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Impact of Secondary User's Mobility on System Throughput of Cognitive Radio

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Abstract: In this paper, we investigate the impact of secondary user's mobility on system throughput for cognitive radio users. In a cognitive radio network, system performance is greatly influenced by selection of decision threshold (γ_{th}) and it is selected based on the tradeoffs between probability of missed detection and probability of false alarm. A general criterion to select the constant value of decision threshold based on fixed low value of probability of false alarm, in order to avoid underutilization of frequency spectrum. In this paper, we propose adaptive selection of γ_{th}, computed as a function of physical separation between primary and secondary receiver. The analysis shows how variable γ_{th} affects system throughput. Further, we consider the case of mobile user to show the impact of CR user's mobility on the system throughput.

Keywords: Cognitive radio (CR), Cognitive radio network (CRN), Primary user (PU), Secondary user (SU), 4th Generation (4G), Channel state information (CSI), Decision Threshold (γ_{th}), Throughput.

1 Introduction

The radio spectrum usage is fundamentally based on licensed access based approach in which the network operators acquire license to operate in particular frequency band for a long term basis. This static spectrum allocation approach results into spectrum underutilization and has left almost no frequency bands to deploy future communication applications [1]. Recently, Cognitive radio (CR) technology has evolved as a one of the promising technologies that allow unlicensed secondary users (SUs) to exploit the licensed frequency bands opportunistically by sensing the presence or absence of licensed primary users (PUs) in a channel. Since the wireless channel characteristics and the frequency bands availability are time varying, cognitive radios are anticipated to support time varying quality-of-service (QoS) requirements. For this purpose, it is assumed that all SUs can observe the changes in cognitive radio environment (presence or absence of PUs), learn and take decisions autonomously in order to control their transmission power and maximize their throughput. To sense the idle channel, number of spectrum sensing techniques has been proposed by the researchers. The study of spectrum sensing techniques reveals that while selecting a sensing method, some tradeoffs must be considered between the desired accuracy, sensing time, computational intricacy, and network requirements. So far, the energy detection technique is considered the fastest sensing technique with low computational complexities [2- 6]. This is the only technique which requires no prior information about signal characteristics and thus the technique has been exploited extensively by researchers. Another very popular sensing technique suggested by IEEE802.22 WRAN system works on a hybrid method. The technique uses two stage sensing (combination of fast and fine sensing) to overcome the shortcoming of other sensing techniques [7]. In general, the overall performance for any sensing technique is measured by probability of detection (P_d) and probability of false alarm (P_{fa}). The high value of P_d ensures that PU is all time protected from harmful interferences from secondary user where as if P_{fa} is low, spectrum is utilized efficiently. Both P_d and P_{fa} are affected by choice of γ_{th} and thus proper selection of γ_{th} becomes very important for efficient spectrum utilization. In our previous work, CR receiver sensitivity based sensing free power control scheme was proposed [8].The adaptive power control technique works upon distance estimation according to which SU power is controlled. A protection radius was defined to limit the interference created by SU to PU. It was shown that SU can make decision on transmission power level based upon receiver sensitivity. In [9], authors investigated the ergodic channel capacity for underlay spectrum sharing system under maximum and received power constraints at licensed primary receiver.

Although spectrum sensing is an important parameter affecting the system throughput, it has also been proved by the researchers that system throughput is greatly influenced by sensing time. One of such studies has been presented in [10] with the aim to find optimal sensing time by formulating sensing throughput tradeoff problem. To improve the system performance a novel frame structure is proposed recently that offers parallel sensing and data transmission to improve system throughput [13, 17]. The author has exploited low channel gain parameter between the secondary transmitter and the primary receiver to achieve high detection probability of PU signal that helps to achieve high system throughput [17].

In this paper, we investigate how the system throughput is affected by selection of decision threshold γ_{th}. We study the throughput maximization scheme and determine the decision threshold as a function of distance using CDR principle. We have also shown how the system throughput varies as cognitive user moves towards or away from primary receiver. In section I, we have presented the related work. In section II, the system model is proposed. The simulation results followed by conclusion are presented in section III and IV respectively.

2 Proposed System Model

To analyze the performance of the cognitive radio system, we assume that the network comprises a primary transmitter (P_{Tx}) operating in the range of a protection radius R_p (Fig.1). P_{Rx} and S_{Tx} are primary receiver and secondary transmitter respectively. Inside the region defined by this protection radius, no secondary user can communicate as it would create interference to primary receiver and therefore will degrade the quality of service for primary receiver. We consider the low signal plus interference noise ratio (SINR) by placing the primary receiver at the boundary of protection radius.

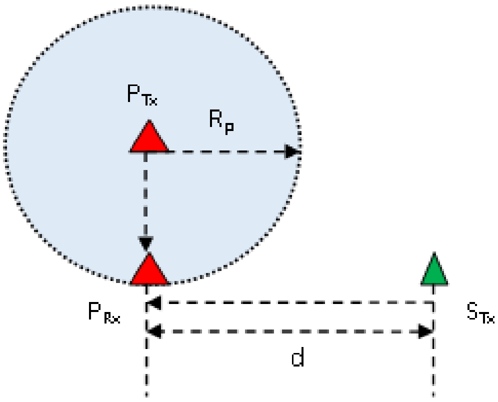

Figure 1 The system model for performance analysis.

To share the spectrum with licensed user, cognitive users make use of spectrum sensing technique using which a SU identifies spectrum holes. The term spectrum hole may be defined as a spectrum band that can be utilized by secondary user (SU) in the absence of legacy primary users [1]. Cognitive radio detects the spectrum hole by computing the received power and comparing it with a fixed threshold defined as a decision metric [11, 12]. This technique is popular as energy detection method. We also consider that CR users are equipped with the necessary hardware required to perform spectrum sensing using energy detection technique and the discrete signal received at CU end can be used to interpret idle or active PU. Based upon the received signal strength x(n) following hypothesis can be assumed:

$$H_1 : x(n) = s(n) + u(n) \quad (1)$$

$$H_0 : x(n) = u(n) \quad (2)$$

Where, *s(n)* is PU signal and *u(n)* represents additive white Gaussian noise (AWGN) signal. Assuming the noise signal is circularly symmetric complex Gaussian (CSGC) with zero mean and variance σ_w , the probability of detecting a free channel as a free channel (P_d) and probability of detecting a free channel as busy channel (P_{fa}) using energy detection scheme can be specified as follows in relation with the hypothesis that legacy user is absent or present as $P(H_0)$ and $P(H_1)$ respectively.

$$P_d = Q\left(\left(\frac{\gamma}{\sigma_w} - SNR_P - 1\right)\sqrt{\frac{N}{2SNR_P + 1}}\right) \quad (3)$$

$$P_{fa} = Q\left(\left(\frac{\gamma}{\sigma_w} - 1\right)\sqrt{N}\right) \quad (4)$$

where, γ is the detection threshold, σ_w is noise power, SNR_P is signal to noise ratio of primary user received at its sensing end and N is representing number of samples collected at the sensing node. For N = τ *fs*, τ is the sensing time defined by frame structure used for data transmission and *fs* is the sampling frequency [13]. Using the constant detection rate (CDR) principle, higher throughput can be achieved by a CR system as P_{fa} is decreased under the constraint to maintain a targeted value of P_d. Therefore, for a specific value of P_d, the equation (3) and (4) can be used to define γ_d and P_f as:

$$\gamma_d = \sigma_w^2\left(\left(Q^{-1}(P_d).\sqrt{\frac{2SNR_P+1}{N}}\right)+SNR_P+1\right) \quad (5)$$

$$P_f = Q\left(\left(\frac{\gamma_d}{\sigma_w^2}-1\right)\sqrt{N}\right) \quad (6)$$

From equation (6) it is clear that the P_f is dependent on signal to noise ratio (SNR_P) of a PU signal at its receiver. Q (.) is the cumulative density function used to determine the probability that received signal level (in dB) will exceed a certain value of defined by detection threshold γ_{th} In our previous work, we have shown that transmitted power can be represented as a function of distance [7]. The transmitted power received at PU receiver can be represented as:

$$P_{pr}(d_0) = \frac{P_p G_p G_s h_p^2 h_s^2}{d_0{}^n} \quad (7)$$

Where, P_p is the transmitted power, G_p and G_s are antenna gains at transmitting and receiving end respectively, h_p and h_s are height of transmitting and receiving antenna respectively, d_0 is the distance between transmitting and receiving antenna and n is the path loss factor. The received power at the sensing node located at any distance d in reference to distance d_0 can be expressed as:

$$P_{pr}(d) = P_{pr}(d_0)\left(\frac{d_0}{d}\right)^n \quad (8)$$

Using equation (8) to calculate the SNR_p, P_f can be modelled as a function of distance. It is seen that the probability of false alarm varies as the distance between transmitter and receiver varies. P_f rises to 1 as the distance between CR transmitter and primary receiver increases thus leading to fall in throughput of the CR system. To observe the effect on throughput of CR system, we consider the system throughput Th_0 when the channel is detected idle or PU is absent and Th_1 when the channel is detected busy or PU is present,

$$Th_0 = \log_2(1+SNR_s) \quad (9)$$

$$Th_1 = \log_2\left(1+\frac{SNR_s}{1+SNR_p}\right) \quad (10)$$

Where, SNR_s and SNR_p are signal to noise ratio of secondary and primary user respectively. Considering the conventional frame structure used by CR system as mentioned in [4], it is assumed that one frame used by CR system comprises a channel sensing slot and a data transmission slot. Spectrum sensing is performed using energy detection technique for time interval τ (in ms) and data transmission takes place for remaining duration T-τ (in ms). Therefore, using equation (9) and (10), the average achievable throughput (Th) of cognitive user can be specified as:

$$Th = \left(\frac{T-\tau}{T}\right)\left(P(H_0)(1-P_f)Th_0 + P(H_1)(1-P_d)Th_1\right) \quad (11)$$

In the equation (11), $P(H_0)$ and $P(H_1)$ represent the probability with which the targeted frequency band is sensed free or busy by energy detector. For the system model presented in fig.1, if the CR user is considered mobile, the distance d will keep on varying as the user moves from one location to another. The distance between primary transmitter and secondary transmitter can be computed using any of the techniques presented in the previous research

[8, 14-16]. To show the effect of user mobility on system throughput we consider the system model shown in figure 2.

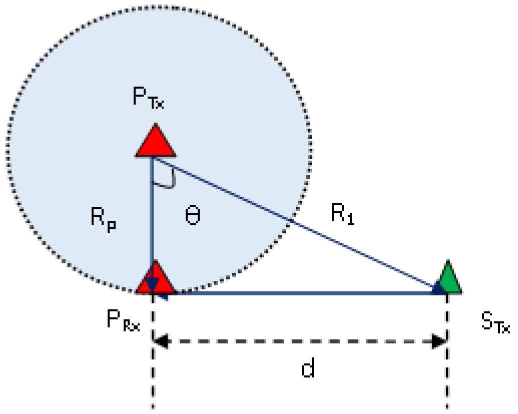

Figure 2. System model for distance calculation between PU and CU receiver.

For the model given in figure 2, the distance d between primary and secondary receiver can be calculated as follows:

$$d = \sqrt{R_1^2 + R_P^2 + 2R_1 R_P \cos(\theta)} \quad (12)$$

where, R_1 is the distance between primary transmitter and secondary receiver, Rp is the distance between primary transmitter and primary receiver and θ is the relative angle between PU and SU receiver.

3 Simulated Results

In this section we present the simulation results carried out for the parameters listed in table 1. In section II, we have derived decision threshold γ_d and P_f.

Table 1. The numeric values of simulation parameters.

S.No.	Parameter	Symbol	Value
1	Frame duration	T	100ms
2	Sensing time	τ	14ms
3	Primary power	Pp	1watt (30dBm)
4	Secondary power	Ps	0.1 -1 watt (0-30dBm)
5	Primary protection radius	Rp	450 meters
6	Reference distance	d_0	10 meters
7	Path loss factor	n	5

It has been shown in figure 3 that cognitive user's power received at PRx depends upon distance between primary receiver and secondary transceiver. From equation (5)

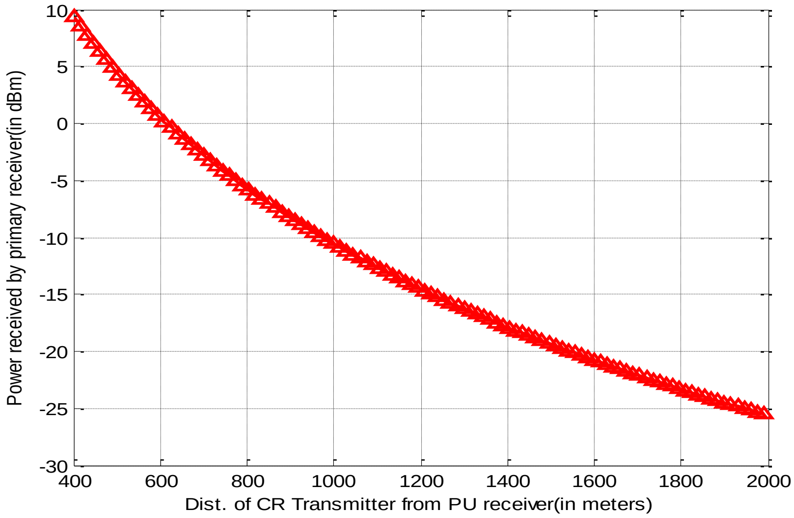

Figure 3 STx's power at PRx versus distance between PRx and STx.

and (6) it is clear that both γ_d and P_f also vary as the distance between primary receiver and secondary transceiver varies. Therefore, the value of P_f is computed first. Once the value of P_f is available, system throughput can be calculated using equation (11).

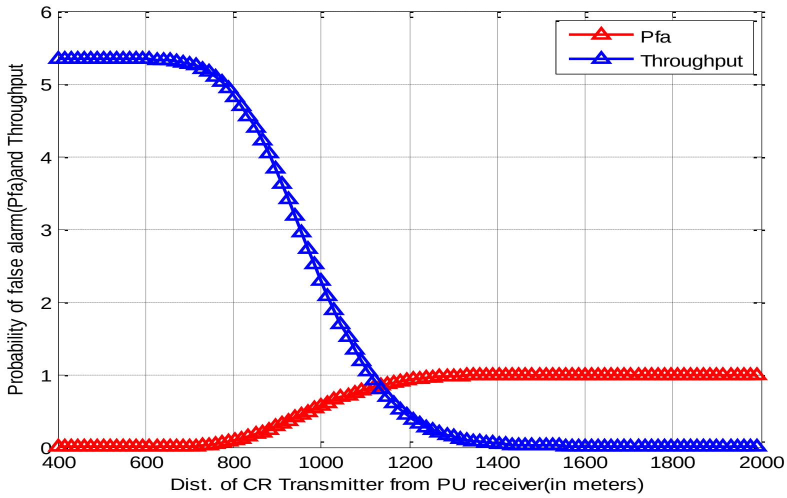

Figure 4. Throughput versus distance between PRx and STx.

In figure 4, we have shown the simulation result obtained for probability of false alarm and system throughput with varying decision threshold. Further in section II, we have shown a system model for mobile CU.

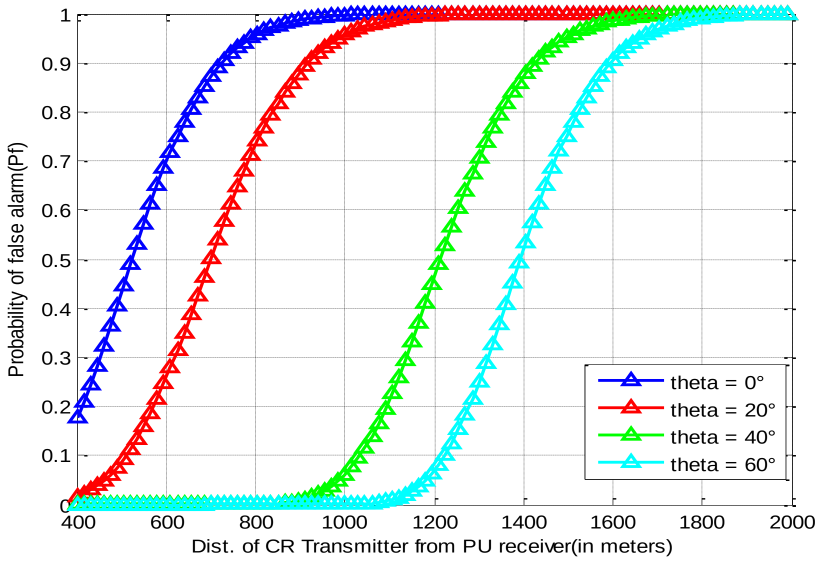

Figure 5. Variation in probability of false alarm for moving cognitive user.

The results obtained in figure 5 and figure 6 is for moving cognitive user. The distance d is now calculated using equation (12). As the cognitive user moves towards or away from the Primary receiver, angle θ varies which results in varying value of distance d. Effect of the same has been shown on both probability of false alarm and system throughput in figure 5 and figure 6 respectively.

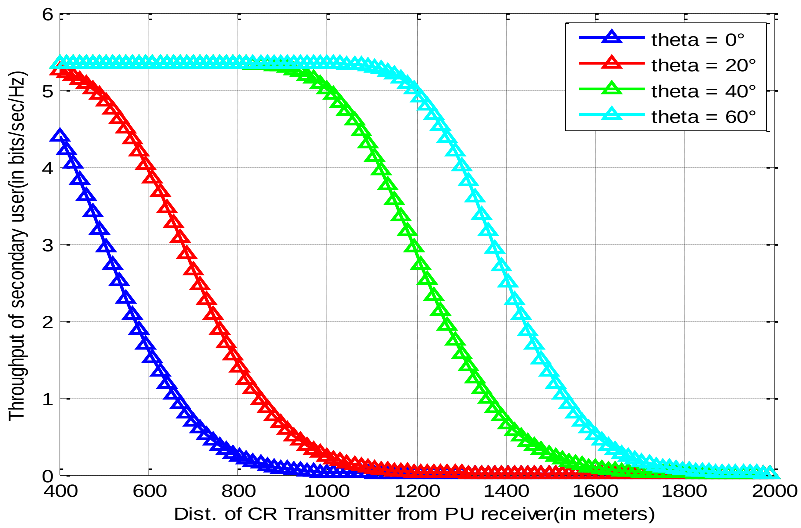

Figure 6. Variation in system throughput for moving cognitive user.

4 Conclusion

In this paper, the throughput variation for cognitive user has been presented under (i) varying decision threshold, modeled as a function of distance between primary receiver and cognitive transceiver and (ii) the condition of moving cognitive user towards or away from primary receiver. It has been shown that the value of decision threshold affects the system throughput and instead of keeping a fix value for this parameter as in conventional approaches, it should be adaptive according to the location of secondary user. As the probability of false alarm is affected by selection of decision threshold, system throughput and hence overall system performance is improved. Further, we have also shown more realistic performance evaluation by investigating how the system throughput varies as the cognitive user moves from one location to another keeping primary receiver reference.

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