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ORIGINAL ARTICLE

Performance enhancement of steady-state Markov analysis for cognitive radio networks via channel reservation

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Abstract Cognitive radio wireless networks CRNs have been considered as an efficient communication paradigm to the utilization of scarce spectrum. The main purpose of channel reservation of dynamic spectrum access (DSA) is to access these idle channels intelligently which are specialized for primary users (PUS) to be used by unlicensed users temporarily, which are called secondary users (SUS) without causing critical interference to the licensed user's activity. In this paper, continuous-time Markov chain paradigm is improved via channel reservation to show the best usage of the radio spectrum bands, and the transition matrix are deduced for the proposed model. Moreover, the probability state vector is proved by performing steady state analysis. The deduced expressions of the suggested model are illustrated in the numerical results section.

1. Introduction

The significant inefficiency of radio spectrum usage has led to increasing research works in cognitive radio in plentiful wireless networks [1]. One of the ideas in CR is that a cognitive or secondary user is permitted to share the spectrum with primary users [2] with constraint achieving demanded level quality of service (QoS) [3] without making interference with PUs [4]. The CR concept is that SUs must leave the channels immediately as soon as the PU appears and make handoff to another possible unoccupied channel [5].

The main purpose of the cognitive radio structure is the coordination usage between primary and secondary users [6] in the spectrum band. Dynamic spectrum access (DSA) is the most necessary application and allow the cognitive radio to exploit the available vacant channels [7,8]. A Markov approach is expanded to analyze the suggested spectrum access projects and improve its performance to a model of CRN without reserved channels [9]. On the other hand, continuous-time Markov chain which is called (CTMC) paradigm validates for instant-time measurements in DSA to be shared by the radio systems in the same frequencies [10]. In CTMC, each state contains the numbers of both the PUs and the SUs. The transition

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matrix is calculated through the arrival rates and service rates of both PUs and SUs between states.

Channel reservation policies have been presented a solution for improving the SU transmission quality and taking in consideration minimizing their interference with PUs. Dynamic channel reservation (DCR) reduces the blocking probability of secondary users by reusing channels [11].

In a CTMC [12] model is intended to predict the attitude of vacant bands which can be utilized by unlicensed users. The CTMC model supposes a simple case which consists of one primary user and also N secondary users.

Through this work, a cognitive network is composed of N secondary users with different traffic conditions, one idle state, one primary user and one reserved channel.

$$\mathbf{Q} = \begin{bmatrix} -\left(\sum_{i=1}^{N}\lambda_i + \lambda_P\right) & \lambda_1 & \lambda_2 & \cdots & \lambda_N & \lambda_P & 0 \\ \mu_1 & -(\mu_1 + \lambda_p + \mu_{q1}) & 0 & \cdots & 0 & \lambda_P & \mu_{q1} \\ \mu_2 & 0 & -(\mu_2 + \lambda_p + \mu_{q2}) & \cdots & \vdots & \lambda_P & \mu_{q2} \\ \mu_3 & 0 & 0 & \cdots & \vdots & \lambda_P & \mu_{q3} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \mu_N & 0 & 0 & \vdots & -(\mu_N + \lambda_P + \mu_{qN}) & \lambda_P & \mu_{qN} \\ \mu_P & 0 & 0 & \cdots & 0 & -\mu_p & 0 \\ 0 & \lambda_{q1} & \lambda_{q2} & \cdots & \lambda_{qN} & 0 & -\left(\sum_{i=1}^{N}\lambda_{qi}\right) \end{bmatrix} \quad (2)$$

The occupancy of radio spectrum is characterized as a CTMC model; hence the transition matrix will depend on the model theoretically is applied. Moreover, a steady-state method is performed to deduce the stationary state probability (SSP) vector. Numerical results are calculated to compare the current model with the available performed models.

The rest of work is arranged as follows: Section 2 discusses the model of the system and methodical analysis of work to deduce the transition matrix and SSP vector. In Section 3, numerical analysis is calculated. Finally, the paper is concluded in Section 4.

2. System model

A CR system consists of one primary user and N secondary users as presented in Fig. 1, the secondary users can access the vacant primary bands which are used by the primary users. Accordingly the primary user has the priority to use the spectrum; the secondary users must be preempted by primary users. Furthermore, secondary user could be served by the reserved channel if the primary user arrives to the network suddenly.

The traffic arrival processes for both PUs and SUs are assumed to be continuous time Poisson Processes with rates λ_p sec^{-1} and λ_s sec^{-1}, respectively. On the other hand, the departure process follows Poisson Process μ_p sec^{-1} for primary user's traffic and μ_s sec^{-1} for secondary user's traffic [11]. In a similar way, secondary users i ($1 \le i \le$ N) have been modeled by Poisson distribution with rates λ_i sec^{-1} and μ_i sec^{-1} respectively [13]. Furthermore, the arrival rate of the reserved channel is λ_{qi} sec^{-1} and the departure rate is μ_{qi} sec^{-1}.

Additionally, collision will not occur in the spectrum as no more than one service demand would be happened concurrently according to independent Poisson Process.

Subsequently, the spectrum access model can be performed as shown in Fig. 2.

The state space vector $\boldsymbol{x}$ is considered

$$\boldsymbol{x} = \{O, S_1, S_2, \ldots, S_N, P, q\}. \quad (1)$$

So, the transition Matrix $\mathbf{Q}$ for the suggested model can be deduced as demonstrated in Eq. (2).

In (1) state O indicates that no user employs the spectrum, state P shows that the primary user employs the channel and state S_i indicates that the secondary user i ($1 \le i \le N$) occupies the spectrum. State q demonstrates that SU exploits it when PU occupies the specialized channel in state P. The start point of the system is considered to be at state O. While the primary user is existed, so the state P becomes busy with sent arrival rate λ_p from state O to state P and once PU finishes service so it leaves state P and returns back to idle state O with departure rate μ_p. When the system is in state O and the SU_i wants to exploit the spectrum so that the system operates in state S_i with arrival rate λ_i.

Assume that the SU occupies the spectrum and the PU arrives before SU_i completes its service, the system transfers to state P with arrival rate λ_p and the SU will use the reserved channel q to complete the service with arrival rate λ_{qi} and when it completes the service returns by departure rate μ_{qi}. On the other hand, the SU_i returns back to idle state O with departure rate μ_i if it completes its task.

The enhancement of this submitted model is coming from the addition of the external reserved channel q other than previous literatures [13,14] do not have any reserved channels in the network. Where the secondary user SU_i could utilize this reserved channel and complete its required service instead of exposing to forced termination when the primary user P arrives to the network. For simplicity, this model has one reserved channel but in other works more reserved channels