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Performance Evaluation of Cognitive Radio with Emphasis on Uplink and Downlink

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Abstract— **In this paper, we have discussed the effects of channel interference and evaluated the signal-to-interference plus noise ratio (SINR) for the cognitive radio (CR) network. The cognitive radio is a novel concept of reusing licensed spectrum with unlicensed manner. The most challenging part is the introduction of cognitive radio in the primary user spectrum without causing interference to it. The SINR is very significant parameters for evaluation of the performance in a wireless network. Different users have different SINR requirement, so it is very important that the SINR of a particular user is within a certain acceptable range. The calculated SINR is more precise by considering the uplink and down link frequencies.**

Keywords— **Cognitive Radio, Spectrum-Hole, Interference, Licensed Spectrum, Unlicensed Spectrum, SINR.**

I. INTRODUCTION

Recently, there is a continuous increasing demand for the spectrum due to the increase in the number of users and the increasing number of applications, but the available spectrum is limited. So the available spectrum should be utilized efficiently such that there should be minimum wastage of the available spectrum [1]. CR is a new technology used to utilize the unused spectrum by sensing its operational electromagnetic environment and dynamically adjust the radio operating parameters to extenuate interference [2]. It merges artificial intelligence and wireless communication [3] and can change the transmission parameters dynamically based on its interaction with the environment in which it operates to utilize the unused spectrum of primary users or licensed users. There are three stages of a cognitive cycle: 1) spectrum sensing, 2) channel identification and 3) power control with spectrum management [4]. The unused frequency spectrum is detected by spectrum sensing and delayed or inaccurate spectrum sensing can lead to interference to primary users so the accuracy of spectrum sensing algorithm is very significant [4]. CR first senses the spectrum which it wants to use and then find primary users as well as other CRs in that spectrum. Based on that information and regulatory policies applicable to that spectrum, the CR finds spectrum opportunities (frequency, time, and space) and transmits in a manner so that there is minimum interference with primary users and other unlicensed devices operating in its vicinity [1]. CR continuously performs spectrum sensing over a large range of frequencies, identifies the unused spectrum dynamically, and then operates in this spectrum when it is not used by primary users and other CRs [1]. The “Spectrum holes” as shown in Fig. 1 is the unused spectrum which is underutilized in frequency, time and space [5]. A spectrum hole in the frequency is defined as a frequency band in which CR can transmit without interfering with any primary users (across all frequencies) [5]. CRs have the capability to exploit these spectrum holes, so it can solve the problem of radio spectrum scarcity.

For a given time and location 85% of the total spectrum remain unused [6] means that only 15% of the total spectrum is efficiently used and remaining part of the spectrum act as spectrum hole. This low usage of the primary spectrum indicates that the scarcity of spectrum is not due to the physical shortage of spectrum but it is actually due to the inefficient fixed frequency allocation [7]. If we can exploit the rest 85% of the spectrum holes then the capacity of the system will become (85+15)/15 = 7 times the capacity of existing wireless systems. The load or the number of CR users varies with time because of which the performance of the system can reduce. Due to this CR uses the technique of dynamic spectrum allocation (DSA) which adjusts the allocation in time and space as the load changes and improves the efficiency of radio spectrum [8]. The primary users have a higher priority over the licensed spectrum than the secondary users so that the quality of communication of primary users is not affected. It is the responsibility of the secondary users to make sure that its presence is not felt by the primary users because primary users have paid for using the licensed spectrum and moreover the primary users have a greater priority for using the licensed spectrum. One of the most important responsibilities of the CR is interference caused by the unlicensed users with the licensed users should be minimized. Interference limits the usable range of communication signals. The number of cognitive users and their location is obscure which leads to aggregate interference when spectrum sensing is done [7].

II. PROBLEM FORMULATION

The spectrum reuse can be done on two ways:

1) when the primary users are not using the spectrum, and
2) when there are no (or very less) primary users in a particular area [9].

The introduction of unlicensed users in a licensed spectrum obviously degrades the quality of primary system. So the unlicensed users should be smart enough to detect the location of primary users and then use the licensed spectrum on a way such that the interference caused by them to the primary users must be minimized. A CR continuously probe the signal-to-noise ratio (SNR) on a large number of frequency channels, and select the one with the lowest SNR and which has the lowest probability of reoccupation by a primary user for its transmission [1] . Secondary users (CRs) measure the SNR of the primary signal and then according to their distance from the licensed users they adjust their power [10]. The secondary users can increase their transmission power up to a level such that the interference with the primary users remains below a particular threshold value [10]. Secondary users should be placed far away from the licensed users and should have low transmission power levels [9]. The detection of primary users and the exploitation of the spectrum holes are the most challenging tasks for the cognitive radio. Downlink is the communication link for transmitting signals from base station to mobile station or cognitive transmitter to cognitive receiver. Uplink is the communication link for transmitting signals from mobile station to base station or cognitive receiver to cognitive transmitter. In this paper the previous work [9] in which authors only calculates the Signal to Interference plus noise ratio (SINR) experienced by a cognitive receiver in the downlink is extended for uplink. The SINR calculated in the present paper is compared with [9].

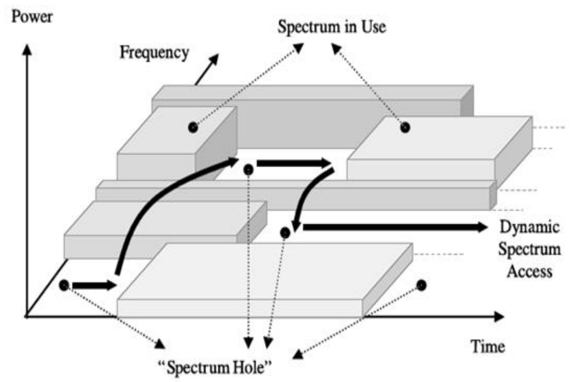

Fig. 1 Spectrum holes.

III. MODEL

We consider the uplink as well as downlink in hexagonal-type frequency reuse pattern [11]. We include the main primary base station and the first tier of co-channel interferers as shown in Fig. 2. The cell radius of the main primary base station (B_0) and other base stations (B_1 to B_6) is r. The distance from B_0 to all the other base stations is $D = (\sqrt{3n}).r$ [12], where n is the cluster size and 1/n is the frequency reuse factor of the primary system. The base stations (B_0 to B_6) are transmitting omni-directionally with a power P_B. For a hexagonal geometry the ratio $Q = D/r = \sqrt{3n}$ is called co-channel reuse ratio [12]. If n is small or Q is small then the capacity of the system is large but the inference will also be large. If n is large or Q is large then the capacity of the system will be less but the interference will also be less. So there is always a tradeoff between capacity of the system and interference. The position of the base station is given by:

$$B = 0 \text{ and } B_m = (D\cos(m\pi/3), (D\sin(m\pi/3))$$

where m = 0,1,2… 5. We assume that the secondary users will be permitted to operate only if they are at a minimum distance of d from the nearest base station [10, 11]. We also assume that N cognitive transmitters are spread out randomly between the ring formed by the two circles, one centered at B_0 with radius d and another circle of radius (D-d) as shown in Fig. 2. For each cognitive transmitter there is a corresponding cognitive receiver at a distance of d_0 and at an angle θ from the cognitive transmitter. The range of θ is [-π, π] but the cognitive receiver can be only inside the above mentioned ring. The position of the cognitive transmitters is:

$T = (x\ , y\ ), j = 1,2...N.$

The positions of the cognitive receiver are denoted by:

$R_j = (x_{Tj} + d_0\cos\theta, y_{Tj} + d_0\sin\theta), j = 1,2...N$

Now we consider the path loss distance dependent model. We define the channel gain function at a distance x,

$$\rho(\mathrm{x}) = \mathrm{x}^{-\alpha} \times 10^{\lambda/10}\ ,\ \lambda \sim \mathrm{N}(0,\beta) \qquad (1)$$

where α is the path loss exponent and β is the standard deviation of lognormal fading in dB. $\rho(x)$ is the function which measures he attenuation of a signal at a distance x from the base station. For example, the power received by a mobile station at a distance of x from the base station is $P_B \times \rho(x)$. So it means that if the mobile station changes its position then the power received by it from the base station also changes. As the distance (d_0) between cognitive transmitter and cognitive receiver is fixed, lognormal fading is responsible for any randomness in the received signal [9]. The base station and cognitive transmitter transmit omni-directionally with a power P_B and P_C, respectively. During uplink the mobile station and the cognitive receiver transmit with a power P_M and P_C. Cognitive transmitter and cognitive receiver have a different transmitting power but in this paper we have assumed that the cognitive transmitter and cognitive receiver are transmitting with the same power P_C. P_B is greater than both P_M and P_C. Also P_C is much less than both P_B and P_M (i.e. $P_B > P_M > P_C$) so that the interference caused by secondary users to the primary users is minimum. Interference caused due to uplink would be obviously less than the interference caused due to downlink (because $P_B > P_M$) but this does not mean that we should neglect the interference caused due to uplink for the calculation of SINR. So in this paper, we have considered both uplink as well as downlink for calculating SINR and therefore the expression of SINR calculated here is more accurate and realistic than the SINR calculated in [9]. Now, we calculate the interference power received by the jth cognitive receiver. The cognitive receiver will receive four types of interference power. First is the interference power from the base station and written as:

$$P_B \times \sum_{m=0}^{6} \rho(|R_{i-}B_m|)$$

Second is the interference power from the mobile stations which can be written as:

$$P_M \times \sum_{p=0}^{H} \rho(|R_{i-}M_p|)$$

where M_p represents the mobile stations and H are the number of mobile stations. Third is the interference power received from all the cognitive transmitters except the jth cognitive transmitter and written as:

$$P_C \times \sum_{i \neq j}^{6} \rho(|R_{j-}T_i|)$$

Fourth is the interference power received from the other cognitive receivers and written as:

$$P_C \times \sum_{i \neq j}^{6} \rho(|R_{j-}R_i|)$$

Area [9] of the cognitive operation is:

$$A = \frac{(D-d)^2 - d^2}{D^2} = (1 - 2\frac{d}{D}) \tag{2}$$

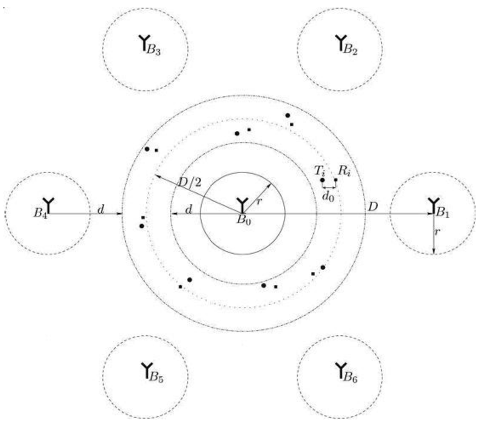

Fig. 2 Cognitive Radio in primary spectrum [9].

This is the total permitted area where CR can operate. We limit the CR power according to the equation: $NP_c = \varepsilon P$. The operating point of primary system is [9]:

$$\Psi = \left(\frac{P \sum_{n=1}^{6} \rho(|((r\cos(\partial), r\sin(\partial)) - B_n|)}{\sigma^2}\right) = \frac{P\mu}{\sigma^2} \tag{3}$$

So the expression of the signal to interference plus noise ratio for the jth cognitive receiver becomes:

$$SINR_i = \frac{P_c \times \rho(d_0)}{\begin{aligned}&[\sigma^2 + P_B \sum_{n=0}^{6} \rho(|R_j - B_m|) + P_M \sum_{p=0}^{H} \rho(|R_j - M_p|) \\ &+ P_C \sum_{i \neq j} \rho(|R_j - T_i|) + P_C \sum_{i \neq j} \rho(|R_j - R_i|)]\end{aligned}} \tag{4}$$

where σ^2 is the receiver noise floor. For simplifying the calculations we have assumed that $P_B = P_m = P$.

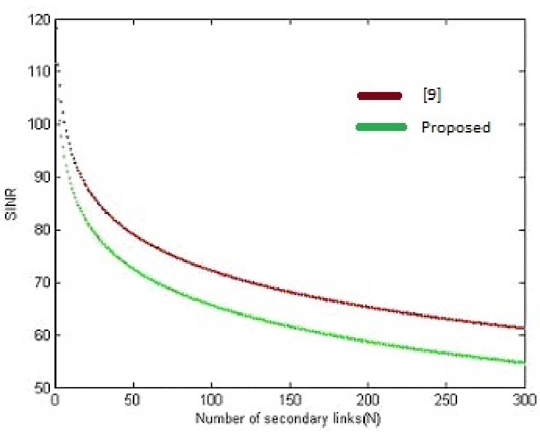

Fig. 3 Comparison of the SINR for α =4, β =6db, n=7, A=25%, Ψ =5, $\in$ = -15.

IV. RESULTS

The area of cognitive operation is dependent on aggregate power ratio ($\in$) and primary system operating point (Ψ) [11]. Larsson and Skoglund [11] measured the primary system operating point as a function of aggregate power ratio. He calculated this for various areas of cognitive operation where the value of area is given by (2) for various values of areas, A, studied by Larsson and Skoglund [11]. We have picked up one of the value of area A = 25% and assume various other parameters like α = 4, β = 6db, n=7, Ψ =5, $\in$ = -15 as calculated by [11]. Since our focus is to show the effect of uplink on SINR which characterizes a CR. Now, from Fig. 3, we are able to see that our modified SINR has a trajectory similar to the SINR calculated without considering uplink.

V. CONCLUSION

As we know that SINR is a very important parameter for calculating the performance in a wireless communication network so more precise calculation of it help us to improve the performance of the communication network. Since the probability of a CR being affected by uplink is also there the existing literature supports the interference due to downlink but does not cater to the uplink factor. This paper brings this into consideration. Although, the SINR calculated from [9] is more than the SINR calculated from the present approach. In the present approach, we have considered both the uplink and downlink for calculating the expression of SINR. The present paper also paves way for further research by comparing our simulated theoretical results by experimentation. The expression regarding capacity for CR communication network will be discussed in the next communication.

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