Likelihood Estimation Using Continuous-Time Markov Channels for Cognitive Radio Networks in Wireless LAN

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Abstract

Dynamic spectrum access and cognitive radio is a viable solution to solve congestion in ISM band. The dynamic environment of multi-channel wireless LAN is modeled by using continuous time Markov process. Bayes theorem is applied to infer channel access decisions dynamically to ensure current data transmission is switched to only likely candidate channels.

1. Introduction

In previous 5 years, there has been dramatic increase in data communication in which the introduction of smart phones and tablet devices played an important role. These so called smart devices encourage wireless data communication, especially Wi-Fi or Wireless Local Area Network (WLAN) (IEEE 802.11 Standard). This lead to a bottle neck in 2.4 GHz Industrial, Scientific and Medical (*ISM*) radio bands. On the other hand, radio bands lower than 1 GHz which are mainly used for television broadcast is not utilized efficiently [2][3]. Cognitive Radio (CR) was proposed to access these TV White Space (TVWS) [1][2].

Research in TVWS for broadband usage has been conducted for more than a decade and there is an existing standard already. The Regional Area Network (RAN) (IEEE 802.22 Standard) [5]. RAN focuses on broadband access network for rural areas. Their architecture is centralized with base stations controlling the air interface of fixed broadband devices. At present, there is no existing device which uses this RAN standard.

However, the number of devices using Wi-Fi has continued to increase. In addition to smart phones and tablets, Wi-Fi has found its way into digital cameras and video recorders replacing the cables to connect and synchronize with computers. In the near future, there will be more types and number of devices using Wi-Fi. At present, 5.6 billions mobile phones are used worldwide [6] and almost all of them have built-in Wi-Fi interfaces. Taking into account the number of other devices, Wi-Fi is the most widely used wireless technology in the world. It is cheap, flexible and relatively easy to set up.

As mentioned earlier, ISM band (2.4 GHz) is getting overcrowded and congested. Cognitive Radio (CR) is a viable solution and so IEEE 802.11af task group was formed. IEEE 802.11af is an active project and currently under development.

The goal of the CR is to access the unused TVWS without interfering with licensed or Primary Users (PUs). The unlicensed or Secondary Users (SUs) have to vacate the channel when they detect PU signal. SU devices must have spectrum sensing capability in order not to cause interference to PU signal. But Federal Communications Commission (FCC) ruled spectrum sensing requirement as optional and authorize an access scheme with a geo-location database of TVWS [8]. However, this database needs to be maintained and updated periodically. And spectrum sensing is necessary to perform these updates. In other words, TVWS are changing dynamically with respect to location, time and spectrum (frequency). The highly dynamic nature of the database cannot be maintained by the specialized devices that perform sensing exclusively. Rather, it will be much cheaper if spectrum sensing capability is built into Wi-Fi devices.

The Cognitive Radio (CR) environment is different from any other kinds of network in that its data transmission can be interrupted anytime by Primary Users (PUs). In other words, when designing the CR systems, we must ensure robustness and delay tolerance for such interruptions. CR uses multiple channels to compensate for these interruptions by switching to another idle channel where the PU signal is absent. However, communication in multiple channels can have drawbacks in resource allocation and scheduling and rendezvous with peer SUs. In our proposal, we model the multichannel environment

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using continuous time Markov process and apply Bayes theorem to find the most likely candidate channel to access or switch.

2. Network Model

We will consider the conventional WLAN architecture for our proposal. There is an Access Point (AP) or wireless router acting as a gateway which is connected to the backbone network. There are N_2 number of SUs which the AP is serving as shown in Fig (1).

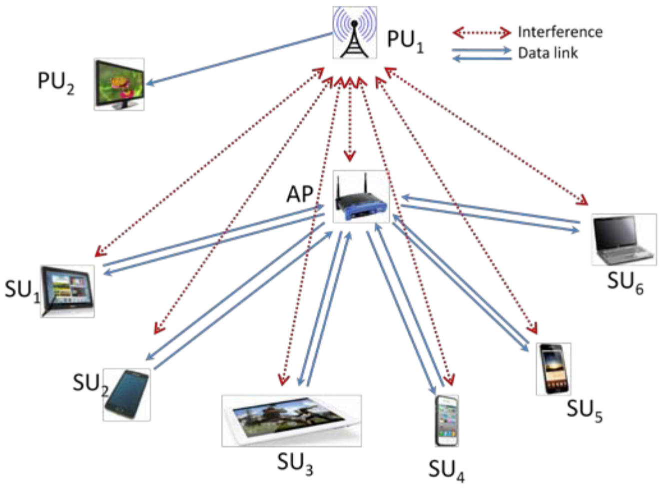

Figure 1. A Typical Wireless LAN in TVWS

The devices can be any wireless device with a Wi-Fi interface which means that although there are different types of devices, AP views only the Wi-Fi interface and it is homogeneous. There is a pair of PUs which reflects TV broadcasting.

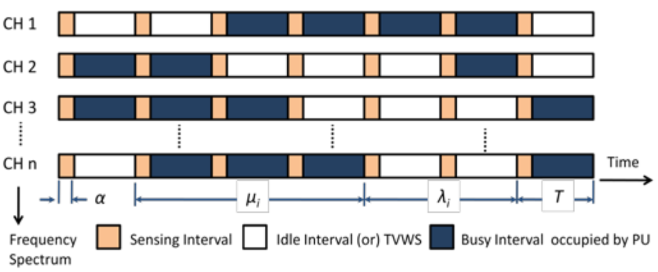

Figure 2. Spectrum Sensing Policy and White Spaces

As depicted in Fig.(2) there are *n* channels from which the system can access idle portions. Although only a pair of PUs are shown in Fig.(1), we consider that there are some PU activity on every channel. We can model each channel by a two-state continuous time Markov process [9]. By this assumption, the busy and idle time intervals are exponentially distributed with parameters μ_i (busy) and λ_i (idle). The goal of the SUs is to maximize the overall channel utilization while avoiding collision with PUs. For simplicity, we use periodic spectrum sensing policy in our proposal and α is the sensing duration, and $\alpha = kT$ *where* T is the time interval of sensing cycle, k is a constant and $k \in (0,1)$.

3. Spectrum Sensing

We assumed that each SU has a single channel spectrum sensor and energy detection is used for spectrum sensing. Idle SUs sense different channels and send the channel information to the AP which will maintain the local spectrum information within its network wireless coverage. Then a collection of APs will provide their information to create a geo-location database of TVWS for the area. We can draw hypothesis of either idle channel state, H_0 or busy channel state H_1 in discrete time as:

$H_0: y(\tau) = u(\tau)$ (OR) $H_1: y(\tau) = x(\tau) + u(\tau)$

where $u(\tau)$ is complex-valued independent and identically distributed (i.i.d) Gaussian with zero mean and variance σ_u^2; $x(\tau)$ is the PU signal and $y(\tau)$ is the received signal at SU spectrum sensor. $x(\tau)$ is also assumed to be i.i.d complex Gaussian with zero mean and variance σ_x^2. The testing using optimal energy detector with sufficient statistic is:

$$T(y) = \frac{1}{N_s}\sum_{n=1}^{N_s}|y(n)|^2 \underset{S_0}{\overset{S_1}{\gtrless}} \varepsilon \quad (1)$$

where ε is the decision threshold and N_s is the total number of samples. The outcomes of sensing process are S_0 for idle and S_1 for busy. And we can define probabilities of miss detection and false alarm as in Table 1. From SUs point of view, the goal is to minimize miss detection and false alarm. We have the false alarm and miss detection probabilities, respectively as follows [10]:

$$\eta = P(S_1|H_0) = 1 - \Gamma(N_s, \tfrac{\varepsilon}{\sigma_u^2}) \quad (2)$$

$$\xi = P(S_0|H_1) = 1 - \Gamma(N_s, \tfrac{\varepsilon}{\sigma_x^2+\sigma_u^2}) \quad (3)$$

where $\Gamma(x;t) \triangleq \int_0^t \frac{e^{-y}y^{x-1}dy}{\Gamma(x)}$ is the incomplete gamma function and $\Gamma(x) \triangleq \int_0^\infty e^{-y}y^{x-1}dy$ is the gamma function.

Table 1. Definition of 4 possible sensing hypotheses

Define		Channel State H_0	Channel State H_1
Sensing Outcome	S_0	$P(S_0\|H_0)$: WS Detected	$P(S_0\|H_1)$: Miss Detection
	S_1	$P(S_1\|H_0)$: False Alarm	$P(S_1\|H_1)$: PU Detected

4. Markov Channel Model

Let $G_i(\kappa) = [g_i^0(\kappa); g_i^1(\kappa); g_i^2(\kappa); \dots g_i^\theta(\kappa); \dots g_i^{\tau-1}(\kappa)]$ denote the vector that contains the sensing outcomes of channel i for past τ intervals. $g_i^0(\kappa) = 0$ indicates that the most recent sensing outcome of channel i is idle and channel i's current sensing outcome is stored in θ-th position of database where $\theta = \kappa\, mod(\tau)$ and τ is the number of previous channel states. We then have

$$P(g_i^\theta(\kappa) = 0) = P(S_0) = \frac{\mu_i}{\mu_i+\lambda_i}(1-\eta_i) + \frac{\lambda_i}{\mu_i+\lambda_i}\xi_i \qquad (4)$$

$$P(g_i^\theta(\kappa) = 1) = P(S_1) = \frac{\mu_i}{\mu_i+\lambda_i}\eta_i + \frac{\lambda_i}{\mu_i+\lambda_i}(1-\xi_i) \qquad (5)$$

where we have used the stationary distribution of the θ-th channel state. For each channel i, Maximum Likelihood Estimates (MLE) for next sensing interval can be obtained using Bayes decision rule. We are only interested in idle intervals so it follows that:

$$P(H_0|S_0) = P(S_0|H_0)\frac{P(H_0)}{P(S_0)} \qquad (6)$$

$$P(H_0|S_1) = P(S_1|H_0)\frac{P(H_0)}{P(S_1)} \qquad (7)$$

where $P(H_0) = e^{-\lambda_i}\sum_{m=0}^{\lfloor\kappa\rfloor}\frac{{\lambda_i}^m}{m!}$ is the cumulative distribution function (cdf) of Poisson distribution. From equations (6) and (7), we can find the most likely channel which will be free in next time slot when current operation interval reaches average duration of idle time interval. Similarly, we can predict busy intervals with MLE.

Energy detection operation is conducted by SUs and estimation is carried out by AP which also maintains a channel state database in descending order for every channel. This database is routinely updated by idle SUs which observe assigned channels for a time interval. When PU signal is detected, the AP will switch to the most likely idle channel and serves SUs. The new SUs have to perform rendezvous with AP for the first time. After contacting the AP, the SU will download the channel state database. The updated database is distributed to SUs whenever they contact AP for data transmission or channel update.

5. Conclusions

In this paper, we proposed an estimation based channel access and switching for Wireless LAN in cognitive radio environment. We model the system using continuous time Markov process. Maintaining a separate centralized geo-location database to dynamically access TVWS is impractical. Our proposal keeps the spectrum sensing functionality in SUs which can sense the channel to update the local database maintained in local access point.

REFERENCES

[1] J. Mitola, "Cognitive radio: An integrated agent architecture for software defined radio," Doctor of Technology, Royal Inst. Technol. (KTH), Stockholm, Sweden, 2000.

[2] Simon Haykin, "Cognitive Radio: Brain-Empowered Wireless Communications", in IEEE Journal on Selected Areas in Communications, Vol. 23, No. 2, pp 201-220, February 2005.

[3] Federal Communications Commission, Spectrum Policy Task Force, "Report of the Unlicensed Devices and Experimental Licenses Working Group", Rep. ET Docket no. 02-135, November 2002.

[4] Free Press and New America Foundation, "Measuring the TV "White Space" Available for Unlicensed Wireless Broadband", January 2006.

[5] IEEE Standard 802.22TM – 2011.

[6] http://en.wikipedia.org/wiki/List_of _ countries_ by_number_ of_mobile_phones_in_use

[7] http://standards.ieee.org/ develop/ project/ 802.11af .html

[8] Federal Communications Commission, "FCC FREES UP VACANT TV AIRWAVES FOR "SUPER WI-FI" TECHNOLOGIES", Rep. ET Docket Nos. 03-280 and 04-186, September 2010.

[9] Xin Li, Qianchuan Zhao, Xiaohong Guan, Lang Tong,"Sensing and Communication Tradeoff for Cognitive Access of Continuous-Time Markov Channels", IEEE WCNC, 2010.

[10] H. Vincent Poor, "An Introduction to Signal Detection and Estimation", 2nd Edition. New York: Springer-Verlag, 1994. ISBN: 0387941738.