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AN IMPROVED FAIR GUARD BAND ALLOCATION SCHEME IN COGNITIVE NETWORKS

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ABSTRACT

In this paper, an improved fair dynamic channel algorithm allocation based on guard band scheme is presented. The adoption of the channel strategy in wireless communication has been ensuring the normal communication of important systems, such as coal mine wireless emergency support entity. But future study shows that the secondary users' blocking probability is relatively higher than that of primary user in original 1D Markov states model, which is not conducive to the fairness of network access. Based on deep analysis of model parameters, this paper presents mathematical model of an improved guard channel scheme in wireless communications, simulation results show that users' access performance has been improved significantly.

Keywords: *Wireless communications, Guard Channel Scheme, Continuous Time of Markov Chain(CTMC)*

1. INTRODUCTION

Traditionally, the licensed radio spectrum allocations are regulated by official authorities. The public and government use of radio spectrum is managed by the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC) is in charge of commercial radio resources respectively in the USA. However, as more and more applications of wireless devices, the rapid increasing requisition for radio spectrum licensing has led to current shortage of radio spectrum allocations and put their governing bodies into trouble. In fact, FCC's recent research has shown that these fixed static frequency channels are always idle or not occupied in most of time. Spectrum bands are not efficiently used and underutilization either at a temporal or on a geographical level. By seeking "spectrum holes" (unused frequency channels), cognitive radio (CR) can highly improve spectrum resources efficiency and solve these problems presented above in "secondary utilization"(with lower priority than legacy users) way. Hemalatha, M. , et al.[1] focus on the problem of spectrum sensing, provides an insight into various Spectrum Sensing technologies in cognitive radio and Venkateswari, S. and Muthaiah, R.[2] proposed a new architecture. By using Lyapunov theory, Karthikeyan, A., et al.[3] find the optimum power that is to be transmitted from the base station and also the optimum routes with optimum channel allocation, so that the interference is reduced and frequency reuse is possible. Said, S., et al.[4] consider cooperative diversity, using Fixed Ratio Combining (FRC) to increase detection probability, while Shokair, M., et al.[5] study the effect of variable channel gain on the cooperation between secondary users in cooperative relay performance. By using a new collaborative algorithm for the spectrum sensing based on SNR, Zhenchao, W., M. Chao, and W. Zhe[6] improve the credibility of spectrum detection, because it has the characteristics of the detection conclusion of every cognitive user. Valarmathi, J., D.S. Emmanuel, and S. Christopher[7] present data fusion using the generalized quasilinearization technique to obtain a monotone sequence of iterates in Cognitive systems. In cognitive learning, Pang, T., et al.[8] utilize the Growing Self-organizing Map (GSOM) to build the environment topology cognitive map based on A* and Q-Learning.

In the fair issue, Xing Y., et al.[9] concern about the user fairness and design random channel access protocol based on different bandwidth

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requirements. Raspopovic M., Thompson, C., Chandra, K.[10] find that increasing the number of channels or reducing the broadband business inflow rate can effectively reduce the call blocking probability. To ensure primary users' normal communication and minimize interferes by CR, guard frequency channel scheme was first introduced by HUANG Z.[11]. However, theoretical analysis and simulation results indicate that this scheme poses too much unfair approach to secondary users as apparently high block probabilities compared to legacy counterparts. To balance access chances and reduce high blocking probability of secondary cognitive radio (SCR) in mixed networks consisting of legacy users from the original works, an improved fair blocking term were newly introduced, only slightly posing little impact on primary users that can be completely ignored.

The rest of this paper is presented as follows. In section 2, the guard band scheme is described and simulation steps are also given. Next, we perceive the unfairness aspect of the guard band scheme and propose a new fair guard band allocation scheme in cognitive radio networks in section 3. Then the simulation results comparison and analysis are presented in section 4. In the end the conclusion comes in the final section 5.

2. SYSTEM MODEL

In this scenario, the wireless network is a hybrid network with two types of different access level users: Primary Users (PUs) and Secondary Users (SUs), and PUs have higher network access priority than SUs. The system adopts centralized wireless spectrum resources (channels) control strategy with Dynamic Access Control (DAC). Both PUs and SUs share the local radio spectrum resources with Interweave manner and the spectral overlap at the same time will produce communications interference.

To simplify scene analysis complexity, according to HUANG Z.[11], more assumptions will be introduced. Assume that the user of the hybrid network for each communication occupying only one communication channel. The request rates of PUs' and SUs' channel resources use for communication satisfy Poisson process distribution, denoted by λ_p and λ_s respectively. Also, the channel occupancy time of PUs and SUs meet Exponential distribution of normal mean $\overline{T} = 1/\mu$.

Guard channel strategy will be interpreted for a given local hybrid network with available radio spectrum resources channel number N, will be divided into common channel C and guard channel G, which meets

$$N = C + G$$

Or

$$G = N - C$$

When channel occupancy number is less than or equal to C, the newly arrived channel resource use request of each user is allowed to access into the mixed network; When more than C and less than N channels are occupied, newly arrived PUs will be still accepted while SUs' channel resource use request will be rejected. When the channel occupancy reaches N (no channel resource is available), all newly arrived users will be blocked.

This theory scene can be modeled and analyzed by Markov chain. If $E(t)$ can be defined as the state of the channel occupancy number of the mixed network channel at time t, then $\{E(t), t \geq 0\}$ represents a Continuous Time of Markov Chain(CTMC), and it has N+1 finite number of state from 0 to N. If we denote $P(i)$ as the probability of steady state i, then $P(i)$ satisfies

$$P(i) = \lim_{t\to\infty} P\{E(t), t = i\}$$

The state transition diagram can be illustrated in Figure 1.

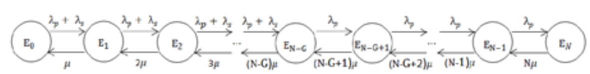

Fig. 1 Guard Channel State Transition Diagram

The recursive form of $P(i)$ is

$$P(i) = \begin{cases} \dfrac{\lambda_p + \lambda_s}{i\mu} P(i-1), i = 1,2,3,\dots,N-G \\ \dfrac{\lambda_p}{i\mu} P(i-1), \quad i = N-G+1,\dots,N \end{cases}$$

and $P(i)$ meets the equation of

$$\sum_{i=0}^{\infty} P(i) = 1$$

Consider the initial value of $P(0)$, $P(i)$ can also be rewriten as

$$P(i) = \begin{cases} \dfrac{(\lambda_p + \lambda_s)^i}{i!\,\mu^i} P(0), \quad i = 1,2,3,\dots,N-G \\ \dfrac{(\lambda_p + \lambda_s)^{N-G} {\lambda_p}^{i-(N-G)}}{i!\,\mu^i} P(0), i = N-G+1,\dots,N \end{cases}$$

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In which

$$P(0) = \left[\sum_{j=0}^{N-G} \frac{(\lambda_p + \lambda_s)^j}{j!\,\mu^j} + \sum_{j=N-G+1}^{N} \frac{(\lambda_p + \lambda_s)^{N-G} \lambda_p^{\,j-(N-G)}}{j!\,\mu^j}\right]^{-1}$$

According to the state transition diagram, the blocking probability of PUs, denoted as $BP(G, N)$ is the state probability when hybrid network channel occupancy number reaches N, that is

$$BP(G, N) = P(N) = \left[\frac{a^{N-G} b^G}{N!}\right] \Big/ \left[\sum_{i=0}^{N-G-1} \frac{a^i}{i!} + \sum_{i=N-G}^{N} \frac{a^{N-G}}{i!} b^{i-(N-G)}\right]$$

The blocking probability of SUs, denoted as $BS(G, N)$ is the total of state probabilities of hybrid network channel occupancy number from C(or N-G) to N, that is

$$BS(G, N) = \sum_{i=N-C}^{N} P(i) = \frac{\left[\frac{a^{N-G}}{(N-G)!} + a^{N-G} \sum_{i=1}^{G} \frac{b^i}{(N-G+i)!}\right]}{\left[\sum_{i=0}^{N-G} \frac{a^i}{i!} + a^{N-G} \sum_{i=1}^{G} \frac{b^i}{(N-G+i)!}\right]}$$

Where

$$a = \frac{\lambda_p + \lambda_s}{\mu}, \qquad b = \frac{\lambda_p}{\mu}$$

In [11], the following parameters are assigned. Local hybrid network radio spectrum resources available channel number N is 12. The request rate of PUs' channel resources use for communication λ_p equals to 2, while the request rate of SUs' channel resources use for communication λ_s is 5. The channel occupancy completion rate μ values 1. Matlab simulation results are shown in Figure 2.

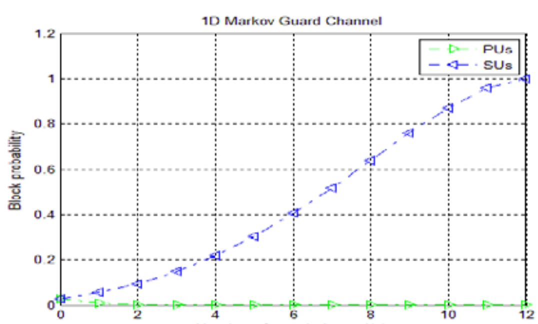

Fig.2 Diagram Of Simulations' Results

In the figure above, the blue dotted line represents the blocking probability of PUs while the green dotted line represents the blocking probability of SUs. From parameter assignments in this section, it can be seen that the mathematical model does not distinguish channel occupancy completion rate between the PUs and SUs. This is not suitable for the real communication environment, and not conducive to network performance analysis of different PUs' and SUs' channel occupancy completion rate. While it can be seen from Figure 2, the blocking probability of SUs has been exceeded 50% when the number of guard channel reaches 7. This means that more than half of SUs channel call requests will be denied, which is not conducive to network access fairness principle. To reduce the high blocking probability of SUs, an improved guard channel access control policy will be introduced in next section.

3. IMPROVED MODEL

In order to further refine and analyze PUs' and SUs' channel occupancy completion rate, a 2D Markov chain is used to established improved model. If i is marked as the channel occupancy number of PUs, and j is marked as the channel occupancy number of SUs, then its 2D Markov chain state is (i,j), in which $0 \leqslant i \leqslant C$, $0 \leqslant j \leqslant N$. The channel occupancy completion rate of PUs is expressed as μ_p, while the channel occupancy completion rate of SUs is denoted as μ_s, then new wireless communication policy mathematical model of the guard channel state transition diagram is shown in Figure 3.

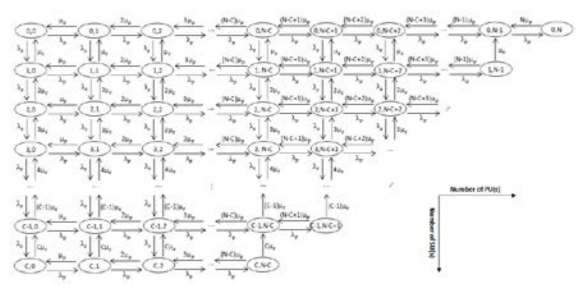

Fig. 3 Guard Channel State Transition Analysis Diagram

Define P(i,j) as the probability of state (i,j) in Markov chain, the following equations are established based on Markov state conversion relationships

$$(\lambda_p + \lambda_s) P(0,0) = \mu_p P(0,1) + \mu_s P(1,0)$$

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$$(\lambda_p + i\mu_p)P(0,i) = \lambda_p P(0,i-1) + \mu_p(i+1)P(0,i+1), \quad \text{where } 0 < i < N, C = 0$$

$$(\lambda_p + \lambda_s + i\mu_p)P(0,i) = \lambda_p P(0,i-1) + \mu_s P(1,i) + \mu_p(i+1)P(0,i+1), \quad \text{where } 0 < i < C \le N$$

$$(\lambda_p + i\mu_p)P(0,i) = \lambda_p P(0,i-1) + \mu_s P(1,i) + \mu_p(i+1)P(0,i+1), \quad \text{where } 0 < C \le i < N$$

$$\mu_p N P(0,N) = \lambda_p P(0,N-1)$$

$$(\lambda_p + \lambda_s + i\mu_s)P(i,0) = \lambda_s P(i-1,0) + \mu_p P(i,1) + \mu_s(i+1)P(i+1,0), \quad \text{where } 1 < i < C < N$$

$$(\lambda_p + \lambda_s + j\mu_p + i\mu_s)P(i,j) = \lambda_s P(i-1,j) + \lambda_p P(i,j-1) + \mu_s(i+1)P(i+1,j) + \mu_p(j+1)P(i,j+1), \quad \text{where } 1 < i < C, 1 < i+j < C < N$$

$$(\lambda_p + j\mu_p + i\mu_s)P(i,j) = \lambda_s P(i-1,j) + \lambda_p P(i,j-1) + \mu_s(i+1)P(i+1,j) + \mu_p(j+1)P(i,j+1), \quad \text{where } 1 < i < C, i+j = C < N$$

$$(\lambda_p + j\mu_p + i\mu_s)P(i,j) = \lambda_p P(i,j-1) + \mu_s(i+1)P(i+1,j) + \mu_p(j+1)P(i,j+1), \quad \text{where } 1 < i < C, C < i+j < N$$

$$(\mu_p j + \mu_s i)P(i,j) = \lambda_p P(i,j-1), \quad \text{where } 0 < i \le C < N, i+j = N$$

$$(\lambda_p + C\mu_s)P(C,0) = \lambda_s P(C-1,0) + \mu_p P(C,1), \quad \text{where } 0 < C < N$$

$$C\mu_s P(C,0) = \lambda_s P(C-1,0), \text{where } C = N$$

$$(\lambda_p + i\mu_p + C\mu_s)P(C,i) = \lambda_p P(C,i-1) + \lambda_s P(C-1,i) + \mu_p(i+1)P(C,i+1) \quad \text{where } 0 < i \le C < N$$

$$(\lambda_p + i\mu_p + C\mu_s)P(C,i) = \lambda_p P(C,i-1) + \mu_p(i+1)P(C,i+1) \quad \text{where } 0 < C < i < N - C$$

The probability of each state can be obtained by applying the above relations to the matrix operation according to the state transition diagram, the blocking probability of PUs, $BP(C,N)$ is the total of state probabilities which satisfy $i + j = N$, that is

$$BP(C,N) = \sum_{i=0}^{C} P(i, N-i)$$

Also, the blocking probability of SUs, $BS(C,N)$ is the total of state probabilities which satisfy $C \le i + j \le N$, that is

$$BS(C,N) = \sum_{i=0}^{C} \sum_{j=C-i}^{N-C} P(i,j)$$

Based on analysis above, improved guard channel access control strategy also differentiate channel occupancy completion rate between the PUs and SUs separately. Improved guard channel access control strategy is expressed as follows: Set the total available channel number of local node is N, if the number of SUs' channel occupancy is less than or equal to C, the hybrid network will always allow the new SUs channel access. When the number of SUs' channel occupancy is higher than C, the new SUs' channel call request will be rejected. While the total number of the channel occupancy is less than N, the PUs channel access will be unaffected, but all new users will be blocked when the total number of the channel occupancy reaches N. Improved guard channel state transition diagram is shown in Figure 4.

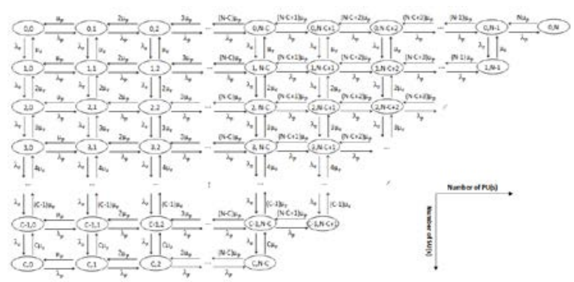

Fig. 4 Improved Guard Channel State Transition Diagram

Define P(i,j) as the probability of state (i,j) in Markov chain, the following equations are established based on Markov state conversion relationships

$$(\lambda_p + \lambda_s)P(0,0) = \mu_p P(0,1) + \mu_s P(1,0)$$

$$(\lambda_p + i\mu_p)P(0,i) = \lambda_p P(0,i-1) + \mu_p(i+1)P(0,i+1), \quad \text{where } 0 < i < N, C = 0$$

$$(\lambda_p + \lambda_s + i\mu_p)P(0,i) = \lambda_p P(0,i-1) + \mu_s P(1,i) + \mu_p(i+1)P(0,i+1), \quad \text{where } 0 < i < N, 0 < C \le N$$

$$\mu_p N P(0,N) = \lambda_p P(0,N-1)$$

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$$(\lambda_p + \lambda_s + i\mu_s)P(i,0) = \lambda_s P(i-1,0) + \mu_p P(i,1) + \mu_s (i+1)P(i+1,0), \quad \text{where } 1 < i < C < N$$

$$(\lambda_p + \lambda_s + j\mu_p + i\mu_s)P(i,j) = \lambda_s P(i-1,j) + \lambda_p P(i,j-1) + \mu_s (i+1)P(i+1,j) + \mu_p (j+1)P(i,j+1), \quad \text{where } 1 < i < C, 1 < i+j < N$$

$$(j\mu_p + i\mu_s)P(i,j) = \lambda_s P(i-1,j) + \lambda_p P(i,j-1), \quad \text{where } 0 < i \le C < N, i+j = N$$

$$(\lambda_p + C\mu_s)P(C,0) = \lambda_s P(C-1,0) + \mu_p P(C,1), \quad \text{where } 0 < C < N$$

$$C\mu_s P(C,0) = \lambda_s P(C-1,0), \text{where } C = N$$

$$(\lambda_p + i\mu_p + C\mu_s)P(C,i) = \lambda_p P(C,i-1) + \lambda_s P(C-1,i) + \mu_p (i+1)P(C,i+1), \quad \text{where } 0 < C < N, 0 < i < N-C$$

The probability of each state can be obtained by applying the above relations to the matrix operation according to the state transition diagram, the blocking probability of PUs, $BP(C,N)$ is the total of state probabilities which satisfy $i + j = N$, that is

$$BP(C,N) = \sum_{i=0}^{C} P(i, N-i)$$

Also, the blocking probability of SUs, $BS(C,N)$ is the total of state probabilities which satisfy $i = C$ or $i + j = N$, that is

$$BS(C,N) = \sum_{j=0}^{N-C-1} P(C,j) + \sum_{i=0}^{C} P(i, N-i)$$

The next section will analyze network performance of different PUs' and SUs' channel occupancy completion rate, and also conduct improved guard channel access control strategy comparison using Matlab simulation.

4. SIMULATIONS

In order to facilitate comparative analysis, we use the same parameters assigned by HUANG Z.[11] in this paper: local hybrid network radio spectrum resources available channel number N is 12. The request rate of PUs' channel resources use for communication λ_p equals to 2, while the request rate of SUs' channel resources use for communication λ_s is 5. First, we analyze the impact on PUs' network performance by the channel occupancy completion rate of PUs and SUs. The simulation results of the impact on PUs' network performance by different channel occupancy completion rate of PUs $\mu_p (\mu_s = 1)$ are illustrated in Figure 5.

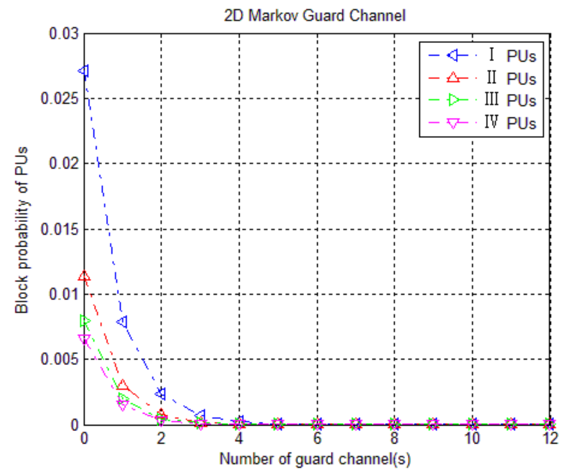

Fig. 5 Different M_P To Pus' Performance($M_S = 1$)

In the figure above, the blue dotted line represents I: the blocking probability of PUs under the channel occupancy completion rate of PUs $\mu_p = 1$; the red dotted line represents Ⅱ: the blocking probability of PUs under the channel occupancy completion rate of PUs $\mu_p = 2$; the green dotted line represents Ⅲ: the blocking probability of PUs under the channel occupancy completion rate of PUs $\mu_p = 3$; the pink dotted line represents Ⅳ: the blocking probability of PUs under the channel occupancy completion rate of PUs $\mu_p = 4$.

The simulation results of the impact on PUs' network performance by different channel occupancy completion rate of SUs μ_s ($\mu_p = 1$) are illustrated in Figure 6.

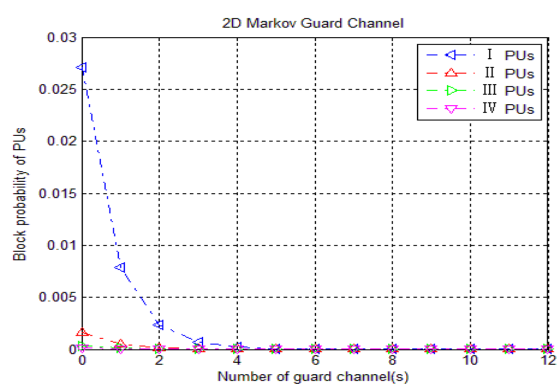

Fig. 6 Different M_S To Pus' Performance($M_P = 1$)

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In the figure above, the blue dotted line represents I: the blocking probability of PUs under the channel occupancy completion rate of SUs $\mu_s = 1$; the red dotted line represents Ⅱ: the blocking probability of PUs under the channel occupancy completion rate of SUs $\mu_s = 2$; the green dotted line represents Ⅲ: the blocking probability of PUs under the channel occupancy completion rate of SUs $\mu_s = 3$; the pink dotted line represents Ⅳ: the blocking probability of PUs under the channel occupancy completion rate of SUs $\mu_s = 4$.

By comparing the two charts above, it can be clearly seen that the blocking probability of PUs reduces as the channel occupancy completion rate of PUs or SUs increases. Here it should be noted that, the impact of SUs' channel occupancy completion rate on PUs' network performance is much greater than that of PUs'.

Then, we analyze the impact on SUs' network performance by the channel occupancy completion rate of PUs and SUs. The simulation results of the impact on SUs' network performance by different channel occupancy completion rate of PUs $\mu_p(\mu_s = 1)$ are illustrated in Figure 7.

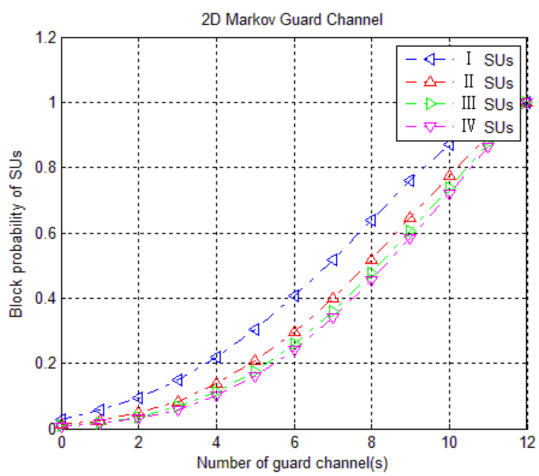

Fig. 7 Different M_P To Sus' Performance$(M_S = 1)$

In the figure above, the blue dotted line represents I: the blocking probability of SUs under the channel occupancy completion rate of PUs $\mu_p = 1$; the red dotted line represents Ⅱ: the blocking probability of SUs under the channel occupancy completion rate of PUs $\mu_p = 2$; the green dotted line represents Ⅲ: the blocking probability of SUs under the channel occupancy completion rate of PUs $\mu_p = 3$; the pink dotted line represents Ⅳ: the blocking probability of SUs under the channel occupancy completion rate of PUs $\mu_p = 4$.

The simulation results of the impact on SUs' network performance by different channel occupancy completion rate of SUs μ_s ($\mu_p = 1$) are illustrated in Figure 8.

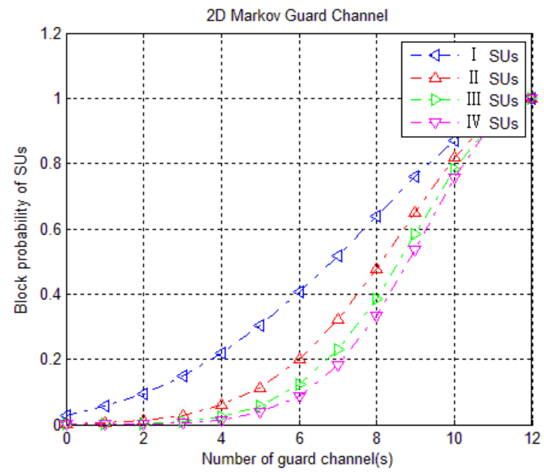

Fig. 8 Different M_S *To Sus' Performance*$(M_P = 1)$

In the figure above, the blue dotted line represents I: the blocking probability of SUs under the channel occupancy completion rate of SUs $\mu_s = 1$; the red dotted line represents Ⅱ: the blocking probability of SUs under the channel occupancy completion rate of SUs $\mu_s = 2$; the green dotted line represents Ⅲ: the blocking probability of SUs under the channel occupancy completion rate of SUs $\mu_s = 3$; the pink dotted line represents Ⅳ: the blocking probability of SUs under the channel occupancy completion rate of SUs $\mu_s = 4$. By comparing the two charts above, it can be clearly seen that the blocking probability of SUs reduces as the channel occupancy completion rate of PUs or SUs increases.

In comparison of Figure 7 and Figure 8, we found something interesting. The impact of SUs' channel occupancy completion rate on SUs' network performance is inconsistent with that of PUs'. When the number of guard channels is small ($C \leq 8$), the impact of SUs' channel occupancy completion rate on SUs' network performance is more than that of PUs'. However, as the number of guard channels increase, the impact of PUs' channel occupancy completion rate on SUs' network performance is bigger than that of SUs' eventually. The reason for this will be the future of scientific research in a more in-depth investigation

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and analysis. In the end, we will make a comparison between improved guard channel access control strategy and the original model.

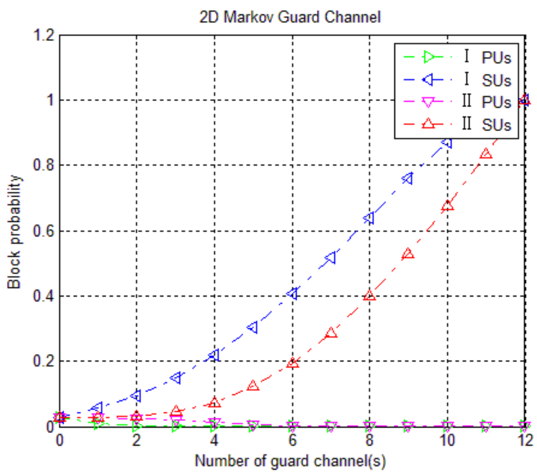

Fig.9 Comparison Of Simulations' Results

In order to facilitate comparative analysis, we use the same parameters assigned by HUANG Z.[11]. Apart from the above-mentioned assignment of parameters, the channel occupancy completion rate of PUs μ_p and SUs μ_s are the same and value 1, that is, $\mu_p = \mu_s = \mu = 1$. The comparison results are shown in Figure 9, the red dotted line represents the blocking probability of PUs and the pink dotted line represents the blocking probability of SUs of improved guard channel access control strategy, while the blue dotted line represents the blocking probability of PUs and the green dotted line represents the blocking probability of SUs of original model. We still investigate the blocking probability of SUs under the number of guard channel of 7, it can be seen that the blocking probability of SUs has been reduced to less than 0.3 as the blocking probability of PUs has no significant abnormal changes. As a result, this improved guard channel access control strategy has been successfully reduced the blocking probability of SUs while contemporarily guarantying PUs' communication essentially unaffected.

5. CONCLUSIONS

In this paper, an improved guard channel access control strategy has been proposed to analyze network performance of different PUs' and SUs' channel occupancy completion rate and reduce high blocking probability of SUs. Simulation results show that, by increasing the channel occupancy completion rate of PUs or SUs can reduce channel requests blocking probability of both users and improve network performance in varying degrees and that of SUs has more effect. The improved guard channel access control strategy can reduce the blocking probability of SUs to a desired level while successfully guarantying PUs' normal communication, which enhance and improve the performance of SUs' network access performance, and eventually ensure fairness between different users' access in the hybrid network.

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