A Comprehensive P-Persistent Algorithm in Multi-channel and Multi-interface Cognitive Network*

Junwei Lv, Weili Lei, and Tigang Jiang

School of Communication and Information Engineering,
University of Electronic Science and Technology of China, Chengdu, China
`ljwsunny@sina.com`

Abstract. In this paper, we design a multi-interface model on single mobile node and every node in the cognitive network is implemented multiple transceivers. *P*-persistent slotted CSMA is used as the access protocol. Interfaces with different channels may have different values of *p*s. To avoid crosstalk, multiple transceivers of each node must work in the same state, only sending or receiving, at one time. This requirement limits the performance of *p*-persistent algorithm. To solve this problem, we propose the Comprehensive *P*-Persistent Algorithm (CPPA), which is to find an optical value of *p* shared by one node's multiple interfaces. Simulation experiments are conducted to evaluate the performance of our algorithm in terms of the throughput and the jitter. Results show that our algorithm performs better.

Keywords: cognitive radio, OFDM, p-persistent slotted CSMA, multi-interface.

1 Introduction

The concept of cognitive radio (CR) was introduced to improve the frequency spectrum utilization in wireless networks. CR is able to do self-cognition, user-cognition and radio-cognition [1]. It is adapted for use of frequency without interference to primary user. Therefore, the secondary user in cognitive network should continuously perceive channels and master the channel occupancy of the primary user. Then it makes decision on which channel can be used. To meet this demand, in this paper, the mobile node in the cognitive network is designed with multiple interfaces, and every interface can work for different purposes independently.

OFDM (Orthogonal Frequency Division Multiplexing) is chosen as the modulation. OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate inter-symbol interference (ISI) [2]. It can support flexible selection of frequency, implement adaptive bandwidth allocation, and divide the

---

* This work is supported by the National Natural Science Foundation of China under Grant No.60802024, the 863 Project of China under Grant No.2009AA011801, the National S&T Major Project of China under Grant No. 2008ZX03006-001 and 2008ZX03003-005).

Y. Cai et al. (Eds.): Mobilware 2010, LNICST 48, pp. 499–506, 2010.

channels into several narrow sub-channels. So that OFDM provides good implementation foundation of spectrum sensing for cognitive radio. Due to the Frame synchronization of OFDM, [3] shows that OFDM with slotted aloha does a better job than unslotted aloha, and [4] indicates that CSMA provides better performance than aloha. So we adopt p-persistent slotted CSMA as the access protocol for single interface. Moreover, all of the multiple transceivers of one node only can be either transmitters or receivers (ETOR) at one time. It is not admitted that some transceivers of one node are transmitting packets while the others are receiving packets. To meet this requirement, the performance of p-persistent slotted CSMA is limited. To solve this problem, in this paper, the Comprehensive P-Persistent Algorithm (CPPA) is put forward, which is to find the optimal value of p shared by the multiple interfaces of a mobile node.

The rest part of the paper is organized as follows: First, we describe the system model in Section II. Then we present the Comprehensive P-Persistent Algorithm (CPPA) in Section III. In Section IV, we analyze the performance of the CPPA according to simulation results.

2 System Model

In this paper, the mobile nodes work in the hybrid network including centralized and distributed network. In overlapping coverage area of the two kinds of networks, one or more nodes become the gateways, interconnecting the centralized and distributed network.

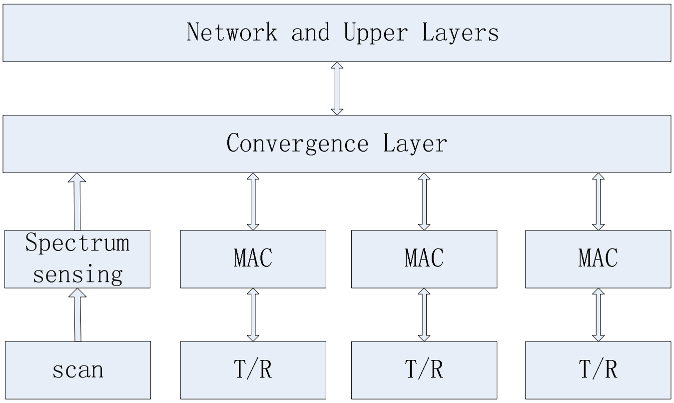

Fig. 1. The protocol stack of a mobile node

As described in Fig.1, each node has one PHY/MAC pair for spectrum sensing and three pairs for data communication. In the PHY, multiple transceivers work concurrently and independently. The channel device for spectrum sensing has to scan all channels continuously, sense and master the state of each channel, and provide the information for data channel devices to choose spectrum holes to work. The three data channel devices are independent with each other and have the same software and hardware structures. Moreover, the data channel devices work in the same range of frequency, so that one's working frequency is close to other ones. In order to avoid the crosstalk between different transceivers, the transceivers working roles of a single mobile node are confined to be either transmitters or receivers (ETOR) uniformly. For example, at *t*th time slot, if a transceiver is sending packets, the other two also have to be in sending state or shut down even if there is no packet to be sent.

The three MACs use *p*-persistent slotted CSMA as the access protocol separately. Each MAC entity is implemented with two working modes, one working in the centralized network and the other working in the distributed network. With the restriction of ETOR mode, given that the three MACs may determine different transmission probability *p*, the channel device that has lower probability can neither transmit nor receive data packets when the one that has higher probability is sending data packets. This may lower the channel utilization. The CPPA calculates the optimal value of transmission probability that can be used by three data channel devices commonly so that they can work under the same policy.

The convergence layer, where the CPPA locates, decides working modes of MAC entities and completes the spectrum resource allocation and synchronization management of the three data channels.

3 The Comprehensive P-Persistent Algorithm (CPPA)

In this paper, we assume that the channel is error free and there is no capture phenomenon. So the collision is the only reason of packet error or packet loss. The collision is divided into two kinds: a) Primary users arrive when secondary users are using the same channel. B) Two or more secondary users using the same channel to send packets simultaneously.

The CPPA is aimed to lessen the performance loss from the ETOR mode. So the optimal value of *p* is a number which can make the throughput difference between CPPA with ETOR and non-CPPA without ETOR as small as possible.

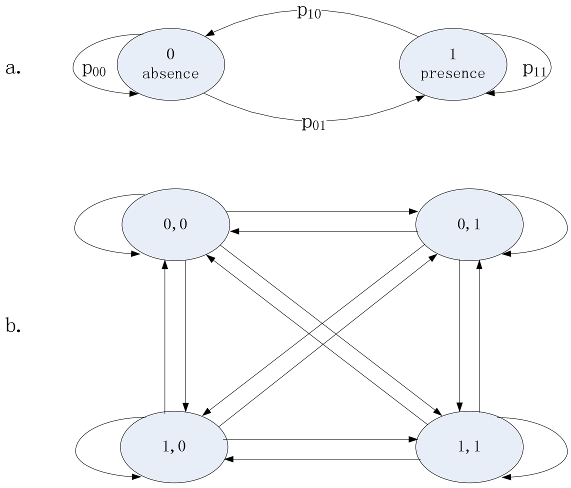

Fig. 2. State transition diagrams

In the environment of cognitive radio network, secondary user scans channels and selects a spectrum hole to send packets. According to [5], we use a multi-state Markov process to model this environment.

As illustrated in Fig.2.a, the primary user transits from state 0 (absence) to state 1 (presence) with probability p_{01} and stays in state 1 with probability p_{11}. Then the state is defined as (*Xt*, *Yt*). *Xt* denotes the real status of the primary users at time *t*, and *Yt* denotes the sensed status of the primary users by the secondary users. In addition, we define the probabilities of misdetection and false alarm as p_{md} and p_{fa}. Then we get the transition probability matrix of multi-state Markov process described in Fig.2.b as follows:

$$\begin{pmatrix} p_{00}(1-p_{fa}) & p_{00}p_{fa} & p_{01}p_{md} & p_{01}(1-p_{md}) \\ p_{00}(1-p_{fa}) & p_{00}p_{fa} & p_{01}p_{md} & p_{01}(1-p_{md}) \\ p_{10}(1-p_{fa}) & p_{10}p_{fa} & p_{11}p_{md} & p_{11}(1-p_{md}) \\ p_{10}(1-p_{fa}) & p_{10}p_{fa} & p_{11}p_{md} & p_{11}(1-p_{md}) \end{pmatrix}$$

The secondary user can only send packets in the states (0, 0) and (1, 0). When the state is (1, 0), the collision probability of the secondary users is 1, because this is a misdetection state. Based on the above transition probability matrix, we can determine the steady-state probability π_{00} and π_{10} which indicate the stationary probabilities of state (0, 0) and (1, 0) respectively.

We consider the case when the number of stations is much larger than that of sub-channels. Let *N* represents traffic load (the number of stations waiting for data transmission at *t*th slot) while there are *M* sub-channels. If *m* sub-channels are idle, with a probability *p* the station selects one idle sub-channel and transmits a packet; or with a probability $1-p$, the station defers the decision for transmission by one time slot. In sub-channel selection, the station randomly selects one among idle sub-channels.

We assume that the activity of each sub-channel is independent from each other. Let $M_{idle}(t)$ be the stochastic process representing the number of idle sub-channels among the $M-1$ sub-channels for the time slot index *t*. We can get the probability equation (1) that *k* stations transmit their packets in the sub-channel 1, conditioned on that *m* + 1 sub-channels including sub-channel 1 are idle [4].

$$\Pr(A_1 = k \mid M_{idle} = m) \equiv \sum\nolimits_{a=k}^{\infty} \Pr(A(m+1) = a) \bullet \binom{a}{k} \frac{m^{a-k}}{(m+1)^a} \tag{1}$$

$$\Pr(A(m) = k) = \frac{(Np)^k}{k!} e^{-Np}, k = 0,1,\cdots \tag{2}$$

When calculating the comprehensive *p*, we consider the channel occupancy of all nodes in the network is similar. Let *m* be a constant. We denote the steady-state probabilities by P_i, P_s, and P_c that the Markov process is in the idle, success, and collision states, respectively. According to [4], we can get the equations as follows:

$$P_s = P_i \cdot \pi_{00} \cdot \Pr(M_{idle} = m)\Pr(A_1 = 1 \mid M_{idle} = m), \tag{3}$$

$$P_c = P_i \cdot \pi_{00} \cdot \{\Pr(M_{idle} = m) \cdot \sum\nolimits_{k=2}^{\infty} \Pr(A_1 = k \mid M_{idle} = m)\} + \pi_{10}, \tag{4}$$

$$P_i = 1 - P_s - P_c \tag{5}$$

The probability that the transmission on a sub-channel finishes at a certain slot is given by $\frac{\sigma}{\mathrm{LM}}$ for the packet transmission time *LM* and the slot duration *σ* [6]. The saturated throughput of a sub-channel is

$$S = \frac{P_s LM}{P_i \sigma + (P_s + P_c) LM} \tag{6}$$

Substituting the expressions (6) obtained for P_s (3), P_c (4) and P_i (5), we have the finally established (7).

$$S = \frac{L \cdot M \cdot \Pr(M_{idle} = m) \cdot (1 - \pi_{10}) \cdot \pi_{00} \cdot e^{-\frac{Np}{m+1}} \cdot \frac{Np}{m+1}}{(1 - \pi_{10}) \cdot \sigma + L \cdot M \cdot \pi_{10}}, \tag{7}$$

Using equation (7), we can get the value of the comprehensive *p* in theoretically. *P*-persistent algorithm is researched in many articles [7]-[9], and in this paper, it does not be discussed.

Supposed at *t*th time slot, the transmission probabilities of the three channels are p_1, p_2, p_3, and the throughputs are S_1, S_2, S_3. The throughput of one interface with transmission probability *p* is *S*. *F(p)* is defined as below:

$$F(p) = S_1 + S_2 + S_3 - 3S$$

When *F(p)*=0, *p* is the optimal value, thus we can get the formula as below:

$$e^p \cdot p = \frac{1}{3}(e^{p_1} \cdot p_1 + e^{p_2} \cdot p_2 + e^{p_3} \cdot p_3) \tag{8}$$

4 Simulation and Analysis

First, we analyze the influence of the primary user on the throughput of the secondary user using the equation (7) we proposed.

To simplify the simulation, we assume that the number of channels is the same as that of the interfaces of the mobile node. For the parameters, we set the slot duration to 250μs; the packet transmission time, *L*, to 2.5 ms; misdetection, p_{md}, to 0.2; false alarm, p_{fa}, to 0.2; and the transmission probability, *p*, to 0.1.

The saturated throughput of a sub-channel for $p_{00} = 0.1$, p_{00}=0.5 and $p_{00} = 0.9$ are plotted in Fig.3. p_{01} is set as the same as p_{00}. From the Fig.3, we notice that the higher the probability of absence is, the higher the throughput of the secondary user is, which is in line with the realities.

In order to characterize the feature of the algorithm accurately, we compare the performance of CPPA to that of non-CPPA by simulation. We simulated a system of 50 nodes on a 500×500 grid. The nodes could move in all possible directions with displacement varying uniformly between 0 to 5, per unit time. Each node had 3 interfaces, and transceivers worked in ETOR mode as mentioned above. The simulation started at $t = 0s$, and data flows increased as time went on.

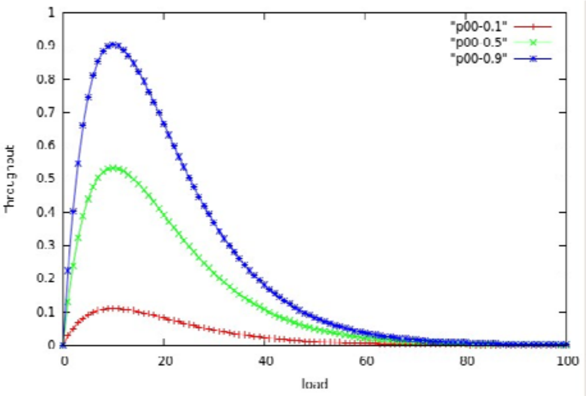

Fig. 3. The throughputs under different p00s

Fig. 4 and Fig. 5 show the performances of a data flow at $t = 19s$. p.out is the throughput with CPPA and 3p.out is that without CPPA. As shown in the figure, the throughput of CPPA is greater than that of non-CPPA. With the same transmission probability, the chance that three interfaces of one node are in the same state is larger, so that the channel utilization is improved. This will make throughput higher.

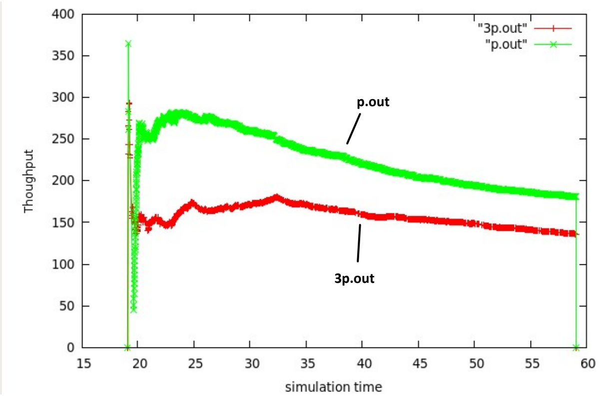

Fig. 4. The comparison of throughputs

But in the long haul, 3p.out curve is more stable, and p.out curve declines while time goes on. The reason is that each interface decides its own p according to its using channel condition, so as to keep its performance at a good level. With the data flows increasing, the state difference between channels may be greater. At this time, the way of using the common policy may not be suitable. The probability p calculated by CPPA is a compromise value, which may make a channel in good condition has a low probability p, and one in bad condition has a high probability p. It needs more researches on that in what range of the difference between the minimum and maximum of p_i (i is the number label of a interface), the CPPA is more efficient. Fig. 5 is the comparison of jitters. Obviously, the difference is not very significant.

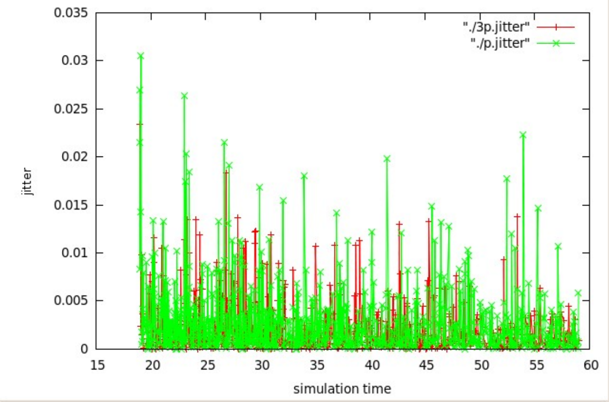

Fig. 5. The comparison of jitter

Future work is needed to determine that under what conditions the CPPA perform well. As mentioned above, the throughput degrades when the channel states among interfaces are very different. A threshold value should be calculated to guarantee the efficiency of the CPPA. An adjustment algorithm should be applied when the maximum difference goes up to threshold. For example, we choose the minimal p_i among the three interfaces as the comprehensive p to ease the network collision, and choose the p calculated by (8) when the maximum difference is less than threshold.

5 Conclusion

We propose the comprehensive p-persistent algorithm (CPPA) which is an optimization of p-persistent algorithm when the multiple transceivers of a mobile node in the multi-channel and multi-interface cognitive network work in the ETOR mode. CPPA can minimize the performance loss and improve the channel utilization, so that the throughput of the network can be enhanced by CPPA. Furthermore, the simulation result shows the algorithm need further researches to perform better.

References

1. Haykin, S.: Cognitive Radio: Brain-Empowered Wireless Communications. IEEE JSAC 23(2), 201–220 (2005)
2. Keller, T., Hanzo, L.: Adaptive multicarrier modulation: A convenient framework for time-frequency processing in wireless communications. Proc. IEEE 88, 611–640 (2000)

3. Chung, J.-M.: OFDM frame synchronization in slotted aloha mobile communication systems. In: Proc. IEEE Vehicular Technology Conference 2001, vol. 3, pp. 1373–1377 (2001)
4. Kwon, H.: Generalized CSMA/CA for OFDMA systems: protocol design, throughput analysis, and implementation issues. IEEE Trans. Wireless commun. 8, 4176–4187 (2009)
5. Jeon, S.-Y.: An ARQ mechanism considering resource and traffic priorities in cognitive radio systems. IEEE Communication Letters 13, 504–506 (2009)
6. Park, S.Y., Lee, B.G.: An analysis on the state-dependent nature of DS/SSMA unslotted ALOHA. J. Commun. Networks 8, 220–227 (2006)
7. Bruno, R., Conti, M., Gregori, E.: Optimal capacity of p-persistent CSMA protocols. IEEE Communications Letters 7(3), 139–141 (2003)
8. Long, K.P., Li, Y., Zhao, W.L., Wang, C.G., Sohraby, K.: p-RWBO: a novel low-collision and QoS-supported MAC for wireless ad hoc networks. Science in China Series F: Information Sciences 51(9), 1193–1203 (2008)
9. Zha, W., Hu, R.Q., Qian, Y., Cheng, Y.: An adaptive MAC scheme to achieve high channel throughput and QoS differentiation in a heterogeneous WLAN. In: Cheng, X.Z. (ed.) Proc. of the 3rd International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, pp. 26–35. ACM, New York (2006)