

## Throughput Analysis of Unslotted CSMA Based on SU's Priority in Heterogeneous Cognitive Radio Networks

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### Summary

In this paper, we analyze the spectrum access scheme of secondary users (SUs) in heterogeneous cognitive wireless networks environment.

We propose a carrier sense multiple access (CSMA) scheme based on SU's priority in heterogeneous networks environment and analyze the system performance. The numerical results show that the performance of our proposed scheme is better than the schemes without considering SU's priority.

*Keywords* : cognitive radio network, CSMA, priority, heterogeneous, throughput, HoL

### 1. Introduction

With the rapid development of the wireless communication industry, the coexistence of different networks and personalized requirements of different users have become one of the most important features of the next generation communication network. At the view point of network, SUs with personalized requirements can be classified several SUs with different priorities. High priority SUs need to transmit packet faster and they want to access the network with a faster service rate; low priority SUs can access the network with a slower service rate. Therefore, sharing the spectrum resources and satisfying the personalized requirements of different users in heterogeneous cognitive wireless networks environment is an important issue that needs to be solved.

There have been many studies on the opportunistic spectrum access schemes for cognitive radio network. We divide these studies as the centralized [1, 2] and decentralized [3~11]. The decentralized can be further divided into slotted structure [3, 4] and unslotted structure[5~7]. Literature [5] proposed three decentralized MAC protocols: VX (Virtual-Xmit-if-Busy), VAC (Vacation-if-busy) and KS (Keep-Sensing-if-Busy). Literature [6] proposed an m-sensing access scheme. Literature [8] proposed a spectrum access scheme based on the priority of SUs in homogeneous cognitive wireless network environment. These papers only consider the spectrum sharing scheme in homogeneous cognitive radio network environment.

Literature [9] proposed a p-select CSMA scheme in heterogeneous cognitive wireless networks environment. Literature [10] research the spectrum resource allocation of heterogeneous cognitive wireless networks. But these papers only consider the spectrum access scheme of the same priority SUs, without considering the heterogeneous environment combined with different priorities SUs. This is the motivation of this paper. In this paper, we propose a spectrum access

scheme based on SU's priority in heterogeneous cognitive wireless networks environment.

The rest of this paper is organized as follows: In Section 2, the CSMA scheme based on SU's priority in heterogeneous cognitive wireless networks is described in detail. In Section 3, we analyse the performance of CSMA scheme based on SU's priority through continuous-time Markov processes. Numerical examples are given in Section 4 and the summary is given in Section 5.

### 2. System Model

We consider that there are two different networks  $A$  and  $B$  with different service rate. Network  $A$  is the primary network and has a faster service rate than network  $B$ . Primary users(PUs) follow On/Off usage pattern in network  $A$  and is independent with other's channel usage patterns.

We assume that there are two kinds of SUs which are high and low priority SUs. All SUs can access network  $B$  but high priority SUs also can access network  $A$  opportunistically in order to satisfy its requirement.

We assume that each SU senses the channel without any error (i.e., no misdetection and no false alarm). Each SU is saturated at any time, that is, each SU always has the data packet to transmit. The delay caused by the SU sensing the channel is ignored. Each SU will vacate the channel when a PU returns to the channel.

The CSMA scheme based on SU's priority in heterogeneous cognitive wireless networks is operated as follows:

**Step 1.** When a low priority SU has a packet to send, it senses network  $B$ . If the SU finds idle channels, then the SU selects randomly one among those channels and transmits a packet and then the SU goes to back-off state after packet transmission in order to prevent the channel being exclusively used by one SU. If the SU does not find any idle channels, then the SU goes to back-off state and senses network  $B$  again.

**Step 2.** When a high priority SU has a packet to send, it senses  $A$  and  $B$  networks with all sensing. If the SU finds idle channels in both  $A$  and  $B$  networks, then the SU selects randomly one among those channels from network  $A$  and transmits a packet and then the SU goes to back-off state after packet transmission. If the SU does not find any idle channels in network  $A$  but find idle channels in network  $B$ , the SU selects randomly one among those channels from network  $B$  and transmits a packet and then the SU goes to back-off state after packet transmission. If the SU does not find any idle channels in both  $A$  and  $B$  networks, the SU goes to back-off state and repeat step2.

**Step 3.** High priority SU in network  $B$  also listens to network  $A$  channels' occupancy. If there has a channel vacated in network  $A$ , system chooses one of high priority SUs from network  $B$  randomly to perform spectrum handoff from network  $B$  to network  $A$  immediately in order to satisfy the network service rate requirement of high priority SUs.

**Step 4.** When a PU returns to the channel before the SU finishes its packet transmission on the channel, then the SU will vacate the channel to the PU and sense all channels immediately. If the SU finds idle channels, the SU continues to transmit its current packet on one of the idle channels, otherwise, the SU goes to back-off state and the transmission of current packet is regarded as unsuccessful.

### 3. Performance Analysis

To simplify the analysis, we assume that network  $A$  has  $m_1$  channels and network  $B$  has  $m_2$  channels. The transmission time of SUs in network  $A$  and network  $B$  are exponentially distributed with mean  $\mu_1^{-1}$  and  $\mu_2^{-1}$ , respectively. The On-periods and Off-periods on the channel in network  $A$  have exponential distribution with mean  $\alpha^{-1}$  and  $\beta^{-1}$ , respectively. We assume that there are  $N_1$  high priority SUs and  $N_2$  low priority SUs in the system. The back-off time of high and low priority SUs are exponentially distributed with mean  $\nu_1^{-1}$  and  $\nu_2^{-1}$ , respectively.

Let

$N_p(t)$ —the number of on-period PUs in network  $A$  at time  $t$ ;

$N_s(t)$ —the number of channels used by high priority SUs in  
 $A$  at time  $t$ ;

$N_{s1}(t)$ —the number of channels used by high priority SUs  
in  $B$  at time  $t$ ;

$N_{s2}(t)$ —the number of channels used by low priority SUs in  
 $B$  at time  $t$ .

Then  $\{(N_p(t), N_s(t), N_{s1}(t), N_{s2}(t)) | t \geq 0\}$  forms 4-dimensional Markov process with state space

$$S = \{(i, j, k, l) | 0 \leq i \leq m_1, 0 \leq j \leq m_1 - i, 0 \leq k \leq m_2, 0 \leq l \leq m_2 - k\}.$$

Since the process  $\{(N_p(t), N_s(t), N_{s1}(t), N_{s2}(t)) | t \geq 0\}$  is an irreducible Markov process with finite state space, it is always ergodic and exists the steady state probability. Let  $\pi_{i,j,k,l}$  be the

joint probability that the Markov chain is in state  $(i, j, k, l)$ , then we can obtain the following balance equations:

1) If  $j < m_1 - i, k = 0, l < m_2$ ,

$$[i\alpha + (m_1 - i)\beta + j\mu_1 + (N_1 - j)\nu_1 + l\mu_2 + (N_2 - l)\nu_2]\pi_{i,j,0,l} = (i+1)\alpha\pi_{i+1,j,0,l} + (m_1 - i + 1)\beta\pi_{i-1,j,0,l} + (j+1)\mu_1\pi_{i,j+1,0,l} + (N_1 - j + 1)\nu_1\pi_{i,j-1,0,l} + (l+1)\mu_2\pi_{i,j,0,l+1} + (N_2 - l + 1)\nu_2\pi_{i,j,0,l-1}$$

2) If  $j < m_1 - i, k = 0, l = m_2$ ,

$$[i\alpha + (m_1 - i)\beta + j\mu_1 + (N_1 - j)\nu_1 + l\mu_2]\pi_{i,j,0,m_2} = (i+1)\alpha\pi_{i+1,j,0,m_2} + (m_1 - i + 1)\beta\pi_{i-1,j,0,m_2} + (j+1)\mu_1\pi_{i,j+1,0,m_2} + (N_1 - j + 1)\nu_1\pi_{i,j-1,0,m_2} + (N_2 - l + 1)\nu_2\pi_{i,j,0,m_2-1}$$

3) If  $j = m_1 - i, k = 0, l < m_2$ ,

$$[i\alpha + (m_1 - i)\beta + j\mu_1 + (N_1 - j)\nu_1 + l\mu_2 + (N_2 - l)\nu_2]\pi_{i,m_1-i,0,l} = (i+1)\alpha\pi_{i+1,m_1-i,0,l} + (m_1 - i + 1)\beta\pi_{i-1,m_1-i,0,l} + \mu_2\pi_{i,m_1-i,1,l} + (N_1 - j + 1)\nu_1\pi_{i,m_1-i-1,0,l} + (l+1)\mu_2\pi_{i,m_1-i,0,l+1} + (N_2 - l + 1)\nu_2\pi_{i,m_1-i,0,l-1}$$

4) If  $j = m_1 - i, k = 0, l = m_2$ ,

$$[i\alpha + (m_1 - i)\beta + j\mu_1 + l\mu_2]\pi_{i,m_1-i,0,m_2} = (i+1)\alpha\pi_{i+1,m_1-i-1,0,m_2} + (m_1 - i + 1)\beta\pi_{i-1,m_1-i,0,m_2} + (N_1 - j + 1)\nu_1\pi_{i,m_1-i-1,0,m_2} + (N_2 - l + 1)\nu_2\pi_{i,m_1-i,0,m_2-1}$$

5) If  $j = m_1 - i, k > 0, l < m_2 - k$ ,

$$[i\alpha + (m_1 - i)\beta + (k+l)\mu_2 + j\mu_1 + (N_1 - j - k)\nu_1 + (N_2 - l)\nu_2]\pi_{i,m_1-i,k,l} = (i+1)\alpha\pi_{i+1,m_1-i-1,k,l} + (m_1 - i + 1)\beta\pi_{i-1,m_1-i,k,l} + (k+1)\mu_2\pi_{i,m_1-i,k,l+1} + (N_1 - j - k + 1)\nu_1\pi_{i,m_1-i,k-1,l} + (l+1)\mu_2\pi_{i,m_1-i,k,l+1} + (N_2 - l + 1)\nu_2\pi_{i,m_1-i,k,l-1}$$

6) If  $j = m_1 - i, k > 0, l = m_2 - k$ ,

$$[i\alpha + (m_1 - i)\beta + (k+l)\mu_2 + j\mu_1]\pi_{i,m_1-i,k,l} = (i+1)\alpha\pi_{i+1,m_1-i-1,k,l} + (m_1 - i + 1)\beta\pi_{i-1,m_1-i,k,l} + (N_1 - j - k + 1)\nu_1\pi_{i,m_1-i,k-1,l} + (N_2 - l + 1)\nu_2\pi_{i,m_1-i,k,l-1}$$

By solving the above linear equations, we can obtain  $\pi_{i,j,k,l}$ .

The throughput  $T_{s1}$  (or  $T_{s2}$ ) of high (or low) priority SUs is defined as the number of successfully transmitted packets on channels per unit time.

To find  $T_{s1}$  and  $T_{s2}$ , let  $\lambda_e$  be the effective packet arrival rate of all SUs in the system and  $\tilde{\pi}_{i,j,k,l}$  be the arrival-point probability that the SU finds the system in the state  $(i, j, k, l)$  upon sensing after its back-off time.

Let  $\lambda_{e1}$ ,  $\lambda_{e2}$  be the effective packet arrival rate of high and low priority SUs, then

$$\lambda_{e_1} = \sum_{i=0}^{m_1} \sum_{j=0}^{m_1-i} \sum_{k=0}^{m_2} \sum_{l=0}^{m_2-k} (N_1 - j - k) v_1 \pi_{i,j,k,l}$$

$$\lambda_{e_2} = \sum_{i=0}^{m_1} \sum_{j=0}^{m_1-i} \sum_{k=0}^{m_2} \sum_{l=0}^{m_2-k} (N_2 - l) v_2 \pi_{i,j,k,l}$$

$$\lambda_e = \lambda_{e_1} + \lambda_{e_2} = \sum_{i=0}^{m_1} \sum_{j=0}^{m_1-i} \sum_{k=0}^{m_2} \sum_{l=0}^{m_2-k} (N_1 - j - k) v_1 \pi_{i,j,k,l} + \sum_{i=0}^{m_1} \sum_{j=0}^{m_1-i} \sum_{k=0}^{m_2} \sum_{l=0}^{m_2-k} (N_2 - l) v_2 \pi_{i,j,k,l}$$

Then, the arrival point probability of SUs  $\tilde{\pi}_{i,j,k,l}$  is

$$\tilde{\pi}_{i,j,k,l} = \frac{(N_1 - j - k) v_1 \pi_{i,j,k,l} + (N_2 - l) v_2 \pi_{i,j,k,l}}{\lambda_e}$$

During a high priority SU transmits a packet on the channel of network  $A$ , it may be interrupted by PU. We can obtain that the interrupted probability  $P_I$  of the high priority SU as follows

$$P_I = \frac{\beta}{\beta + \mu_1}$$

The probability of high priority SUs in network  $B$  find that network  $A$  has an idle channel and perform spectrum handoff to network  $A$  is given by

$$P_h = \sum_{i=0}^{m_1} \sum_{k=1}^{m_2} \sum_{l=0}^{m_2-k} \pi_{i,m_1-i,k,l} \frac{(m_1 - i) \mu_1 + i \alpha}{(m_1 - i) \mu_1 + i \alpha + k \mu_2} \frac{1}{k}$$

The probability of high priority SUs occupying channels in network  $A$  or  $B$  are given by

$$P_A = \sum_{i=0}^{m_1-1} \sum_{j=0}^{m_1-i-1} \sum_{l=0}^{m_2} \tilde{\pi}_{i,j,0,l}, P_B = \sum_{i=0}^{m_1} \sum_{k=0}^{m_2-1} \sum_{l=0}^{m_2-k-1} \tilde{\pi}_{i,m_1-i,k,l}$$

The probabilities that a high priority SU is interrupted and finds idle channels in network  $A$  or the SU does not find any idle channels in network  $A$  but finds idle channels in network  $B$  are given by

$$P_1 = \sum_{i=1}^{m_1-1} \sum_{j=0}^{m_1-i-1} \sum_{l=0}^{m_2} \tilde{\pi}_{i,j,0,l}, P_2 = \sum_{i=1}^{m_1} \sum_{k=0}^{m_2-1} \sum_{l=0}^{m_2-k-1} \tilde{\pi}_{i,m_1-i,k,l}$$

The probability that a high priority SU is interrupted and does not find any idle channels in both  $A$  and  $B$  networks is given by

$$P_3 = \sum_{i=1}^{m_1} \sum_{k=0}^{m_2} \tilde{\pi}_{i,m_1-i,k,m_2-k}$$

The probability that a high priority SU does not find any idle channels in both  $A$  and  $B$  networks and the probability that a low priority SU does not find any idle channels in network  $B$  are given by

$$P_{b_1} = \sum_{i=0}^{m_1} \sum_{k=0}^{m_2} \tilde{\pi}_{i,m_1-i,k,m_2-k}, P_{b_2} = \sum_{i=0}^{m_1} \sum_{j=0}^{m_1-i} \sum_{k=0}^{m_2} \pi_{i,j,k,m_2-k}$$

Since SU's packet may be forced to termination after a number of interruptions by PUs, then we can obtain following relations:

The probability that a high priority SU being interrupted in network  $A$  and eventually be forced to interrupt is  $P_F = P_A P_{F_1} + P_B P_{F_2}$

Where  $P_{F_1}$  and  $P_{F_2}$ , given by

$$P_{F_1} = \frac{P_I P_3}{1 - P_I P_1 - P_I P_2 P_h}, P_{F_2} = \frac{P_I P_3 P_h}{1 - P_I P_1 - P_I P_2 P_h}$$

Therefore, the throughput of high and low priority SU are given by

$$T_{s_1} = \lambda_{e_1} P_A (1 - P_{F_1}) + \lambda_{e_1} P_B (1 - P_{F_2}), T_{s_2} = \lambda_{e_2} (1 - P_{b_2}).$$

#### 4. Numerical Examples

In this section, we present numerical examples for the performance of SUs. We assume that  $m_1=10, m_2=5, N_1=N_2=20, \mu_2^{-1}=10\text{ms}, \alpha^{-1}=350\text{ms}$  and  $\beta^{-1}=650\text{ms}$ .

Fig. 1 depicts the throughput of different priorities SUs as the back-off rate of SUs increases when  $\mu_1^{-1}=5\text{ms}$ . Fig.1 shows the throughput of different priorities SUs increases as the back-off rate of SUs increases. Because as the back-off rate increases, the probability, that SUs find idle channels increases, resulting an increase in the throughput. And the throughput of high priority SUs is larger than low priority SUs.

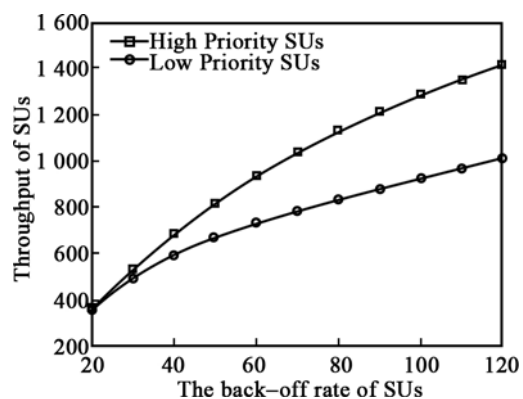


Figure 1. Performance of the system versus the back-off rate of SUs

Fig. 2 depicts the throughput of different priorities SUs as the service rate of network  $A$  increases when  $v_1^{-1}=v_2^{-1}=100\text{ms}$ . Fig.2 shows the throughput of high priority SUs increases as the service rate of network  $A$  increases. Because as the service rate of network  $A$  increases, high priority SUs transmit packets faster, resulting in an increase in the throughput. And the throughput of high priority SUs is larger than low priority SUs.

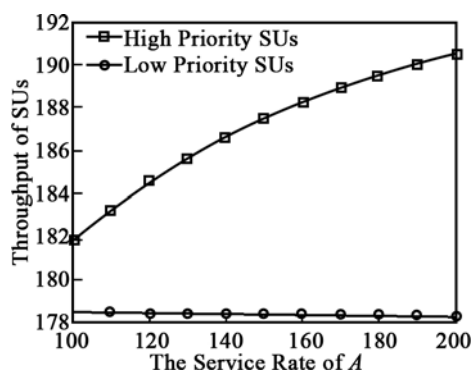


Figure 2. Performance of the system versus the service rate of network  $A$

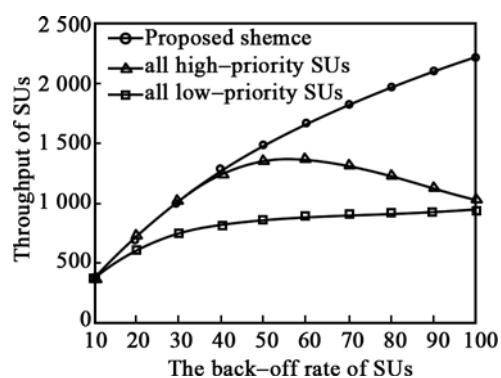


Figure 3. Performance comparison among the proposed scheme and other schemes versus the back-off rate of SUs

Fig. 3 compares the performance of the proposed scheme, all high and all low priority SUs systems as the back-off rate of SUs increases. Fig.3 shows the throughput of the proposed scheme is larger than all high and all low priority SUs systems.

## 5. Conclusion

This paper proposes a spectrum access scheme based on SU's priority in heterogeneous cognitive networks environment,

and analyzes the system using a four-dimensional continuous-time Markov process. This paper obtains the steady state probability of the system and performance measures of SUs such as the throughput and HoL packet delay. It can be seen from the above numerical results that the proposed scheme performs better than all high and all low priority SUs systems. And high priority SUs performance better than low priority SUs in the proposed scheme. Parameters such as the back-off rate of SUs and the service rate of network  $A$  have a great impact on system.

## References

1. Jin, S. F. and Xu, D., 2012. A Novel Centralized Spectrum Allocation Scheme in Cognitive Radio Networks and Performance Evaluation. *International Journal of Advancements in Computing Technology*, 4, 197–206.
2. Lee, H. and Cho, D. H., 2009. VoIP Capacity Analysis in Cognitive Radio System. *IEEE Communications Letters*, 6, 393–395.
3. Gao, R. and Wang, H., 2011. A Novel Multi-channel MAC Protocol for Distributed Cognitive Radio Networks. *AISS*, 3, 132–139.
4. Kim, K. J., Kwak, K. S. and Choi, B. D., 2013. Performance Analysis of Opportunistic Spectrum Access Protocol for Multi-Channel Cognitive Radio Networks. *Journal of Communications and Networks*, 15, 77–86.
5. Huang, S. H., Liu, X. and Ding, Z., 2008. Opportunistic Spectrum Access in Cognitive Radio Networks. *INFOCOM*, Phoenix, USA.
6. Zhu, D. B., Park, J. S. and Choi, B. D., 2010. Performance Analysis of Unslotted CSMA in the Multi-Channel Cognitive Radio Networks. *QINA2010, Beijing*, 24–26 July, 156–161.
7. Fang, H. Q. and Zhu, D. B., 2016. Power Consumption and Delay Analysis for Grouped Sensing Scheme in Multi-Channel Cognitive Radio Network. *International Journal of Advancements in Computing Technology*, 8, 15–20.
8. Cai Cheng, 2017. Research on spectrum access scheme based on priority of unauthorized users [D]. Yanbian University.
9. Dongbi ZHU, Zhengnan CAO, Yihu XU, 2017. Performance Analysis of Unslotted CSMA Scheme for SUs in Heterogeneous Wireless Network[C]. *ISMII 2017*, 118–124.
10. Xie Bing, 2016. Research on spectrum resource allocation of heterogeneous cognitive wireless networks [D]. Jilin University