

# Performance Analysis of Cognitive Radio Network with Primary User Activeness Consideration

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**Abstract**—With the development of the communication industry, the spectrum scarcity problem is appearing. Cognitive radio is a popular wireless communication technology. it can solve this problem efficiently[1].In the conventional model .we assume that the occupancy state of the primary user is constant ,which is either active or idle . However, the primary user can be allowed to depart and arrive at the licensed channel randomly .So we propose a new model where the state of the primary user is able to change in the whole frame .Then we compare the two model in the system throughput, and we find that the new performance when the primary user changes its state at any time is taken into account is worse than the conventional network .It means that the network performance is related to the primary user traffic intensity.

**Keywords**-cognitive radio; frame structure; spectrum resource; spectrum sensing; optimal power

## I. INTRODUCTION

With the development of communication service ,the spectrum resource we can use is becoming less and less .Cognitive radio is an efficient technology that can solve this problem and improve the spectrum utilization .In [3], we can know the frame structure of the cognitive radio consists a sensing slot at the beginning of the frame and a data transmission slot .Besides , the length of the frame is constant ,as depicted in Fig 1 .Spectrum sensing in the sensing slot is an essential process of the cognitive radio ,as the secondary user need to detect the channel state .The most common spectrum sensing technique is energy detection[6] .After sensing ,in order to use the spectrum efficiently ,the secondary user will access the channel with the allocated power under the condition of protecting the quality of service of the primary user .In [7],the author proposed the dynamic spectrum access method ,and one of the most simple access methods is opportunistic spectrum access where the secondary user can only use the licensed channel when the channel is idle ,otherwise it should find another one [4] .Another method is described in [8] called spectrum sharing ,which means that the secondary user will be allocated a high power when the channel is detected to be idle ,while it will be allocated a low power when the channel is detected to be active .This method can increase the throughput efficiently and make full use of spectrum resource.

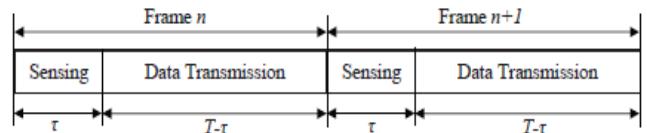


FIGURE I. FRAME STRUCTURE

In spectrum sensing ,the probability of false alarm and the probability of detection can influence system throughput directly .Refers to the probability of false alarm ,it means that the target is considered to be detected as the noise is above the detection threshold .And the probability of detection is that the secondary user detect the target correctly . In [5],the author introduces the two probability from two aspects. On the one hand ,the lower the probability of false alarm is ,the more chance the secondary user will access licensed frequency bands ,and the achievable throughput will be improved . On the other hand ,the higher the probability of detection ,the better protection it will receive from the secondary user. Hence, the sensing result is crucial in the cognitive radio system . To obtain a good sensing result ,we need a longer sensing slot ,However , the increase in the sensing slot will result in a decrease in the data transmission slot .So the achievable throughput will be reduced . Thus, there will be a tradeoff between the sensing quality and the throughput which has been discussed in [5]and [9] .And in [3], the author considers a method can solve this problem by proposing a new frame structure. To maximize the throughput ,we should also propose an algorithm to obtain the optimal power allocation strategy .

In the conventional model ,to maximize the throughput ,we assume that the occupancy state of the primary user is constant ,which is either active or idle .However ,the state of the primary user can change at any time ,so the assumption in the conventional model is unrealistic .In this paper ,we consider a more realistic model where the occupancy state of the primary user can change only once .Then we allocate a optimal power for the new model which is obtained in the conventional one and compare the system throughput between the two models .

The rest of the paper is organized as follows .In section II ,we present the conventional system model and find the optimal power .Then we calculate the throughput in the conventional model .In section III ,we propose a new model ,and use the power we get in section II to calculate the throughput .In section IV ,we present and discuss the

simulation result .In the end ,we draw a conclusion in section V.

## II. CONVENTIONAL MODEL

In the conventional model ,the occupancy state of the primary user is assumed to be constant .And the sensing result is given by[5]:

$$Y = \begin{cases} \sum_{i=1}^I n_i^2, & H_0 \\ \sum_{i=1}^I (s_i + n_i)^2, & H_1 \end{cases} \quad (1)$$

$n_i$  represents the noise , $s_i$  represent the signal of the primary user .Y is the signal detected by energy detection method. With a large number of samples ,the probability density function of Y can be described by a Gaussian distribution [5].So the probability of false alarm and the probability of detection can be written as

$$\begin{aligned} P_{fa}(\eta, I) &= P(H_1 | H_0) = \Pr(Y > \eta | H_0) \\ &= Q\left(\left(\frac{\eta}{\sigma^2} - 1\right)\sqrt{\frac{\tau f_s}{1}}\right) = \frac{1}{2} \operatorname{erfc}\left(\left(\frac{\eta}{\sigma^2} - 1\right)\sqrt{\frac{I}{2}}\right) \end{aligned} \quad (2)$$

$$\begin{aligned} P_d(\eta, I) &= P(H_1 | H_1) = \Pr(Y > \eta | H_1) \\ &= Q\left(\left(\frac{\eta}{\sigma^2} - \gamma_p - 1\right)\sqrt{\frac{\tau f_s}{2\gamma_p + 1}}\right) \\ &= \frac{1}{2} \operatorname{erfc}\left(\left(\frac{\eta}{\sigma^2} - 1\right)\sqrt{\frac{I}{2(2\gamma_p + 1)}}\right) \end{aligned} \quad (3)$$

$\gamma_p$  is the signal-to-noise ratio at the receiver , $\eta$  is the detection threshold . $I$  is the number of samples , $f_s$  is the sampling rate.

After sensing ,the secondary user is ready to transmit data with the a power .In this paper we consider the opportunistic spectrum access as the method for accessing the spectrum and allocate two powers for the secondary user .when the sensing result is active ,we do not transmit data and the power is 0 ,while the result is idle ,we allocate the power P .So the instantaneous transmission rate of cognitive radio system when the channel is idle is given by

$$R_0 = \log_2\left(1 + \frac{g_{ss}P}{N_0}\right) . \quad (4)$$

And there is another case that the channel is falsely detected to be idle while the actual result is active .The instantaneous transmission rate is given by

$$R_1 = \log_2\left(1 + \frac{g_{ss}P}{g_{ps}P_u + N_0}\right) . \quad (5)$$

$g_{ss}$  denotes the instantaneous channel power gain from the secondary transmitter to the secondary receiver,  $g_{ps}$  denotes the instantaneous channel power gain from the primary transmitter to the secondary receiver.

Then the system throughput for the conventional model is formulated as

$$C = \frac{T - \tau}{T} E\{P(H_0)(1 - P_{fa})R_0 + P(H_1)(1 - P_d)R_1\} \quad (6)$$

This function is convex with respect to the transmit power , $P(H_0)$  and  $P(H_1)$  are the probability that the frequency band is idle and active .

In order to find the optimal power, we can use the method described in [8] which needs to use Lagrange function with applying the Karush-Kuhn-Tucker(KKT) conditions . Then the optimal power is given by

$$P = \frac{\log_2(e)[P(H_0)(1 - P_{fa}) + P(H_1)(1 - P_d)]}{\lambda_1[P(H_0)(1 - P_{fa}) + P(H_1)(1 - P_d)] + \mu_1[P(H_1)(1 - P_d)g_{sp}]} \quad (7)$$

$g_{sp}$  denotes the instantaneous channel power gain from the secondary transmitter to the primary receiver.

In order to get the correct optimal power ,the optimal values of the Lagrangian multipliers  $\lambda_1$  and  $\mu_1$  need to be found by employing the ellipsoid method .

The proof is omitted here .Relevant proof is given in [11].

## III. NEW MODEL

In Section II,we assume that the occupancy state of the primary user is constant ,which is either active or idle . However ,the state of the primary user can change at any time ,so the assumption in the conventional model is unrealistic and we should take it into consideration .

In the new model ,we assume that the state of primary user can change randomly and only change once .One case is that when the sensing result is idle ,the state of the primary user at the transmission period can be idle or active .Another case we assume that when the sensing result is active , the state will not change anymore which means that at the transmission slot ,the state is always active .So there will be two cases with respect to the system .(1)The primary user is always idle  $H_{00}$  .(2)The sensing result is idle and the state will be changed to active at transmission slot at any time  $H_{01}$ .

In this section ,in order to make the research process more simple and intuitionistic , we apply the optimal power to the

new model which is calculated in Section II ,and compare the throughput between the two models .In the end ,we can conclude that what impact the change of the primary state has on the system performance .

In this model ,the primary user traffic is represented as a 1-0 random process ,where 1 represents a busy channel ,and 0 represents a idle channel . The holding time of the states are corresponding to the exponential distribution of the parameters  $\lambda$  and  $\mu$  .When the channel is busy ,the probability is

$$P_b = \frac{\lambda}{\lambda + \mu} , \text{while the probability of the idle channel is}$$

$P_e = 1 - P_d$  .So after  $T_s$ ,the transition probability is given by [5]

$$\begin{aligned} P(T_s) &= \begin{pmatrix} P_{00}(T_s) & P_{01}(T_s) \\ P_{10}(T_s) & P_{11}(T_s) \end{pmatrix} \\ &= \frac{1}{\lambda + \mu} \begin{pmatrix} \lambda + \mu e^{-(\lambda+\mu)T_s} & \mu - \mu e^{-(\lambda+\mu)T_s} \\ \lambda - \lambda e^{-(\lambda+\mu)T_s} & \mu + \lambda e^{-(\lambda+\mu)T_s} \end{pmatrix} \quad (8) \end{aligned}$$

In this paper ,we only discuss the case that the state of the primary user at the sensing slot is idle ,so the probability of  $P_{00}(T_s)$  and  $P_{01}(T_s)$  need to be used .

In the above formula ,the transition probability is considered not to be changed over time .It means that whenever the state is changed ,the probability is always the same .In this model ,we assume the transition probability is different over time .We divide the transmission slot into n segment .The time interval is  $T_s$  ,and the state transition probability in each segment is different which will be affected by the transition probability of the last period .Here, we assume that the state of the first segment is idle , from the beginning of the second segment, we have concluded that the state transition probability of the new model is as follow

$$P_0(i) = \frac{P_0(i-1)P_{00}(T_s)}{P_0(i) + P_1(i)} . \quad (9)$$

$$P_1(i) = \frac{P_1(i-1) + P_0(i-1)P_{11}(T_s)}{P_0(i) + P_1(i)} . \quad (10)$$

To make the result more accurate ,the probability is normalized .  $P_0(i)$  denotes the probability that the period of i is idle ,  $P_1(i)$  denotes the probability that the state of the primary user is changed from idle to active in the period of i .And the throughput in the new model can be formulated as follows

$$C = \sum_{i=1}^n \frac{T_s}{T} E \left\{ P_e P_0(i)(1 - P_{fa})R_0 + P_b P_1(i)(1 - P_d)R_1 \right\} \quad (11)$$

In order to make the research process more simple ,we can use the values of  $P_{fa}$  ,  $P_d$  ,  $R_0$  ,  $R_1$  which are proposed in the Section II .And then ,we use the optimal power we have found in the last part to calculate the system throughput .And the result is presented in the simulation .

#### IV. SIMULATION RESULTS AND ANALYSIS

In this part ,we present the simulation results for the two models . In Fig.2 ,the frame duration is set to  $T = 0.1s$  ,the time interval  $T_s = 20\mu s$  , the signal-to-noise ratio at the receiver is considered to be  $\gamma_p = -8dB$  , the maximum average transmit power is considered to be  $P_{av} = 10dB$  , the maximize average interference power is set to  $\Gamma = -10dB$  ,and the detection probability is considered to be  $P_d = 0.9$  .We make a simulation for the two models in the two cases that the parameters are  $\lambda = \mu = 10$  and  $\lambda = \mu = 20$  ,and then analyze the result .

In Fig . 2 ,we can see that the achievable throughput in the new model is reduced when the random departure or arrival of the primary user is considered .From the point of view of the equation ,the throughput in the new model consists the part of the state transmit probability which is less than 1 ,so the throughput in the new model is smaller than the conventional model .We can also see that the achievable throughput will reduce when the values of  $\lambda$  and  $\mu$  are bigger .This is because the higher values of  $\lambda$  and  $\mu$  can lead to the higher primary user traffic intensity .So the throughput will be influenced.

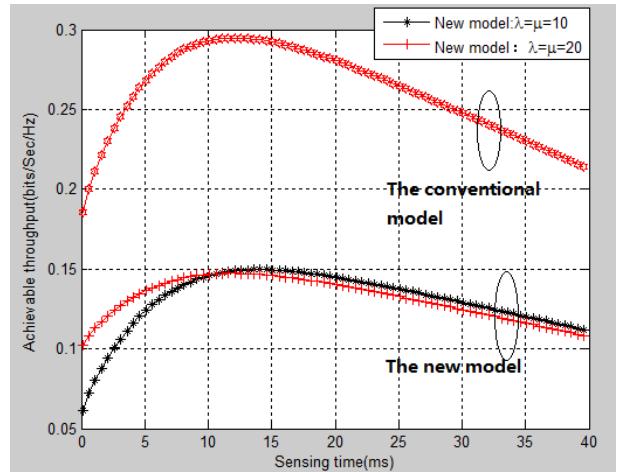


FIGURE II. A SIMULATION FOR TWO MODELS

#### V. CONCLUSION

In the paper ,we propose a new model and compare it with the conventional one .The simulation results show that the achievable throughput in the new model is reduced when the random departure or arrival of the primary user is considered .Besides ,the performance of the system has relationship with the primary user traffic intensity .

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