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Dynamic Channel Reservation for Cognitive Radio Networks

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Abstract— **In cognitive radio networks channel reservation has been a branch of deploying more efficient way to the utilization of spectrum. Because of the dominating status of primary users, secondary users have to make room for them when they come. Channel reservation is defined to reserve several fixed channels only for primary users, which will lead to less frequency spectrum handoffs comparing with no reservation mechanism. However, it is a waste of secondary traffic when the reserved channels are not all occupied. In this paper we define a new way to control the number of reserved channels with flexibility so as to enable more secondary user traffic to serve in the cognitive radio networks. We define system maximum tolerable conditions as Grade of Service to judge the performance. Simulation results show that under the same circumstances of the system maximum tolerable probabilities, dynamic channel reservation mechanism works better than fixed channel reservation mechanism by an increase of about 26% traffic gain.**

Keywords— **cognitive radio; channel reservation; dynamic mechanism; Grade of Service; secondary user traffic**

I. INTRODUCTION

According to the US Federal Communications Commission (FCC) frequency allocation [1], many allocations for various licensed operations are in the frequency spectrum from 3 kHz to 300GHz. As a result, higher frequencies have to be deployed due to the overcrowded frequency spectrum occupation with low efficient usage. However, reports by the Spectrum Policy Task Force (SPT) and other interested bodies also indicate the low utilization of the limited frequency spectrum, which is regarded as spectrum holes [2-5]. To enable more efficient usage of spectral resources and the spectrum provision for emerging wireless communication technologies, it is suggested that secondary access to momentarily unoccupied spectral resources within the allocated frequencies of licensed operation be permissible.

The concept of cognitive radio networks [6-7] falls nicely into this new paradigm of spectrum sharing, hoping to make the limited band of frequency spectrum being used more efficiently. In cognitive radio networks we divide all users into two groups, primary users (PU) and secondary users (SU). A primary user has priority of accessing the channel at any time while a secondary user could only access the channel when no user is using the channel at that time. So secondary users could only use the frequency spectrum holes to finish their services and help enhance the whole system throughput in this way. Since primary users have priority to use the channel so the secondary user has to face the problem that when a primary user is coming back it must transit to another idle channel to continue its service or just drop service and leave. In cognitive radio we commonly have three statistical numbers to overview the whole system performance, drop probability, block probability and handoff probability. We hope to enable more secondary users to serve in the whole system under the condition that three statistical numbers should fulfill the system maximum tolerable probabilities. Only in this way, the extra secondary user traffic will do well to the cognitive radio network resulting in the whole system throughput.

Channel reservation scheme is one way to enhance the system performance by leaving several specific channels only for primary users to serve, which will decrease handoff and drop probability so as to enhance the system throughput. Previous study has shown that different reserved number of channels may affect the three probabilities in some aspects. The more channels are reserved, the less handoff and drop probability the system will get, along with the larger block probability. So the trade off between handoff and drop probability and block probability limits the system performance, which results in the best number of reserved channels [8].

The paper is organized as follows: Section II describes basic system model. Section III shows dynamic channel reservation mechanism in details. Section IV gives simulation and results. Finally concluding remarks are made in Section V.

II. SYSTEM MODEL

We consider the cognitive radio network has infinite primary users and infinite secondary users waiting to access to the channels. In our model, we assume that there are a total number of N channels of identical bandwidth in the spectrum and all PUs and SUs could only use one channel to transmit. In our dynamic channel reservation scheme the number of reserved channels is set to R as the initial value and could change from 1 to N according to the controlling mechanism, which will be described in details below. The PUs and SUs are assumed to follow a Poisson arrival process with mean rates λ_P and λ_S respectively. They have negative exponential service time distribution with mean rate $1/\mu_P$ and $1/\mu_S$. For secondary users we define a drop call as PU comes to the occupied channel when SU have no other idle channel to transit. We define a block call as new arrival SU has no idle channel to join in. Also we define a handoff call when PU comes to the existing SU's channel and takes its position while the SU

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has at least one other channel to access and continue its service. The three above statistical numbers reflect the system performance of the cognitive radio network.

III. Dynamic Channel Reservation Mechanism

Despite the improvements of the channel reservation scheme, the fixed number of reserved channels may limit the system throughput in some aspects. If the reserved channels are not all occupied while the rest channels are all being used by secondary users, the new arrival secondary user could not access even though there is at least one idle channel left. At this time if the number of reserved channels can be changed smaller, the system will enable another secondary user to access. On the other hand, if the reserved channels are all occupied by the primary users while at some time the rest channels are not full, the new arrival primary user have to randomly access to the non-reserved channels, which may cause spectrum handoff of the secondary user. In this situation if we enlarge the number of reserved channels, the new arrival primary user will access to the specific channel and cause no trouble to the secondary users. So the number of reserved channels may vary according to the specific channel occupation status and we hope to develop a controlling mechanism of dynamic channel reservation. And we define the controlling mechanism works not more than one time in each slot.

Considering the current number of reserved channels is *R*, we define *i* and *j* as the number of users in reserved channels and non-reserved channels. Since a secondary user cannot serve in the reserved channels while a primary user may access to the non-reserved channel when spectrum handoff happens, *i* only refers to primary users in reserved channels and *j* may consist of secondary users and primary users.

Since $i \le R$ and $j \le N - R$, according to the specific number among *i*, *j*, *N* and *N-R*, we divide all the channel status into several parts below:

1) $i = R, j = N - R$: All the channels are occupied with primary users and secondary users. *R* doesn't change.
2) $i < R, j = N - R$: All the non-reserved channels are occupied and we change one channel for SU rather than PU to access so as to enable more SU serve as a result of increasing the system throughput. Decrease *R* to *R*-1.
3) $i < R, j < N - R$: There is at least one idle channel in reserved channels and non-reserved channels respectively. *R* doesn't change.
4) $i = R, j < N - R$: All the reserved channels are occupied and the new coming PU will cause spectrum handoff trouble to other SUs, however the controlling mechanism depends on the specific number of *j* further more:
   a) $i = R, j = N - R - 1$: There is only one non-reserved channel left in the system. Since we hope to enable more SU, at this moment we leave the last one channel for SU, meaning that we don't change *R*.
   b) $i = R, j < N - R - 1$: There are at least two idle non-reserved channels in the system while all reserved channels are occupied. As a result to avoid more spectrum handoffs we increase *R* to *R*+1 in order to let the new PU access to the reserved channel.

In our dynamic channel reservation mechanism we control the number of reserved channels *R* in above ways. Among all the conditions we must emphasize two important ones again, $i = R - 1, j = N - R$ and $i = R, j = N - R - 1$, where they share the same point that only one idle channel is left in the system. Since we hope to enable more SU to serve in the system, we decide to set this only one channel to the non-reserved channels part. Besides if we don't make a discriminative decision about these two conditions, they will transit from one to another all the time, which leads to the failure and the unexpected control of the mechanism. Finally if we combine all the conditions that *R* doesn't change, we will get a concrete and clear diagram in Figure 1 below.

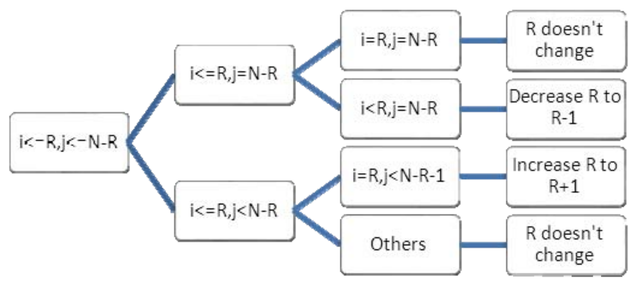

Figure 1. Dynamic controlling mechanism

IV. Simulation and Results

In our simulation there are 9 channels in all. The PUs and SUs are assumed to follow a Poisson arrival process with mean rates λ_P and λ_S respectively. They have negative exponential service time distribution with mean rate $1/\mu_P$ and $1/\mu_S$. The number of reserved channels is *R* and the number of non-reserved channels is *N-R*. If the reserved channels are not all occupied, the new arrived PU will access to one of the idle reserved channels randomly. But when all the reserved channels are occupied, the coming PU will have to access to one of the non-reserved channels randomly and won't leave until finishing its service. We use four statistical numbers (handoff, drop, block and all generated service times) and we define three probabilities (handoff probability, drop probability and block probability) below as the Grade of Service (GoS) to judge the performance of the system.

$$P_{Handoff} = \frac{N_{Handoff}}{N_{AllGeneratedService}} \quad (1)$$

$$P_{Drop} = \frac{N_{Drop}}{N_{AllGeneratedService}} \quad (2)$$

$$P_{Block} = \frac{N_{Block}}{N_{AllGeneratedService}} \quad (3)$$

Since our simulation of channel reservation is different from those in previous papers done with Markov chains and probability analysis, we set up a dynamic simulation program to perform this procedure. The four statistical numbers above are all counting along with the simulation process and will work until the end of the simulation procedure. Thus our new dynamic mechanism alters the number of reserved channels along with the simulation process.

The simulation of our paper will be done in two parts. In part one, we will firstly perform our dynamic simulation on the fixed number of reserved channels mechanism to get the best R which allows the largest secondary user traffic under the basic principle that all three probabilities should satisfy the maximum tolerable probabilities. In part two, we will use the optimal outcome of part one as a comparing sample to meet with our result of the dynamic channel reservation mechanism. If our new mechanism can generate a better outcome than the previous best one, it will mean that our mechanism really does work. We define the system maximum tolerable handoff probability as p_h, maximum tolerable drop probability as p_d, and maximum tolerable probability block probability as p_b. All three maximum tolerable probabilities limit the worst condition that our system could suffer. The concrete simulation parameters are shown in Table I below.

TABLE I SIMULATION PARAMETERS

Number of channels	9
λ_P	0.4
λ_S	range from 0.1 to 1.0
μ_p	0.1
μ_s	0.1
p_h	0.2
p_d	0.05
p_b	0.1
Simulation time slots	3000

A. Fixed channel reservation simulation

In this part we will vary R from 0 to N in order to get a whole view of the system performance caused by the number of reserved channels. For each R we will simulate λ_S from 0.1 to 1.0 all the way and draw a comparison figure of the three probability curves along with different λ_S.

$$C = \max\left\{ \max_{R=0,1,\ldots,N} \{\lambda_S^{(R)} \mid P_{handoff} < p_h, P_{block} < p_b, P_{drop} < p_d\} \right\} \quad (4)$$

The three statistical outcome probabilities should satisfy the system maximum tolerable probabilities and by comparison we will get the largest λ_S as the secondary traffic C that the system could accept. Below in Figure 2 we will show all simulation results.

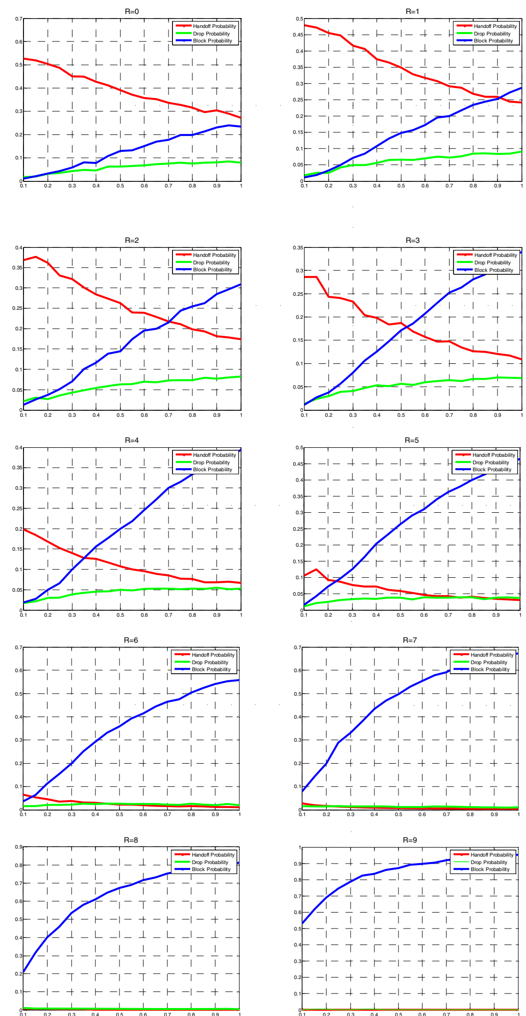

Figure 2. Simulation of fixed channel reservation

According to system maximum tolerable probabilities and the equation above, we can get the largest λ_S of each R as Table II shows below:

TABLE II FIXED CHANNEL RESERVATION RESULTS

R	0	1	2	3	4	5	6	7	8	9

λ_S	0	0	0	0	0.30	0.26	0.18	0.12	0	0

From the table result above we can see the optimal number of *R* is 4 in our system model with nine channels. And by setting *R* to 4 the system will accept a maximal secondary traffic with $\lambda_S = 0.3$ to work along with the existing primary network, which is the best result of the fixed channel reservation mechanism of the cognitive radio network.

B. Dynamic channel reservation simulation

On the basis of the previous part one, we initialize the number of reserved channels *R* to *N/2*. By following the controlling scheme, *R* will alter from 0 to 9 in the simulation process. The simulation result is shown in Figure 3.

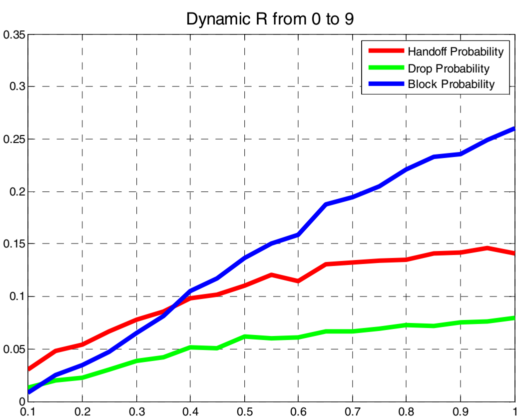

Figure 3. Simulation of dynamic channel reservation

Under the limits of the system maximum tolerable handoff probability, we can see the largest λ_S in dynamic channel reservation mechanism is 0.38. Comparing the secondary user traffic with the previous optimal one in fixed channel reservation mechanism, we can clearly draw the conclusion that dynamic channel reservation really does help improve the system performance. The comparison of the two mechanisms can be illustrated in the Figure 4 below:

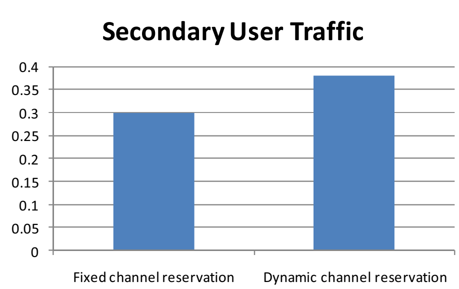

Figure 4. Comparison of fixed and dynamic mechanisms

From the results above, we can see the improvement between dynamic channel reservation and fixed channel reservation. To make better use of the reserved channels, dynamic channel reservation mechanism can enhance the whole secondary user traffic by about 26% in all. Due to the high and flexible efficient use of reserved channels, dynamic channel reservation mechanism can both satisfy the system basic working conditions and enable more secondary users to join in.

V. Conclusions

We study the classical channel reservation mechanism and use a different dynamic way to perform the simulation. From the simulation of the fixed channel reservation mechanism we can get the optimal number of the reserved channels which can fulfill the largest secondary user traffic. By altering the number of reserved channels in a reasonable controlling mechanism we can dynamically decrease or increase the reserved channels according to the specific condition, which will enable more secondary users to join and serve. As a result more secondary users will have opportunities to access to the channels, which enhance the total number of generated service times and decrease the block probability and handoff probability of the cognitive radio network. Also under the same circumstances of the system maximum tolerable probabilities, dynamic channel reservation mechanism works better than fixed channel reservation mechanism by an increase of about 26% traffic gain. So our dynamic channel reservation mechanism can really help the cognitive radio network increase the system throughput performance.

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