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Estimating the channel uplink capacity of a CR based central access MIMO network

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ABSTRACT

The major objective of this paper is to study the performance analysis of CR-MIMO (Cognitive Radio-Multiple Input Multiple Output) network with various fading channels. Specifically, the research objectives are modeling and evaluation of outage probability in CR-MIMO network in both faded and non-faded environment & modeling and evaluation of uplink ergodic MIMO channel capacity in CR based central access network in different fading channel techniques.

Keywords: *Cognitive Radio, MIMO, Fading, Shadowing, Uplink Capacity.*

1. INTRODUCTION

There seems no end in sight to the growth of the wireless applications for mobile users. Moreover most of the available radio spectrum has already been allocated to existing wireless systems, however and only small parts of it can be licensed to new wireless applications. The major factor that leads to inefficient use of the radio spectrum is the spectrum licensing scheme itself. In traditional spectrum allocation based on the command-and-control model where the radio spectrum allocated to licensed users is not used, it can't be utilized by unlicensed users and applications [1]. Due to this static and inflexible allocation, legacy wireless systems have to operate only on a dedicated spectrum band, and cannot adapt the transmission band according to the changing environment. The main goal of cognitive radio is to provide adaptability [2] to wireless transmission through dynamic spectrum access so that performance of wireless transmission can be optimized, as well as enhancing the utilization of frequency spectrum. It is a future generation intelligent wireless technology. There are two key motivators for this cognitive radio research. First one is scarcity of the available frequency spectrum and another one is increasing demand caused by the emerging wireless applications [3]. MIMO uses the principle of spatial diversity when received signals from different antennas are made uncorrelated by maintaining sufficient spacing between them. Since they are uncorrelated, the probability that all signal copies are in a deep fade simultaneously is small. CR based central access MIMO network is very much sensitive to primary users and parameter variations [4]. Uncorrelated channel coefficients for multiple channels between cognitive transmitter and cognitive receiver are generated by MIMO channel modeling.

2. PROPOSED METHODS DESCRIPTION

A. Cognitive Radio (CR)

A Cognitive Radio is a radio frequency transmitter/receiver that is designed to intelligently detect [5] whether a particular segment of the radio spectrum is currently in use and to jump into the temporary unused spectrum very rapidly without interfering with the transmission of other authorized users. This is nothing but dynamic spectrum resource management. The major functionalities of a cognitive radio system include spectrum sensing and analysis, spectrum allocation, sharing and spectrum handoff, spectrum sharing technologies. Capacity analysis is very useful in investigating the ultimate performance limits and thus potential applications of CR systems. In particular for interference-tolerant CR networks it is necessary to analyze the network capacity under received interference power constraints, which can be specified in terms of either average power or peak power.

Through spectrum sensing, CR can obtain necessary observations about its surrounding radio environment, such as the presence of primary users and appearance of spectrum holes. Spectrum sensing and analysis is the first critical step towards dynamic spectrum management [6]. There are three different aspects in spectrum sensing analysis. They are temperature model, spectrum wholedetection and cooperative sensing.

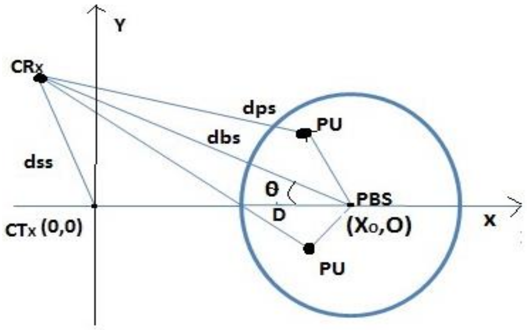

Fig.1: Working scenario of cognitive radio network

B. Multiple Input Multiple Output (MIMO)

MIMO refers to multiple-input multiple-output system. MIMO is a technique which can significantly increase the data throughput and link range [7] without additional bandwidth or transmit power. MIMO uses the principle of spatial diversity where received signals from different antennas are made uncorrelated by maintaining sufficient spacing between them. MIMO is the ability to transmit two or more unique radio streams simultaneously, delivering two or more items the data rate per channel. Few advantages of using multiple antennas are array gain, interference suppression, spatial diversity.

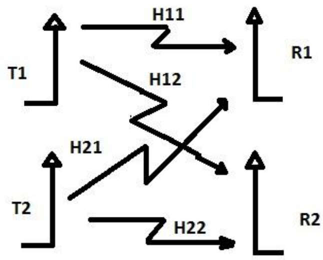

Fig.2: 2*2 MIMO System

C. Fading

The wireless radio channel poses a severe challenge as a medium for reliable high speed communication. It is not only susceptible to noise, interference, and the other channel impediments, but these impediments change over time in unpredictable ways due to user movement. In wireless systems, signal strength is changed rapidly over a small travel distance or time interval, the reason behind this is multipath propagation of the signal. Due to the fading effects, the signal received by mobile at any point in the space may consists of a large number of plane waves having randomly distributed amplitude, phase and angles of arrival. The degradation of transmission quality due to channel fading cannot be simply overcome by increasing the transmitted signal power [8]. In general, there are four types of fading techniques. They are Rayleigh fading, Rician Fading, Nakagami fading and Weibull fading.

i) Rayleigh Fading

This is the most used signal model in wireless communication. The phase is uniformly distributed and independent from the amplitude. When the components of h (t) are independent the probability density function of the amplitude r =h=α has Rayleigh Probability Density Function (PDF)

$$f(r) = \frac{r}{\sigma^2} \exp(\frac{-r2}{2\sigma^2})$$

Where, E $\{r^2\} = 2\sigma^2$ and $r \geq 0$.This represent the worst fading case because LOS is not considered. The power is exponentially distributed. The phase is uniformly distributed and independent of the amplitude. This is the most used signal model in wireless communications.

ii) Rician Distribution

In case the channel is complex Gaussian with non-zero mean (LOS is present), the envelope r=h is Racian distributed.

Here $h = \alpha * \exp(j\phi) + v * \exp(j\theta)$.Where α follows the Rayleigh distribution and v>0 is constant such that v2 is the power the LOS signal component. The angle Φ and θ are assumed to be mutually independent and uniformly distributed on $[-\pi;\pi)$, Racian PDF can be written as

$$F(r) = \frac{r}{\sigma^2} \exp\left[-\frac{r^2 + v^2}{2\sigma^2}\right] Io\left(\frac{rv}{\sigma^2}\right)$$

iii) Nakagami Distribution

In this case $h = r\exp(j\emptyset)$, where the angle ∅is the uniformly distributed on $[-\pi,\pi)$. The variable 'r' and '∅' are assumed to be mutually independent .The Nakagami PDF can be expressed as

$$f(r)=\frac{2}{\Gamma(k)}\frac{k}{2\sigma^2}r^{2k-1}\exp(\frac{-kr^2}{2\sigma^2})\qquad r\geq 0$$

Where, $2\sigma^2 = E\{r^2\}$, $\Gamma(.)$ is the Gamma function and k≥ ½. It was originally developed empirically based on measurements.Instantaneous receiver power is gamma distributed with k=1 the Nakagami is equal to the Rayleigh PDF.

iv) Weibull Distribution

Weibull Distribution represents another generalization of the Rayleigh distribution When X and Y isi.e. zero Gaussian variables. The envelop of R=(X2+Y2)1/2 is Rayleigh distributed. However the envelope is defined as R=(X2+Y2)1/k, the corresponding PDF is Weibull distributed.

$$F(r)=\frac{kr^{k-1}}{2\sigma^2}\exp\left(-\frac{r^k}{2\sigma^2}\right).\ \text{Where, } 2\sigma^2 = E\{r^2\}.\backslash$$

A. Shadowing

Shadowing is caused by obstacles between the transmitter and receiver that attenuate signal power through absorption, reflection, scattering and diffraction [9]. A signal transmitted through a wireless channel will typically experience random variation due to blockage from objects in the signal path, giving rise to random variations of the received power at a given distance. Such variations are also caused by changes in reflecting surfaces and scattering objects. The most common model for this additional attenuation is log-normal shadowing. This model has been confirmed empirically to accurately model the variation in received power in both outdoor and indoor radio propagation environments. In the log-normal shadowing model the ratio of transmit-to-receive power $\psi=\frac{p_t}{p_r}$ is assumed random with a log-normal

Distribution given by

$$p(\psi)=\frac{\xi}{\sigma\psi_{db}\psi\sqrt{2\pi}}\exp[\frac{(10\log_{10}\psi-\mu\psi_{db})^2}{2\sigma^2\psi_{db}}]$$

B. Uplink Capacity

Main focus is on system level capacity analysis of a CR network where multiple CR transmitters and multiple primary receivers are present. The channel from the CR transmitter to the CR BS is defined as the CR access channel [10]. The underlying instantaneous channel power gain is denoted by hA. It follows that the instantaneous uplink channel capacity is given by

$$C_{CA}=W\log_2(1+\frac{I_0}{I_N}\frac{h_b^2}{h_p^2r^4}d_{\min}^4g_s^Ag_m^A)$$

Where W is the signal bandwidth, 'IN' is the noise plus interference power at the CR base station, 'r' is the distance between target CR transmitter and call center. gmA and gsA are the power gains of multipath fading and shadowing. 'hb' and 'hp'are the antenna heights of CR BS(Base Station) and CR transmitter respectively. 'dmin' is the minimum distance between CR transmitter and primary receiver. 'I0'is the interference.

In MIMO CR network, two antennas placed at each cognitive transmitter (CTx) and cognitive receiver (CRx). Although the distance from each primary user or primary transmitter to each antenna of cognitive transmitter and receiver is different, their difference is negligible at the operating frequencies of whole network. This is because antenna spacing is considered as λ /2 [11] and this value is negligible when compare with D.

3. SIMULATION RESULTS

Simulation algorithm for CR based central access network

1. Locate primary user coordinates and CR coordinates
2. Calculate the distance between cognitive transmitter and every primary user in a circular cell.(for each iteration consider one cognitive transmitter)
3. Find the minimum distance (d_{min}) among those distances.
4. Assume hb=30m,hp=1.5m, α = 4, I0/IN = 1, R=1000 m and r value varying from 100 to 400.
5. Using different types of multipath fading (g_m^A)
   A. For Rayleigh distribution, consider standard deviation of 1/√2 with zero mean underlying real Gaussian process.
   B. For Racian distribution, consider Racian parameter k as 6
   C. For Nakagami distribution, consider control spread 'W' as 6 and Nakagami parameter 'M' as 4.
   D. For Weibull distribution, consider Weibull parameter as '12' with gamma function.
6. Shadowing factor (g_s^A) is lognormal distributed with standard deviation as 8 dB.
7. Calculate the channel capacity and average it over 10,000 iterations.

Here, considering the normalized ergodic channel capacity for r/R=0.1. The uplink normalized ergodic capacity is shown in Fig.3

as a function of number of primary users for different fading channel techniques. Rayleigh fading follows an exponential distribution with standard deviation of the underlying real Gaussian process and is normalized to. Consider that Rice parameter k as 6. The Nakagami fading follows a gamma distribution with Nakagami parameter M is 4 and control Spread W is 6. Consider that Weibull parameter W as 6. The capacity decreases with increase in the number of primary users. As 'r' value increases CR transmitter will go away from the cell center.

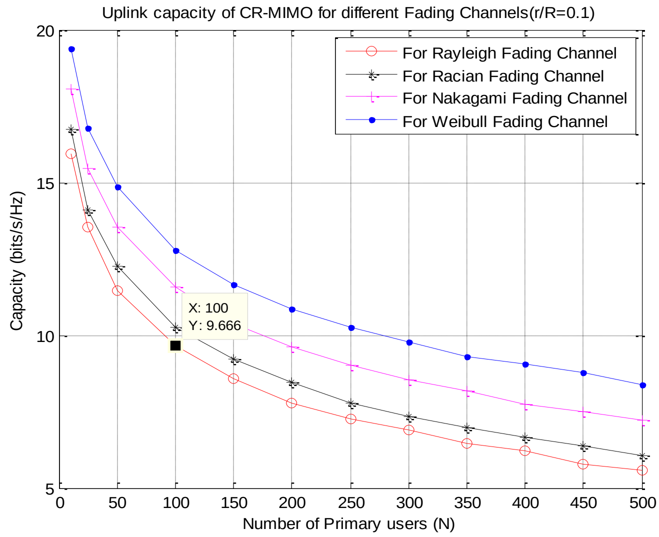

Fig. 3: Uplink normalized ergodic capacity of the CR based central access network for different channels(r/R=0.1)

Here, considering the normalized ergodic channel capacity for r/R=0.2. The uplink normalized ergodic capacity is shown in Fig.4 as a function of number of primary users for different fading channel techniques.

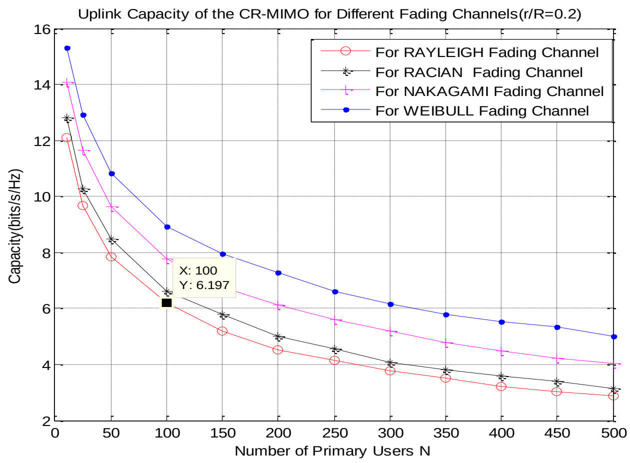

Fig. 4: Uplink normalized ergodic capacity of the CR based central access network for different channels(r/R=0.2)

Here, considering the normalized ergodic channel capacity for r/R=0.5. The uplink normalized ergodic capacity is shown in Fig.5 as a function of number of primary users for different fading channel techniques.

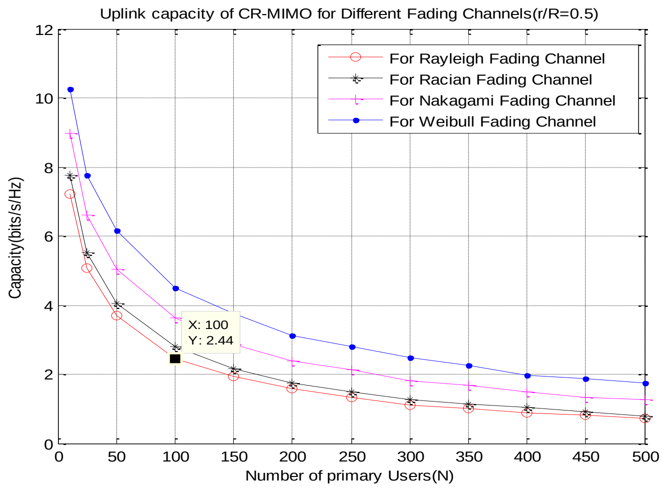

Fig. 5: Uplink normalized ergodic capacity of the CR based central access network for different channels(r/R=0.5)

We are considering the normalized ergodic channel capacity for r/R=0.8. The uplink normalized ergodic capacity is shown in Fig.6 as a function of number of primary users for different fading channel techniques.

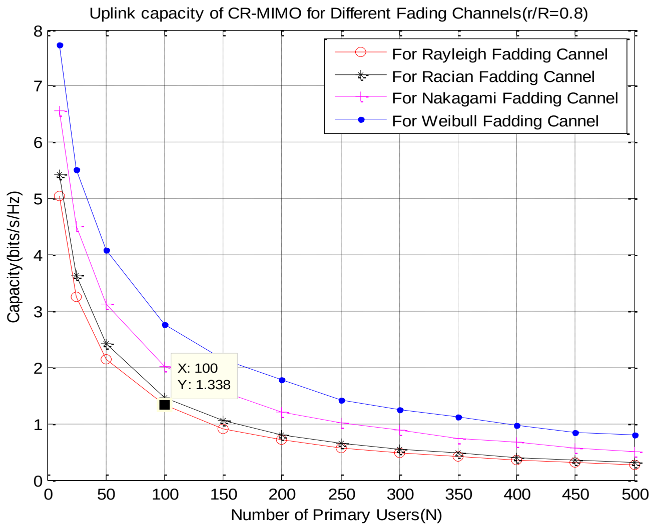

Fig. 6: Uplink normalized ergodic capacity of the CR based central access network for different channels(r/R=0.8)

Among the four different fading channels Rayleigh fading is more efficient when compared to Rician, Nakagami and Weibull fading techniques andWeibull fading technique is less efficient compared to other fading techniques.

4. CONCLUSION

The interference from the primary network is the main cause for the outage of a CR user. As the number of users increases, interference increases. The outage probability increases with increase in SIR threshold, and the outage probability increases with more number of primary users. This analysis indicates that the CR based central access MIMO network is more suitable for less populated rural areas. The uplink ergodic channel capacity of a CR based central access network is relatively large when the number of primary users N is small, but it decreases rapidly with increase of N. Different diversity schemes like Maximum ratio combining and equal gain combining can be used for the performance analysis of MIMO Cognitive network.

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