Analysis of Active Spectrum Handoff Effect Based on Cooperative Spectrum Prediction

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Abstract. In the cognitive radio network environment, because the sub-user opportunistic use of "spectrum hole" to communicate, resulting in the inevitable uninterrupted system for spectrum switching, and frequent spectral switching system performance significantly reduced. In this paper, an active spectrum switching method based on improved cooperative spectrum prediction is proposed based on the existing active spectrum switching based on single user prediction. This method can effectively improve the performance of spectrum switching by introducing the cooperative prediction module into the frame structure and the idea of dividing the frame structure frequency domain. Based on the experimental simulation, it is proved that the performance of the method is improved compared with the traditional single-user prediction active spectrum switching method and the periodic spectrum sensing switching method, the average switching delay, channel switching frequency and collision rate and other performance indicators have been effectively improved.

1. Introduction
Spectrum switching is a key link in the cognitive radio to realize the effective reuse of the idle spectrum. It determines whether the secondary user can switch to the idle channel which meets the requirements effectively, and then completes the communication task. It is found that the active spectrum switching method based on spectrum prediction is widely used in practice. [1] and [3] optimize the channel switching discriminating method by introducing the two-factor sorting method of switching cost function and joint switching delay and switching times respectively. So that the secondary user can choose the best switching time to switch, in order to achieve the purpose of reducing the switching delay. And compared with the literature [2] and [4] respectively, it is verified that the improved active switching method can reduce the number of switching times and then reduce the effect of delay. But this way only from the perspective of optimization theory to alleviate a certain delay, and did not solve the fundamental problem of delay, that is, spectrum sensing efficiency. In the literature [5] - [9], by introducing the spectrum prediction module, on the one hand, the efficiency of spectrum sensing is improved, and the delay problem due to perceived efficiency problem is solved to a certain extent. On the other hand, this prediction mode can make the secondary user more accurate in advance to make the switch action, reducing the primary and secondary users between the collision rate. However, the problem that the accuracy of this local spectrum prediction method is not high is still a fatal injury that limits perceived efficiency improvement and reduced collision rate. And in this traditional "perception - transmission" of the cognitive frame structure model to join the prediction module, and can not solve this mode on the time domain work caused by the transmission interrupt problem.

In view of the above problems, this paper proposes the introduction of collaborative prediction...
module, in order to further improve the prediction accuracy of the target channel, reduce the collision between primary and secondary users. In addition, the structure of the communication data module is optimized by the idea of frequency domain segmentation. The optimized data structure module can complete the idle probability prediction of the target channel in real time without interrupting the communication data. Through this data structure changes, can effectively reduce the active spectrum switching delay.

2. System model

2.1. Channel model
Assume that there are N authorized primary users in the cognitive network, and each master user uniquely corresponds to one channel, so there are N channels. Because the secondary user can only use the authorization channel according to the main user activity situation, that is, the secondary user's working mode is a kind of "perception-transmission" alternately, so it is suitable for establishing the ON/OFF model for the main user activity. As shown in Figure 1, where ON represents the channel is occupied, OFF means that the channel is idle.

![Figure 1 Channel Status ON/OFF Model](image)

Here we assume that the channel occupancy or idle conditions subject to Poisson distribution, so you can use the service time and service requests to reach the interval to describe the two states of the channel. According to the theory of queuing theory, it can be seen that the occupied and idle time of the channel obeys the exponential distribution.

The exponential distribution parameters of the duration X of the idle state of the channel and the duration Y of the occupied state are respectively and then the probability density function is:

\[
f(x) = \begin{cases} 
\lambda e^{-\lambda x}, & x > 0 \\
0, & \text{other} 
\end{cases}
\]

\[
f(y) = \begin{cases} 
\mu e^{-\mu y}, & y > 0 \\
0, & \text{other} 
\end{cases}
\]

Thus, the ratio of the utilization rate of the primary user to the channel k to the occupied state time and the two arrival time interval is:

\[
\eta_p = \frac{Y}{X + Y} = \frac{\mu^{-1}}{\lambda^{-1} + \mu^{-1}} = \frac{\lambda}{\lambda + \mu} 
\]

For the secondary user, the ratio of the channel utilization to the idle state duration and the user's two arrival time interval is:

\[
\eta_s = \frac{X}{X + Y} = \frac{\lambda^{-1}}{\lambda^{-1} + \mu^{-1}} = \frac{\mu}{\lambda + \mu} 
\]

2.2. Spectral Idle Probability Estimation
Since the active state of the primary user channel is established as an ON/OFF model, this ON/OFF alternating channel state process can be described using the Markov process. That is, each channel contains two states, Indicated by \( S = \{0,1\} \), 0 for free, 1 for occupancy. The definition \( P_{i,j}^k \) represents the probability that the channel state transitions from \( i \) to state \( j \) after channel K passes time \( \Delta t \). For example, \( P_{10}^k \) indicates the probability that the channel K is converted from the original ON state to the OFF state after the elapsed time \( \Delta t \). The channel state transition model is shown in Figure 2:
From (1) to (4) and Laplace inverse transform, we can get the idle state transition probability of the main user under ideal conditions [10], as shown in Eq. (5):

\[ P_{00}^{k}(\Delta t) = \frac{\mu_{\rho}^{k}}{\lambda_{\rho}^{k} + \mu_{\rho}^{k}} e^{-\lambda_{\rho}^{k} \Delta t} + \frac{\lambda_{\rho}^{k}}{\lambda_{\rho}^{k} + \mu_{\rho}^{k}} e^{-(\lambda_{\rho}^{k} + \mu_{\rho}^{k}) \Delta t} \] (5)

\[ P_{10}^{k}(\Delta t) = \frac{\mu_{\rho}^{k}}{\lambda_{\rho}^{k} + \mu_{\rho}^{k}} e^{-\lambda_{\rho}^{k} \Delta t} - \frac{\lambda_{\rho}^{k}}{\lambda_{\rho}^{k} + \mu_{\rho}^{k}} e^{-(\lambda_{\rho}^{k} + \mu_{\rho}^{k}) \Delta t} \] (6)

The probability of the next slot idle for channel K is [10]:

\[ P_{0}^{k} = \begin{cases} P_{00}^{k}(\Delta t) \\ P_{10}^{k}(\Delta t) \end{cases} \] (7)

2.3. Spectrum residual free time prediction

According to the channel idle probability of 2.2 and the result of reference [12], the idle time of channel K can be predicted by channel state transition probability and channel correlation state parameter, as shown in equation (8)

\[ T_{s} = P_{0}^{k} / \lambda_{\rho}^{k} \] (8)

However, it is found that the state time that the channel k has been continuously idle will affect the predicted value of the available time of the channel. Therefore, according to the literature [11] on the channel available time prediction method to improve, as shown in (9):

\[ T_{s} = \begin{cases} P_{00}^{k} / \lambda_{\rho}^{k} \\ P_{00}^{k} / (\lambda_{\rho}^{k} - n\Delta t) \end{cases} \] (9)

In equation (9), n represents the number of time slots that the channel K has been continuously idle before the current idle state, \( n = 1, 2, 3, \ldots \). Since in the cognitive network environment, the secondary user communicates on the "spectrum hole" in the "sensing-transmission" communication mode, and "perceived - transmitted" is \( \Delta t = \tau_{s} + \tau_{t} \), where \( \tau_{s} \) is the sensing time and \( \tau_{t} \) is the transmission time. Therefore, it can be considered that the length of time that has been idle is an integer multiple of the "perceived - transmitted" duration.

2.4. Active Spectrum Switching Method Based on Improved Perception Frame Structure

In the traditional perceptual frame structure, the data structure in each time slot is shown in Fig. 3, which periodically perceives the use channel. If it is perceived that the primary user reoccurs the channel, the secondary user immediately terminates the currently engaged communication task and goes to the waiting state. When the new available holes are again perceived, jump to the new hole to continue the data transmission. If the channel is still found after all the channels have been detected, the communication traffic of the secondary user is interrupted until the available holes are perceived again. In addition, in this structure, spectrum sensing and data transmission are performed over time in time. This results in the end of each perceptual period T, and the secondary user's data transmission has to be interrupted once to enter the next stage of the perceptual phase. This inevitably leads to the secondary user to complete the communication process, if the n times the perception, it will lead to the
emergence of \( n(\tau_p + \tau_s) \) time delay.

\[
\begin{array}{cccccc}
\tau_p & \tau_s & T - \tau_s - \tau_p & \tau_p & \tau_p \\
\text{Spectrum prediction} & \text{Spectrum sensing} & \text{data transmission} & \text{Spectrum prediction} & \text{data transmission}
\end{array}
\]

Figure 3 Perceptual frame structure for traditional active handover methods

The improved frame structure used in this paper is shown in Figure 4, in each hole using the frequency domain on the frequency for work. That is, a small part of the bandwidth for real-time spectrum prediction and perception, another part of the bandwidth is used for data transmission. This method adds the cooperative prediction mechanism on the basis of the traditional spectrum sensing frame structure, improves the prediction accuracy, thus improves the sensing efficiency and shortens the delay of the spectrum switching. On the other hand, the frame structure effectively solves the problem that in the traditional frame structure, each of the sensing periods ends and the secondary user communication must be interrupted once. Because, in the sense frame structure, the perception and data transmission is divided at the same time. Thus effectively reducing the time it takes to complete a communication task.

\[
\begin{array}{cccccc}
\tau_p & \tau_c & \tau_s & \tau_p & \tau_c & \tau_s \\
\text{Spectrum prediction} & \text{User cooperation} & \text{Spectrum sensing} & \text{Spectrum prediction} & \text{User cooperation} & \text{Spectrum sensing}
\end{array}
\]

Figure 4 Perceptual frame structure of improved active switching method

2.5. Spectrum switching process

The criteria for determining the frequency switching are usually based on the channel idle probability or the channel remaining idle time. However, the study found that switching based on channel idle probabilities often results in frequent channel switching, and frequent switching results in increased collision rates for primary and secondary users and increased communication latency. At the same time, if only according to the longest channel length to determine the principle, there will be useless switch, resulting in increased switching times. Therefore, this chapter uses the comparison between the channel idle idle time and the theoretical transmission time to determine whether to carry out channel switching, as shown in equation (10):

\[
\begin{cases}
\text{Do not switch}, & \text{if } T_s - l_a \geq 0 \\
\text{switch}, & \text{if } T_s - l_a < 0
\end{cases}
\]

(10)

According to the above analysis, it can be seen that under the distributed network architecture, the proposed method mainly includes the sharing of spectrum sensing information, the establishment of the remaining idle time and the establishment of the long channel list of the theoretical transmission, the adjustment of the conditional judgment, the implementation of switching and data transmission. The specific switching process is shown in Figure 5:
3. Simulation verification and analysis

Assuming that the simulation environment is based on a distributed architecture in a distributed architecture, there are 20 primary users, namely 20 authorized channels, 5 secondary users, and the state usage of the primary user satisfies the ON/OFF index alternation model. Other simulation parameters [3] [11], the specific values shown in Table 1, the three switching methods as shown in Table 2.

Table 1 Simulation parameter settings

| Simulation parameters | Parameter value |
|-----------------------|-----------------|
| "Perceived - transmitted" slot length T | 500ms |
| Channel switching execution time | 25ms |
| Simulation time | 10000s |
| The main user OFF and ON states obey the mean exponential distribution of the even distribution | $[\mu_{\min} \cdot \mu_{\max}]$, $\mu_{\min}$ is 0.5, $\mu_{\max}$ change the range of 0.5 to 5 |
| Secondary user service duration parameter | 0.01 |
### Table 2 Comparison of switching schemes

| Switch method                                                                 | Scheme comparison                                                                 |
|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Active Spectrum handoff Method Based on Probabilistic Selection (SHM-BPS)     | Traditional sense frame structure, advance switch, select the maximum probability of idle channel |
| Active Spectrum handoff Method Based on Residual Idle Time Selection (SHM-RITS) | Traditional sense frame structure, early switch, select the longest idle time longest channel |
| Active Spectrum handoff Method Based on Spectrum Prediction (SHM-SP)           | Improved sense frame structure, early switch, select the best length of the idle channel |

#### 3.1. Switching delay analysis

![Graph showing the relationship between average switching delay and rate parameter $\mu_{\text{max}}$](image)

From the simulation results in Figure 6, we can see that with the increase of the $\mu_{\text{max}}$ ratio, the average switching delay of the three active switching methods shows a decreasing trend, and the decreasing trend gradually slows down. This is because the ratio of $\mu_{\text{max}}$ indicates the occupation of the channel by the primary user. The larger the ratio of $\mu_{\text{max}}$, the lower the frequency of the occupied channel of the primary user, and the more the idle channel available for the secondary user to select the handover access. Thus, the secondary user takes less time to sense the available channels in the environment, so the channel switching delay is getting shorter and shorter. At the same time, it can be concluded that the average switching delay of this method is the lowest, which is that the improved perceptual frame structure introduced in this chapter introduces the cooperative prediction module to make the prediction accuracy higher. Thus it improves the efficiency of spectrum sensing, thereby shortening the handover delay.
3.2. Comparison of handoffs
From the simulation results in Figure 7, we can see that the improved active spectrum switching method has the lowest number of channel switching in the sub-user communication, and the overall system performance is the best. And the average number of handovers is reduced by about 12.8% compared to the active switching method based on probabilistic selection. In particular, when the ratio of $\mu_{\text{max}}$ decreases, the difference in channel switching is greater. It can be seen that the switching method has higher value when using the cognitive network of the main users occupying the channel with high frequency. The reason why the number of times to switch the active handover method based on the remaining idle time is more than that of the method. The method is based on the time of the remaining idle time. The secondary user will still make a handover operation if the remaining idle time in the alternative idle channel has a longer idle time than the remaining idle time of the current communication channel when the communication task duration is satisfied, thereby increasing the number of handover. This switching is useless for the entire communication time requirement, so it is called useless switching, but this useless channel switch will increase the system cost, resulting in system performance degradation. In contrast, this method can reasonably choose whether to carry out channel switching by comparing the length of the theoretical transmission time and the idle communication time of the idle channel as the basis of judgment, which greatly reduces the number of times of switching in the secondary user communication process.

![Figure 7 Comparison of Total Channel Switching Times](chart.png)

3.3. Primary and secondary user collision rate
As can be seen from Figure 8, the collision rate of the three switching methods decreases with the increase of $\mu_{\text{max}}$ ratio. Mainly because the greater the ratio of $\mu_{\text{max}}$, the main user occupies the probability of authorized channel smaller, so the primary and secondary users between the collision rate is lower. At the same time, it is found that the collision rate under the switching method is the lowest because the switching method adopts the improved perceptual frame structure to carry on the perception and transmission. The high prediction accuracy caused by the cooperative prediction module in the frame structure improves the accuracy of the secondary user's perception and makes an accurate handover judgment in advance, thus effectively avoiding the occurrence of the collision between the primary user and the secondary user. In addition, the frame structure in this frequency domain on the frequency of the work so that the perception and transmission can be carried out simultaneously in the time domain to achieve real-time channel awareness and free channel list updates, to further improve the perceived efficiency and predictive accuracy, So that the secondary user can efficiently and accurately make the switch action, and thus effectively reduce the primary and secondary user collision rate.

4. Conclusion
In this paper, an improved active spectrum switching method based on spectrum prediction is proposed to solve the problem of collision interference and switching delay between primary and secondary users due to the low perceived efficiency and the active active spectrum switching method. This method improves the perceived efficiency by using the improved perceptual frame structure instead of the traditional perceptual frame structure, which effectively reduces the average switching delay and improves the switching efficiency. At the same time, the high prediction accuracy of the cooperative prediction method can make the handover method to make accurate handoff judgment in advance, thus effectively reducing the collision rate of primary and secondary users. Finally, the simulation is compared with the active switching method in [8] and [12]. It is proved that the performance of the method is better than the other two methods in the three parameters of switching delay, switching frequency and primary and secondary user collision rate, Which proves the validity and superiority of the method proposed in this paper.
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