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Research Article

RAP Framework for Spectrum Management in Cognitive Radio

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Abstract: The Spectrum Management schemes currently in use overlook the need for interference measurements at the receiver end. The negligence culminates in an underwhelming performance of the Cognitive Radio Network (CRN) due to the presence of hidden/exposed primary senders. Our aim was to implement the RAP framework for spectrum management in a cognitive Radio. The scheme chosen deems it a necessity to take into consideration the inaccuracy of spectrum sensing in order to achieve the desired optimal performance. Unlike the widely used schemes which solely depend on local interference measurements, the proposed probabilistic framework aims at enhancing the CRN good put by incorporating interference measurements performed at the receiver into the protocol. Moreover, the spectrum management scheme, discussed in the study, makes most of the least exploitable spectral opportunities by relying on low power rate communication robust to interference. The issued spectrum access policy ensures fair distribution of spectral opportunity to its multiple secondary users. It, in contrast to the existing greedy spectrum access policies, prevents any user from monopolizing the available spectral opportunity as it is regulated and operated in a strictly probabilistic framework. It also diligently makes useful, provisions in the policy to ensure that every spectral opportunity, even while being exploited, appear available at all times to see to it that no Secondary User (SU) misidentifies the spectral opportunity as unavailable.

Keywords: Cognitive radio network, Dynamic spectrum management, RAP framework

INTRODUCTION

The Federal Communication Commission (FCC) (FCC (Federal Communications Commission), 2003) has proven that the idea of spectrum being scarce is merely a myth. The FCC statistics point out the fact that licensed spectrum remains unused for 15 to 85% of the time depending on geographical locations. This interesting observation went on to motivate the design of cognitive radio networks for effective utilization of the spectrum (Mitola, 2000). The whole idea behind the working of a Cognitive radio rests entirely on the concept of spectrum holes. Any spectrum band which is not in use at a particular time in a particular geographical location can be defined as a spectrum hole. The CRN plans to allocate the licensed spectrum band to a secondary user whenever it identifies the same as a spectrum hole. The legacy MAC protocols allow the secondary users to greedily exploit the sensed spectral opportunity. Hence the MAC protocol has been criticized for its seemingly unfair spectrum access policy which often results in certain secondary users dominating over others. The cooperative MAC approaches, developed recently, rely heavily on explicit coordination among the different users. The reliance turned out to be a challenge as it required extensive gathering and timely distribution of spectrum information to all the users.

Medium Access Control (MAC) has an important role in several cognitive radio functions such as spectrum sensing, spectrum mobility, resource allocation and dynamic spectrum sharing (Akyildiz *et al*., 2006). The multichannel MAC protocol face the multiple channel hidden terminal problem and these multichannel MAC protocols are characterized as first step in the development of MAC protocols for the development of the ad-hoc scenario of cognitive wireless networks (So and Vaidya, 2004). In Akyildiz *et al*. (2008) CR MAC protocols are categorized according to exploited mechanisms of channel negotiation reservation. In Akyildiz *et al*. (2009), MAC functionalities and current research challenges of Cognitive Radio Ad Hoc Networks (CRAHNs) are discussed. In Zhao *et al*. (2007), they adopted a reservation scheme, when a node wants to transmit CR data, it first reserves a data channel and by sensing the channel the CR node checks whether the channel can be or not used for data transmission. The CR node may possibly suffer a long delay to acquire the channel for data transmission, since the CR node repeats the work to reserve a channel and sense it until an empty channel is got, Jia *et al*. (2008) has proposed a scheme so as to reduce the above mentioned delay by using a polling

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approach where the nodes having data traffic contend for obtaining the right of using the entire channel and the winner acquires all channels Tian and Giannakis (2007). Then, the winner senses sequentially the channels until finding a many empty channels as it needs and transmits its traffic over the found empty channels. Since only the winner can use the data channels, the concurrent transmission by several nodes is not allowed even though there remain empty channels.

Under the multi hop ad hoc environment, the signal range of PU does not always cover the whole CR network (Jeong *et al*., 2012), specifically when wireless microphones are considered as PU. In this case, the nodes can have different sensing outcomes for the same channel, depending on whether they are in or not in the PU signal coverage. In Timmers *et al*. (2007) to mitigate the hidden PU problem in inherent to multichannel CR networks where the PU signal is detectable only to some nodes, a MAC scheme is proposed that adjusts the sensing priorities of channels at each node with the PU detection information of other nodes and also limits the transmission power of a CR node to the maximum allowable power for guaranteeing the quality of service requirement of PU (Yucek and Arslan, 2009).

With respect to these previous surveys, the proposed MAC probabilistic framework overcomes the shortcomings of the above mentioned spectrum management schemes to enhance the CRN good put. In this study, a novel method realizing spectrum management scheme for CRNs that overcome the erroneousness spectrum measurements, hence improve the performance of both CRN and PRN and also introduce fairness in CRN (Jeong *et al*., 2012). A RAP frame work for spectrum management and the MAC layer protocol is realized. The basic idea behind the RAP framework is that, even if there is a high interference temperature level a spectrum can be discovered available with a certain probability, since the local interference measurement by a secondary receiver doesn't mean that there is interference for the nearby primary receiver. Unlike other spectrum management schemes where a greedy approach is used to acquire a spectral opportunity, in our proposed scheme the CRN transceiver uses a probabilistic approach to switch between a higher and lower permissible power/rates. This will reduce the interference introduced by a CR node to a primary user. Also the generous behavior of the CR transceiver will improve the fairness in the CRN.

OVERVIEW AND DISCUSSION OF THE BASIC PROBLEM

Before any spectrum management can be implemented, a cognitive radio needs to explore the spectrum and identify the spectrum holes. Thus it is required to have a high sensitivity with high processing speed. Since a spectrum band remains idle only for a finite duration, it is imperative that the CRN transceiver completes sensing the entire spectrum of concern in a small interval of time in order to make sure that it does not miss any spectral opportunity. It is difficult to conceive a hardware design to meet these stringent requirements. Hence, the accuracy of spectrum sensing has been limited by the hardware limitations.

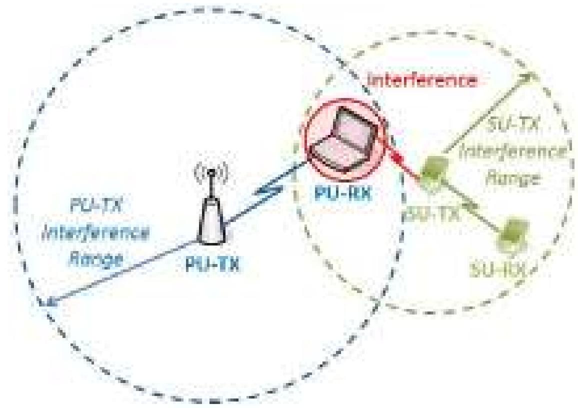

Fig. 1: Hidden primary sender scenario

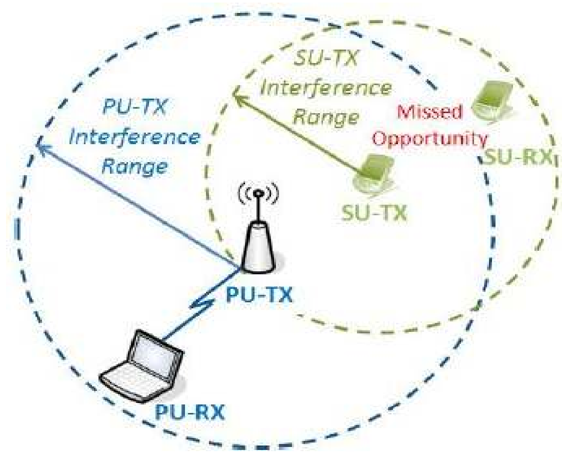

Fig. 2: Exposed primary sender scenario

Moreover, the hidden and exposed primary sender scenarios further limit the accuracy of spectrum sensing and they have done so to an extent that the inaccuracies have become unavoidable. It is important to note that the primary user network is passive, it does not communicate with the secondary users, simply because it does not need to as it has a licensed band of spectrum allocated to it. Furthermore, one must keep in mind that all interference measurements made by a CRN node is strictly on what a primary user transmitter transmits, this also implies that a CRN node can sense only the existence of a primary transmitter. Figure 1 shows the hidden primary sender scenario in which the secondary user begins its transmission without knowing the existence of a primary receiver in its range. Hence the secondary user misinterprets the spectral opportunity and its transmission interferes with that of the primary user.

In the exposed primary sender scenario shown in the Fig. 2, the SU refrains from any kind of transmission after sensing the existence of the PU transmitter located with its transmission range. However the SU could have commenced and finished its transmission successfully as the PU receiver is located well outside the transmission range of the SU. Alas it misses out on, for all practical purposes, a clear spectral opportunity.

System model: The study proposes a Rate Adaptive Probabilistic (RAP) framework for spectrum management. The RAP has its roots in the idea that any spectrum band can be explored with a specific probability even when the interference inferred is high as any local interference measurement made does not include or take into account the interference at the primary user receiver. The RAP probabilistically swaps maximum and minimum permissible power transmission rates to ensure that even the least feasible spectral opportunity is utilized to its greatest potential. The principle helps the CRN nodes to decide the tone of its transmission especially when it holds no prior knowledge of spatial location of the primary receiver. It readily assures fairness in competition for access to a spectral opportunity by leaving free a spectral margin for other SU (s) to transmit. The proposed scheme does not require high sensitivity in a wide spectrum as it assumes the CRN transceiver to have a narrow band sensing capability. Thus, the RAP framework dismisses the need for an ideal hardware design rendering the idea more realistic.

Primary network model: The wireless spectrum is assumed to consist of N non-overlapping channels with each channel allocated to each of the N primary users. The primary user activity is denoted by α. The primary user defines the maximum transmission power as P_{PU} and maximum permissible interference margin from the secondary user network as P_{mask}. The model is designed such that the cumulative interference of the secondary users doesn't exceed P_{mask} with a probability β.

Secondary network model: The secondary users are of secondary importance for all spectrum access related issues. A single ad hoc secondary network, geographically collocated with the PRN, has been considered (Liang *et al*., 2008). The secondary users can opportunistically access the licensed spectrum bands and more than one secondary user can transmit in a given channel at a time (Raman *et al*., 2005). The secondary user selects the transmission power and the corresponding rate before every packet transmission in accordance with the equation below:

$$\frac{P_i}{P_j} = \frac{2^{R_i-1}}{2^{R_j-1}} \quad \forall\, i \neq j \tag{1}$$

Functioning of RAP: There are four kinds of scenarios that can arise when the interference measurements, of the selected spectrum, are made at both the receiver and the transmitter of a secondary user. A clear spectral opportunity is created when the interference levels are low at both transmitter and receiver. An unclear spectral opportunity arises when the interference at the SU receiver is low and that at SU transmitter exceeds P_{mask}. The remaining scenarios with strong interference at the receiver end are not considered as the receiver will not be able to receive the data correctly.

Given $r_s(j)$ rate associated with secondary user and is formulated in terms of p and q. The optimization problem is explained using RAP-MAC parameters as follows (Ahmed *et al*., 2011):

$$\begin{aligned} &\text{Maximize} \quad \sum_{j=1}^{N} \frac{1}{N} r_S(j) \\ &\text{subject to} \\ &P_M^j \leq \frac{P_{mask}^j - P_{(1-\gamma)p}^j}{g_{d_{\min}}^j} \; \forall j = 1, 2, \cdots, N \\ &\beta \leq p \leq \frac{\beta}{1 - pd_{\min}} \\ &\beta \leq q \leq \frac{\beta}{1 - pd_{\min}} \end{aligned} \tag{2}$$

In a clear spectral opportunity, the RAP-MAC allows the secondary user to exploit the opening in the spectrum with the maximum tolerable transmission power/rate only with a probability 'p' and send the data at the lowest rate with a probability (1-p). It also ensures that no secondary user claims the spectral opportunity for itself.

In an unclear spectral opportunity, the RAP framework permits the SU transmitter to exchange data at the lowest rate only with a probability q. It does so to make sure that no partially viable spectral opportunity goes underutilized. RAP framework propose that the data be sent at increasing rates in the time instants following a successful transmission at the lowest rate assuming that the interference levels will not double or triple in a small interval of time (time in ms) in order to maximize the spectrum usage. Low power rates have been found to be robust to interference and hence ideal in the above described scenario.

SIMULATION RESULTS

In this section, we showcase the results we acquired with figures and graphs supporting the same. We consider 9 PRNs collocated with a CRN in a 500×500 m^2 area. Each network has 200 nodes forming

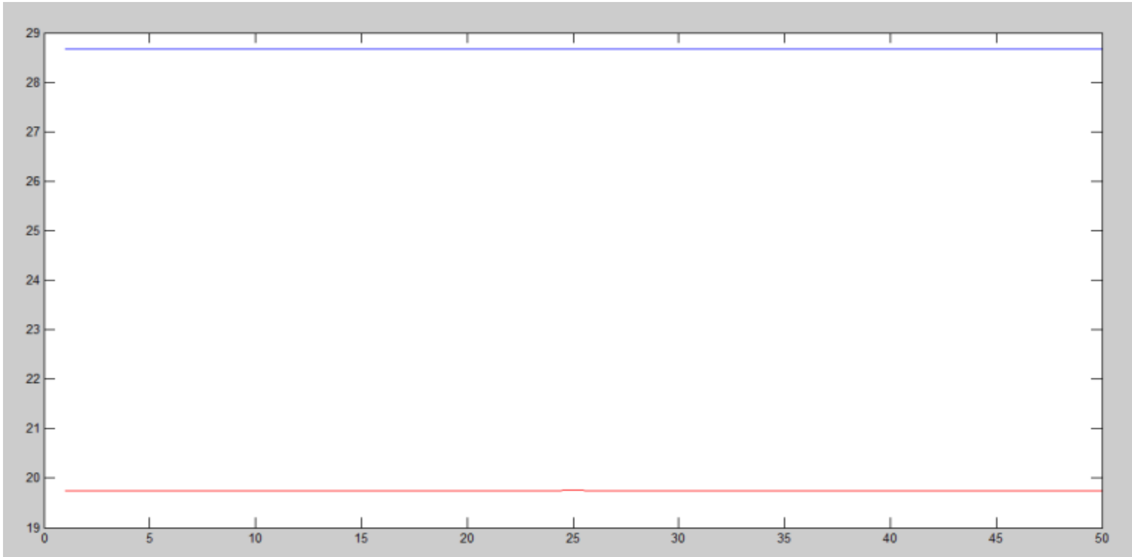

Fig. 3: R_{SU} with β = 0.5

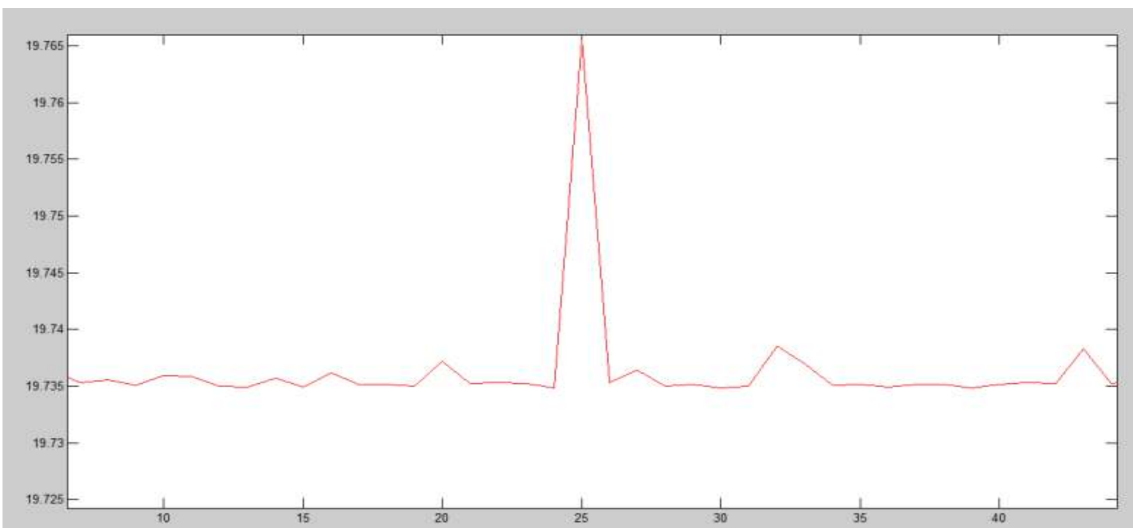

Fig. 4: Secondary user rate obtained for p and q values occurring randomly in the model

100 sender-receiver pairs. The operating frequencies of the 9 PRNs are (0.769, 0.789, 0.809, 2.412, 2.432, 2.462, 5.180, 5.200, 5.220) GHz with respective activity factors of (0.1, 0.5, 0.9, 0.1, 0.5, 0.9, 0.1, 0.5, 0.9). The bandwidth of each channel is 20 MHz and the power mask is 2 nW for all PRNs. The PRN transmit power is 1W and the antenna gains of transmitter and receiver are assumed to be equal and is unity for all PRNs. Three traffic matrices are generated for each topology; the stated results are the average of these runs for each arrival rate value. The error bars represent the 95% confidence interval of the multiple runs. The optimal values of p and q are computed for different values of β.

Analysis of secondary user rate with β: From Fig. 3 we see that the rate of the secondary user calculated at 50 instants of time is about 20 Mbps for β = 0.5. The 'red' line shows the average rate calculated for the random p and q values obtained. The 'blue line' shows the maximum average rate that could have been achieved with the ideal values of p and q.

From Fig. 4 and 5 we infer that the secondary user rate decreases with a decrease in the value of β. We attribute the noted decrease of the RSU to the lower values of 'q' obtained due to the decrease in the value of β. Lower values of 'q' mean that the probability of sending any data at robust low rate in a unclear spectral opportunity is low.

Analysis of RSU and distribution of transmission rates: In this section, we analyze RSU and the distribution of rates for both low and high values of primary user density.

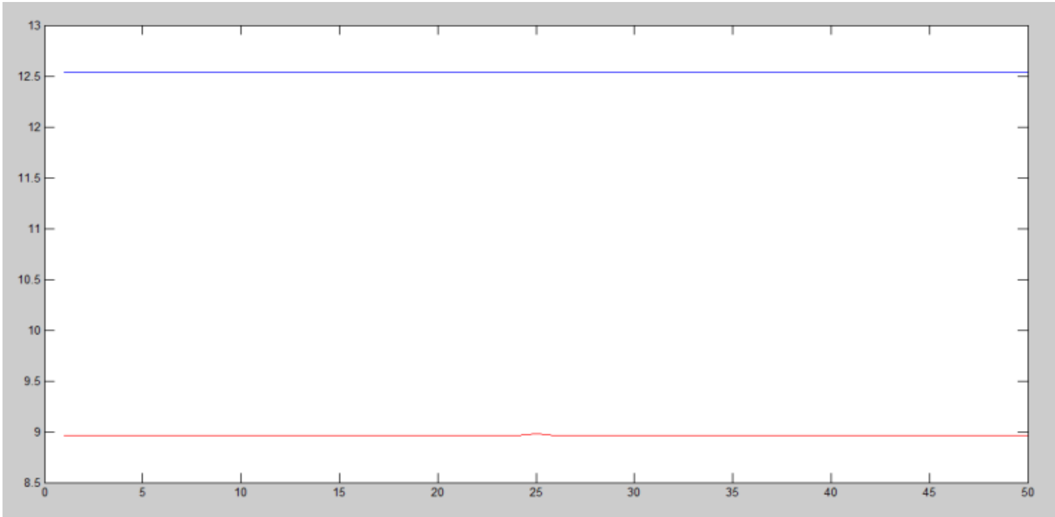

Fig. 5: R_{SU} with $\beta = 0.2$

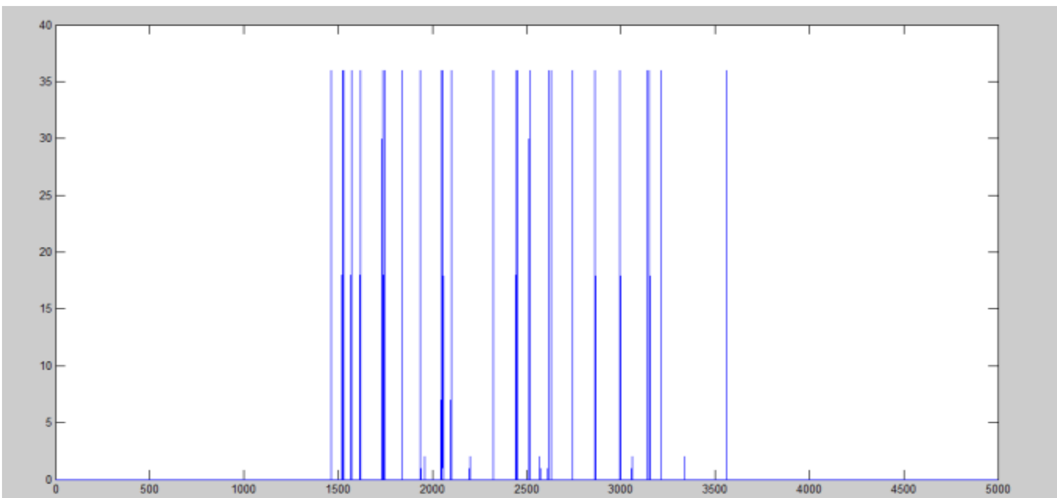

Fig. 6: Rate distribution for user density = 0.2 at the n^{th} channel

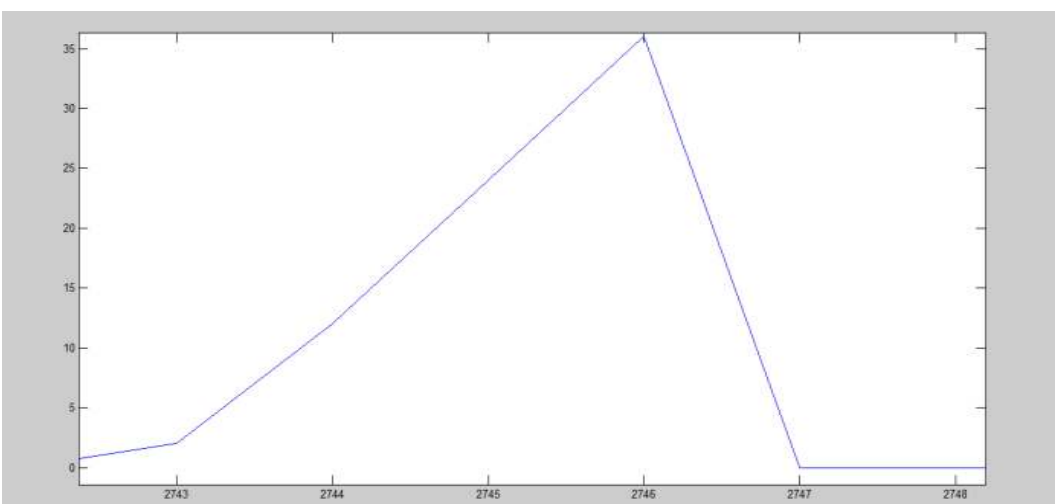

Fig. 7: Ramp-up

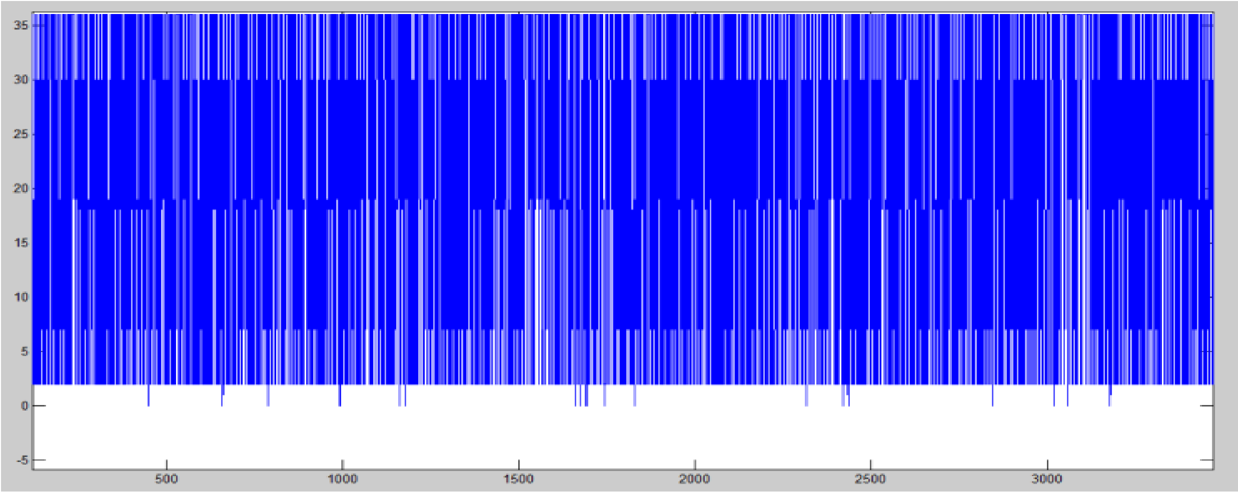

Fig. 8: Rate distribution with user density = 0.8 at the n^{th} channel

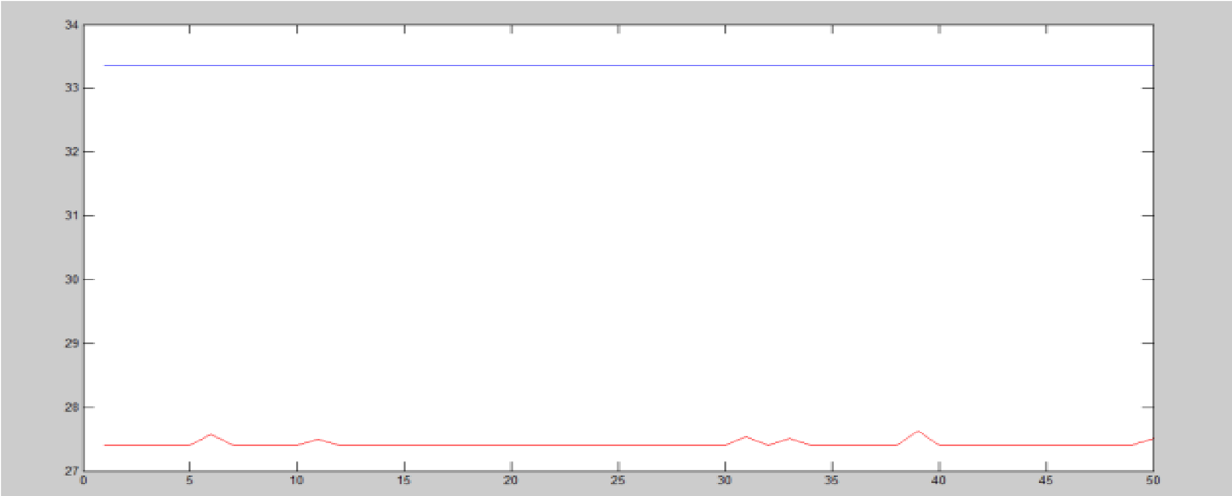

Fig. 9: R_{SU} for user density = 0.2

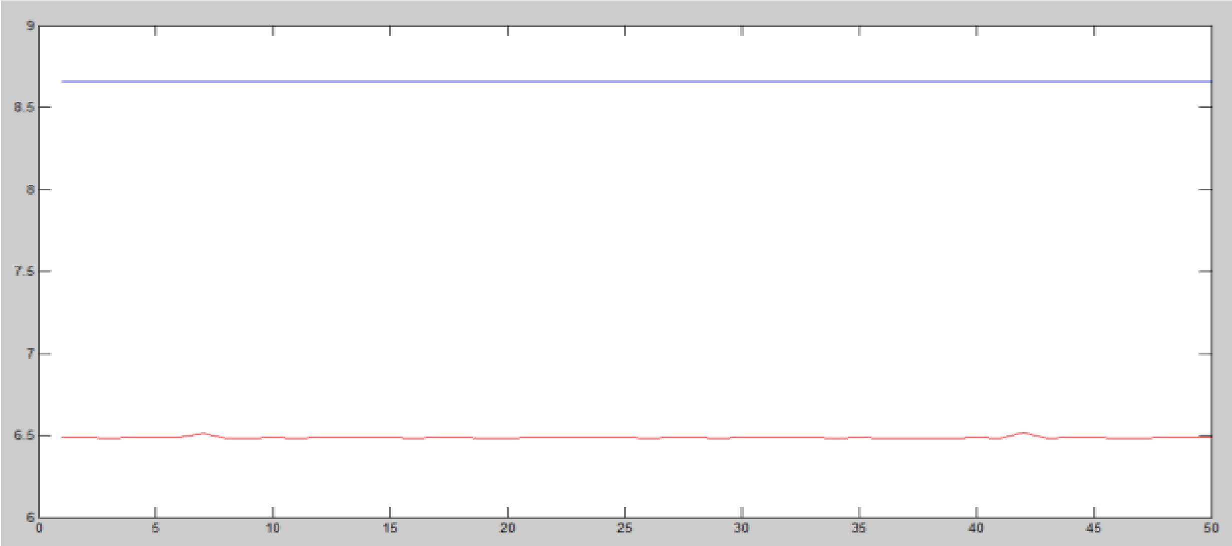

Fig. 10: R_{SU} for user density = 0.8

The blue bars in Fig. 6 in the graph represent the usage of the channels by secondary users. The secondary users transmit data at different rates depending upon clear or unclear spectral opportunity. A successful packet transmission at the lowest rate possible would give way to a steady increment in the rates over the next 3 instants of time. The ramp-up has been illustrated in the following Fig. 7.

Following a successful packet transmission, the rates are incremented from 2 to 36 through 12 and 24.

The rate distribution graph in Fig. 8 is more packed for a higher value of user density. This goes on to show that more spectral opportunities are being exploited.

From the above Fig. 9 and 10 we infer that the secondary user rate drops with an increase in user density value. This is due to the fact that more unclear spectral opportunity scenarios are encountered and this forces the secondary users to be conservative and refrain from transmissions at higher rates.

CONCLUSION

We have successfully implemented a version of the RAP framework. No spectrum management scheme takes into account the inaccuracies inherent in spectrum sensing and the inability of a CRN node to measure the interference at the primary receiver let alone the scheme implemented in the project. It further realizes the need to relax the complexity of the hardware and realizes the same by assuming the CRN nodes to have a narrow band sensing capability. The RAP framework, in stark contrast to the existing techniques, probabilistically allows the secondary users to share the spectral opportunity leaving no margin for complete dominance by any one sender-receiver pair. The mechanism of probabilistically switching between the available rates to suit the interference scenarios helps the RAP framework to satisfy the PRN user constraints. Another striking feature that sets it apart from the greedy herd of management schemes is that it willingly makes use of robust low data rates for packet transmissions under seemingly high but innocuous interference levels guaranteeing higher secondary user rates.

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