LETTER

Log-Based Admission Control Scheme for Dynamic Spectrum Access Networks*

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SUMMARY Dynamic spectrum access (DSA) has drawn immediate attention recently since it can opportunistically exploit any spectrum holes and thus improve bandwidth utilization. From the perspective of medium access control (MAC) design, the QoS requirement of SU is one of the design issues in DSA network. In this paper, we propose a new admission control scheme referred to as log-based dynamic spectrum access admission control (DSAC) aiming at (1) protection of the primary users and (2) QoS prioritization for the existing secondary users. The DSAC algorithm protects the PU by limiting SUs' access using PU's arrival log or statistics. Furthermore, the DSAC reserves a channel for previously admitted SU to reduce frequent service disruption of the SU. Reservation of channels is carried out without assuming any specific arrival process, and thus the DSAC would be practical for general user arrival patterns unlike the existing admission control techniques. Performance evaluation has shown that the proposed DSAC outperforms existing admission control schemes with respect to the PU blocking rate, SU communication stability, and SU aggregate throughput by about 13%, 26%, and 20%, respectively.

key words: *dynamic spectrum access, PU, SU, admission control, QoS*

1. Introduction

Along with significantly growing demands on spectrum resource for wireless systems, there will be an acute shortage of bandwidth in the future. For example, ISM and UNI bands (unlicensed spectrum) are heavily populated. Nevertheless, FCC [2] announces that about 70% of the bands (licensed spectrum) are still under-utilized. In order to better utilize the licensed spectrum, the dynamic spectrum access (DSA) concept [1] has been proposed for enabling wireless devices to efficiently exploit the white spaces [3].

In the DSA, the secondary (unlicensed) users can periodically search and identify available channels in the spectrum. Based on the scanned results, the secondary users (SUs) dynamically tune their transceivers to one of the identified channels to communicate among themselves without disturbing the primary (licensed) users. When the SU detects the PU, the SU has to release the channel to the primary user (PU) and continues to use one of the available channels if any. In this basic principle, the PUs have the exclusive right to occupy the channel.

From the perspective of MAC design, the QoS requirement of SU is one of the design issues in DSA networks. In order to improve the QoS of SUs, a few admission control schemes have been proposed [4]–[7]. In [4], Zhu et al. proposed the optimal channel reservation scheme for DSA networks. In their scheme, the fractional guard channel reservation scheme is applied in order to limit the forced termination probability of SUs. Similarly, in [5], Pacheco et al. proposed the optimal admission control scheme. They not only use the fractional guard channel reservation but also detect the optimum number of guard channels through the cost function where the objective is to maximize the throughput of SUs. In [6], Xue et al. proposed a call admission scheme for different kinds of services in DSA networks. In their policy, they consider the three classes of services, i.e., handoff voice call, new voice calls, and data calls depending on their priority. As a result, the class-based call admission control scheme can provide different kinds of services in DSA networks. In [7], Yu et al. proposed the cross-layer optimized call admission control scheme, in which the parameters of call admission control strategy and spectrum sensing scheme are simultaneously tuned to minimize the dropping rate.

The above schemes do not consider the PU protection by simply relying upon the role of the SU, i.e., the SU has to release the channel to the PU when it detects the PU. Instead, our scheme takes both the PUs and SUs into account for computing the SU dropping probability. Further, the above techniques are designed under the assumption that the PUs and the SUs arrive in a Poisson fashion. However, in the practical DSA networks, the arrival patterns are not always Poisson process. Therefore, applying the above schemes does not guarantee protection of PUs nor the QoS of the SUs. In this paper, we proposed a new admission control scheme referred to as dynamic spectrum access admission control (DSAC) which computes the maximum number of channels by taking into account both PUs and already admitted SUs. The DSAC admits SU's channel request only when the maximum number of channels is less than or equal to the available number of channels. Consequently, our scheme can protect PUs and provide communication stability to the existing SUs. For computation of the maximum number of channels, the DSAC algorithm exploits PU's arrival pattern by collecting PU's arrival log per channel. Furthermore, the DSAC reserves a channel for previously admitted SU to improve communication quality of the SU. Reservation of the channels is carried out without assuming any specific arrival process, and thus the DSAC would be practical for general

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user arrival pattern.

The rest of this paper is organized as follows. In Sect. 2, we introduce our DSAC. In Sect. 3, various performance results are provided and analyzed. Finally, we draw conclusions in Sect. 4.

2. DSAC: Dynamic Spectrum Access Admission Control

2.1 System Model and Assumptions

We assume that the spectrum of interest is divided into C channels which are licensed to C PUs, respectively. The PUs are assumed to arrive randomly on each channel. In the same area, a dynamic spectrum access network is deployed where each SU node is denoted by S_i $(i = 1, \ldots, N)$. They are assumed to be equipped with one wireless transceiver and thus they can operate on any one of the given set of C channels at a time. We assume S_i $(i = 1, \ldots, N)$ performs channel sensing during its quiet periods for all C channels to explore any spectrum hole and to determine PU's arrival pattern on all C channels. The arrival pattern is to be stored at the log of S_i $(i = 0, \ldots, N)$. Further, we assume there is a special secondary node (S_0) called base station that gathers spectrum information from S_i's $(i = 1, \ldots, N)$.

We denote α_i^j the channel occupancy time of the ith PU, and β_i^j the inter-arrival time between ith and $(i + 1)$th PUs on channel j, respectively as in Fig. 1. Moreover, let $f_{\alpha_i^j}(\cdot)$ and $f_{\beta_i^j}(\cdot)$ the probability density functions of α_i^j and β_i^j, respectively. We assume α_i^j, α_{i+1}^j, β_i^j, and β_{i+1}^j are mutually independent. Furthermore, we assume α_i^j's are identically distributed for all i and β_i^j's are also identically distributed for all i. However, we assume α_i^j's and β_i^j's are not identically distributed for channel j. Therefore, the PU's arrival patterns may be different per channel. We assume further that this arrival pattern is monitored and logged at each S_i and transmitted to S_0 so that S_0 can obtain PU's arrival pattern on overall spectrum bands.

2.2 Admission Control Algorithm

In our scheme, a SU that wants to communicate requests a channel with the channel request time denoted by Θ^j. Θ^j is the time that the SU will use channel j[†]. Our scheme provides the following mechanism:

1. To protect the PU on channel j, the SU requesting channel j should not interfere to the PU during Θ^j.
2. Additionally, once the requesting SU is admitted to use channel j, the request time, i.e., Θ^j should be maintained as much as possible for the SU.

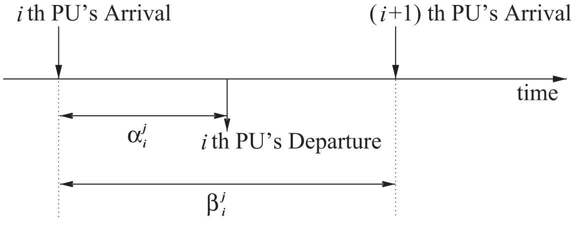

Fig. 1 The PU occupancy model on channel j.

In our scheme, we model the first condition as the blocking probability of the PU should be less than a certain threshold $\mathcal{B}$. For this, we first need to evaluate the blocking probability of the PU. In Fig. 2, we denote δ^j the time elapsed from the latest PU's arrival to the instant that the SU requests a channel. If we assume the PU's arrival follows Poisson, then δ^j can be ignored because of the memoryless property of the Poisson. However, for general PU's arrival process, δ^j cannot be ignored[††]. To compute the blocking probability of the PU, we take δ^j into consideration, i.e., the probability that the PU finds a SU during Θ^j given that δ^j has been elapsed since the latest PU arrival is given by

$$P_B\left(\Theta^j, \delta^j\right) = P\left(\beta_i^j \leq \delta^j + \Theta^j\right) \tag{1}$$

where $P_B(A, B)$ is the PU's blocking probability during A time units given that B time units have been elapsed since the latest PU's arrival. As in Fig. 2, in order for PU to be blocked, PU's inter-arrival time should be less than $\delta^j + \Theta^j$.

The necessary and sufficient condition for the second condition is that the maximum number of channels used during Θ^j should not be greater than C. In the following, we compute the maximum number of channels used during Θ^j by already admitted SUs including the requesting SU which is denoted by $\Phi(\Theta^j)$. To evaluate $\Phi(\Theta^j)$, consider the time is further divided by mini-slots where the duration of the mini-slot is represented by Δ as in Fig. 3. Δ is assumed to be sufficiently small so that Θ^j is an integer multiple of Δ. That is:

$$\mathbb{M} = \Theta^j / \Delta \tag{2}$$

where $\mathbb{M}$ is the number of mini-slots during Θ^j.

Then, $\Phi(\Theta^j)$ is given by

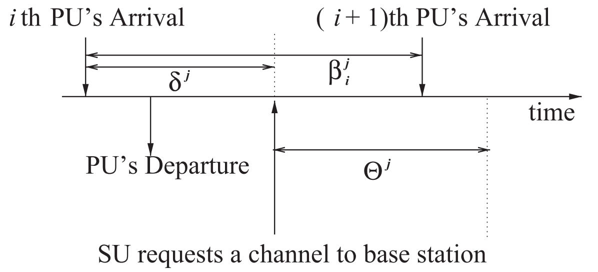

Fig. 2 The request time of SU.

[†] This mechanism is similar to the network allocation vector (NAV) used in the IEEE 802.11 standard. This realization can be done simply by a control frame similar to request to send (RTS) in the IEEE 802.11.

[††] The previous work assumed Poisson arrival of the PU. However, our scheme considers a general arrival process of the PU.

$$\Phi(\Theta^j) = \max_{m=1}^{\mathbb{M}} \left[\sum_{j=1}^{C} I_j^m \cdot \{1 + P_B(\Delta, \delta^j + m\Delta)\} \right] \tag{3}$$

where the indicator function(I_j^m) is defined by

$$I_j^m = \begin{cases} 1, & \text{Channel } j \text{ is occupied at slot } m \\ 0, & \text{otherwise.} \end{cases}$$

Figure 4 shows a pseudo code used in the DSAC algorithm. When the SU requests channel j with Θ^j, the base station maintains the set of candidate channels Ω which has been obtained from S_i's. The base station excludes channels which do not satisfy required SNR from Ω. Then, the base station sorts Ω according to less populated channels in order to increase channel utilization. After sorting, the base station checks channel j ($j = 1, \ldots, C$) so that it determines whether it can admit the requesting SU on the channel j or not. For this, the base station calculates $P_B(\Theta^j, \delta^j)$. β_i^j and δ^j are provided from PU arrival log at channel j to compute $P_B(\Theta^j, \delta^j)$ as in (1). If $P_B(\Theta^j, \delta^j)$ is greater than $\mathscr{B}$, the base station considers that the PU on channel j may not be protected. Therefore, the base station asks the reduction of Θ^j to the requesting SU[†]. If the reduced Θ^j satisfies the condition in line 7, then, it checks the condition in line 8. If $\Phi(\Theta^j) < C$, the base station accept the requesting SU because this implies that enough number of channels is available to protect the PU and to guarantee the communication quality of existing SUs. Otherwise, the base station searches for the next channel and performs the same behavior as above. If all the channels in Ω are exhausted, the requesting SU is rejected.

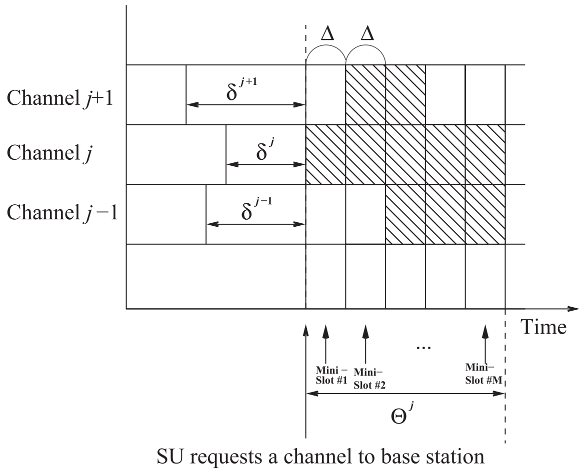

Fig. 3 The request times of SUs from the multi-channel perspective.

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1: $\Omega \Leftarrow$ The candidate channel set obtained from $S_i$'s;
2: $\Omega' \Leftarrow$ the set of channels that experience worse channel conditions;
3: $\Omega \Leftarrow \Omega - \Omega'$
4: Sort $\Omega$ according to less populated channels
5: $C \Leftarrow$ length($\Omega$);
6: for $j = 1$ to $C$ do
7:     if $P_B(\Theta^j, \delta^j) \leq \mathscr{B}$ then {PU can be protected}
8:         if ($\Phi(\Theta^j) < C$) then {Enough number of channels}
9:             Accept the request with $\Theta^j$;
10:        end if
11:    else {$\Theta^j$ is too long}
12:        $\Theta^j \Leftarrow \arg\max_{\Theta^j} \left(P_B(\Theta^j, \delta^j) < \mathscr{B}\right)$
13:        Go to step 7;
14:    end if
15: end for
16: Reject the channel request
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Fig. 4 The DSAC algorithm.

3. Performance Evaluation

In this section, we evaluate performance of the DSAC algorithm compared with an existing admission control scheme [5] introduced in Sect. 1. The simulation parameters are listed in Table 1. In this simulation, we measure the SU communication stability, the aggregate throughput of SUs, and the PU blocking rate by varying the arrival rate of PUs. To compare with the existing scheme [5], we chose the PUs'arrival model as exponential, uniform, Gaussian, and Cauchy. The last three model characterize non-Markovian so that we verify our DSAC algorithm performs well under non-Markovian arrival unlike [5]. The metrics are defined by

- **The SU communication stability (Γ):** The ratio of the number of SUs completed communication without forced termination to the number of all SUs who are admitted to the network,
- **The aggregate throughput of SUs (ξ):** Total data traffic transferred from all SUs divided by time, and
- **The PU blocking rate (ψ):** The probability that an arriving PU to a certain channel finds SU in the channel.

Figure 5 shows the SU communication stability (Γ) versus the PU arrival rate. As shown in the figure, [5] provides similar Γ to our scheme at low loads of PUs and Γ decreases sharply at high loads of PUs. In high loads of PUs, SUs in

Table 1 Simulation parameters.

Parameters	Value
Base Station	1
Data Channels	5
Time Slots	20 on each data channel
Primary Users	1 on each data channel
Secondary Users	15 on each data channel
Primary User Arrival Pattern	Exponential, Uniform, Gaussian, and Cauchy stochastic process
Secondary User Using Time	100 ~ 300 seconds
Primary User Using Time	100 ~ 300 seconds
Secondary User Arrival Rate	0.01 %
Time Slot Length	10 (ms)
Bandwidth	10 (Mbps) on each data channel

[†] The reduced Θ^j can be informed to the SU by a control frame similar to clear to send (CTS) in the IEEE 802.11.

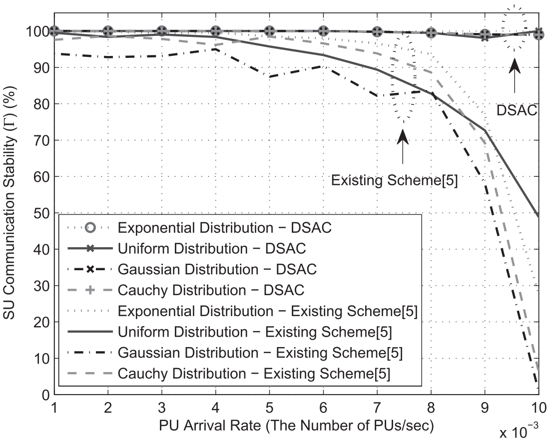

Fig. 5 The SU communication stability (Γ) vs. PU arrival rate ($\mathscr{B}$=0.1).

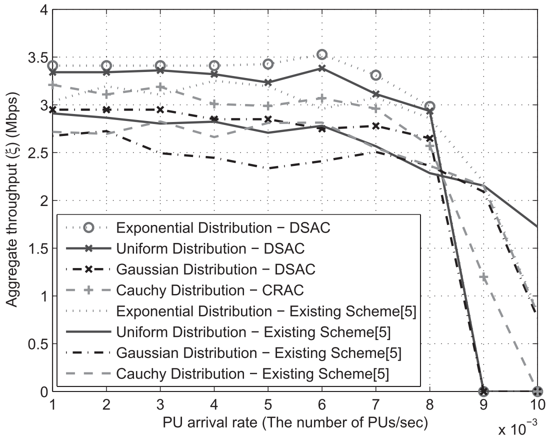

Fig. 6 The SU aggregate throughput (ξ) vs. PU arrival rate ($\mathscr{B}$=0.1).

communication are forced to be terminated by more PUs. As a result, the communication quality of SUs is significantly degraded. Furthermore, since [5] is designed under the assumption of exponential traffic model, Γs at uniform, Gaussian, and Cauchy models are mostly smaller than Γ at the exponential model. Especially, we observe that Γ at the Gaussian model is much less than Γ at the others. However, the proposed admission scheme achieves Γ almost 100% for all traffic models (providing seamless communications of SUs). Moreover, Γ is independent upon the PU arrival rate. This is because our scheme analyzes the PU arrival patterns and admits the SUs only when PU's blocking ratio is sufficiently less than $\mathscr{B}$. Finally, we observe Γ of our scheme is greater than [5] by about 26% on average.

Figure 6 depicts the aggregate throughput of SUs (ξ) depending on the PU arrival rate. As shown in the figure, ξ decreases as the PU arrival rate increases for all two schemes. This is because increasing PU arrival rate causes increasing dropping probability of SUs. We observe further from the figure that the proposed admission scheme can achieve the throughput about 20% higher than [5] on average. One interesting finding is that ξ of our scheme falls sharply compared with [5]. The rationale behind this effect

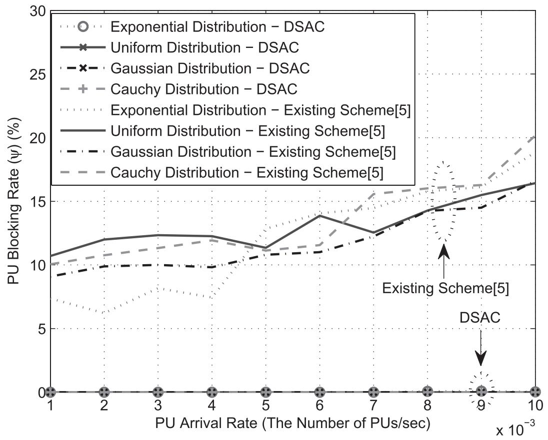

Fig. 7 The PU blocking rate (ψ) vs. PU arrival rate ($\mathscr{B}$=0.1).

is as follows. At high loads of PUs, a significant number of PUs request a channel. Consequently, the base station cannot admit the requesting SU in order to protect the PU. However, [5] allows the SUs to access the channel because [5] does not take PUs in consideration in their admission policy. Instead, [5] avidly reserves guard channels for SUs resulting in higher ξ than our scheme. However, in reality, this higher ξ cannot occur since SUs should vacate the channel once PU arrives to the channel. Figure 7 complements this observation. ψ of our scheme can achieve zero blockings of the PU while ψ of [5] is about 13%.

4. Conclusion and Future Direction

In this paper, we proposed a new admission control scheme referred to as dynamic spectrum access admission control (DSAC) aiming at (1) protection of the primary users and (2) QoS prioritization for the existing SUs. A performance evaluation has shown that the proposed DSAC outperforms existing admission control schemes with respect to the PU blocking rate, SU communication stability, and SU aggregate throughput by about 13%, 26%, and 20%, respectively.

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