Spectrum Handoff in Cognitive Radio Network Based on Hidden Markov Model

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Abstract: Cognitive Radio Network (CRN) is one of areas promising to enhance the spectrum utilization by using unlicensed users to exploit the spectrum in an opportunistic manner. In CRN, the function of detecting idle frequencies is so important. Due to the randomness of the appearance of Primary Users, disruptions to communications of Secondary Users are often difficult to prevent. This may also lead to low throughput of CRN. The state of each channel at any time, either idle (unoccupied by a PU) or busy (occupied by a PU), is hidden with CRN. With this observation, we proposed the Hidden Markov model to validate the state of each channel which determines the spectrum handoff for CRN. In our proposed framework, we also simulate this method with random channel selection in proactive spectrum handoff framework.

Index terms – Cognitive radio network, Cognitive Radio, Hidden Markov Models, Spectrum sensing, Viterbi Algorithm

1. INTRODUCTION

The concept of Cognitive radios was first introduced by Joseph Mitola [1]. Over the recent years, CRN is one of regarded technologies and get more achievements. One critical challenge is that SUs should avoid causing harmful interference to Primary Users (PUs) and support seamless communications regardless of the appearance of PUs. Therefore, the most important function of CRN is spectrum mobility which refers to the capability of SUs to switch idle channels. Spectrum mobility gives rise to a new type of handoff called spectrum handoff which refers to the process that when the current channel used by a SU is interrupted by the occupancy of PUs, the SU must determine switching to a new idle channel to continuously transmit data. However, there is not any negotiation between PUs and CRN, the CRs just base on spectrum sensing results. Various models have been proposed to analyze the function of spectrum handoff with two categories: reactive approach and proactive approach [3]. Reactive approach bases on the result of sensing channels then select the channel to switch. SUs predict the status of PU's behavior in the future and perform spectrum handoff before the disruptions with PU transmissions, namely the proactive approach [3].

However, in [3] there are still limitations in the analysis model. In the existing proposals of the proactive approach, a predictive model for dynamic spectrum access based on the past channel usage history is proposed in [4]. A cyclostationary detection and Hidden Markov Model (HMM) for predicting the channel idle times are proposed in [4]. But the authors just used HMM to model channel usage patterns in the same manner as the speech production model in speech processing applications. They did not analysis about transition stages of SU from one channel to another. In [3], a proactive spectrum handoff framework for CRN Ad hoc networks is proposed with Markov chain model to analyze the collision between SUs and PUs. In this paper, we proposed HMM in channel selection schemes and compare with traditional proactive approach (random channel selection).

The rest of the paper is organized as follows: section 2 presents the network model and the assumptions. Section 3 shows network topology and proposes the Hidden Markov Chain model in spectrum handoff. We show the simulation result of the model in section 4 and conclusion in Section 5.

2. NETWORK TOPOLOGY

Throughout this paper, we consider that a network scenario has a group of SUs which controls by a base station (BS). In that, there is no other SNs collision or cooperating with the SN. We also assume that every SU in the SN is equipped with a unique antenna that can be tuned to any combination of N consecutive licensed channels. Moreover, this paper also assumes that all SUs in an SN should participate in sensing a channel at the same time for each scheduled measurement period to enhance the detection of PU signal even. Sensing information will be collected and coordinated by a BS. So that, all cognitive functions are centralized and maintained by a BS. This paper only focuses on the selected channel scheme of SN which avoids interference from PUs and get more opportunities transmitting data.

3. THE PROPOSED HIDDEN MARKOV CHAIN MODEL

In traditional methods, the authors often assume that SUs can sense all the channels simultaneously and make the correct decisions. In reality, the true states (occupancy by PUs) of each channel are never known to the SUs. In our method, we propose a HMM for spectrum handoff to exploit a novel idea defining the emission probabilities. In that, we consider true states of each channel, which is occupied by PUs or SUs. Based on the analysis with HMM, we propose a handoff method for SUs.

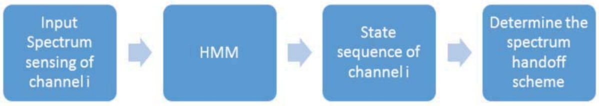

Fig 1. The system model implemented for enhanced spectrum handoff by HMM

In Fig 1, the proposed HMM model is described. Information about sensing spectrum in each channel are the input of system model. With the retrieved output of HMM, we collect the state sequence of all channels in sensing duration and determine the spectrum handoff scheme. Our model uses the maximum likelihood sequence of HMM to optimize the false alarm and mis-detection of sensing spectrum. In addition, from the maximum likelihood, the SUs can switch to another channel correctly.

Base on the time slotted channels, we define parameters for model in this paper:

a) An observation period τ = {1,2,3,⋯,T} , where each i in represents the ith duration in each slot. For each time slot, the observed status on each channel is busy or idle.

b) A sequence Y={y_1,y_2,⋯,y_T}, which represents the hidden states in the corresponding time periods. At the ith time instant, each channel has four states:

  - y(0,0) if the channel is idle and SU doesn't occupy on this channel.
  - y(0,1) if the channel is idle and SU is occupying on this channel.
  - y(1,0) if the channel is busy (PU claims the channel) and SU doesn't occupy on this channel.
  - y(1,1) if the channel is busy (PU claims the channel) and SU is occupying on this channel.

c) The CR sensing output generated is represented by a sequence X={x_1,x_2,⋯,x_T} of sensed states in the corresponding time periods. We also has four states of sensing at the ith sensing slot: the entity x(0,0) if the state of the channel is sensed to be free and the SU is not in it; x(0,1) = 0 when the SU is occupying and sensing on the free; entity x(1,0) is the state of busy channel is sensed by the CR and it is not occupied by any SU and entity x(1,1) is the state of sensing is the busy channel is occupied by the SU.

In this paper, we assume that all information is controlled by a BS so that the SN can have information about the channel which is occupied by SUs.

d) The state transition probability distribution P={p_{ij}} where

$$\begin{aligned}&\Pr(y_n = j \mid \mathrm{y}_1 = \mathrm{i}_1, \ldots, y_{n-2} = i_{n-2}, y_{n-1} = i)\\&= \Pr(y_n = j \mid y_{n-1} = j) = pij\end{aligned} \quad [1]$$

for every i_1, i_2, · · · , i_{n-2}, i, j ∈ S and 2 ≥ n ≤ T with state space S={S_i} (four state of y_i).

e) The observation symbol probability distribution in state k, E={$e_k(b)$}, where

$e_k(b) = \Pr(X_n = b \mid Y_n = k)$ [2]:emission probability.

k=1,2,3,4: the hidden state of system and b=1,2,3,4 is the observation state.

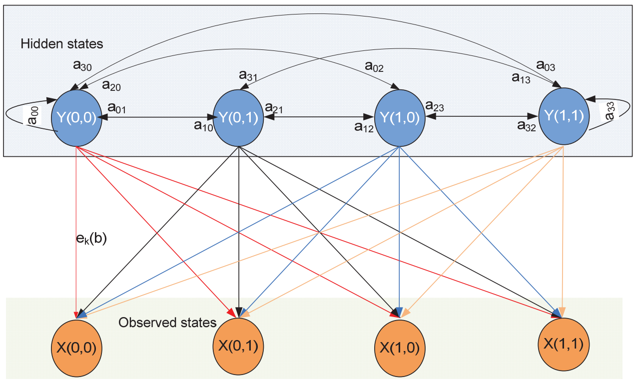

Fig. 2 The transition diagram of the proposed Markov model

f) When the SUs sense the channels, they can be prone to errors. The probability of predicting a state to be free when it is reality occupied is the probability of mis-detection (PMD) [3] denote by e_m. In addition, probability of predicting a state to be occupied when it is free is known as probability of false-alarm (PFA) denoted by e_f. As mentioned earlier, the BS controls spectrum handoff so that the SN knows clearly about the information of occupancy by SUs. Therefore, the emission probability is specified:

$Pr(X_n = (0,k) | Y_n = (0,t)) = e_0(0)=e_0(1)=e_1(0)=e_1(1)=1-e_m$
$Pr(X_n = (0,k) | Y_n = (1,t)) = e_2(0)=e_2(1)=e_3(0)=e_3(1)=e_m$
$Pr(X_n = (1,0) | Y_n = (0,0)) = e_0(2)=e_0(3)=e_1(2)\ e_1(3)=e_f$
$Pr(X_n = (1,0) | Y_n = (1,0)) = e_2(2)=e_2(3)=e_3(2)=e_3(3)=1-e_f$ [4]

g) The initial state distribution $\pi=\{\pi_i\}$ where $\pi_i = P[y_1 = S_i], 1 \le i \le 4$

Input the spectrum sensing sequence into the HMM model, the probability of the hidden sequences can be obtained. This sequence is the channel occupancy sequence $Y^* = \{y_1^*, y_2^*, ..., y_T^*\}$ in the duration T slot time. That sequence occupancy of SUs, computed maximum likelihood, is the output of Viterbi algorithm.

h) Viterbi algorithm: to find the best state sequence $Y = \{y_1^*, y_2^*, ..., y_T^*\}$ for the given observation sequence $X = \{X_1, X_2, ..., X_T\}$, given the model λ. We define the quantity:

$$\delta_t(i) = \max_{y_1, y_2, .. y_{t-1}} P[y_1, y_2, ..., y_t = i, X_1, X_2, ... X_t \mid \lambda] \quad [5]$$

i.e., $\delta_t(i)$ is the best score (highest probability) along a single path, at time t, which accounts for the first t sensing and end in state S_i. Applying Viterbi algorithm, we calculate

$$y_T^* = \arg\max_{1 \le i \le N} [\delta_T(i)] \quad [6]$$

4. SIMULATION AND NUMERICAL RESULTS

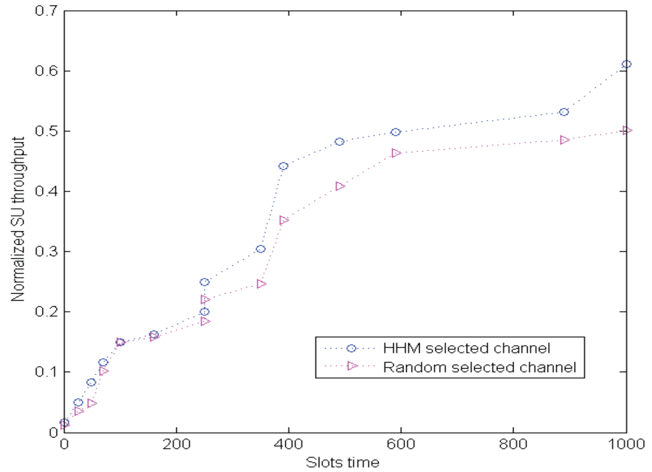

Fig. 3 The simulation results of the normalized SU throughput in HMM selected channel and random selected channel.

In this section, we simulate our model HHM with duration time T=1000 slots, 3 license channels. About sensing of SUs, we simulate with PMD e_m=0.05 and PFA e_f=0.05. Furthermore, we also assumed that each sensing times takes 3ms and the period sensing on each channel takes 10ms. In each channel, we simulate the state us ON/OFF base on the Poisson distribution probability. The period sensing on each channel is based on the proactive sensing algorithm [2]. From Fig. 3, it can be seen that the simulation result of SU throughput in HMM is better than the random selection.

5. CONCLUSIONS

In this paper, we propose a model spectrum handoff in CRN based on HMM to analyze the state of channel in each slot time. In addition, we propose a model spectrum handoff with HMM to determine switching channel method. The analysis shows that our proposed by HMM is adaptive and can be applied to the spectrum mobility function of CRN. Finally, although we focus on the spectrum handoff scenario in CRNs, our model is regardless the collision between PUs and SUs, SUs and SUs which is one of the problems in spectrum handoff.

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