How much you pay more for multimedia traffic in Cognitive Radio Networks?

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Abstract

The economics of spectrum sharing, which is referred to as spectrum trading, is the focus of this article. The price of the primary user spectrum is calculated by using M/G/1 preemptive priority resume queuing model. The simulation results are compared with the theoretical analysis and good agreement is reported.

1. Introduction

Radio spectrum is one of the most scarce and valuable resources for wireless communications. Cognitive radio (CR) has been proposed as a way to improve spectrum efficiency by exploiting the unused spectrum in dynamically changing environments [1], [4]. In network, the real time traffics (i.e., voice or video sessions) often require high priority and low latency. Therefor the end-user must pay more for real-time traffic. In this paper, we derive the average waiting time of packets with different priorities in CR networks by employing a preemptive priority M/G/1 model. In this system, we have three kind of traffic as: the Primary User (PU)'s traffic, the Secondary User (SU)'s real time traffic, the SU's best effort traffic. Then, the PU's traffic has the highest priority and the SU's best effort traffic has the lowest priority. Having higher priority than the best effort traffic, the SU's real time traffic imposes the extra waiting time on the best-effort traffic. However, the waiting time in the system will incur a cost $\boldsymbol{C}$ per unit time. Thus, we can calculate the price for the real time traffic based on the extra waiting time imposed upon the best-effort traffic. In this work, we consider heterogeneous users in this paper, meaning that the users can have: 1) different types of delay deadlines; 2) different traffic priorities and rates.

2. System model

According to the access technology of SU, we assume spectrum sharing between SU and PU is categorized as spectrum overlay. It means that the SU can only use the licensed spectrum when the PU is not transmitting. When the PU wishes to transmit, it is given a priority over the SU. This channel occupation behavior can be described by a preemptive priority queuing model [2]. We assume that the SU is a service provider (i.e., it serves many secondary users) that aggregates connections, calls, packets that can be served over the PU channel.

We assume that packets arrive at the PU and the SU according to a Poisson process with the parameters as λ_P for the PU's traffic, λ_S^R for the SU's real time traffic and λ_S^B for the SU's best effort traffic. The service time of both the PU's and the SU's traffic are arbitrary distributions. To evaluate the expected delay of the PU's packets and the SU's packets, a priority virtual queue interface is proposed [2] as in Fig.1. The packets of the PU and the SU both are served according to a first come first served discipline (FCFS). The PU is assumed to be able to preempt the transmission of the SU. When the transmission of the SU's packets is preempted by the PU's packets, the rest of the secondary transmission would be taken up into the priority queue. Note that this discipline is called preemptive resume [3]. Under these schemes, lower priority transmission would always wait in the queue for the transmission of higher priority class.

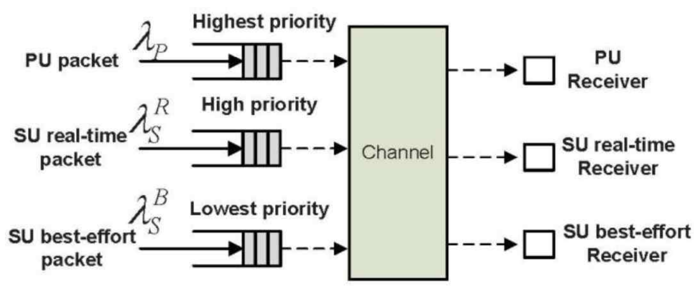

Figure.1 Priority service discipline.

3. Pricing for the real time traffic

In this section, we use the M/G/1 preemptive priority resume queuing model [3] to analyze the expected delay time of the SU's real time packets and best effort packets. Based on that, the price for the SU's real time packets are determined.

At first, we derive the expected delay time of the SU's and the PU's packets. Following similar approach as in [3], we have expected delay $\boldsymbol{T_P}$ for the PU which has the highest priority class as

$$T_P = \frac{1}{\mu_P} + \frac{R_P}{1-\rho_P}. \quad (1)$$

For the real-time traffic of SU, the average delay in the system is:

$$T_S^R = \frac{1}{\mu_S^R(1-\rho_P)} + \frac{R_P+R_S^R}{(1-\rho_P-\rho_S^R)(1-\rho_P)}. \quad (2)$$

For the best-effort traffic of SU, the average delay in the system is:

$$T_S^B = \frac{\frac{1-\rho_P-\rho_S^R-\rho_S^B}{\mu_S^B}+R_P+R_S^R+R_S^B}{(1-\rho_P-\rho_S^R)(1-\rho_P-\rho_S^R-\rho_S^B)}. \quad (3)$$

The above nomenclatures are shown in Table I.

Symbol	Explanation
$1/\mu$	the mean of the service time
$\overline{X^2}$	The second moment of the service time
$R = \lambda\overline{X^2}/2$	The mean residual time
$\rho = \lambda/\mu$	The utilization factor
λ	The arrival rate

Table 1: Model Parameters with $\mathbf{n_P}$ denotes the PU's packets, $\mathbf{n_S^R}$ denotes the SU's real time packets, $\mathbf{n_S^B}$ denotes the SU's best effort packets.

If the real-time traffic does not buy the priority, then its priority equals the best-effort traffic. Thus, only PU traffic has higher priority than SU real-time and SU best-effort traffic. Therefore, both real-time traffic and real-time traffic have the same expected delay T_S^{BR} and it consists of three terms:

1. The average service time of both kinds of traffic: $\frac{\lambda_S^R}{\lambda_S^R+\lambda_S^B}\frac{1}{\mu_S^R} + \frac{\lambda_S^B}{\lambda_S^R+\lambda_S^B}\frac{1}{\mu_S^B}$
2. The average waiting time required, upon arrival of the SU packet, to service the PU packet and also the SU packets already in the system (i.e., the average unfinished work). It can be seen that this time is equal to the average waiting time in the corresponding, ordinary M/G/1 system (without priorities), that is calculated in [3] as $\frac{R_P+R_S^R+R_S^B}{(1-\rho_P-\rho_S^R-\rho_S^B)}$.
3. The average waiting time for the PU packets which arrive while the SU packets are being processed in the system. This term is $\rho_P T_S^{BR}$.

By summing the three components of the delay above, we can establish the equation for the expected delay of both real-time and best-effort traffic as

$$T_S^{BR} = \left(\frac{\lambda_S^R}{\lambda_S^R+\lambda_S^B}\frac{1}{\mu_S^R} + \frac{\lambda_S^B}{\lambda_S^R+\lambda_S^B}\frac{1}{\mu_S^B}\right)\frac{1}{1-\rho_P} + \frac{R_P+R_S^R+R_S^B}{(1-\rho_P-\rho_S^R-\rho_S^B)}\frac{1}{1-\rho_P}. \quad (4)$$

Then, the price SU's real-time traffic would pay to get higher priority than SU best-effort is

$$P_R = C\lambda_S^R(T_S^{BR} - T_S^R). \quad (5)$$

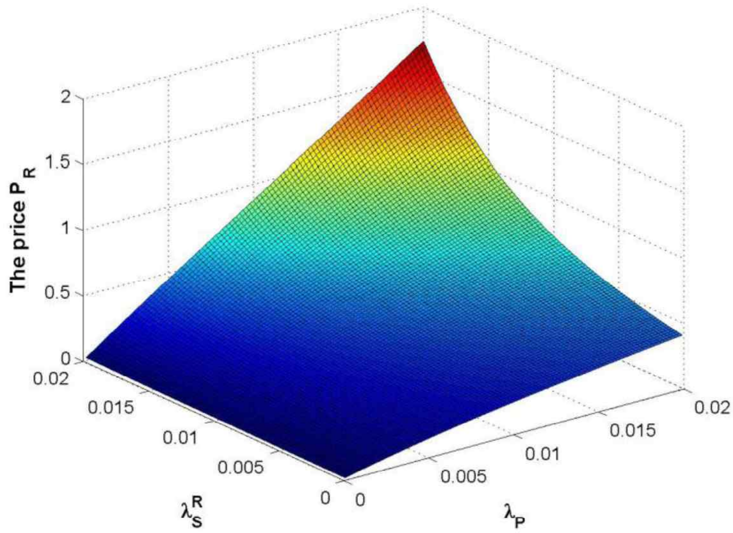

Figure. 2 The Price for the SU's real time traffic.

The numerical analysis is performed by Matlab and the parameters are set as $1/\mu_P = 20, \overline{X_P}^2 = 400, \frac{1}{\mu_S^R} = 2.5, \overline{X_S^R}^2 = 6.25, \frac{1}{\mu_S^B} = 5, \overline{X_S^B}^2 = 25, C = 10.$ In Figure 2, we choose the SU's best effort arrival rate is $\lambda_S^B = 0.03$ and the result shows that the price P_R rise up when the SU's real time arrival rate λ_S^R and the PU arrival rate λ_P increase. However, the price rise up more sharply in case of increasing the PU arrival rate λ_P. The reason is that the PU has higher priority over the SU's real time traffic, therefore it affects the delay time of the SU's real time traffic more than the SU's traffic.

4. Admission Control Based on The Expected Delay Time

Assume D_R is the deadline delay for SU real-time traffic. Because $T_S^R(\lambda_S^R)$ is an increasing function by λ_S^R variance, a arrival rate threshold λ_R^{th} to keep the deadline delay can be found by solving $T_S^R\left(\lambda_S^R\right) = D_R$.

The analytical results developed in this paper can be used to design the admission control rule for the arriving SU's real time traffic subject to their latency requirement. Fig. 3 shows the admissible region for the SU's real time traffic arrival rates when the delay requirement is bounded by 11 time unit. One can sees, when the time PU occupy the channel decrease (as the value of λ_P increases), a Cognitive Radio network can accept more arrival requests from the SU's real time traffic. Then, the admission control policy can be designed according to this figure.

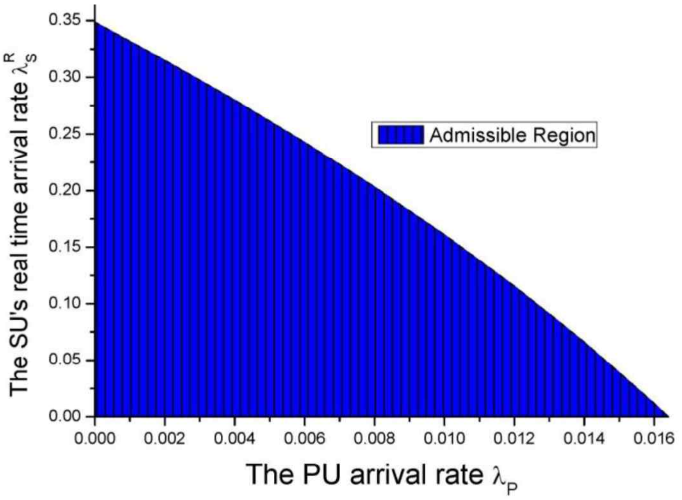

Figure. 3 Admissible region for the SU's real time arrival rate where the delay constraint is smaller than 11 time unit.

5. Conclusion

In this paper, based on the analysis of expected delay of the PU and the SU packets, the price for the real time packet have been derived. Our numerical results show that the distribution of packets of the secondary user depends on the data traffic characteristics of the primary users. Furthermore, the performance of the secondary user is connected with the delay constraint.

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References

[1] J. Mitola, "The software radio architecture", IEEE Commun. Mag., vol. 33, pp. 26-38, May 1995.
[2] H. P. Shiang and M. van der Schaar, "Queuing-Based Dynamic Channel Selection for Heterogeneous Multimedia Applications Over Cognitive Radio Networks", IEEE Transactions on Multimedia, vol. 10, no. 5, pp. 896-909, Aug. 2008.
[3] Bertsekas D, Gallager R. 1992, Data Networks 2nd Prentice Hall.
[4] Cuong T. Do, Nguyen H. Tran, Choong Seon Hong and Sungwon LEE, "Finding an Individual Optimal Threshold of Queue Length in Hybrid Overlay/Underlay Spectrum Access in Cognitive Radio Networks", IEICE Transactions on Communications, Vol.E95-B, No. 06, pp.1978-1981, June 2012