

Queuing Analysis in Cognitive Radio With Relay Capability

Cuong The Do, Nguyen H. Tran, Choong Seon Hong

Department of Computer Engineering, Kyung Hee University

E-mail: {dtcuong, nguyenth, cshong}@khu.ac.kr

Abstract

Recently the concept of cognitive radio is proposed to address the issue of spectrum efficiency and has been receiving an increasing attention. This paper presents queuing analysis in Cognitive Radio with and without relaying capability. We perform theoretical analysis by applying M/D/1 queuing scheme in order to find the waiting queuing time. Results indicate that the benefit of the relaying strongly depends on the data traffic characteristics of the system.

I. INTRODUCTION

Cognitive radio is the key enabling technology that enables the next generation communication networks to utilize the spectrum more efficiently in an opportunistic fashion without interfering with the primary users. As described in [1], users from a secondary network (who are referred to as the secondary users) can access the spectrum owned by the primary network provider (whose users' are referred to as the primary users) using spectrum underlay or spectrum overlay. In the spectrum overlay paradigm, secondary users are only allowed to access spectrum resources (i.e., channels) owned by the primary network provider if these channels are not being used by the primary users. For the spectrum underlay paradigm, it is required that an interference limit corresponding to an interference level be maintained at the receiving points of the primary network. In order to enhance network performance, the idea that combines cognitive and cooperative in a capacity view is presented by [2], which adds relaying capability to the secondary transmitter and relies on stability (i.e., finiteness of all the queues in the system at all times) as the criterion of performance. The priority queuing analysis based on M/D/1 priority queuing scheme with perfect sensing conditions was presented in [4]. In this paper, we perform waiting time analysis in the system model based on [2]. Poisson processes are assumed for packet arrivals and we used the modified M/D/1 system to analyze the network performance. We use queuing results to study time slotted cognitive radio systems with one primary and one secondary link in case of not perfect sensing because of the false alarm and missed detections problem.

II. SYSTEM MODEL

We adopted a similar model to the one used in [2], where the authors considered a cognitive network with one primary and one secondary links as follows.

We assume that the primary transmitter (primary user) has a buffer Q_P to store the incoming traffic packets, while the secondary transmitter (cognitive user) has two buffers, Q_S to store its own generated traffic packets and Q_{PS} containing packets received by the primary transmitters to be relayed to the primary destination, as seen in Fig.1. A packet transmitted by the primary node can be erroneously

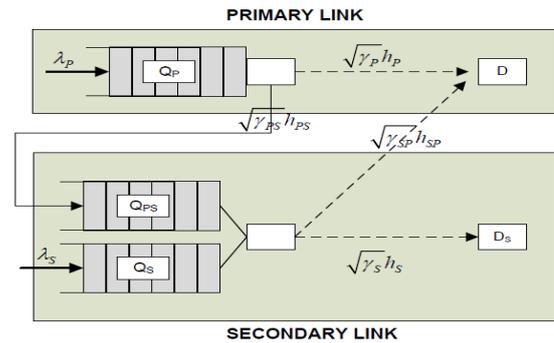


Fig.1. MAC and PHY layer view with one primary and one secondary single link with cognitive relaying capability

received by the intended destination and a NACK message is signaled, but it is correctly received by the secondary transmitter sending an ACK message. In this case, the primary source drops the packet from its queue, as if it was correctly received by the destination, and the secondary user puts it in its queue Q_{PS} . We consider a time-slotted transmission where all packets have the same size and one time slot is required for transmission of a single packet. In addition, we assume that the size of all buffers is of infinite length. The packet arrival process at each node is independent and stationary with mean arrival rates λ_p and λ_s (packets per slot) for the primary and secondary users respectively. Note that the transmission of packets can only start at the beginning of the slot, so that even if a packet arrives at the middle of the slot, it has to wait half of the slot duration even if the channel is free.

The radio propagation between any pair of nodes is assumed to be affected by independent stationary Rayleigh flat-fading channels $h_i(t)$ with $E[|h_i(t)|^2] = 1$, where t denotes time and runs over time slots. The channel is constant in each slot (block-fading). The average channel power gain, due to shadowing and path loss, is denoted by γ_i , where i becomes "P" for the primary connection, "S" for the secondary, "SP" for the channel between the secondary transmitter and the primary receiver, and "PS" for the channel between the primary transmitter and the secondary transmitter.

The primary node transmits with normalized power $P_p = 1$ and the noise power spectral density at all receivers is also normalized to 1. The power transmitted by the secondary node, when active, is $P_s \leq 1$. The transmission of a given

packet is considered successful if the instantaneous received SNR $\gamma_i|h_i(t)|^2 P_i$ is above a given threshold β_i , which is fixed for a given transmission mode. The cognitive node is able to correctly detect the transmission of the primary user if the instantaneous SNR $\gamma_{PS}|h_{PS}|^2$ is larger than a threshold α (recall that $P_p = 1$). Moreover, the detection process is characterized by false alarm probability P_{FA} and missed detection probability P_{ER} . The false alarm probability is the probability that a free slot is decided to be occupied. The miss detection probability is the probability that an occupied slot is detected incorrectly as a free slot.

III. ANALYSIS BASED ON QUEUING

The queuing analysis of the primary user is analyzed in this section of the paper. The waiting time of a packet consists of three parts: time until the beginning/start point of the next slot, time spent in a queue waiting for the service to begin, and the average service time (transmission time). The packets of both users are served according to a first come first served discipline (FCFS).

Starting from the analysis result of M/G/1, also known as Pollaczek-Khinchin, and the fact that the M/D/1 (where service times are assumed to be deterministic) is a special case of M/G/1 [3], we have the average waiting time in queue W_p^Q for the primary user without relaying as:

$$W_p^Q = T_D + N_p^Q / \mu_p \quad (1)$$

Where T_D is the waiting time until the beginning of a slot, μ_p is the service rate of the primary user without relaying, and N_p^Q is the average number of packets in queue without relaying. Using Little's theorem [3], we have $N_p^Q = \lambda_p W_p^Q$, therefore we obtain:

$$W_p^Q = T_D + N_p^Q / \mu_p = T_D + W_p^Q \lambda_p / \mu_p \quad (2)$$

Then we got:

$$W_p^Q = \frac{T_D}{1 - \lambda_p / \mu_p} \quad (3)$$

The total waiting time in the system is given by the summation of the waiting time in queue and the average service time of the packet. Therefore, we have the expressions for the waiting time for the primary user, W_p , without relaying as follows:

$$W_p = \bar{X} + \frac{T_D}{1 - \lambda_p / \mu_p} \quad (4)$$

where $\bar{X} = 1/\mu_p$ is the average service time. We assume that on average a newly arrived packet has to wait for 1/2 slots before the beginning of a new slot. In [2], the primary user selects its own arrival rate λ_p ignoring the presence of a secondary node. It is then the task of the cognitive user to select its transmission node with power P_s , in order to exploit as much as possible the idle slots left available by the primary activity while not affecting the stability of the system. Hence, we assume that with an arrival rate λ_p , primary user can choose the service rate to maximize the

stable throughput of the system. With this assumption, we obtain the following expression for W_p as:

$$W_p = \frac{1}{\mu_p} + \frac{1/2}{1 - \lambda_p / \mu_p} \quad (5)$$

where μ_p is defined in [2]. Similarly, we obtain the average waiting time for the primary user with relaying as:

$$W_p^{\text{rel}} = \frac{1}{\mu_p^{\text{rel}}} + \frac{1/2}{1 - \lambda_p / \mu_p^{\text{rel}}} \quad (6)$$

where μ_p^{rel} is the service rate of primary user with relaying and calculated in [2].

In [4], the sojourn time of the secondary user's packet depends on subsequent arrivals at the primary user's queue, but in [2] the sojourn time of the secondary user's packet in queue Q_s depends on only the secondary user's service rate for queue Q_s . Therefore, the average waiting time of secondary user's packets is obtained similarly to the primary user. Hence, we have the expression for the waiting time of secondary user, W_s , without relaying as follows:

$$W_s = \frac{1}{\mu_s} + \frac{1/2}{1 - \lambda_s / \mu_s} \quad (7)$$

In a similar manner, the waiting time of the secondary user W_s^{rel} with relaying is:

$$W_s^{\text{rel}} = \frac{1}{\mu_s^{\text{rel}}} + \frac{1/2}{1 - \lambda_s / \mu_s^{\text{rel}}} \quad (8)$$

Where μ_s is the service rate of the secondary user without relaying and described in [2], μ_s^{rel} is the service rate of the secondary user for queue Q_s with relaying capacity and defined in [2]. Both μ_s^{rel} and μ_s are the maximum service rates solved by the optimization problem, therefore W_s and W_s^{rel} are the lower bound values of the average waiting time of the secondary user's packet.

Applying Little's formula to W_p, W_p^{rel} and W_s^{rel} , we have the expected number of packets delay for the primary user and the secondary user as follows:

$$N_p = \frac{\lambda_p}{\mu_p} + \frac{\lambda_p \mu_p}{2(\mu_p - \lambda_p)} \quad (8)$$

$$N_p^{\text{rel}} = \frac{\lambda_p}{\mu_p^{\text{rel}}} + \frac{\lambda_p \mu_p^{\text{rel}}}{2(\mu_p^{\text{rel}} - \lambda_p)} \quad (9)$$

$$N_s^{\text{rel}} = \frac{\lambda_s}{\mu_s^{\text{rel}}} + \frac{\lambda_s \mu_s^{\text{rel}}}{2(\mu_s^{\text{rel}} - \lambda_s)} \quad (10)$$

IV. NUMERICAL RESULTS

The parameters implemented are $\beta_p / \gamma_p = \beta_s / \gamma_s = -5$ dB, $\gamma_{SP} = 10$, and $\alpha / \gamma_{PS} = -5$ dB. With these parameters the probability of error detection is $P_{ER} = 0.27$ and the

maximum service rate of the primary user is $\mu_p^{\max} = 0.73$, we also choose a probability of false alarm $P_{FA} = 0.3$. In this section of the paper, we examine how the average waiting time of the primary user and the secondary user respond with relaying capability.

Fig.2 presents the average waiting time for the primary user, it can be seen that without relaying, the average waiting time of primary user increases when the arrival rate goes up to μ_p^{\max} . However, in case of relaying, the average waiting time of the primary user is small and stable when λ_p goes to μ_p^{\max} .

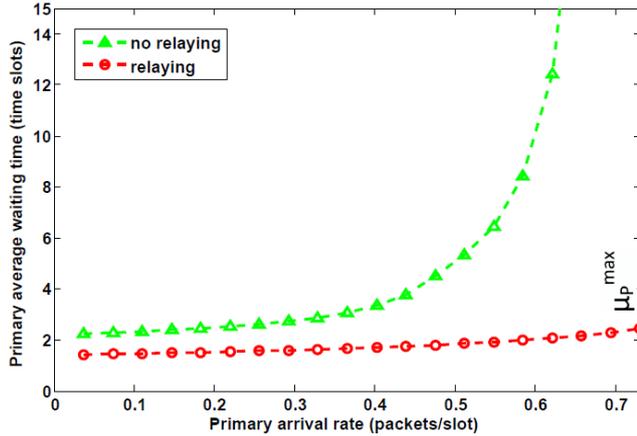


Fig.2. Average waiting time for the primary user.

Fig.3 shows the delay for the secondary user regarding two cases of the primary user's arrival rate. It can be seen that when the arrival rate of the secondary user increases, the affection of relay is clearer. When the primary user's traffic is light, the primary user's arrival rate λ_p is 0.2, the secondary can transmit more packets, the service rate μ_s^{rel} can reach to 0.39 and the gap between the average waiting time of the secondary user with relaying and without relaying is smaller than when the primary user's traffic is heavier i.e. when the primary user's arrival rate λ_p is 0.4, the secondary user's service rate μ_s^{rel} can only reach to 0.28.

Fig.4 shows the average number of packet delay of the primary user and the secondary user when the primary user's arrival rate λ_p increases. In this scenario, we fix the secondary user arrival rate λ_s to 0.2, and it can be seen that while λ_p increases, the secondary service rate decreases. Therefore, the number of delay packet of the secondary user goes up quickly and tends to infinite value when the service rate approximates the arrival rate.

V. CONCLUSION

This paper presents queuing analysis in Cognitive Radio with and without relaying capability in case of imperfect sensing by using the M/D/1 model. The analysis showed the great effect of relaying capability on the average waiting time of the primary user. The results can also be used to evaluate the performance of the cognitive radio regarding the queuing waiting time. In the future, research will focus on the analysis of a multi-user system.

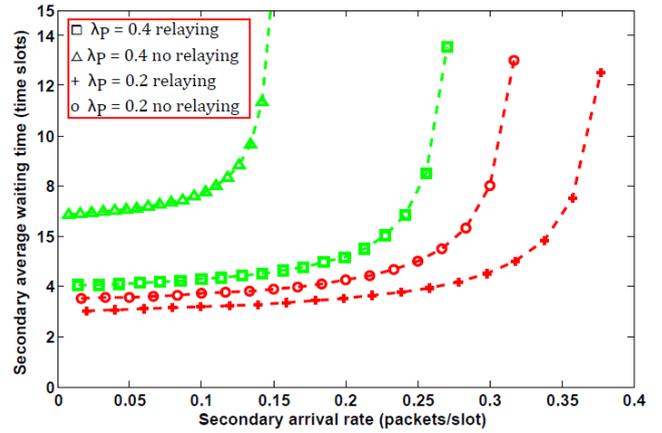


Fig.3. Average waiting time for the secondary user.

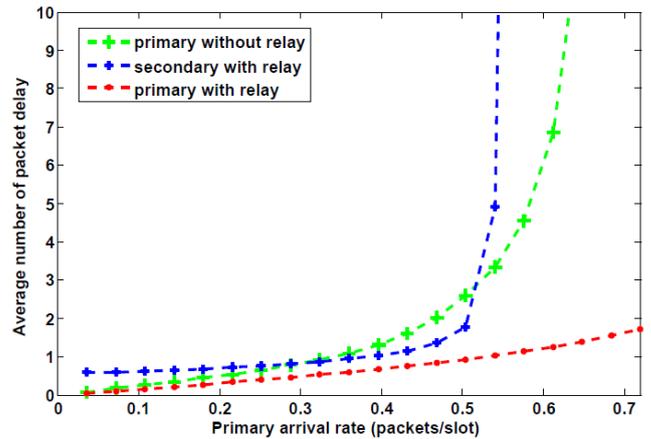


Fig.4. Average number of packet delay.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by MEST (No. 2010-0027645). Dr. CS Hong is corresponding author.

REFERENCES

- [1] Q. Zhao and B. M. Sadler, "A survey of dynamic spectrum access: Signal processing, networking, and regulatory policy," *IEEE Signal Processing Mag.*, pp. 79-89, May 2007.
- [2] O. Simeone, Y. Bar-Ness and U. Spagnolini, "Stable Throughput of Cognitive Radios With and Without Relaying Capability," *IEEE Transactions on Communications*, vol. 55, no. 12, pp. 2351-2360, Dec. 2007.
- [3] Bertsekas D, Gallager R.1992, *Data Networks*(2nd edn). Prentice Hall.
- [4] Isameldin Suliman and Janne Lehtomäki, "Queueing Analysis of Opportunistic Access in Cognitive Radios", *IEEE CogArt 2009*, pp. 153-157, May 2009.