Location Assisted Proactive Channel in Heterogeneous Cognitive Radio Network

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***Abstract*— Cognitive Radio Network is an emerging technology to increase spectrum efficiency by intelligently accessing the spectrum in an opportunistic manner. The secondary user must sense every spectrum band available in order to prevent harmful interference to primary user. However, in heterogeneous environment, spectrum opportunity varies when the secondary user is mobile according to its' geographical location. There is a certain transmission region surrounding the primary users where their transmission ranges will not exceed which therefore provides a platform for secondary user to define new policies to capture spectrum opportunities. Therefore, in this paper, we explored and proposed a proactive based spectrum decision framework based on secondary users mobility to capture more spectrum opportunities. The results showed significant improvements in throughput and switching performance when localization is inherited in the cognitive radio system.**

***Index Terms*— Cognitive radio; Proactive channel selection; HMM; Mobile; Localization; Heterogeneous.**

I. INTRODUCTION

Wireless technology had motivated the advancement in various wireless applications and devices leading to exponential growth in spectrum usages. This had caused the radio resources to become scarce and is insufficient to fulfill the growing demand. Thus, cognitive radio (CR) was introduced by Mitola, [1] in his thesis, to enhance the efficiency of the spectral utilization while lowering spectrum wastage. Federal Communications Commission (FCC) had then allowed the service provider to open up the television broadcast frequency bands for unlicensed users such as WLAN and WiFi [2]. Consequently, in 2004, IEEE announced the IEEE 802.22 standard, the first wireless network standard for Wireless Regional Area Network (WRAN). Its aim is to specify how cognitive radio users utilize and share the white spaces in the TV frequency [3] while protecting the licensed users. In CR network, there are two main components; (1) CR user and (2) Primary User (PU). The CR user basically operates in an opportunistic manner where spectrum access is only allowed when the spectrum band selected is detected idle. Every CR user must periodically conduct spectrum sensing at each spectrum band to determine the PU transmission states in every time slot. However, spectrum detection relies heavily on PU traffic pattern and sensing errors [4]. Here, this problem is described as protecting the PU, i.e., maximize the probability of detection, Pd under the constraint of probability of false alarm, Pf [5]. Spectrum mobility is an essential component in CR system. It aims to provide an efficient exploitation of the unused portions of the radio spectrum and resource allocation. Though many studies and state of the art schemes had been proposed to maximize the accuracy of spectrum sensing, spectrum mobility had very little exposure in the present literatures. In CR networks, spectrum mobility can be referred as time domain and space domain opportunistic access. In time domain, the spectral occupancy is because of the time varying PU traffic pattern while in space domain, it is due to CR or PU movement in time [6]. In related work, [7, 8], spectrum mobility is done by CRs prior to returning PU to the channel. This is done by predicting the future spectrum availability beforehand. The so-called proactive spectrum mobility scheme is proven to reduce the CRs interference to PUs. Spectrum prediction had also been demonstrated to alleviate the processing delays in switching process and hence improve the efficiency of spectrum utilization [9]–[11]. Past sensing results are stored in a CR database and used for sequence training and then is used to estimate the future channel PU states. While in Zheng et al. [12], proposed an optimal target channel sequence selection scheme for proactive spectrum mobility with Poisson arriving PUs. It is shown to successfully reduce the collisions between CRs and PUs and also increase the channel utilization efficiency.

In practical systems, the spectrum availability occurrence not only due to PU traffic pattern but also influenced by the heterogeneity of CR network. In wireless network, ability for CR users to be mobile is essential. Hence, this introduces various effects of network characteristics, i.e. network capacity, connectivity, coverage, routing, etc. [13]. For example, in CR network, the CR user mobility may relatively experience different spectrum opportunity at different location at each time slot. A PU transmitter-receiver has a specified limited transmitting range due to hardware resources and fixed network policies. Beyond this transmission range, the CR user may transmit without harming the PU transmission. This range can be defined as PU protection range [14]. The changing relative distances between PU and CR user will impact sensing decision and routing policies. Thus, new challenges arise for the spectrum decision design when the wireless users are mobile.

In Figure 1 example, a CR user is mobile and the PU transmitter is surrounded by a protection region which is in shaded area. The CR user may move at a certain speed and arrive at different destinations at each timeslot thereby the distance between the CR node and the PU transmitter varies. The CR user in the shaded region must always sense the arrivals of PU since it causes interference to PUs' transmission. Once the CR user moves outside the protection region, it can transmit without interruption as long it is beyond PU protection range. In this paper, our key contribution is to investigate analytically the importance of location information to CR system in order to achieve higher spectrum utilization thus gain better network performance. The objective of this paper is to propose a location assisted proactive channel selection approach which showed that when the CR user is mobile, it is necessary to know its location to improve its transmission performance.

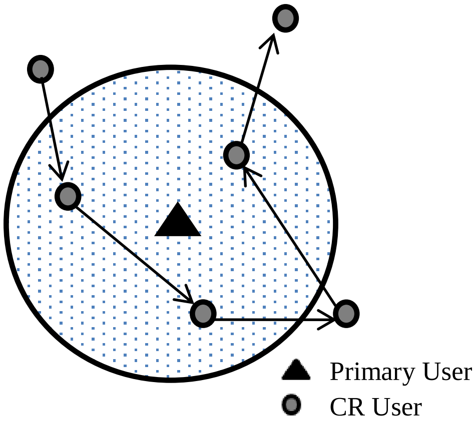

Figure 1: Heterogeneous cognitive radio system

II. METHODOLOGY: LOCATION ASSISTED PROACTIVE CHANNEL SELECTION

In this section, we will derive our methodology and describe our proposed framework to investigate analytically the necessity of localization in CR spectrum decision.

A. *System Description*

In this paper, we adopted a similar framework as in [15]. A CR network was considered as a time slotted system, *{0, 1,.. , t+1,t+2,..T}*. Each CR user divides its data frame into equal-sized timeslots. Each timeslot is divided into two fragments. The first fragment is for spectrum sensing while the second fragment is for data transmission. When a CR user wants to transmit in channel *i*, this channel must be sensed periodically in every timeslot, *ts*. If the sensing result showed that the current channel, *i*, is idle, the transmission will be initiated in the next fragment of the slot, where   is the length of timeslot duration. Otherwise, the CR user must select other channel and repeat sensing procedure. Once the PU is active again, any current transmission of CR user on the channel must be ceased and resume back to the searching procedure. These will introduce spectrum switching where the CR user will restart their transmission to other potential idle channel in order to complete their transmission. It is possible in some cases; the CR user may not able to find any idle spectrum band. Thus, they have to stop transmission until they find another available channel. Here, its performance will be degraded. The CR continuous time received signal is denoted as:

$$y(t) = hs(t) + w(t) \tag{1}$$

where $y(t)$ represents the continuous received signal,   is the channel gain from the PU transmitter to the secondary user receiver,   is the PU signal and   is the Additive White Gaussian Noise (AWGN) with variance. This signal denoted the channel availability of whether there is a PU signal present or not. We employed energy detector mechanism in order to detect available channel. Energy detector is the most common sensing technique in the literature due to its simplicity and its blindness regarding the signal features [17]. The decision threshold is defined as in the following two hypotheses:

$$\begin{aligned} H0 &: y(n) = w(n) \\ H1 &: y(n) = hs(n) + w(n) \end{aligned} \tag{2}$$

where $H0$ represents the absence of the PU and $H1$ denotes the presence of the PU. The test statistic generated from the energy detector, over N signal samples, can be written as $E = \left(\sum_{n=1}^{N} y_n^2 \right) \Big/ N$. In order to distinguish between the two hypotheses above, the test statistic E is compared with a decision threshold, λ $(H0 : E \le \lambda, H1 : E > \lambda)$. In this paper, the value for λ is fixed followed the required minimum probability of false alarm, $\lambda = \frac{Q^{-1}(P_t)}{N} + 1$ as in [17]. $Q^{-1}(.)$ is the inverse $Q(.)$ which is the complimentary distribution function of standard Gaussian as given by, $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\left(-\frac{t^2}{2} \right) dt$. N is specified as the number of sensing samples at each sensing period.

B. *Primary User Activity Model*

We assume that each PU accesses the licensed channel that described as an alternating renewal two state birth-death model with birth rate, α and death rate, β [5]. An ON/OFF state, S= {0,1}, represents a PU is occupying a channel. The channel state alternate between state ON (busy) and state OFF (idle). The CR user can transmit only during the OFF time slots. Each channel follows the exponential ON/OFF distribution [17]. The probability density function of the time intervals for the ON/OFF states respectively satisfy,

$$f_{on}(t) = \begin{cases} \beta e^{-\beta t} & t \ge 0 \\ 0 & t < 0 \end{cases} \tag{3}$$

$$f_{off}(t) = \begin{cases} \alpha e^{-\alpha t} & t \ge 0 \\ 0 & t < 0 \end{cases} \tag{4}$$

The probability of channel availability is the normalized period that is available for CR user. Let p_{on} denote the probability of idle channel. Then,

$$p_{on} = \frac{\beta}{(\alpha+\beta)}, p_{off} = \frac{\alpha}{(\alpha+\beta)} \qquad (5)$$

C. CR Mobility Model

CR technique allows CR user to share the spectrum band with the PU temporally and spatially. However, once the PU starts transmitting at their specified channel again, CR user must vacant the channel immediately to prevent disruption to PU transmission. In mobile scenario, as the CR user moves further away from the PU transmission range, the mutual distance increases significantly. The CR user will move outside the PU protection range. Thus, the CR user may resume their operation without disturbing all PU s' communication. Therefore, a spectrum opportunity is defined as available when at a specific time, location and frequency of a spectrum band is permissible for a CR user to transmit while avoiding harmful interference to all PUs transmission. In spatial definition, we can modeled another hypothesis testing problem as defined in [18]:

$$\begin{aligned} &S0: D_{LP} < d_i \le D_{CR} \\ &S1: 0 \le d_i \le D_{LP} \end{aligned} \qquad (6)$$

where $S0$ represents the case that CR user, *i* is located outside the protected region of PU and a spectral opportunity is available for it. The hypothesis $S1$ denotes the case that CR user is located inside the PU protected region and is not allowed to transmit in that channel. In this paper, it is assume that a CR user is moving according to Random Way Point Mobility (RWPM) model inside a specified CR network region A, $p_t(t) = [x(t), y(t)]$ states the coordinates of the *l*-th PU at each timeslot, *t*. The CR user location is uniformly chosen. CR user moves with a speed uniformly distributed between 5-10 m/s. When it reaches a destination point, a new target location is selected and the whole process is repeated again. When a destination point is reached, the mobile CR user can either pause for a random period of time before moving towards the new destination point again [20]. It is assumed that the CR users are aware of their own location through GPS or other suitable localization methods [19]. We also assume that there is a central CR base station that broadcast any information through a common dedicated channel periodically. The CR user and PU can only occupy one channel at a time at each timeslot, *t*.

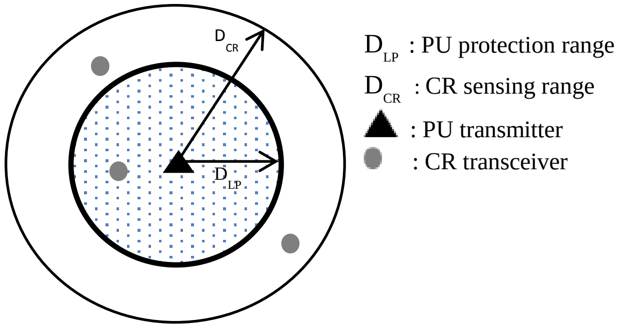

Figure 2: PU Protection Region

D. Location Assisted Proactive Channel Selection

In this paper, we had implemented a framework of a proactive channel selection method based on future channel state prediction that exploited the past history of the previous sensing results which were assumed to be gathered by CR base station. This scheme is implemented and compared with random channel selection with and without location known. Our aim in this paper is to show that the localization of the CR user is essential in the CR system to exploit the spectrum efficiently. We use a learning method based on Hidden Markov Model (HMM) as in [5] as a channel status prediction method to update the parameters of PU traffic model periodically. Proactive based channel selection is shown to have effectively minimize the interference to PU by predicting the future idle timeslot and by shifting to better channels before the PU appears back on the current operating channel [5]. By using prediction as our method, we will show the importance of location information to CR users. This is because most prediction based scheme in the literature did not take account the CR user mobility which vital in wireless network. Consequently, from the joint channel decision perspective, we model the following hypothesis testing problem according to (1) and (2) in our proposed framework:

$$\begin{aligned} &K0: x_{i(t)} = \begin{cases} w_i[t]*P0_i[t*], & d_i \le D_s \\ P0_i[t*]\left(h_i*s_i[t]+w_i[t]\right), & D_p < d_i \le D_s \\ P1_i[t*]\left(h_i*s_i[t]+w_i[t]\right), & D_p < d_i \le D_s \end{cases} \\ &K1: x_i[t] = P1_i[t*]\left(h_i*s_i[t]+w_i[t]\right), \quad 0 < d_i \le D_p \end{aligned} \qquad (6)$$

where $K0$ denotes the channel is available spatially and temporally for CR users and $K1$ as otherwise. Spectrum availability is achieved when it is either sensed idle or found that the CR user is outside the PU protection range, D_p. This proactive decision is done based upon the channel status prediction made at timeslot, t*=t-1 which is in previous slot where $P1_i$ and $P0_i$ is the probability is predicted busy or idle at channel i respectively.

III. NUMERICAL PERFORMANCE EVALUATIONS

To evaluate the performance of our proposed framework, we employ simulation model on MATLAB environment. We compare the following four schemes to evaluate the necessity of location information to the CR system: (i) random channel selection (RCS), (ii) random channel selection with location assisted (RCS-LA), (iii) proactive channel selection (PCS) and (iv) Proactive channel selection with location assisted (PCS-LA). There are four PU in one cell for CR use with 1MHz bandwidth each. The PU activity of each spectrum band, α ranges are over [0.05, 0.25] and β is equivalent to 0.3. The past sensing data of 600 recent timeslots is collected for HMM training and simulation is done over 5000 timeslots. The length of each time slot is 100ms. The spectrum sensing slot duration is 10ms. The spectrum switching time delay, δ is 1ms. We will assume for low SNR of received PU signal of -20dB in order to investigate our framework. The threshold for spectrum sensing is set at Pf=0.1 according to [17]. We placed the size of the network area as 500mx500m. The protection range of the PU on its occupied channel is fixed to 250m. The CR user will move according to RWPM model in the network region with uniform speed in the interval of [5, 10] m/s. This paper also assumes that the CR system can perfectly determine its relative position given by GPS or any other positional methods and can thereby recover all the area beyond the PU protection range. Using these mutual distance between the CR user and PU calculated by the CR network, the decision to select a suitable channel is perform accordingly.

In Figure 3 and Figure 4, we compare the normalized throughput and number of collisions in terms of PU arrival rate of each scheme with and without the aid of location known to CR system. We can see that the location information had benefits both the CR system and primary system. The CR system had managed to achieve better throughput and capable to reduce harmful interference to the primary system transmission with RCS-LA and PCS-LA. It can be observes that the lower the probability of PU being active, the higher the performance achieved.

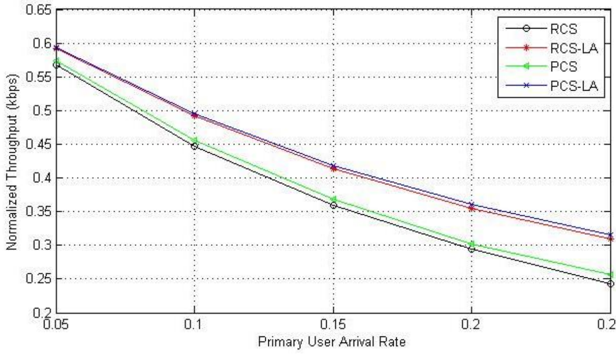

Figure 3: Comparison Normalized Throughput Performance in Spectrum Heterogeneous CR System

In Figure 5, it can be seen that with PCS the number of switchings is lower than in RCS-LA schemes. Since the switchings times occurs dependent on the relative distance from the PU, it is reasonably to have frequent events occurrence where CR user is in the protection region of PU. Thus, in RCS-LA has to observe frequent busy traffic from primary system when the CR is the protection region showing higher performance in PCS. In this events, PCS-LA had outperform all schemes due to its location information provided. It is shown that Figure 6, delay can be reduced with the aid of location information known to CR system. The delay of channel switching and searching for idle channel decreases substantially when both prediction and location estimation functionality is embedded in spectrum decision.

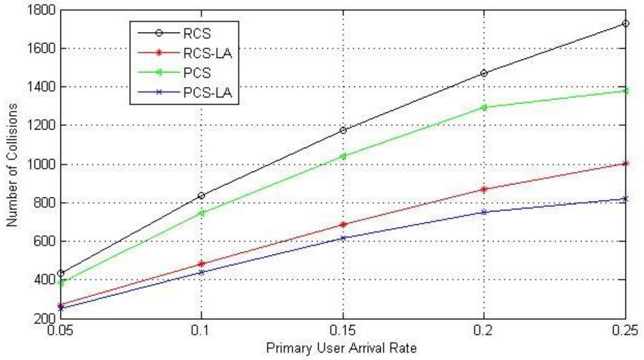

Figure 4: Comparison Number of Collisions Performance in Spectrum Heterogeneous Secondary System

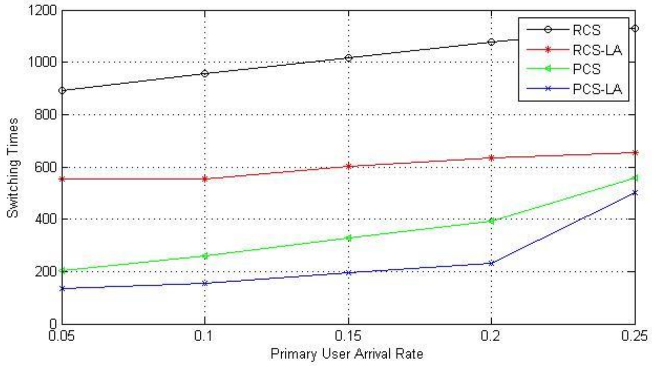

Figure 5: Comparison of Switching Times Performance in Spectrum Heterogeneous Secondary System

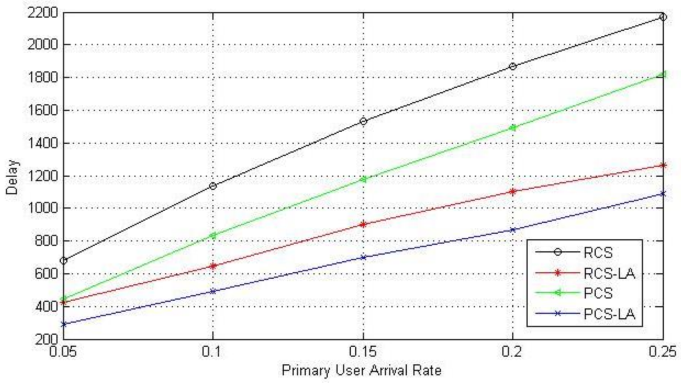

Figure 6: Comparison of Delay Performance in Spectrum Heterogeneous Secondary System

IV. CONCLUSION

In this study, we had successfully showed that the availability of spectrum opportunity varies in time and location. We had also demonstrated that, although the proactive based decision schemes had shown better efficiency in network performance [7-8], it is essential that CR user knows its current location and future movement. Hence, CR can dramatically improve its network performance and further enhance its exploitation of the unused spectrum. Hence, SU localization and proactive based spectrum mobility should be jointly designed to maximize the network performance of CR users while limiting the interference to PUs. However, there are still other important issues that impact the CR performance in heterogeneous environment. In the future, we will study the localization issues in terms of both CR user and PU mobility scenarios.

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