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Distributed Channel Allocation for Ad-hoc Multichannel Cognitive Radio Networks

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Abstract

Cognitive radio network was proposed to use the spectrum resource more efficiently. In a multichannel ad-hoc cognitive radio network, there is no central station and requires distributed channel scheduling. An important requirement of the cognitive radio network is to avoid interference to primary networks. In this paper, the authors propose the distributed packet scheduling scheme for ad-hoc multichannel cognitive radio networks. Each secondary user calculates independently its own priority with probabilistic manner and selects one of multi channels considering the primary user's traffic pattern to minimize interference to the primary networks.

Keywords*: Cognitive Radio network, Ad-hoc Network, Medium access control, Proportional fair scheduling, Multichannel*

1. Introduction

Recently, the demand of wireless spectrum is rapidly increasing due to the increase of various wireless services and applications. To cope with the shortage of the spectrum and improve spectrum usage efficiency, Cognitive Radio (CR) has been proposed [1]. The cognitive radio is expected to solve the spectral limitation by exploiting the spectrum hole in conventional wireless networks. Multichannel ad-hoc CR networks have advantages that it can make arbitral networks independent of the other networks and the nodes can join and drop the network freely [2].

In a multichannel CR network, spectrum allocation is one of the most important issues [3]. Many studies have been made on the topic of spectrum allocation in CR networks and focused on the efficient utilization of spectrum, but most of the studies do not consider the fairness of secondary users (SUs). The opportunistic channel access can induce serious problem of unfairness among the SUs. Design issue of channel allocation in CR network is to minimize interference to the primary users and also to increase the fairness among the secondary users. Proportional Fair (PF) scheduling algorithm [4], which is designed to guarantee performance of entire system as well as fairness among users, is one of the widely deployed schemes for resource allocation in conventional wireless networks. However, conventional PF scheduling was designed for the centralized networks. For the ad-hoc CR networks, distributed scheduling scheme is required and it should consider the dynamic nature of CR networks due to the primary traffic [5].

In this paper, the authors propose a distributed packet scheduling protocol for the ad-hoc multichannel CR networks. Using the backoff time set by priority, each secondary user can access the channel in the distributed network. The proposed channel allocation scheme considers the primary user's traffic pattern and predicts the spectrum hole to minimize interference to the primary users. The remainder of this paper is organized as follows. Section 2 shows the method to calculate the priority in distributed manner and predict the spectrum hole. In section 3, the authors propose the distributed channel allocation scheme. Simulation results are discussed in section 4, and conclusion is given in section 5.

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2. Priority for User Fairness and Spectrum Hole Prediction.

2.1. Distributed Priority Calculation

In the ad-hoc CR networks, each SU should decide its own priority. Each SU calculates its proportional fairness factor. When the i-th SU tries to transmit data to j-th SU with data rate $R_{i,j}$, the proportional fairness priority $PF_{i,j}$ is defined by (1) and we will call it as proportional farness factor.

$$PF_{i,j}(t) = \frac{R_{i,j}(t)}{T_i(t)} \tag{1}$$

where T_i is average transmission rate of i-th SU. Average data rates of candidate SUs are included in the beacon message in the reporting phase. At every transmission of data packet, each SU updates average data rate. Average data rate T_i of i -th SU is updated according to the following equation.

$$T_i(t+1) = (1-1/T_{MAC}(t))T_i(t) + \left(1/T_{MAC}(t)\right) R_i(t) \tag{2}$$

where T_{MAC} is one MAC period. In ad-hoc CR networks, each SU can calculate its own priority, but does not know the other SUs' fairness factor. To figure out other SU's priority, the authors obtained the following probability that i-th SU has the highest priority than others.

$$\gamma_i(t) = \prod_{j=1, j\neq i}^{N} \Pr(PF_i(t) > PF_j(t)) \tag{3}$$

with the probability $\gamma_i(t)$, the SU i can guess its priority among the SUs. To calculate the probability $\gamma_i(t)$, the authors should know the probability density function of data rate. The authors use the fact that transmission rate is inversely proportional to the distance. The probability that the proportional fairness factor of i-th receiver is greater than that of j-th SU can be calculated by

$$\Pr\left(PF_i > PF_j\right) = \Pr\left(\frac{T_j}{T_i} R_i > R_j\right) = P_{R_j}\left(0 < d < \frac{T_j}{T_i} R_i\right) \tag{4}$$

Each SU can get its own priority, PO, with threshold, β [6].

$$PO_i(t) = \begin{cases} 1 & if \;\; \beta_{M-1} \le \gamma_i(t) \\ 2 & if \;\; \beta_{M-2} \le \gamma_i(t) < \beta_{M-1} \\ & \quad \cdots \\ M & if \;\; \gamma_i(t) < \beta_1 \end{cases} \tag{5}$$

2.2. Prediction Of Spectrum Hole Using Statistical Properties Of The Primary Networks

In the multichannel network, secondary users must decide to find the appropriate available channels for the data transmission. To opportunistically use the spectrum and reduce interference to the primary networks more, the statistical properties of the primary networks can be used. By using the statistics of the primary network traffic, secondary users can predict the collision probability of each channel, and should find the channel that can reduce the interference to the primary network.

To predict the collision probability, the authors calculate the length of spectrum hole. To predict the spectrum hole of channel, i, the authors should obtain the probability that the PU's packets do not appear until the time t_0.

$$s_i(t) = 1 - \int_0^{t_0} \lambda_i e^{-\lambda_i t} dt = e^{-\lambda_i t_0} \tag{6}$$

where λ_i is the PU's packet arrival rate in channel i. When a CR user transmits a packet using spectrum hole T_{free}, the success probability must be greater than threshold α. Threshold limits the interference to the PU in a channel. The spectrum hole T_{free} indicates the maximum time duration that can be used by the CR users while maintaining the success rate α. Spectrum hole, T_{free}, can be different value according to the packet arrival rate.

$$\alpha = e^{-\lambda_i T_{free,i}} \tag{7}$$

As shown in Fig. 1, to obtain the spectrum hole T_{free}, each CR user should know the initial time value. To obtain this value, multiple CR users within a certain area should share channel information. Each CR user in the area periodically senses the channel. If a CR user detects the arrival of a PU, it broadcasts the arrival time and enables the other CR users to update the channel information table. Even though, they share the information of PU's arrival, each SU cannot know the exact spectrum hole because of discrete sensing time. And so, the expected arrival time of PU should be modified as shown in Fig. 1.

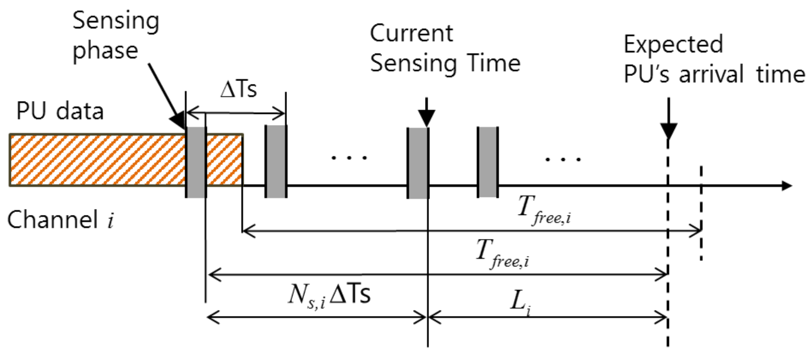

Figure 1. Expected Spectrum Hole

Effective spectrum hole, L_i, is the remaining time period, during which the SU can transmit data. Effective spectrum hole can be obtained by (8).

$$L_i = T_{free,i} - N_{s,i}\Delta T_s \tag{8}$$

where ΔT_s is time interval of channel sensing, and N_s is the number of sensing periods between the last sensing time of PU data and the current sensing time

3. Distributed Multichannel Scheduling

In the ad-hoc cognitive radio networks, there is no centralized base station to control the channel scheduling, and the distributed medium access control is required. In this paper, the proposed channel allocation scheme is based on the OP (opportunistic) MAC protocol [7]. OP-MAC is composed of 4 phases such as sensing phase, network reporting phase, transmission reservation phase, and data transmission phase.

In the proposed channel allocation, once a SU has data to transmit, the SU calculates its own priority, PO_i. Each candidate SU does not know the priorities of the others', and they differentiate the transmitting time according to its own priority. Fig.2 shows the example of the proposed medium access procedure when four different candidate SUs have different or same priority. Each SU calculates its own backoff time using the PO parameter.

$$Backoff_i = SIFS + (PO_i - 1)Time\_slot \tag{7}$$

The SUs try to access the channel which has the highest effective spectrum hole L_i value, and if the channel is already occupied, then the SUs try to access the channel with the next highest L value.

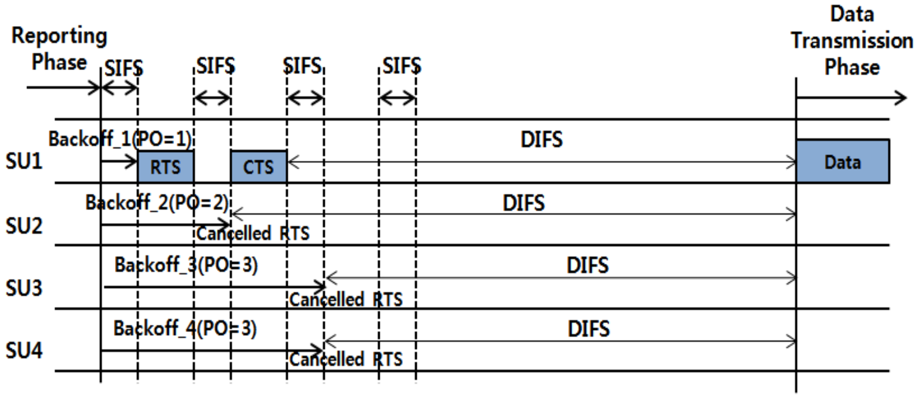

Figure 2. Illustration of Distributed Channel Access

Also the SUs should determine a channel to transmit data among the channels. Each SU finds the channel which has the maximum effective spectrum hole. Each SU has different backoff time and all the SUs monitor the channel which has highest L value. If there is no RTS packet in the channel, the SU transmits RTS packet at the backoff time. If the channel is busy, the SUs monitor the next channel which has next longest effective spectrum hole L, and wait until it becomes its own backoff time.

In this distributed channel allocation scheme, even though there is no centralized base station, each SUs can calculate its own priority and avoid collision using different backoff time, and the better channel can be allocated to the SU with higher priority. In case that the SUs have the same priority, the SUs have collision. In that case, the other waiting SUs change the target channel and continue to monitor the next channel and the SUs with the collision generate random backoff time and access the same channel again.

4. Simulation and Results

To evaluate the performance of the proposed scheduling scheme, a computer simulation was performed. The authors consider multi-rate transmission according to the standard of IEEE 802.11g, and the data rates are 6, 9, 12, 18, 24, 36, 48, 54 Mbps. The time interval of MAC was assumed as 10ms, and the packet arrival rates of primary users are assumed to be 0.02, 0.01, 0.005 per 1 MAC. To evaluate fairness performance, the authors defined unfairness index in (9) [8].

$$\sigma = \frac{1}{N}\sum_{i=1}^{N}\overline{T}_i^{\,2} - (T_{av})^2 \tag{9}$$

Where $\overline{T_i}$ is the average throughput of receiver i and N is the number of total receiver in the system. T_{av} is the average receiver throughput. The larger unfairness index in (9) indicates that the distribution of throughputs among receivers becomes more unfair.

Fig. 3 shows the throughput according to the number of secondary users. As the number of SUs increases, throughput decreases and the throughput performance of the proposed scheduling gets better than the conventional OP-MAC. Fig. 4 shows the unfairness index according the number of SUs. As the number of SUs increases, fairness gets improved and also the proposed scheme shows the better fairness than the conventional OP-MAC.

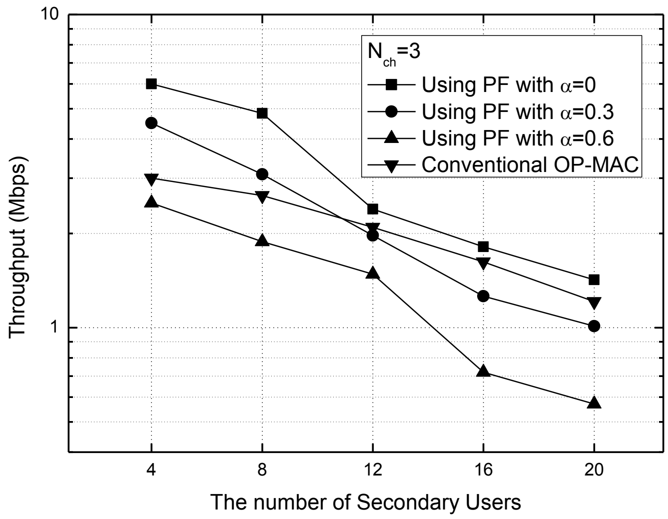

Figure 3. Data Throughput in Multichannel CR Network (N_{ch}=3)

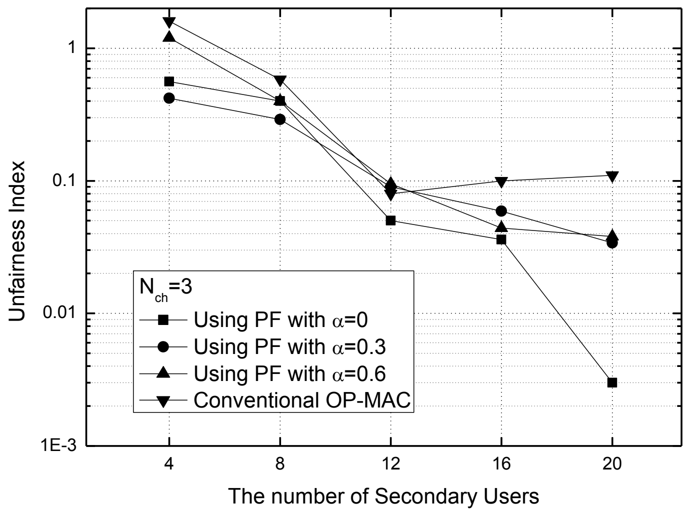

Figure 4. Unfairness Index in Multichannel CR Network (N_{ch}=3)

Fig 5 and 6 shows the collision probability and system throughput. Throughput of conventional method is more or less than the proposed one, but the collision probability is much higher than the proposed one. In CR network, interference to the primary user is the most important problem and the conventional scheme is not proper for the CR networks. The proposed scheme can control the collision rate and throughput using the parameter α.

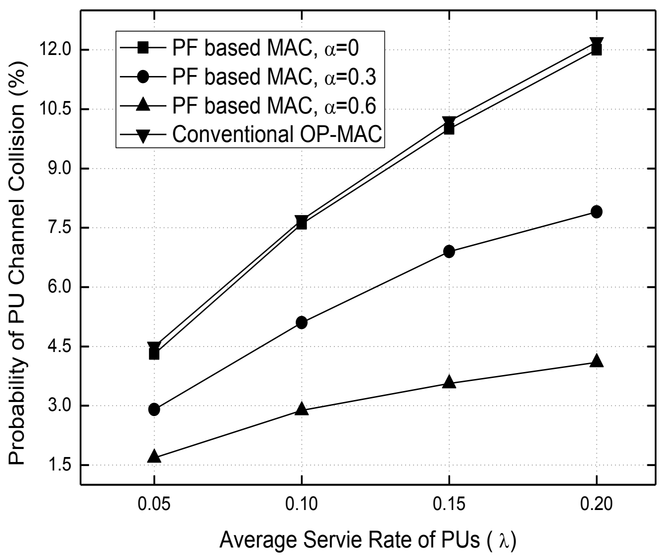

Figure 5. Probability of Collision with PU's Packet

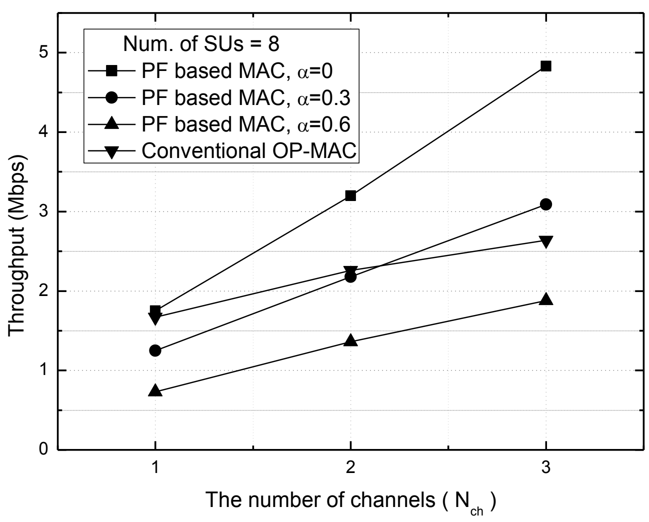

Figure 6. Throughput According To the Number of Channels

5. Conclusions

Channel scheduling is one of the important processes in multichannel CR networks. Channel allocation should consider not only the interference to the primary network but also fairness among the secondary users. In an ad-hoc CR network without base station, centralized channel scheduling is impossible and the distributed channel scheduling is required. In this paper, distributed channel allocation scheme was proposed to improve the fairness among the secondary users. Secondary users calculate its own priority using the proportional fairness. Secondary users also should consider the properties of primary users' traffic, and channels should be allocated to minimize interference in the primary users. In this paper, these channel scheduling and channel access was designed for the distributed CR networks. Simulation results shows that the proposed distributed channel scheduling enables the distributed channel access and it can reduce the unfairness among the secondary users and interference to the primary network.

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