

Receiver Localization for Underlay CRs Using Bayesian Approach

Ms.Sayali S. Mane

*Assistant Professor, Department of Electronics Engineering,
D.Y.Patil College of Engg. & Technology, Dist. Kolhapur,
Maharashtra, India*

Prof. Dr. S. V. Sankpal

*Professor, Department of Electronics Engineering,
D.Y.Patil College of Engg. & Technology, Dist. Kolhapur,
Maharashtra, India*

Prof. Dr. A. N. Jadhav

*H.O.D., Department of Electronics Engineering, D.Y.Patil
College of Engg. & Technology, Dist. Kolhapur,
Maharashtra, India*

Mr. S. C. Shinde

*Assistant Professor, Department of Electronics Engineering,
D.Y.Patil College of Engg. & Technology, Dist. Kolhapur,
Maharashtra, India*

Abstract

Traditionally, the frequency spectrum is licensed to users by government agencies in a rigid manner where the license has the exclusive right to access the allocated band. From a practical standpoint, an unlicensed (secondary) user may share a frequency band with its licensed (primary) owner as long as the interference it incurs is not harmful by the licensee. This paper considers cross layer optimization of resources for underlay multi-hop cognitive radio networks. Also secondary network variables are optimized under long term probability of interference constraints. For localization of primary receiver, map is designed using Bayesian approach, based on 1 bit message. Whenever primary user (PU) system is interfered, this message will be broadcasted by PU. Based on output of spectrum sensing stage, secondary users implement resource allocation to maximize network performance, while protect PU system from excessive interference.

Keywords: resource allocation; cognitive radio; Bayesian approach; receiver localization.

Introduction

Spectrum is naturally a limited resource regulated by government agencies such as FCC. With the emergence of new wireless applications and devices, there is excessive demand for radio spectrum thus FCC has started to review their spectrum allocation policies for selection of best available band. The traditional approach for management of spectrum is very inflexible. So that spectrum scarcity is a largely due to inefficient and rigid regulation instead of physical shortage of the spectrum.

The main purpose of localization of primary user (PU) receiver is to optimize performance of secondary network by reducing the interference across primary user. Bayesian approach is based on 1-bit interference tweet. So after resource

allocation if PU is interfered, one can find out its location and limit the interference to those locations.

The rest of paper is organized as follows. Section II presents system flow along with primary and secondary state information, to account for CSI imperfections. In section III a simplified resource allocation problem is formulated. Section IV shows all numerical results. Conclusions and future work in section V wrap-up this paper.

System Model

The proposed system involves following steps as shown in Fig.1. After resource allocation communication will take place in between secondary users. There is receiver map as a tool to locate a primary user receiver. The location is tracked using recursive Bayesian approach, which is based interference tweet. Receiver map as a tool for unveiling areas where PU receivers are located, with the objective of limiting the interference inflicted to those locations.

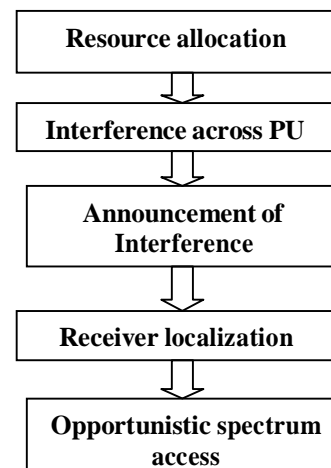


Figure 1: System Model

A. State information of primary and secondary channel

Consider a multi-hop secondary user (SU) network with M no. of nodes. $\{U\}_m=1$ deployed in area $A \in \mathbb{R}^2$. Based on the output of the spectrum sensing stage such as maximum tolerable power, probability of interference across primary user, average link gain, coverage region etc. SUs implement adaptive RA, [1] while protecting the PU system from excessive interference.

When resources are shared in a hierarchical setup, the available channel state information (CSI) over different SU network is different. Here, we assume the state of the SU-to-SU channels is already known. The instantaneous gain of link $U_m \rightarrow U_n$ is denoted as $g_{m,n}$.

Suppose now that PU transmitters communicate with Q PU receivers located at $\{x^{(q)} \in A\}_{q=1}^Q$. With $h_{m,x^{(q)}}$ is the instantaneous channel gain between U_m and position $x^{(q)}$. Here we can obtain average link gain based on locations $\{x^{(q)} \in A\}_{q=1}^Q$, but the instantaneous value of the primary link cannot perfectly determined due to random fast fading effects. Therefore, SU m may cause interference to PU q . Next, it is assumed that only $\{h_{m,x^{(q)}}\}$ i.e. the joint distribution of processes is known to the SU network, which is denoted as $\phi_h(\{h_{m,x^{(q)}}\})$ [2]. Let I be the maximum instantaneous interference power tolerable by the PUs, the secondary network can determine the interference probabilities at each location $x^{(q)}$. For instance, if U_m is scheduled to access the channel with a transmit-power P , the probability of causing interference to PU receiver q is $\Pr\{ph_{m,x^{(q)}} > I\}$.

Sometime locations $\{x^{(q)} \in A\}_{q=1}^Q$ are generally uncertain. For this, let $z_{x^{(q)}}$ is a binary variable having value 1 if PU receiver q is located at $x \in A$. Let $G = \{x_g\}$ are grid points representing potential locations for the PU receivers. Instead of $\{z_{x^{(q)}}\}$, the idea is to use the probabilities $\beta_{x^{(q)}} = \Pr\{z_{x^{(q)}} = 1\}, \forall x \in G$, to identify areas where a PU receiver q is more likely to reside, and limit the interference accordingly.

The PU system is protected by setting $I = -70$ dB and $i^{\max} = 0.05$. Let, sets $s = \{\phi_h\} \cup \{\beta_{x^{(q)}}\}$ and $g = \{g_{m,n}\}$ are Statistical primary state information (PSI) and available secondary CSI, respectively.

Resource Allocation Based On Interference Constraints:

Application-level data packets are generated at the SUs, and routed throughout the network to the intended destination(s).

Packet streams are referred to k . The each flow for the destination is denoted by $d(k)$. Packet arrivals at U_m , for each flow k , are modelled by a stationary stochastic process with mean $a_m^k \geq 0$.

There are some notations are used for further calculation:

At the medium access layer, let $w_{m,n}$ be the binary scheduling variable such that, $w_{m,n}=1$ for U_m transmits to its neighbouring node U_n , otherwise zero. Assume that one secondary link is scheduled per time slot, it as follows

$$\sum_{(m,n) \in \mathcal{E}} w_{m,n}(g,s) \leq 1$$

Where, $\mathcal{E} = \{(m,n): n \in N_m, m=1, \dots, M\}$ represents the set of SU-to-SU link [6].

At physical layer, instantaneous rate and transmit power variables are coupled, and this rate power coupling is modelled. Let average transmit-power of U_m is,

$$\bar{p}_m = E_{g,s} [\sum_{n \in N_m} w_{m,n}(g,s) p_{m,n}(g,s)] \dots \dots \dots (1)$$

Where $E_{g,s}[\cdot]$ denotes expectation with respect to random variable g, s . Powers transmitted by the SUs have to obey two different constraints. First, the instantaneous power $p_{m,n}$ cannot exceed a pre-defined limit p_m^{\max} . Second, the average power satisfies $\bar{p}_m \leq p_m^{-\max}$. The binary variable $i^{(q)}(\{p_{m,n}, s\})$ represents interference inflicted to the PU system as,

$$i^{(q)}(\{p_{m,n}, s\}) = \sum_{(m,n) \in \mathcal{E}} \{ \sum_{(m,n) \in \mathcal{E}} w_{m,n}(g,s) p_{m,n}(g,s) h_{m,x^{(q)}} \} > I \} z_{x^{(q)}} \dots \dots \dots (2)$$

Where $\square_{\{x\}}$ the indicator function ($\square_{\{x\}} = 1$ if x is true, otherwise zero). If $i^{(q)}(\{p_{m,n}, s\}) = 1$ then one or more PU receivers are interfered. Finding the condition for stochastic resource allocation, let us consider $i[t]$ be the interference across PU, as [7]

$$\bar{i}[t] = 1/t \sum_{\tau=1}^t i(\{p_{m,n}[\tau], s[\tau]\}) \dots \dots \dots (3)$$

And running average of interference is, $\bar{i}[t] = 1/t \sum_{\tau=1}^t i[\tau]$

Reported in graph of Fig.3. So as $t \rightarrow \infty$

Algorithm 1: Resource allocation & receiver localization

1. Perform following step [9]

$$\bar{B}_X^{(q)} [t-1] = \sum_{x' \in G_X} \Phi_{x,x'}^{(q)} [t] \bar{B}_X^{(q)} [t-1 | t-1] \dots\dots\dots(4)$$

2. Acquire SU-to-SU channels

3. Obtain optimal exogenous rate, optimal rate, optimal average transmit power.

4. Obtain $w_{m,n}^* [t]$, optimal instantaneous transmit power at instant t.

5. Update multipliers λ_m^*, π_m^* .

6. Receive interference tweet

7. Update third multiplier θ^* , using the observed tweet message

8. Perform last step

$$\bar{B}_X^{(q)} [t | t] = \frac{\Pr\{i^{(q)} [t] = o \mid z_X^{(q)} [t] = 1, \bar{H}_t^{(q)}\} \bar{B}_X^{(q)} [t-1]}{\Pr\{i^{(q)} [t] = o \mid \bar{H}_t^{(q)}\}} \dots\dots\dots(5)$$

Simulation Results

The simulation studies involve the deterministic small network scenario as shown in the Figure 2. The proposed technique is implemented with MATLAB. There are 12 SU transceivers (marked with red circles) are placed over 450 * 450 m and cooperate in routing packets to the sink node U_{12} . One data flow is considered, and traffic is generated at SUs $N_s = \{1, 2, 3, 4, 7, 8\}$. A PU transmitter (marked with a cyan triangle) communicates with 2 PU receivers (cyan rhombus) using a power of 3 dB.

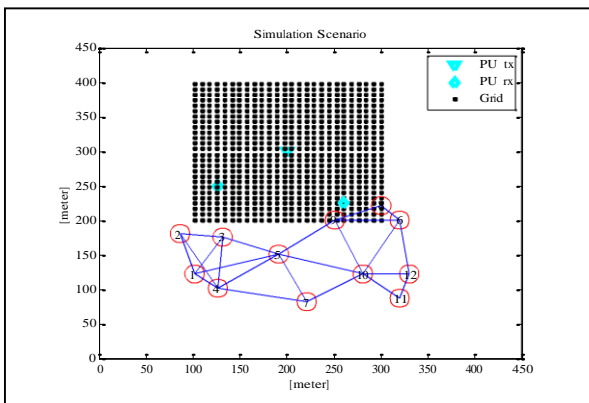
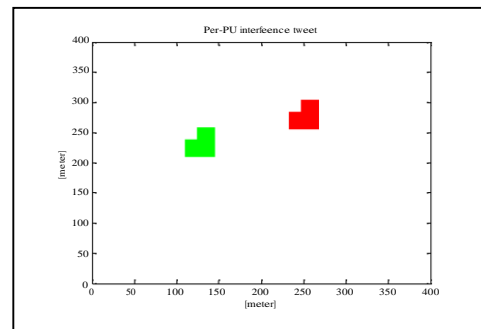


Figure 2: Simulated Scenario

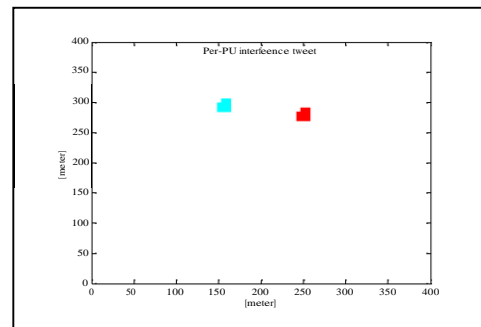
The first PU receiver is located at $x^{(1)} = (x = 250, y = 280)$, static, and it is served by the PU source during the entire simulation interval $t \in [1, 10^4]$. The second PU is located at $x^{(2)} = (130, 240)$ and it is served by the PU source only during

the interval $[1, 6 * 10^3]$. The PU system is protected by setting $I = -70$ dB and $i^{max} = 0.05$ [8]. Here Rayleigh-distributed small-scale fading is also simulated [3]. The SU system can estimate the PU source location, and of its coverage region by sensing phase ([1]–[3]). Now, the PU coverage region is then plotted by using equidistant grid points (marked with black squares in Figure 2.).

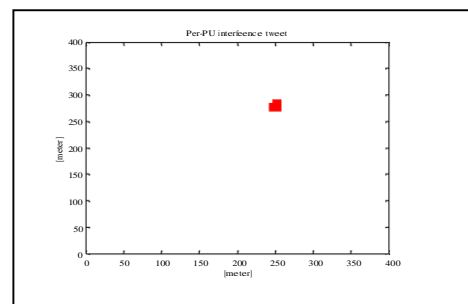
Figure 3 shows interference notification across each primary receiver. Whenever PU is getting interfered due to secondary user, they broadcast interference announcement message, also called as tweet. Initially both receivers are interfered. So by optimizing network parameter such transmit power, rate of data transmission etc. secondary users can limit interference across primary users. Fig.4. shows Interference at different instant due to system parameters. Both receivers are initially interfered. At last interference reduced to negligible amount.



(a) Interference tweet at instant= 100

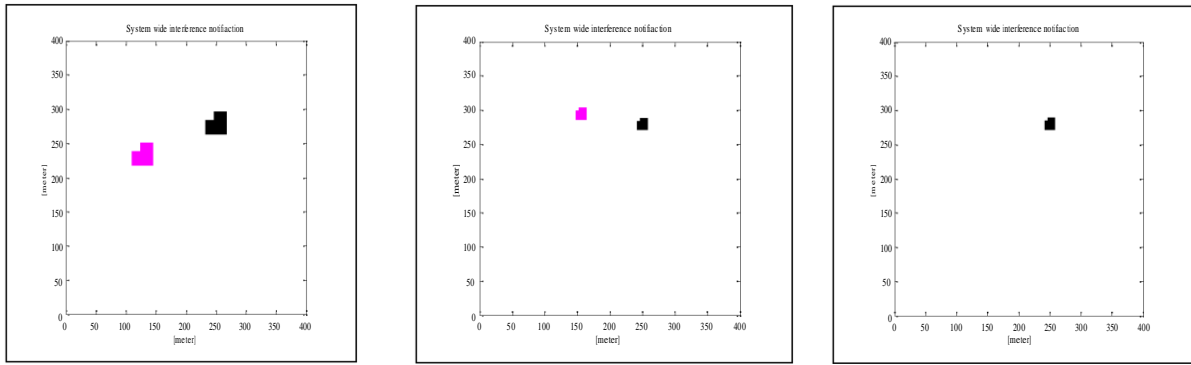


(b) Interference tweet at instant= 6000



(c) Interference tweet at instant= 10000

Figure 3: Per-PU interference tweet across each primary receiver



(a) Interference tweet at instant= 100 (b) Interference tweet at instant = 6000 (c) Interference tweet at instant= 10000

Figure 4: System wide interference notification across each primary receiver

Table 1 Interference across Primary receiver

Time		500	1000	3000	6000	8000	10000
i[t]	Per PU tweet	0.0242	0.0223	0.0291	0.0335	0.0352	0.0350
	Sys. Wide tweet	0.0532	0.0399	0.0344	0.0359	0.0354	0.0361

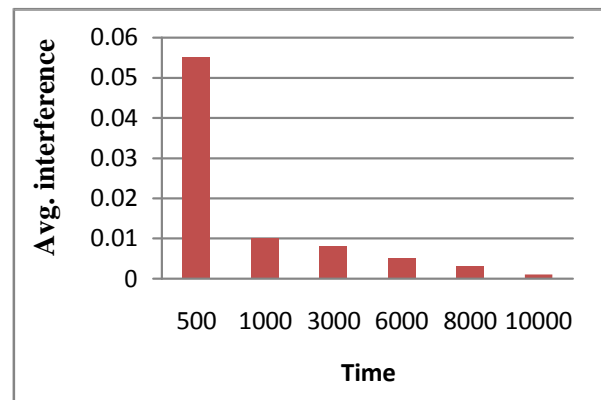


Figure 6: Average interference across coverage region boundary

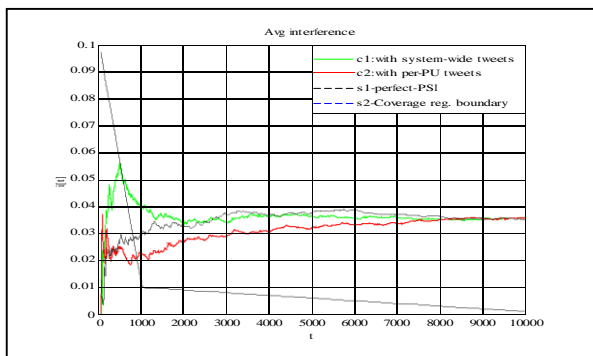


Figure 5: Average interference rates

Figure 5. shows average amount of interference across both primary user and coverage region boundary. The first graph of interference with system wide tweets shows average amount of interference across both PU receiver due to system wide tweets. Second one, interference with per-PU tweets shows same results as pervious graph. But these tweets contain location information of primary receiver. Thus at last amount of interference is less with these tweets, compared with system wide tweets. As optimal resource allocation is achieved interference across coverage region boundary reduces to zero, shown in Figure 6. Running average of interference is,

$$\bar{i}[t] = 1/t \sum_{\tau=1}^t i[\tau]$$

Conclusion

Dynamic cross-layer resource allocation and user localization algorithms for an underlay multi-hop cognitive radio network were designed. A Bayesian approach was developed to estimate (and track) the unknown location of the PU receivers. The inputs of the estimator were the (past and current) power transmitted by the secondary system, and a binary interference notification (tweet). The schemes were found robust to errors on the observations and accounted for PU mobility. In particular, the resource allocation schemes were obtained as the solution of maximization of network-utility that optimized performance of the secondary network.

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