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스펙트럼 핸드오프 호를 위해 버퍼를 활용하는 무선인지시스템의 얼랑 용량

Erlang Capacity of Cognitive Radio Systems Utilizing Buffer for Spectrum Handoff Calls

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요 약 본 논문은 무선인지시스템이 갖는 얼랑 용량을 분석하였다. 무선 인지 사용자들의 신규 호 및 스펙트럼 핸드오프를 요청하는 호들에 대해 버퍼를 사용하는 무선 자원 관리 기법을 고려하였으며, 성능 분석을 위해 마르코프(Markov) 모델을 사용하였다. 이를 기반으로 무선 인지 시스템에서 기사용자 및 무선 인지 사용자가 겪는 호 차단(call blocking) 확률, 강제 호 종료(forced call termination) 확률, 호 서비스 비완료(non-completion) 확률 등을 유도하였다. 시뮬레이션을 통해 버퍼의 크기가 증가함에 따라, 인지 무선 시스템에서 수용될 수 있는 얼랑 용량 또한 증가함을 보였다.

Abstract In this paper, the performance of cognitive radio network is analyzed in terms of Erlang capacity. To improve the Erlang capacity with respect to primary user (PU) and secondary user (SU) traffic, we propose an efficient radio resource management scheme utilizing the buffer for new SUs and interrupted SUs. Markov model is developed, and analyzed to derive the performances of the proposed spectrum sharing scheme in both primary system and secondary system. To determine the Erlang capacity region, the blocking probability, the forced termination probability and the non-completion probability are calculated. Simulation results provide insight into the advantages of the buffer utilization. It is observed that the supportable traffic loads of PU and SU can be increased significantly according to the buffer length.

Key Words : Cognitive radio, Erlang capacity, radio resource management, buffer, spectrum handoff call

Ⅰ. Introduction

Cognitive radio (CR) network is the new paradigm for improving spectrum utilization[1]. A CR can be re-configured to transmit and receive on a variety of frequencies, and use different access technologies supported by its hardware design. Through this adaptability, the best spectrum band and the most appropriate operating parameters can be selected and reconfigured[4,5].

In CR network, secondary users can use the spectrum band that is assigned for primary users (PUs) because PUs do not always use its allocated frequency. Therefore, SU can access PU band when that band is free. SU has ability to be active in all frequency, can sense and learn the surrounding environment. When a SU is using sub-channel and a PU appears on that sub-channel, SU has to vacate that sub-channel. At that time, SU will establish the new connection to

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another available spectrum band, which is called *spectrum handoff*.

CR networks have been paid attention of many researchers. Dynamic spectrum access approaches for CR networks are also mentioned in many literatures [2, 3]. In the reference[2], the analysis of CR spectrum access with optimal channel reservation was proposed. This scheme can reduce the SU forced termination probability. With this system, a SU request will be rejected directly if there is no available resource, which will lead to the intensification of the blocking probability. In another literature[3], dynamic spectrum access schemes in the absence or presence of buffering mechanism for the SUs are proposed and analyzed. However, this approach only uses the buffer for the new SUs. This may be not desirable for the interrupted SUs and for minimizing the SU blocking probability of CR network.

To utilize the properties of spectrum handoff, and in order to overcome the drawbacks of the studies mentioned above, we propose a new spectrum sharing scheme using buffer for both of new SUs and interrupted SUs. In the proposed scheme, when new SUs and the interrupted SUs arrive at the system and there is no available sub-channel and the buffer is not full, the interrupted SU as well as new SU will be put into the queue, and SUs in head of line of the buffer will get a released sub-channel when a PU or SU completes its service and release some sub-channels. For the performance analysis of the proposed scheme, two dimensional Markov model is developed. Based on this, we develope the Erlang capacity of the system, which is defined as a set of the average offered traffic loads of PU and SU that the CR system can support with a given QoS requirements.

The rest of this paper is organized as follows: The system model used in the paper is showed in Section Ⅱ. In Section Ⅲ, we present the proposed scheme for new SUs and interrupted SUs. Erlang capacity analysis are provided in Section Ⅳ. Simulation results are showed in Section Ⅴ. Finally, this paper is concluded in Section Ⅵ.

Ⅱ. SYSTEM MODEL

In this section, a spectrum sharing scheme is proposed for providing an integrated service of both PUs and SUs. This scheme allows SU to use the region reserved for PU with the risk of being preempted by newly arriving PU.

1. System description

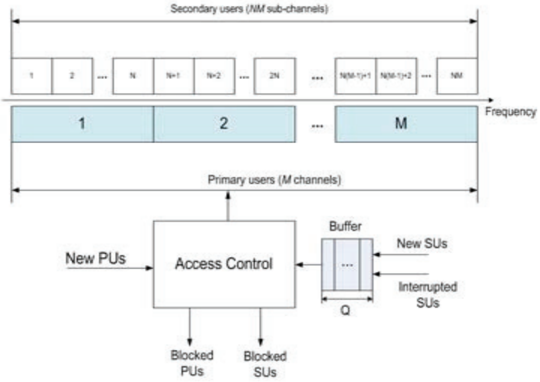

그림 1. 시스템 모델
Fig. 1. System model

Fig. 1 shows the system model for cognitive radio network. We define the channel as a bandwidth unit used in the PU system; and the sub-channel as a bandwidth unit used in the SU system. According to this term, a PU needs one channel for service and a SU needs one sub-channel for service. In the figure, M denotes the number of channels. Each channel is divided into N sub-channels. To avoid interference to PU, SU can use sub-channel only if there is no the presence of PU in that channel. This scheme has finite waiting queue for interrupted SUs and new SUs. Q is the length of the buffer. The new SUs requests and interrupted SUs due to the new PU appearance will be put into the buffer when all sub-channels are occupied. We also use access control to service call requests from PU and SU.

2. Traffic Model

The offered traffic is modeled with two random processes. The arrival traffic is modeled as a Poisson random process with rate λ_s and λ_p for SU and PU, respectively. The radio system access duration of SU and PU are negative exponentially distributed with mean time $1/\mu_s$ and $1/\mu_p$ so the departure of SU and PU are another Poisson random process with rate μ_s and μ_p, respectively. The assumption here is that for each type of the radio system, we have the same traffic load and occupation time.

Ⅲ. Spectrum sharing with buffering for new SUs and interrupted SUs

In this section, we will explain the proposed spectrum sharing scheme with buffering for new SUs and interrupted SUs in more details. Instead of utilizing the buffer for only new SUs, the buffer is also utilized for interrupted SUs. With the proposed CR networks, SU can overflow into the radio resource region reserved for PU. However, SU has to leave the sub-channel when PU arrives. In that case, SU is preempted and moved to queue if there is no resource and the buffer is not full. In addition, the new SU request can be saved in the queue if there is no available sub-channel in the system but empty place in the buffer. In order to process the collected information from SUs and PUs, access control is used. Based on data of channel states, access control will make a decision whether to accept or reject the PU and SU's call request. When PU or SU completes its service and releases some sub-channels, access control will also allocate the released sub-channels to SUs in head of line of queue.

1. Call arrival and call completion

We make the flow charts below for PU and SU call arrivals. Based on the conditions of bandwidth, PU call arrival and SU call arrival can be accepted or rejected. When the PU completes its service, a channel will be released. This means that N sub-channels are available and SUs in head of line of queue will get the released sub-channels. One sub-channel will become to be free if SU completes its service. In this case, the SU in head of line of queue will use that released sub-channel. For performance analysis, we denote i as the total number of sub-channels used by SU, j as the total number of channels used by PU, and k as the total number of SU requests saved in the buffer.

2. Analytic model

For improving the performance of the system by decreasing the SU blocking probability, a finite buffer with length Q is used for both of new SUs and interrupted SUs. When SU arrives, if there is no any available sub-channel in the system, SU call request will be put in the queue. Also, the preempted SU by the newly arriving PU will be put in the queue. Let (i,j,k) represent the system state. The state space Γ_B in this case becomes

$$\Gamma_B = \{(i,j,k) | 0 \le i \le NM; 0 \le j \le M; 0 \le i+jN \le NM; 0 \le k \le Q\} \tag{1}$$

These possible states can be divided into following four sub-state regions :

$$\Omega_a \equiv \{(i,j,k) \in \Gamma_B | i+jN \le N(M-1), k=0\}$$
$$\Omega_b \equiv \{(i,j,k) \in \Gamma_B | N(M-1) < i+jN \le NM, k=0\}$$
$$\Omega_c \equiv \{(i,j,k) \in \Gamma_B | i+jN = NM, k=0\}$$
$$\Omega_d \equiv \{(i,j,k) \in \Gamma_B | i+jN = NM, k>0\}$$

Noting that total rate of flowing into each state is equal to that of flowing out, we can get the steady state balance equation for each state. Moreover, if the total number of all valid states is n, there are $(n-1)$ linearly independent balance equations and the summation of all steady state probabilities satisfies the normalized equation $\sum_{(i,j,k) \in \Gamma_B} p(i,j,k) = 1$, a set of n linearly independent equations is performed as follows[6]:

$$\boldsymbol{\Pi Q} = \boldsymbol{P} \tag{2}$$

where $\boldsymbol{\Pi}$ is the vector of all states, $\boldsymbol{Q}$ is the transit rate matrix, and $\boldsymbol{P} = [0,...,1]$. The dimension of $\boldsymbol{\Pi}$, $\boldsymbol{Q}$ and $\boldsymbol{P}$ are 1xn, nxn and nx1, respectively. All steady state probabilities are obtained by solving $\boldsymbol{\Pi} = \boldsymbol{PQ}^{-1}$.

Ⅳ. Erlang Capacity Analysis

In this section, we consider Erlang capacity as a performance matric of the proposed system, and analyze the Erlang capacity of the dynamic spectrum access system. Erlang capacity is defined as the set of average traffic loads of PU and SU that the system can support with a certain quality and availability of service. In the proposed scheme, Erlang capacity is given as

$$\begin{aligned} C_{Erlang} &= (\widehat{\rho_{\mathrm{p}}}, \widehat{\rho_{\mathrm{s}}}) \\ &= (\rho_{\mathrm{p}}, \rho_{\mathrm{s}}) | \mathrm{P}_{\mathrm{bp}} \leq \mathrm{P}_{\mathrm{bp,req}}, \mathrm{P}_{\mathrm{nc}} \leq \mathrm{P}_{\mathrm{nc,req}} \end{aligned} \tag{3}$$

where $\rho_p = \lambda_p / \mu_p$ and $\rho_s = \lambda_s / \mu_s$. P_{bp} and P_{nc} are the PU blocking probability and the SU non-completion probability, respectively. $P_{bp,req}$ and $P_{nc,req}$ are the required PU blocking probability and SU non-completion probability respectively.

In order to calculate Erlang capacity of the system mentioned above, we should find out some performance metrics such as the PU blocking probability, and the SU non-completion probability. The SU non-completion probability is achieved by calculating the SU blocking probability and the SU forced termination probability. Firstly, let's consider the blocking probabilities of PU and SU calls. A SU call will be blocked when all channels and sub-channels are busy, and the buffer is full. Subsequently, the SU blocking probability is derived as follows:

$$P_{bs} = \sum_{\{(\mathrm{i,j,k}) \in \Gamma_{\mathrm{B}} | \mathrm{i} + \mathrm{jN} = \mathrm{NM}, \mathrm{k} = \mathrm{Q}\}} p(i,j,k) \tag{4}$$

In the case of PU call, the PU call arrival will be blocked when the number of PU in service is M. Subsequently, the PU blocking probability is calculated as follows:

$$P_{bp} = \sum_{(\mathrm{i,j,k}) \in \Gamma_{\mathrm{B}} | \mathrm{j} = \mathrm{M}} p(i,j,k) \tag{5}$$

The SU forced termination probability is determined through the SU interrupted probability. After a SU is accepted, it can be interrupted due to the presence of PU. Hence, let us denote the interrupted probability of a SU call as P_{int}. We should consider two situations to calculate P_{int}. The first case is that current state (i,j,k) belongs to $[N(M-1), NM)$. In this case the number of interrupted SU is equal to $i + jN - N(M-1)$, and the interrupted probability in such situation P_{int1} is given by

$$P_{\int 1} = \sum_{(\mathrm{i,j,k}) \in \Gamma_{\mathrm{B}} | \mathrm{N(M-1)} < \mathrm{i} + \mathrm{jN} < \mathrm{NM}} \frac{\mathrm{i + jN - N(M-1)}}{\mathrm{i}} \mathrm{p(i,j,k)} \tag{6}$$

The other case is that the current state belongs to $i + jN = NM$. In this case, there will be N interrupted when a PU arrives, and the SU interrupted probability P_{int2} is calculated by

$$P_{int2} = \sum_{\{(\mathrm{i,j,k}) \in \Gamma_{\mathrm{B}} | \mathrm{i} + \mathrm{jN} = \mathrm{NM}, \mathrm{i} > 0\}} \frac{N}{i} p(i,j,k) \tag{7}$$

From the two equations above and under the condition that there are SUs in service, we can calculate the interrupted probability of SU as follows:

$$P_{\mathrm{int}} = \frac{P_{int1} + P_{int2}}{\sum_{\{(\mathrm{i,j,k}) \in \Gamma_{\mathrm{B}} | \mathrm{i} > 0\}} p(i,j,k)} \tag{8}$$

When a SU is using a sub-channel and a PU appears in this sub-channel, the SU will be forced to termination if the buffer is full. The forced termination represents the disruption of SU in service. Let P_{ft} denote the forced termination probability of SU, and P_{nc} denote SU non-completion probability. Then, P_{ft} and P_{nc} are given by

$$P_{ft} = \frac{\lambda_p P_{\mathrm{int}}}{\mu_s + \lambda_{\mathrm{p}} \mathrm{P}_{\mathrm{int}}} \tag{9}$$

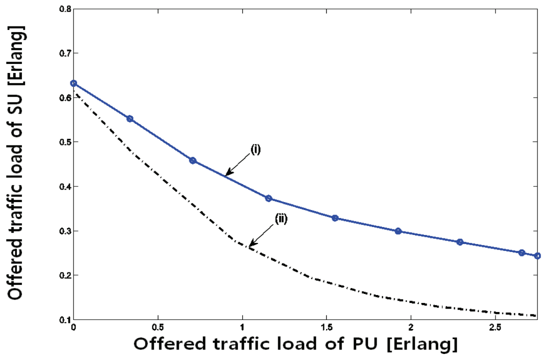

그림 2. $Q=0$, $P_{bp,req}=1\%$, $P_{nc,req}=1\%$으로 주어 졌을 때, 무선 인지 시스템의 얼랑 용량
Fig. 2. Erlang capacity when $Q=0$, $P_{bp,req}=1\%$ and $P_{nc,req}=1\%$

$$P_{nc}=P_{bs}+(1-P_{bs})P_{ft} \tag{10}$$

In conclusion, according to Eqn.(3), Erlang capacity can be discovered as a function of offered traffic loads of PU and SU traffic, by contouring the PU blocking probability and the SU non-completion probability at the level of the required probability. In addition, the total Erlang capacity of the system is determined by the overlapped region of Erlang capacities with respective to each traffic.

Ⅴ. Simulation Results

Based on analytic model, in this section simulation results are presented to evaluate the performance of the proposed scheme. We select the following parameters: The number of total channels in the system M is 4. The number of total sub-channels included in each channel N is 2.

Fig. 2 shows Erlang capacity when there is no buffer, $Q=0$, $P_{bp,req}=1\%$ and $P_{nc,req}=1\%$ The curve represented by (i) is the Erlang capacity which is limited by the required SU non-completion probability, the curve represented by (ii) is the Erlang capacity which is limited by the required PU blocking probability. In this case, a call arrival is blocked if there is no resource in the system. Fig. 2 shows that the Erlang capacity which is limited by the required SU non-completion probability is larger than the Erlang capacity which is limited by the required PU blocking probability. Hence, the total system Erlang capacity is mainly determined by the required PU blocking probability since the system should satisfy the required non-completion probability of SU as well as the required blocking probability PU simultaneously.

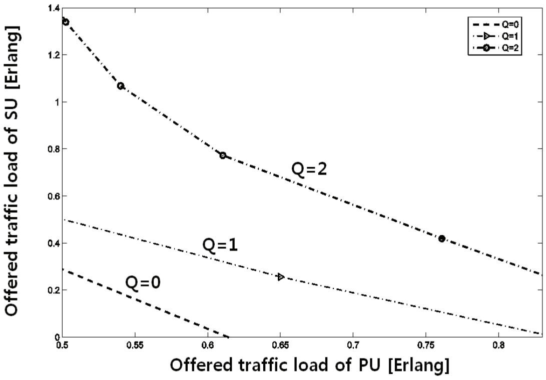

그림 3. 버퍼의 크기에 따른 무선 인지 시스템의 얼랑 용량 변화
Fig. 3. Erlang capacity according to the number of buffer size

Fig. 3 depicts the Erlang capacity according to the buffer length when $P_{bp,req}=1\%$ and $P_{nc,req}=1\%$. It is shown that Erlang capacity regions are affected so much by the length of buffer. In this case, the obtained Erlang capacity region is the largest when $Q=2$. Otherwise, the smallest Erlang capacity region is achieved when $Q=0$. Through the simulations, it can be concluded that the system Erlang capacity can be raised extremely by utilizing buffer for spectrum handoff calls.

Ⅵ. CONCLUSIONS

In this paper, we propose an efficient radio resource management scheme based on the buffer for cognitive radio. Instead of utilizing the buffer for only new SU as in some literatures, this system have utilized the finite queue for both of new SU and interrupted SU, which leads to the increase of SU service completion probability, and the decrease of some noises for PU and also other SUs. Erlang capacity seems to be a useful tool to evaluate the system performance. We can realize the difference of Erlang capacity regions with respective to each traffic easily. With a suitable buffer length in each specific CR network, the system Erlang capacity can be raised extremely. Based on the simulation results, we can select a proper size of buffers for SU calls to optimize the system performance.

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