# A Novel System Model based on Cost-prediction for Spectrum Leasing in Cognitive Radio

Wang Weidong, Wang Ben, Zhang Yinghai, Zhao Xinlei, Wang Shoufeng
Information & Electronics Technology Lab, Beijing University of Posts and Telecommunications, Beijing 100876, China

**Abstract**: In current researches on spectrum leasing, Common model and Property-right model are two main approaches to dynamic spectrum sharing. However, Common model does not consider the obligation of Primary System (PS) and is unfair to Secondary System (SS), while the cooperation based on Property-rights model has problems on its feasibility. This paper proposes a novel system model, in which a Cost-Prediction scheme for Spectrum Leasing (CPSL scheme) is designed to forecast the cost that PS would pay for leasing spectrum. Cost Function is introduced as a criterion to evaluate the potential cost of spectrum leasing for PS. The simulation results show that compared with Common model based scheme, CPSL scheme substantially improves the QoS of the delay-sensitive traffic in SS at the cost of a small degradation of PS performance.
**Key words**: cognitive radio; spectrum leasing; cost prediction; dynamic spectrum sharing; CPSL

## I. INTRODUCTION

Traditionally, radio spectrum is statically allocated to licensed wireless systems. However, it is observed that spectrum utilization is very low in some frequency band. For example, [1] shows that the utilization of frequency band from 300MHz to 3GHz, which has good propagation characteristics, is lower than 6%. Moreover, compared with the low utilization of frequency band, the demand for radio spectrum shows a more rapid growth. According to the International Telecommunications Union (ITU) report[2], the estimated total spectrum bandwidth requirement for the year 2020 ranges from 1280 to 1720MHz. Consequently, researchers began to seek for a more flexible and comprehensive utilization of the available spectrum.

Cognitive Radio (CR), which is proposed by Dr. Joseph[1][3], is designed to improve the spectrum utilization in wireless communication based on the concept of dynamic spectrum sharing[4]. In cognitive radio networks, radio spectrum can be shared between primary and secondary users so as to increase the spectrum utilization.

Dynamic spectrum sharing in CR allows multiple secondary users to access the radio resource dynamically. With dynamic spectrum sharing, users can adaptively and intelligently use the available radio resources in dynamic radio environment. There are many valuable achievements obtained in this field. Among these researches, two main approaches to dynamic spectrum sharing have emerged[5][6][7]:

Common model: In this framework, Primary System (PS) is authorized to use specific frequency band and behaves without considering the existence of Secondary System (SS). SS can sense the spectrum holes and access appropriate spectrum without disturbing the PS.

Property-rights model: In this framework, PS owns the resources of specific frequency band together with the right to decide whether to lease part of its spectrum to SS in exchange for appropriate remuneration.

This paper focuses on the spectrum leasing in Cognitive Radio, which is a solution to dynamic spectrum sharing. In spectrum leasing, SS obtains the rights to access PS's radio resources through renting the frequency band of PS, so that the PS and SS can share spectrum together. Both Common model and Property-rights model are employed by spectrum leasing in previous work.

The main hindrance of Common model is the limitation on guaranteeing the quality of service (QoS) of SS, because PS behaves as if no SS was presented and has the privilege to withdraw the authorized spectrum rented to SS unconditionally, which leads to frequent handovers of secondary users. It is unfair to adopt Common model in spectrum leasing, since PS disregards for the obligation to ensure the right of SS to use the spectrum for rent and guarantee the QoS of SS.

Property-rights model is still a debated issue in researches for the diversities between the spectrum and real property. In the research on spectrum leasing some researchers propose that PS leases spectrum to SS in exchange for the cooperation of SS, but actually the diversity of communication systems make it difficult to design an SS which can cooperate with different PSs. Therefore the cooperation based on Property-rights model has problems on its feasibility

To solve the problems in current researches, system model of spectrum leasing should be modified. The work of this paper starts from the discussion about relationship between the spectrum uses right of SS and the spectrum ownership of PS. Then a novel system model for spectrum leasing is proposed in this paper along with a corresponding spectrum leasing scheme, which is based on cost-prediction. Using the proposed scheme, the QoS of SS is guaranteed, while the performance of PS is also mildly satisfied.

The remaining sections of this paper are organized as follows. Section II introduces the related work in current research on spectrum leasing. The proposed system model is introduced in Section III. Section IV proposes CPSL scheme and discusses the method of making leasing decision. Simulation designed to evaluate the scheme is in Section V. Section VI summarizes the whole paper.

## II. RELATED WORK

In this section, we describe related work on spectrum leasing. The rationality of adopting Common model and Property-right model is discussed and the problems in current researches are analyzed.

Commons model is more widely used together with the tools such as Markov chains, Game theory and so on. [8] employs a two-level game, which jointly considers the benefits of PS and SS. However, the researcher only considers that SS provides service for non-real traffic such as temporary data transmission. [9] proposes a multi-winner spectrum auction framework for spectrum trading, but the traffic demand for QoS has not been considered. In [10], the author designs a system model in which the SS with best-effort admission will avoid the SS with Grade of Service (GoS) requirement. Markov chain is used in the analysis of system model. [11] assigns the users of SS different priority levels and uses a dynamic policy with hybrid priority to calculate secondary user's non-preemptive priority. The researches of [10] and [11] improve the performance of SS by designing a spectrum access algorithm for SS while still guaranteeing that PS has the preemptive priority to use the authorized spectrum.

Although the spectrum leasing schemes using Common model are feasible to some extent, there are still problems. In these researches PS is allowed to get back the spectrum leased to SS unconditionally. Therefore it is difficult to guarantee the QoS of SS. However, considering the specific characteristics of spectrum leasing, adopting Common model in spectrum leasing is unfair to SS. The most significant difference between spectrum leasing and other approaches to dynamic spectrum sharing is that PS can obtain extra revenue from SS through spectrum leasing[12]. Thus as a permitted holder of the spectrum it rents, SS is entitled to use the spectrum continuously without any interruption. In particular, without protection against arbitrary seizure or harmful trespass of a spectrum holder's property interest, individuals and firms are unwilling to make the long term capital investments that are necessary to create products and services dependent on the resources[13]. For this reason, in the research of spectrum leasing it is irrational for Common model to assume that PS has preemptive priority over authorized spectrum.

In the research of spectrum leasing, Property-rights model is also adopted. [5] and [14] propose a framework in which a primary link has the possibility to lease the spectrum to an ad hoc network of secondary nodes in exchange for cooperation via distributed space-time coding. In the system model of [15] the primary user decides whether to exploit cooperation from secondary terminals in order to maximize its own transmission rate while secondary terminals maximize their rate discounted through spectrum leasing. The theory of Stackelberg games is introduced to analyze the problems.

However, as mentioned before, the cooperation in current research demands that SS can support cooperative communications with different PSs, but actually the diversity of communication systems makes it nearly infeasible to design such a secondary node which can cooperate with different types of PSs.

## III. SYSTEM MODEL IN CENTRALIZED ARCHITECTURE

### 3.1 System model based on cost-prediction

The spectrum use right of SS and the spectrum ownership of PS are a pair of contradiction in spectrum leasing. If SS can rent and use the spectrum unconditionally, so long as it is willing to pay for it, the performance of PS will be affected seriously by spectrum leasing. In contrast, if PS can take back its spectrum without regard to SS, SS will be encountered with frequent handovers and its performance will be poor.

In other words, spectrum leasing cannot only be regarded as a technical aspect of spectrum sharing, but also as a trading process in a cognitive radio environment. And that means interests of both sides in trading should be protected. On one hand, PS should have the right to master its authorized spectrum resources. On the other hand, SS should be protected against arbitrary seizure of the spectrum for rent. As a consequence a suitable system model should consider the both sides mentioned above.

Based on the analysis above, this paper proposes a system model based on cost-prediction. Details are shown as follows.

In this system model, both PS and SS are networks with centralized architecture and have their own authorized spectrum. The wireless network who rent radio resources from other system is called SS in this model; while the network who leases radio resources is called PS. Spectrum leasing is necessary and possible in such type of scenario for the diversity of different wireless networks. That means characteristics of different networks, such as network coverage and users' behavior, will cause the imbalance of system load and the variation of spectrum demand in the same area. Therefore spectrum leasing is a suitable solution.

When the resources of SS are exhausted in certain area, the SS base station in this area would request to rent resources from PS nearby to satisfy its users' access demands. Even though the user of SS is using non-authorized spectrum, user's demand for QoS still needs to be guaranteed, which means it is necessary to ensure that the resources that SS use will not be withdrawn arbitrarily. So in this model we assume that once the radio resources are rent to SS, SS can use it without interruption until it releases the resources by itself.

However, the above assumption will deteriorate the performance of PS. Particularly, when system load of PS base station is heavy or the arrival rate of PS traffic is high, the blocking and dropping of users will become more serious for PS because it cannot regain the resources rented by SS timely. So in this model, a cost-prediction scheme for spectrum leasing (CPSL scheme) is adopted, which means PS can decide whether to lease spectrum according to the cost it would pay for spectrum leasing. PS predicts the cost according to the information that it collects from SS and PS itself. Through this scheme, PS can forecast the consequence before making decision, and the negative impact on PS brought by spectrum leasing can be restricted and controlled by PS. Figure 1 shows the system model proposed in this paper.

### 3.2 The Process of Spectrum Leasing

The process of spectrum leasing in the above system model can be divided into three steps, which are shown as follows.

The first step is triggering spectrum leasing. The spectrum leasing is event-triggered. When the resources of SS base station are exhausted and meanwhile there are traffics requesting to access the base station, the base station will trigger spectrum leasing process to avoid the blocking or dropping of users.

The second step is sending spectrum leasing request. SS base station communicates with PS and sends request to PS. The request will contain the information that PS needs for predicting the cost of spectrum leasing, such as Traffic characteristics and so on.

The third step is making spectrum leasing decision. After receiving the spectrum renting request from SS, PS begins to analyze the cost that it would pay for leasing spectrum, using the information from SS request and PS itself. Then PS will decide whether to lease resources to SS and which PS base station will lease spectrum to SS base station based on the cost-prediction. The decision will be made according to the following formula:

$$F_{lease} = \begin{cases} \{F_c \mid \{c \mid \min(\{C_c \mid C_c \le C_{th}\})\}\} & \{C_c \mid C_c \le C_{th}\} \ne \varnothing \\ \varnothing & \{C_c \mid C_c \le C_{th}\} = \varnothing \end{cases} \quad (1)$$

Where

$F_c$ is the frequency band owned by PS *Base Station c*;

$C_c$ is the cost that PS would pay for spectrum leasing according to PS's prediction if *Base Station*

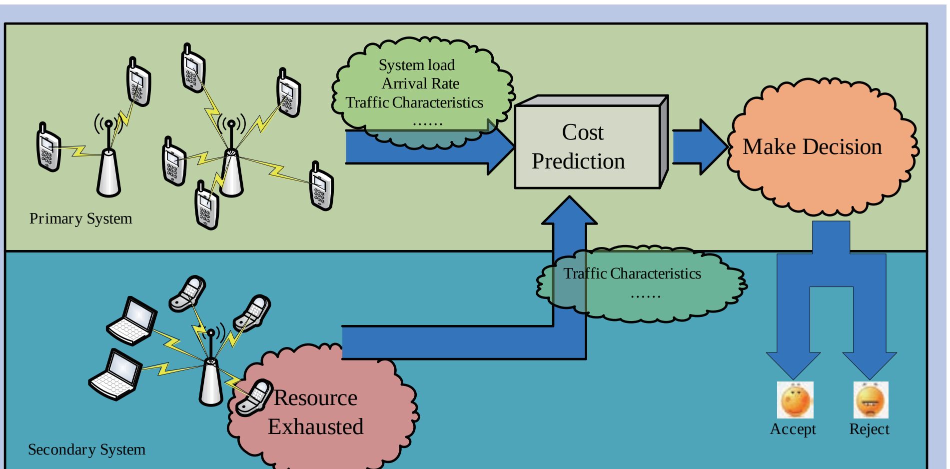



**Fig.1 System Model based on Cost-prediction**

*c* lease radio resources to SS;

$C_{th}$ is a threshold for the decision making of PS, which means only if the leasing cost $C_c$ is lower than $C_{th}$, PS will allow to leased $F_c$ to SS ;

$F_{lease}$ is the frequency band that PS decides to lease to SS after analysis. In (1), if $F_{lease}$ is equal to $\varnothing$, PS will reject the request of SS for there are no suitable radio resources for leasing.

Once PS receives spectrum leasing request from SS base station, it will calculate spectrum leasing cost of all base stations in the same area as the SS base station that sends request. When the spectrum leasing is complete, SS would not release the resources rented from PS until the traffic of SS, who uses the rented radio resources, is completed.

## IV. COST-PREDICTION SCHEME FOR SPECTRUM LEASING (CPSL)

This section introduces corresponding scheme based on the proposed system model, which is called CPSL scheme, to calculate the criterion Cc of decision making for PS. In Section 3.1, the impact of spectrum leasing on PS is analyzed based on the system model proposed above. In Section 3.2, the method to calculate the Transition Probability is discussed.

### 4.1 Criterion of cost-prediction

To simplify the representation, the parameters used in the subsequent discussion are summarized as follows:

*r* is the number of channels that SS requests to rent from PS.

*N* is the number of traffic types that PS supports.

*M* is the number of traffic types that SS supports.

*c* is the serial number of PS base station.

$H_c$ is the total number of channels that PS *Base Station c* has. The channels are mutually orthogonal in frequency domain, For example, PS employs frequency division multiple accessing.

$\xi_c(t)$ is the number of channels which have been used in *Base Station c* at Time .This parameter also denotes the load state of *Base Station c*

*n* represents the traffic type of PS. $1 \le n \le N$.

*m* represents the traffic type of SS. $1 \le m \le M$.

$h_n$ is the number of channels that *Type n* traffic needed.

$\lambda_{n,c}(t)$ is the arrival rate of *Type n* traffic in *Base Station c* of PS at *Time t*. This parameter is a statistic, which is an estimate obtained through observing the arrival rate of traffic in the past.

$\lambda_c'(t)$ is the number of channels needed by the new arriving traffics per second in PS *Base Station c*.

$\mu_{n,c}(t)$ is the departure rate of *Type n* traffic in *Base Station c* of PS at *Time t*. This parameter is also a statistic like $\lambda_{n,c}(t)$.

$\mu_c'(t)$ indicates the number of channels released by completed traffics per second in PS *Base Station c*.

$R_n$ is the average revenue which PS network operator can get from *Type n* traffic, such as one telephone call and so on.

$\overline{T}_m$ is average lasting time of *Type m* traffic of SS.

When SS base station requests to rent spectrum from the PS *Base Station c* (*BS c*), if *BS c* accepts the request and allows SS user to access the radio resources of *BS c*, the resources rented by SS cannot be used by the users of *BS c* and the available resources for *BS c* users will become less. Therefore leasing spectrum to SS will bring the performance degradation to PS, and the blocking rate and dropping rate of *BS c* may rise. It is the potential cost PS would pay for leasing radio resources.

Based on the analysis above, PS has to predict the potential cost that it would pay for leasing spectrum before deciding whether to lease spectrum to SS. For this reason, we introduce Cost Function as a criterion to evaluate the cost.

The Cost Function of single PS base station is firstly considered. Assuming *i* channels of all the $H_c$ channels of *BS c* have been occupied at *Time* $t_0$, namely $\xi_c(t_0)$ is equal to *i* (*BS c* is in the *State i*), and then the state transition probability of *BS c* can be designated as follows:

$$p_{i,j}(t) = P\{\xi_c(t_0 + t) = j \mid \xi_c(t_0) = i\} \quad (2)$$

Let $\Delta t$ denote a very short period of time and during $(t_0+t, t_0+t+\Delta t]$ probability $p_{i,j}(t)$ can be treated as a constant. Then $p_{i,j}(t)\Delta t$ is the time length when *BS c* is in State $j$ during $(t_0+t, t_0+t+\Delta t]$. If the load state $\xi_c(t)$ is contained within the state set $\{H_c-h_n+1, H_c-h_n+2, \ldots\ldots H_c\}$ during $(t_0+t, t_0+t+\Delta t]$, *Type n* traffic of PS will not be allowed to access *BS c*, for there are less than $h_n$ channels left for *Type n* traffic when *BS c* is in these states. The number of *Type n* traffics which would be rejected to access during $(t_0+t, t_0+t+\Delta t]$ can be derived as follows:

$$\sum_{j=H_c-h_n+1}^{H_c} \lambda_{n,c}(t)\, p_{i,j}(t)\Delta t \quad (3)$$

SS would not release the resources rented from PS until the traffic of SS, who uses the rented radio resources, is completed. Then the average lasting time of *Type m* traffic in SS is used as the estimation of time from SS renting the spectrum to releasing it. The number of *Type n* traffic which would be rejected to access during $(t_0, t_0+\overline{T}_m]$ can be derived as follows:

$$\int_{t_0}^{t_0+\overline{T}_m} \sum_{j=H_c-h_n+1}^{H_c} \lambda_{n,c}(t)\, p_{i,j}(t)dt \quad (4)$$

(4) predicts the number of *Type n* traffics which would be rejected to be served by *BS c* during $(t_0, t_0+\overline{T}_m]$. If all these traffics accessed successfully, the revenue which these *Type n* traffics bring to PS would be

$$\int_{t_0}^{t_0+\overline{T}_m} \sum_{j=H_c-h_n+1}^{H_c} \lambda_{n,c}(t)\, p_{i,j}(t) R_n dt \quad (5)$$

We use the potential revenue that *BS c* would lose for system blocking during $(t_0, t_0+\overline{T}_m]$ as the criterion for spectrum leasing decision. Considering PS can support $N$ types of traffics, we define Cost Function as:

$$\mathrm{I}(\overline{T}_m, i, H_c) = \sum_{n=1}^{N} \int_{t_0}^{t_0+\overline{T}_m} \sum_{j=H_c-h_n+1}^{H_c} \lambda_{n,c}(t)\, p_{i,j}(t) R_n dt \quad (6)$$

(6) is the prediction on the potential revenue that BS c would lose for system blocking during $(t_0, t_0+\overline{T}_m]$. If *BS c* agreed to lease the spectrum which corresponds to $r$ ($r \le H_c-i$) channels to SS, the channels available for users in *BS c* would be $H_c-i-r$ instead of $H_c-i$, for PS cannot withdraw channels leased to SS timely. The potential revenue *BS c* would lose for system blocking would increase, for the performance of *BS c* may be degraded by leasing spectrum.

The Cost Functions are calculated separately on condition that spectrum leasing request is rejected and that spectrum leasing request is accepted. The difference between the two Cost Functions is the cost *BS c* would pay for leasing spectrum, which can be derived as follows:

$$C_c = \begin{cases} \mathrm{I}(\overline{T}_m, i, H_c - r) - \mathrm{I}(\overline{T}_m, i, H_c) & 0 \le i \le H_c - r \\ \infty & H_c - r < i \le H_c \end{cases} \quad (6)$$

In (6), $H_c-i \le r \le H_c$ means *BS c* does not has enough frequency bands to lease, so $C_c$ is set as positive infinity under this condition.

When costs of all base stations, which are in the same area as the SS base station that sends request, are calculated, PS will use (1) to decide whether to lease radio resources and which PS base station will lease spectrum to the SS base station.

**4.2 Analysis of transition probability**

In order to calculate the spectrum leasing cost, the variable $p_{i,j}(t)$ should be obtained. Thus this section will discuss the method to work out the transition probability $p_{i,j}(t)$ in the (6).

The arrival rates and departure rates of different types of traffics cannot be used as the arrival rate and departure rate of *BS c*, because the numbers of channels, which different types of traffics need, are not the same. In this case, we use $\lambda_c'(t)$ and $\mu_c'(t)$ as the arrival rate and departure rate of *BS c* separately during $(t_0, t_0+\overline{T}_m]$. $\lambda_c'(t)$ and $\mu_c'(t)$ can be obtained as follows:

$$\lambda_c'(t) = \sum_{n=1}^{N} \frac{\lambda_{n,c}(t) h_n}{\sum_{n=1}^{N} \lambda_{n,c}(t)} \quad (7)$$

$$\mu_c'(t)=\sum_{n=1}^{N}\frac{\mu_{n,c}(t)h_n}{\sum_{n=1}^{N}\mu_{n,c}(t)} \tag{8}$$

Assuming that $\{\xi_c(t),t\geq 0\}$ is a countable homogeneous Markov process and state space is $\{0,1,2......\}$, $p_{i,j}(t)$ meets the conditions of birth-and-death process[16]. Therefore $\{\xi_c(t),t\geq 0\}$ is a birth-and-death process

In this birth-and-death process, the death rate of State $i$ is equal to $i\mu_c'(t)$, while the birth rate of State $i$ is equal to $\lambda_c'(t)$. Considering the condition that PS does not lease spectrum to SS, Markov chain has $H_c$+1 states. The state transition of Markov chain is show in Figure 2. The Kolmogorov equations of this birth-and-death process are

$$\begin{cases} \dfrac{dp_{i,j}(t)}{dt}=\lambda_c'(t)p_{i,j-1}(t)-(i\mu_c'(t)+ \\ \qquad \lambda_c'(t))p_{i,j}(t)+(j+1)\mu_c'(t)p_{i,j+1}(t) \\ \dfrac{dp_{i,0}(t)}{dt}=-\lambda_c'(t)p_{i,0}(t)+\mu_c'(t)p_{i,1}(t) \qquad 0<j<H_c \\ \dfrac{dp_{i,H_c}(t)}{dt}=\lambda_c'(t)p_{i,H_c-1}(t)-H_c\mu_c'(t)p_{i,H_c}(t) \end{cases} \tag{9}$$

The initial condition of the equations is

$$p_{i,j}(t)=\delta_{i,j} \tag{10}$$

If the $BS$ $c$ agreed to lease the spectrum which corresponds to $r$ channels to SS, the number of the states in Markov chain would be reduced to $H_c$-$r$. The Kolmogorov equations on transition probability can be listed similarly.

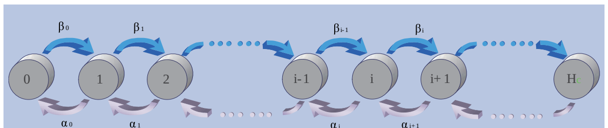



Fig.2 The state transition of Markov chain model

## V. SIMULATION AND RESULT ANALYSIS

### 5.1 Design of simulation

System level simulation is introduced to evaluate CPSL scheme based on the proposed system model. Firstly, we use simulation to study the relationship between leasing threshold $C_{th}$ and system performance. Secondly, we compare the performance of CPSL scheme with the traditional spectrum leasing scheme based on Common model.

The simulation parameters are set as Table 1:

Table 1 Simulation parameters

| Parameters | Value |
|---|---|
| Number of base stations in simulation area | PS:12 SS:8 |
| Numbers of traffic types system supports | PS:1 SS:1 |
| Number of channels each base station owns | PS:32 SS:36 |
| Maximum delay handover user can bear | PS:200ms SS:200ms |
| Maximum delay new user can bear | PS:3s SS:3s |
| Average lasting time of traffic | PS:30s SS:30s |
| Number of channels that traffic occupies | PS:1 SS:2 |
| Simulation time | 200s |
| Simulation step size | 10ms |
| The handover probability of user | 0.74 |
| The distribute of traffic arrival rate | Poisson Distribution |
| The distribute of traffic lasting time | Exponential Distribution |

### 5.2 Result analysis

In the simulation, the traffics of PS and SS are both delay-sensitive. Consequently, dropping rate is used to evaluate QoS of users, and system performance is evaluated through average throughput of base station.

Figure 3 shows the impact of leasing threshold $C_{th}$ on dropping rate and the average throughput of PS and SS. Four curves are obtained under different arrival rate of PS base station, and SS are in heavy load during simulation time. The leasing threshold is normalized in the figures.

In Figure 3(a) and Figure 3(b) it can be observed that along with the increase of leasing threshold, dropping rate of SS decreases while dropping rate of PS increases, and the curves in Figure 3(a) is flatter than that in Figre 3(b).That is because PS restricts the negative impact on QoS of PS brought by spectrum leasing through predicting the potential cost before making decision. Comparing the four curves in Figure 3(a) and Figure 3(b), it can be found that when the arrival rate of PS is low, raising leasing threshold can significantly improve the QoS of SS and the degradation of PS QoS is not serious. By contrast, when the arrival rate of PS is high, the improvement of SS QoS is limited, because PS tends to reject the spectrum leasing request in order to decrease potential spectrum leasing cost when the system load is heavy, which means probability that PS would accept request is smaller.

Figure 3(c) and Figure 3(d) shows the relationship between leasing threshold and average throughput. Similar conclusions about system performance can be drawn from Figure 3(c) and Figure 3(d). The average throughput of PS hardly degrades when the leasing threshold is rising, and there is nearly no marked increase on average throughput of SS when the arrival rate of PS is high.

According to the analysis above, we can draw the conclusion that the CPSL scheme is more suitable for the condition that the system load of PS is not very high. Otherwise, the advantage brought by spectrum leasing will not be very prominent. In addition, the simulation results reveal that PS can adjust the leasing threshold dynamically in accordance with system load so as to adapt the change of traffic arrival rate.

In the simulation the performance of CPSL scheme is compared with the traditional spectrum leasing scheme based on Common model. Figure 4 shows the simulation results, which is obtained when the normalized leasing threshold is equal to 0.4 and the system load of SS is heavy.

Figure 4(a) indicates that the PS dropping rate of CPSL scheme is a little higher than that of Common model based scheme, for PS cannot withdraw radio resources timely. When the arrival rate of PS is high, the dropping rates of the two schemes are nearly the same. Figure 4(b) shows that the dropping rate of SS can be decreased significantly especially when the arrival rate of PS is very high. That is because in Common model, when the system load of PS is heavy, the probability that PS takes back the spectrum is high correspondingly, which will cause the SS users handover frequently. In Figure 4(c) and Figure 4(d) the curves of the two schemes almost coincides, which means the throughput are similar when adopting the two schemes.

Through the analysis of Figure 4, it is shown that compared with the scheme based on Common model, CPSL scheme substantially improves the QoS of the delay-sensitive traffic in SS at the cost of a small increase of PS dropping rate. The simu-

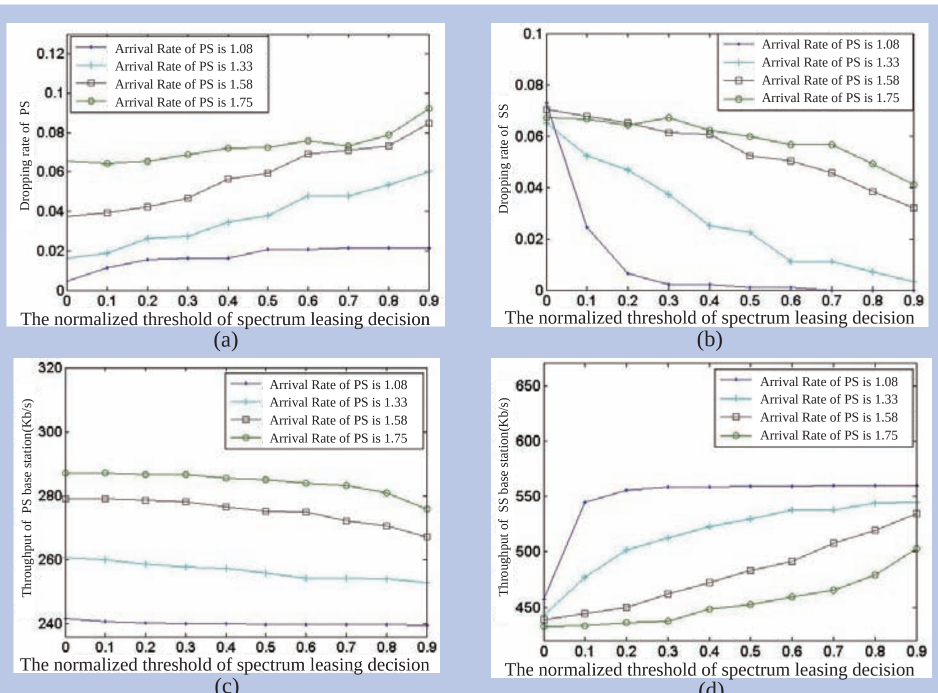



**Fig.3 The impact of spectrum leasing threshold**

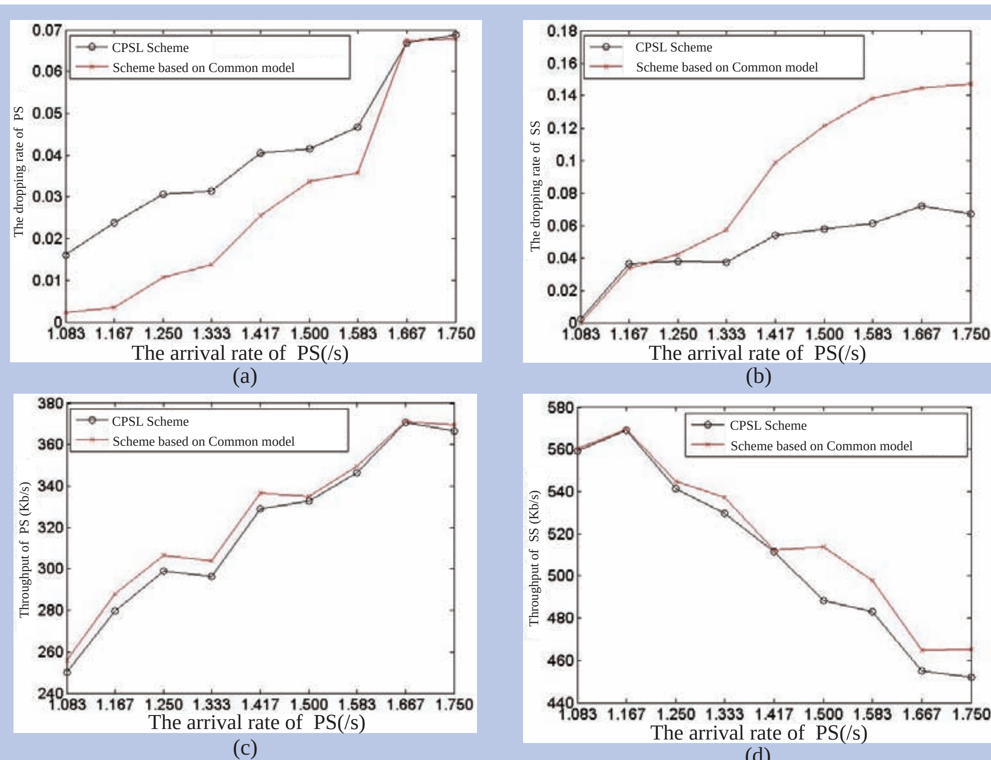



**Fig.4 The comparison between CPSL scheme and the scheme based on Common model**

lation results show the proposed system model has advantages of guaranteeing the QoS of SS over Common model, and the SS adopting proposed model can provide service to real-time traffic.

## VI. CONCLUSIONS

A novel system model for spectrum leasing, which is applied to networks with centralized architecture, is proposed in this paper. In the model, PS decides whether to lease spectrum according to the cost it would pay for spectrum leasing, and SS is permitted to use rented spectrum without interruption. Together with the system model, the CPSL scheme is put forward and Cost Function is defined to evaluate the potential cost that PS would pay for spectrum leasing. Simulation results show that PS can control the effect brought by leasing spectrum through adjusting leasing threshold dynamically. Compared with the scheme based on Common model, CPSL scheme can significantly improve QoS of SS users at the cost of a small increase of PS dropping rate. Through adopting proposed model, SS is able to provide service to real-time traffic. 中国通信

## Acknowledgements

This work is supported by the National High Technology Research and Development Program of China ('863' Program, No.2009AA01Z242) and National Natural Science Foundation of China (60972080).

## References

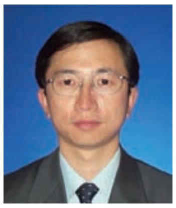
[1] Mitola J. III, Maguire G.Q. Jr.. Cognitive radio: Making software radios more personal. IEEE Personal Communications Magazine. August, 1999: 13-18.

[2] ITU-R M.2078. Estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-Advanced. 2006.

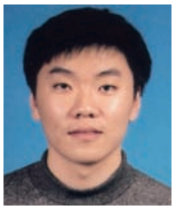
[3] Mitola J. III.. Cognitive radio for flexible mobile multimedia communications. Mobile Multimedia Communications,

1999. November, 1999: 3-10 .
[4] Haykin S. Cognitive Radio: Brain-empowered Wireless Communications. Selected Areas in Communications, IEEE Journal on. February,200: 201-220.
[5] Simeone O., Stanojev I., Savazzi S., Bar-Ness Y., Spagnolini U., Pickholtz R.. Spectrum Leasing to Cooperating Secondary Ad Hoc Networks. Selected Areas in Communications, IEEE Journal on. January, 2008: 203-213.
[6] Peha, J.M.. Approaches to spectrum sharing. Communications Magazine, IEEE. February, 2005: p10-12.
[7] Stanojev I., Simeone O., Bar-Ness Y., Yu T.. Spectrum Leasing via Distributed Cooperation in Cognitive Radio. Communications, 2008. ICC '08. May, 2008: 3427-3431.
[8] Shufang Lin, Xuming Fang. Two-level Game Based Spectrum Lease Framework in Cognitive Radio Networks. Communication Systems, 2008. November,2008: 104-108.
[9] Yongle Wu, Beibei Wang, Liu K., Clancy T.C.. A Multi-Winner Cognitive Spectrum Auction Framework with Collusion-Resistant Mechanisms. New Frontiers in Dynamic Spectrum Access Networks, 2008. October, 2008: 1-9.
[10] Tang Pak Kay, Chew Yong Huat, Ong Ling Chuen, Chin Francois. On the Grade-of-Services in the Sharing of Radio Spectrum. Cognitive Radio Oriented Wireless Networks and Communications, 2007. August, 2007: 85-89.
[11] Ping Zhu, Jinglong Li, Xufa Wang. Scheduling Model for Cognitive Radio. Cognitive Radio Oriented Wireless Networks and Communications, 2008. May, 2008: 1-6.
[12] Niyato D., Hossain E.. Spectrum Trading In Cognitive Radio Networks: A Market-Equilibrium-Based Approach. Wireless Communications, IEEE. December,2008: 71-80.
[13] Hatfield D.N., Weiser P.J.. Property Rights in Spectrum: Taking the Next Step. New Frontiers in Dynamic Spectrum Access Networks, 2005. November, 2005: 43 – 55.
[14] Simeone O., Gambini J., Bar-Ness Y., Spagnolini U.. Cooperation and cognitive radio. Communications, 2007. June, 2007: 6511-6515.
[15] Stanojev I., Simeone O., Bar-Ness Y., Yu T.. Spectrum Leasing via Distributed Cooperation in Cognitive Radio. May, 2008: 3427-3431.
[16] Zikun Wang, Xiangqun Yang. Birth-and-death Process and Markov Chain. Science Press. Second Edition. January, 2005: 185-187.

## Biographies



***Wang Weidong***, got his Ph.D degree from Beijing University of Posts and Telecommunications in 2002. He is now the Associate Professor and Deputy director of Information & Electronics Technology Lab at Beijing University of Posts and Telecommunications. His research focuses on radio resource management and applications in mobile telecommunications.



***Wang Ben***, is a Ph.D candidate in Information & Electronics Technology Lab at Beijing University of Posts and Telecommunications. His research interests include spectrum sharing in Cognitive Radio and interference analysis on wireless communication system.

***Zhang Yinghai***, got his Ph.D degree from Beijing University of Posts and Telecommunications in 2007. He is now a Professor and Director of Information & Electronics Technology Lab at Beijing University of Posts and Telecommunications. His research areas include wireless communications networks and microelectronics.

***Zhao Xinlei***, is a postgraduate student for a Master's Degree in Information & Electronics Technology Lab at Beijing University of Posts and Telecommunications. Her research interests include radio resource management in mobile telecommunications spectrum management in cognitive radio.

***Wang Shoufeng***, is a Ph.D candidate in Information & Electronics Technology Lab at Beijing University of Posts and Telecommunications. His research interests include radio resource management in wireless communications, spectrum detection techniques as well as spectrum management in cognitive radio.