. γ is the call end probability, which obeys the exponential distribution $\gamma = 1 - \exp(-T/Nt_1)$.

The system model involves four states [1,7], which includes silent state, contending state, hindering state and reservation state. The voice terminals are in silent state (SIL) when the talkspurt starts and there is no packet to send. After the first packet generates in the talkspurt, voice terminals move to the contending state (CON). The voice terminals remain in contending state until they acquire the reserve time slot through the base station's feedback information. Hindering state chain HIN_i ($\text{HIN}_{N-1} \sim \text{HIN}_{N-N/n}$) refers

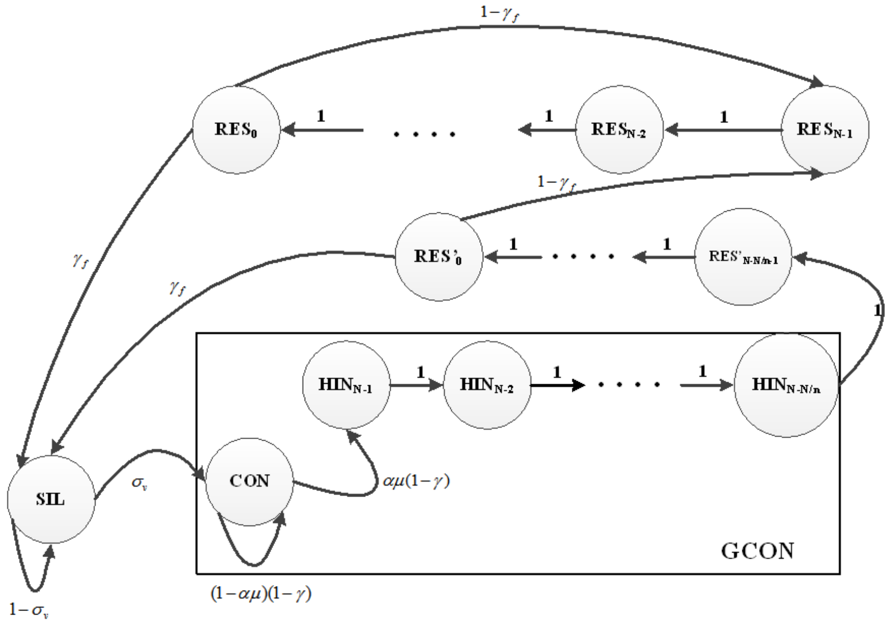


Figure 1. DPRMA-HS state transition diagram

to a state, which voice terminals in sustained contending state move to. Hindering state needs to wait for the maximum tolerance delay $RTD_{\max}$ to know the competition results, which continues to try to compete for reserved time slot with probability p_v. In this paper, we update this transmit permission probability p_v dynamically. Reservation state (RES_i) refers to a state which the voice terminal has been reserved the i-th time slot.

This system model defines $RTD_{\max}$ as the D-th slot length. In order to ensure real-time packet transmission, the voice terminal discards the packet that delay exceeds $RTD_{\max}$. It is difficult for the voice terminals to distinguish the contending state from the hindering state, so the voice terminals regard the two states as GCON (the global contending state). Figure 1 shows the Markov chain model state conversion for the voice system.

As shown in Figure 1, the states transition probabilities are as follows. γ and σ_ν are defined as mentioned earlier. The probability that a talkspurt ends in a particular frame is provided by $\gamma_f = 1 - (1-\gamma)^N$. R denotes the total number of user terminals in the reservation state. The expression of α is obtained by considering two independent events: one is that the next time slot is unreserved, the other is that the user transmit obtains the permission probability p_v to transmit on it. Thus, $\alpha = (1 - R/N)p_v$. H and C are user terminals total number in hindering state and contending state respectively. Therefore, probability μ can be expressed as follows.

$$\mu = \begin{cases} (1-p_v)^H & C \le 1 \\ (1-p_v)^{C+H-1} & C > 1 \end{cases} \tag{1}$$

3. **DPRMA-HS Protocol Design.** DPRMA-HS distinguishes voice period from silence period by voice detection technology. As shown in Figure 2, the protocol divides the upstream channel into time slots in equal length, and the time slots split into the reserved time slots and the available slots. The slots are divided on the basis of the response messages from satellite base station.

During talkspurt period, the user terminals compete for the available time slots by the ALOHA method; it attempts to transmit voice or data with a certain probability p_v in the first available time slots. Due to the large round trip delay of the satellite communication system, the user terminals compete for the next time slots with the same probability

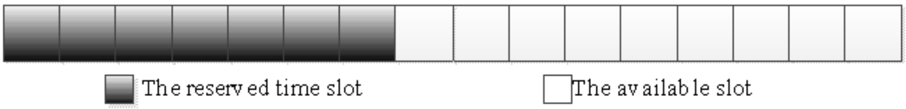


Figure 2. DPRMA-HS's frame structure

while they wait for the competing results. If there is only one user terminal in a time slot, the user terminal will occupy the time slot successfully, and the successful record will be abandoned in the next time slot. When a bursting voice transmits over, the user terminal will release the reserved time slots and change them to the available time slots. Owing to real-time requirement of voice terminals, the packet will be discarded when its delay is greater than the predetermined delay limit.

3.1. **Dynamical changing of transmit permission probability.** PRMA-HS system is much more sensitive to the transmit permission probability's selection. The transmit permission probability is the only parameter that affects throughput rate [4], which should be selected carefully in order to make the system performance optimal. According to researches [1-6], there are three main reasons that cause packet dropping.

(1) When the transmitting permission probability p_v is too small, the terminals cannot acquire the transmit permission for a long time, which causes dropping of the packet.

(2) When the p_v is oversize, which makes many terminals compete in one time slot, resulting in conflict and congestion. The congestion leads to packet retransmission failure and packet dropping.

(3) The voice terminals in talkspurt exceed the maximum number of system support, which will also inevitably cause the packet dropping.

In the PRMA-HS protocol, the user terminals have already competed successfully actually while waiting for the results of the satellite base station feedback, but there are none feedback broadcast messages received due to the round trip delay of the satellite link. The terminals still have the same probability to compete for the time slots, which have impact on the other user terminals that participate in the competition at the same time. All these problems increase the access difficulties, which are unfair to the other pending access terminals.

Therefore, the transmit permission probability is one of key factors to design PRMA-HS protocol. Thus, this paper presents DPRMA-HS protocol based on dynamical changing of the transmit permission probability. The main feature of this protocol is that the probability is not a fixed value, but according to the real-time changed value that is decided by the launched contending numbers. This change ensures that the user terminals access channel fair relatively. The design of dynamically change transmit permission probability is as follows.

(1) In the initial case, p_v is the first transmit permission probability and $p_{\min}$ is the minimum transmit permission probability.

(2) In accordance with the ratio n between maximum tolerance delay $RTD_{\max}$ and the time slot length τ, the decreasing step of transmit permission probability is $p_{step} = (p_v - p_{\min})/n$. The probability of each subsequent transmit is

$$p_v' = p_v - kp_{step} \quad (k = 1, 2, \ldots, n). \tag{2}$$

In this way, the user terminals are no longer based on the same probability to participate in the second and third competition, but based on the number of access, and gradually decreasing transmit permission probability. This mechanism is equivalent to concede to the new access terminals, to ensure new access terminals priority access, which guarantees the access fairness to all user terminals. The reason why retransmit permission probability step decreases by the given minimum value is that if the step is reduced to $p_{\min}$ by large step, it will lead to system instability.

It is clear that, DPRMA-HS protocol is simple and scalable, the mechanism of dynamical changing transmit permission probability proposed in it can be applied to any PRMA-HS's modified versions.

3.2. **Equilibrium point analysis of DPRMA-HS protocol.** The transmit permission probability static invariance is one of the important reasons that cause the system bistable behavior [4]. Bistable behavior refers to the system that has two stable operating points, and the performance of two points is at opposite poles. The terminals' characteristics can be modeled as a Markov process [3]. The number of the system states is $2^{2N}M^2$. However, when N and M have actual value, the precise analysis of the Markov chain is very complex because of the large state space.

In this paper, equilibrium point analysis method is used to analyze DPRMA-HS protocol. Equilibrium point analysis method can solve the above problems effectively, and obtain optimal analysis result. This method assumes that the system is always in the equilibrium point state; thus, a state transition probability is calculated no longer. A point in the state space is an equilibrium point, if and only if it satisfies that the amount of change of each state is equal to 0 within each time slot. In other words, for the user terminals, the rates of leaving one state and entering another state are equal, namely the terminals are in equilibrium state. The stability of the equilibrium point mainly considers contending state's roll-out state, and defines as $G(c,h) = \mu ac(1-\gamma)+\gamma c$. The characteristic of a stable equilibrium point is that $G(c,h)$ is a positive value. In this paper, DPRMA-HS protocol system has $2N+2$ variables [8], $\Omega = \{S, C, R'_0, R'_1, \ldots, R'_{N-N/n-1}, H_{N-N/n}, \ldots, H_{N-1}, R_0, R_1, R_{N-1}\}$, where S and C represent the number of user terminals in silent state and contending state respectively. R'_i is the number of user terminals that have a reservation on the i-th future slot and have left the contending state from a time less than or equal to T_f. In contrast, R_i is greater than T_f. The number of user terminals is represented by H_i, which waits for confirming broadcast information from satellite base station in the $i-(N-N/n)$ time slot. Of course, R'_i, R_i and H_i can be equal with 0 or 1. And, due to a given time slot reserved for only one user terminal, we must consider the following limitations.

$$\begin{cases} R_i + H_i \leq 1 & N - N/n - 1 \leq i \leq N - 1 \\ R_i + R'_i \leq 1 & 0 \leq i \leq N - N/n - 1 \end{cases} \tag{3}$$

The system satisfies the following definitions.

$$H = \sum_{i=N-N/n}^{N-1} H_i \tag{4}$$

$$R^* = \sum_{i=0}^{N-N/n-1} R'_i + \sum_{i=0}^{N-1} R_i \tag{5}$$

$$R = R^* + H \tag{6}$$

$$R + S + C = M \tag{7}$$

Transition of the silent state at balance point should be met

$$\left(\frac{R^* + H}{N}\right)\gamma_f = S\sigma_v \tag{8}$$

Transition of the contending state at balance point should be met

$$S\sigma_v = \left(1 - \frac{R^* + H}{N}\right) Cp_v\varepsilon(C) \tag{9}$$

Wherein, $\varepsilon(C)$ is equivalent to Equation (1). In (7) to (9), when C, R^* and H satisfy Formula (10), and the system is in the equilibrium point state.

$$\frac{(M-C)\omega\gamma_f}{1-(M-C)\omega} - Cp_v\varepsilon(C) = 0 \tag{10}$$

In (8) to (10), $H = \omega\gamma_f(N/d)(M-C)$, $R^* = \omega(d-\gamma_f)(N/d)(M-C)$, $\omega = \sigma_v/(N\sigma_v+\gamma_f)$, $H + R^* = N\omega(M-C)$. Formulae (8)-(10) can be simplified to

$$\begin{cases} \omega\gamma_f(M-C) = CP_v(1-\omega(M-C))(1-p_v)^{C+H-1} & C \geq 1 \\ \omega\gamma_f(M-C) = CP_v(1-\omega(M-C))(1-p_v)^{H} & C < 1 \end{cases} \tag{11}$$

Under the acquirement of a set of system parameters, the Newton iterative method is used to determine the total number of user terminal M, followed by the solution of C, H and R^*. The process of solving C through M involves multiple solutions, and these solutions correspond to different system state and system bistable behavior [1].

The equilibrium point analysis solves the problem efficiently that the state space is too large, and achieves precise analysis on DPRMA-HS relatively.

4. **Performance Simulation and Analysis.** Under the condition of the ideal channel and the random packet error channel, this paper simulates packet drop probability and throughput rate for DPRMA-HS. As well as it, we compare DPRMA-HS with the PRMA-HS.

Packet drop probability refers to the probability that user terminals discard all the data packet if it does not receive feedback message within the maximum tolerable delay $RTD_{\max}$. Formula (12) is the expression of the packet drop probability,

$$P_{drop} = \gamma_f \frac{v^D}{1-(1-\gamma_f)v^D} \tag{12}$$

where, $v = 1 - (1 - R/N)p_v(1-p_v)^{C+H}$, p_v changes dynamically, and its value refer to Formula (1). Meanwhile, due to the fact that speech distortion due to a 1 percent packet dropping is barely audible [7], this paper sets the boundaries of the packet drop probability $p_{drop} = 1\%$.

Throughput rate is the probability that a time slot is reserved successfully. Under the circumstance that time slot is reserved, the user terminals may have three states RES, RES′ and HIN. The formula for throughput rate is as follows [10-12]:

$$\eta = (1-\gamma_f)\frac{R^* + H}{N} + \left(1 - \frac{R^* + H}{N}\right) CP_v\varepsilon(C) \tag{13}$$

Over the ideal channel, we assume that the packet header has no error, and the contending packet collisions are the sole source of system conflicts. Over the random packet error channel, the packet header error causes channel error, which makes the reserved time slots not be acquired by satellite station [2,3,7]. If the error occurs in the terminals' reserved slots, the terminals will end the reservation status in advance and reenter the contending state, and then the packet drop probability increases. Therefore, the random packet error channel has directly impact on the performance of DPRMA-HS. It is assumed that packet header error occurs with a fixed probability Δ. Consistent with equilibrium

TABLE 1. System parameters

Parameter	Rc	Rs	Hv	$RTD_{\max}$	T	t	t_1	t_2
values	720kb/s	32kb/s	64bit	0.032s	0.016s	0.0008s	1.00s	1.35s

TABLE 2. The promotion of system capacity over the ideal channel

Packet drop probability	*PRMA-HS capacity*	*DPRMA-HS capacity*	*Capacity increase Rate*
0.00002	*28*	*36*	*0.286*
0.0001	*32*	*38*	*0.188*
0.001	*38*	*41*	*0.079*
0.01	*42*	*44*	*0.048*
Average increase rate of capacity			*0.150*

point analysis **3.2**, the equilibrium point over the random packet error channel needs to satisfy the following formula.

$$\sigma_v(M-C-R^*-H)+\Delta(R^*+H)(1-\gamma_f)/N-Cp_v\varepsilon(C)(1-\Delta)(1-(R^*+H)/N)=0 \quad (14)$$

where $H=\omega(\gamma_f+(1-\gamma_f)\Delta)(N/d)(M-C)$.

The simulation parameters are shown in Table 1.

4.1. **Simulation and analysis of packet drop probability.** Figure 3 shows the packet drop probability of PRMA-HS protocol and DPRMA-HS protocol over the ideal channel respectively.

In Figure 3, the three different roots of balanced function depended on the predictive values that include 5, M_v and $\min(M_v)$, which are solved by Newton iteration method. One solution is 1, the other two solutions meeting $G(c,h)$ are positive, which meet bistable behavior definition. From different points of view, the bistable behavior mentioned earlier appears. However, DPRMA-HS eliminates the bistable behavior phenomenon effectively.

Table 2 shows that the system capacity of the DPRMA-HS is improved different degrees compared with the PRMA-HS under the premise of different packet drop probability, and the average performance improves significantly, the rate of which is 15%.

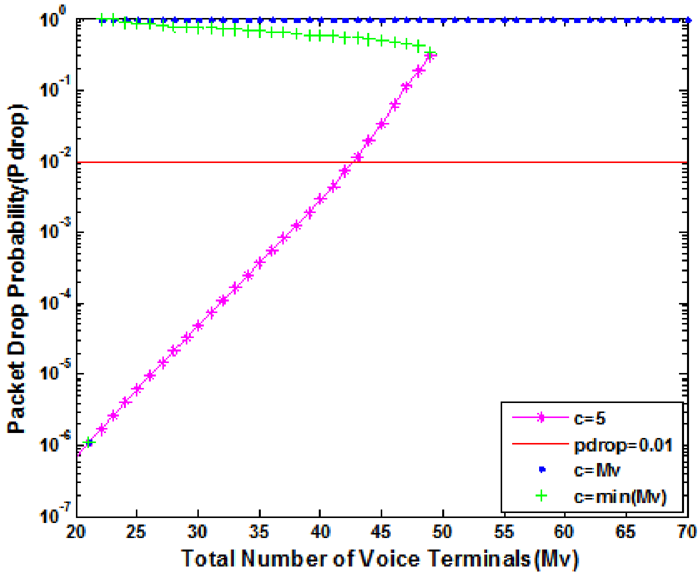
Figure 4(a) shows that bifurcations are not eliminated over the radom packet error channel of PRMA-HS, while Figure 4(b) shows that DPRMA-HS avoids the bistable behavior effectively.

In Figure 4, it could be noticed that the higher the probability of a packet header error is, the higher the packet drop probability is. Compared Figure 4 with Figure 3, under the premise of the same contending terminals, packet drop probability is significantly higher over random packet error channel than the ideal channel.

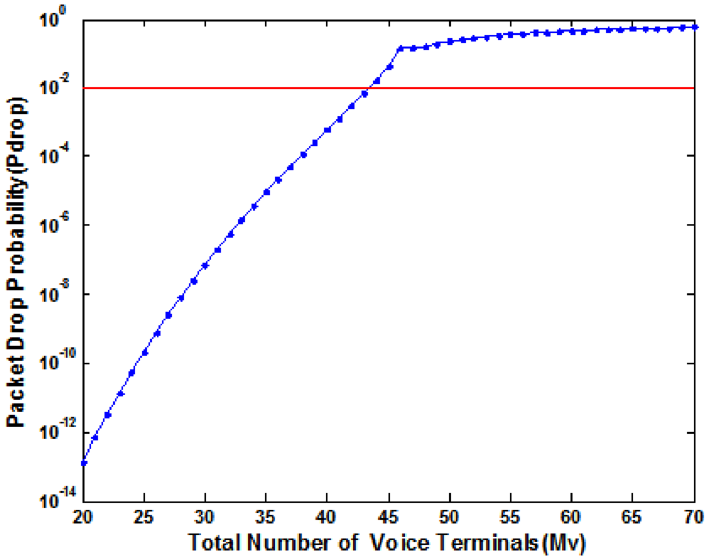
Compared Table 2 with Table 3, it can be obtained that both system capacity of PRMA-HS and DPRMA-HS are much lower over the random packet error channel than the ideal channel, which is due to the increasing of packet drop probability. Similarly, under the premise of the same packet drop probability, the DPRMA-HS's system capacity is much greater than PRMA-HS's, and the average increase rate of capacity is about 15.5%.

4.2. **Simulation and analysis of throughput rate.** Figure 5 shows the throughput rate of PRMA-HS protocol and DPRMA-HS protocol over the ideal channel respectively.

When the number of contending terminals of every contending has different value, Figure 5 shows the variety relationship of throughput rate and the terminals numbers. As shown in Figure 5, there are three different curves. When the predicted number of



(a) PRMA-HS ($p_v = 0.4$)

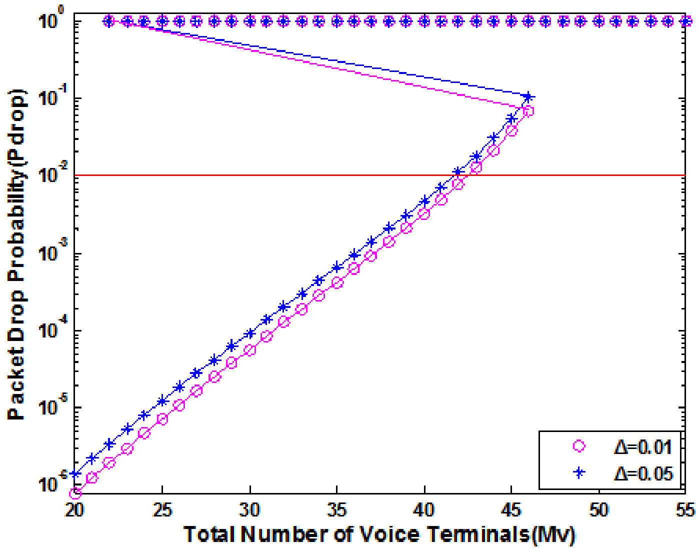


(b) DPRMA-HS

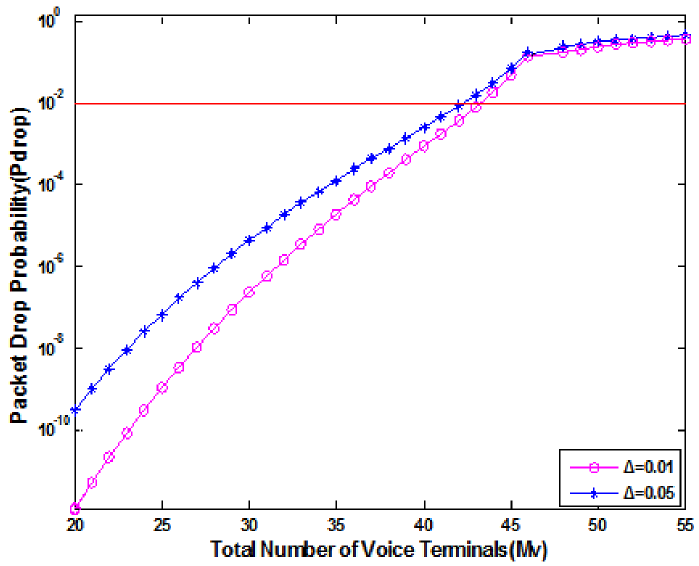
Figure 3. Packet drop probability over the ideal channel

Table 3. The promotion of system capacity over the random packet error channel ($\Delta = 0.05$)

Packet drop probability	*PRMA-HS capacity*	*DPRMA-HS capacity*	*Capacity increase rate*
0.00002	*27*	*35*	*0.296*
0.0001	*31*	*37*	*0.194*
0.001	*37*	*40*	*0.081*
0.01	*41*	*43*	*0.049*
Average increase rate of capacity			*0.155*



(a) PRMA-HS ($p_v = 0.4$)

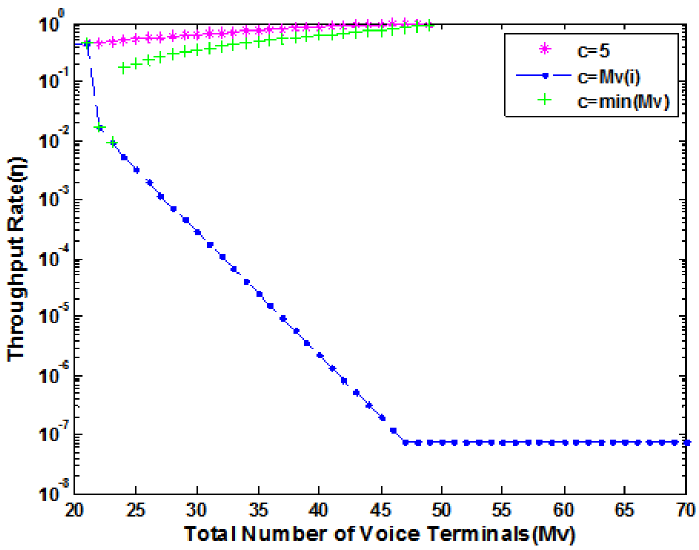


(b) DPRMA-HS

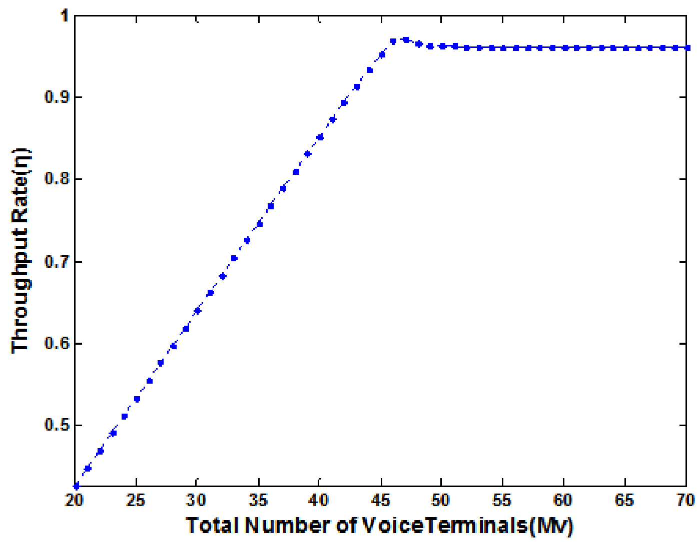
FIGURE 4. Packet drop probability over the random packet error channel

terminals C is 5 or $\min(M_v)$, the system is in a stable region and system's throughput rate is much higher, while throughput rate is from 0.01 to 1. However, when the number of maximum acceptable user terminals equals 44, throughput rate no longer has value. The predicted terminals number C equals $M_v(i)$ since the system is in the congestion state, and when the number of terminals increases, system throughput rate will fall and approach the minimum 10^{-7} gradually.

Relative to Figure 5(a), Figure 5(b) shows that the DPRMA-HS protocol controls bistable behavior effectively with the fixed transmit permission probability due to dynamic changing of the transmit permission probability. At the same time, with the increasing number of user terminals, throughput rate approaches a value gently and the throughput performance improves remarkably.



(a) PRMA-HS ($p_v = 0.4$)



(b) DPRMA-HS

Figure 5. Throughput rate over ideal channel

In summary, the dynamical changing of transmit permission probability guarantees user terminals to access fairly. Over the ideal channel and random packet error channel, packet drop probability of the DPRMA-HS protocol decreases significantly compared with the PRMA-HS protocol. Under the premise of the same packet drop probability, the increase rate of capacity is more than 15%. In addition, DPRMA-HS protocol controls bistable behavior effectively and improves system throughput significantly.

5. **Conclusions.** Based on the study of fixed transmit permission probability in PRMA-HS protocol, this paper proposes the DPRMA-HS protocol which modifies the PRMA-HS protocol by dynamically changing the transmit permission probability. The protocol is simple and extensible. It real-time updates the probability in the light of the launched contending numbers, overcomes the limitation of fixed transmit permission probability, and then ensures the system always in the best condition. Theoretical analysis and simulation

results both show that, DPRMA-HS protocol eliminates the bistable behavior effectively, and the system throughput increases with the increasing number of user terminals. Moreover, the system capacity improves significantly under the premise of the same packet drop probability. How to apply the protocol to varied voice and data terminals business and meet the QOS requirement are the focus of future research work.

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