International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

# Resource Allocation and Outage Performance in OFDMA based Cooperative Cognitive Radio Network for Downlink in Underlay Mode

**Rupali Sawant, Shikha Nema**

***Abstract:*** ***Efficient resource allocation is an important process in any network to improve the capacity of a system. In cognitive radio network the resources are shared among licensed & unlicensed users. User is said to be in outage if it does not get required number of resources hence performance of the system gets affected. In this paper the outage probability in orthogonal frequency division multiple access (OFDMA) based cooperative cognitive radio network (CCRN) system is computed. Due to random user position different users require different number of resources. To determine this it is necessary to know the signal to interference ratio (SIR) experienced by the user. First we determine characteristic of interference to signal power ratio by using method of moments. Once the interference to signal power ratio is characterized, user is allocated a class number. Class number gives the number of subcarriers required by a user. For analysis purpose we use downlink in underlay mode with log normal shadowing and path loss exponent. This analysis helps in allocation of resources to the user depending on SIR experienced and outage behavior irrespective of user's position.***

***Keywords:*** ***Cognitive radio, Cooperative communication, Resource allocation, Correlated interference, Outage probability.***

## I. INTRODUCTION

This modern era of fifth generation (5G) mobile networks require tremendously higher data rates compared to fourth generation (4G) mobile networks. Cognitive radio (CR) is the promising technology to fulfill the need of future requirements of spectrum by allowing presence of primary users (PUs) along with cognitive users (CUs) also termed as secondary users (SUs) using the spectrum in cooperative manner. CU senses for the spectrum which is not being used by PU, also called as spectrum hole [1] [2]. It tries to use it at lower power level in the underlay mode of operation in view of not creating any interference to PU. This way CU can make use of licensed radio resource (RR) opportunistically as well as unlicensed radio resource to have uninterrupted communication. In [3] the work is carried over for hybrid cooperative CR network (HCCRN), in which outage probability is derived and its response for direct system and relayed system against various values of signal to noise power ratio (SNR) for uplink scenario with Rayleigh fading environment is studied.

**Revised Manuscript Received on October 30, 2019.**
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It is observed that outage happens more often in noisy environment which can be brought in control with increase in transmitted power.

Considering Rayleigh fading environment, sum rate is maximized and outage probability is minimized with certain power allocation strategies in [4] and [5]. To utilize the benefits of cognitive radio, orthogonal frequency division multiplexing (OFDM) is best suitable solution to access the spectrum holes. By assigning sufficient number of subcarriers to the user, required data rate can be achieved keeping in mind to even minimize the outage probability. Model in [4] is OFDMA based in which main aim of proposed algorithm is to increase number of subcarriers allocated to SU and paper [5] illustrates the effect of various parameters like arrival rate, interference power threshold, transmit power of PU and maximum total transmit power on outage probability.

Nakagami–m fading environment is also considered widely for underlay mode. In paper [6] asymptotic equation for outage probability is calculated for fixed gain with dual hop amplify and forward (AF) relay. Multiple AF relays are used in [7] for multiple input multiple output (MIMO)-CCRN system which reveals the effect of network parameters on outage probability.

In [8] the authors claim improvement in outage performance in decode and forward (DF) relayed MIMO system in comparison with AF based single input single output (SISO) system. With dual hop DF relay non-orthogonal multiple access (NOMA) system, the derived analytical expression of outage probability is validated with Monte Carlo simulation in [9]. Paper [10] is based on two way DF relaying and power splitting based relaying in which closed form expression for outage probability is obtained for PU and SU.

In [11] the authors analyze energy harvesting protocol, it also analyses outage probability against energy conservation factor and transmission time factor validating results with Monte Carlo simulation. Paper [12] is also based on energy harvesting which also derives outage probability expression along with improvement in energy efficiency (EE) and throughput.

In [13] on NOMA CCRN systems, analytical expressions of cumulative distribution function (CDF) of end to end signal to interference and noise power ratio (SINR) at PU and SU is derived and then used to access outage probability of both the users. To cancel the self interference at SU in [14], zero forcing beam forming schemes and maximum ratio combining schemes are designed along with deriving corresponding outage probability of PU and SU. In [15] the authors consider correlation among different log normal interferers from several co-channel base stations (BS) and CU whose effect is shown on outage probability.

Due to user's position, different user will require different resources. No paper has discussed about distinct requirement of resources by the users. So in this paper the main focus is on different requirement of resources due to random position of users. Users in different classes depending on the interference experienced are defined. Class number gives the number of subcarriers required by a user.

OFDMA based CCRN system with spectrum underlay approach is considered in downlink. The characteristic of interference to signal power ratio, $1^{st}$ and $2^{nd}$ moments are computed by considering log normal shadowing and path loss exponent. Once the interference to signal power ratio is characterized outage probability can be determined. Section II illustrates the system model of OFDMA based CCRN network and the outage probability analysis is in section III. Simulation results are discussed in section IV and the paper is concluded in section V.

## II. SYSTEM MODEL

Downlink OFDMA based CCRN system with spectrum underlay approach is considered as shown in Fig. 1. There is a main cell consisting of primary base station (PBS) surrounded by six cells dedicated for secondary base stations (SBS) i = 1, 2..... 6. All the cells are assumed to have same area, eventually same radius resulting in distance between PBS and SBS to be 2R. Let the position of PU from PBS be at distance 'r' and the position of CU in $i^{th}$ SBS cell from SBS be at distance '$r_i$'. The angle between position of PU and PBS is denoted by 'θ'. The effect of interference from the six co-channel SBS on PU present in the main cell is considered. Let the distance between PU and interfering $i^{th}$ SBS is denoted by '$d_i$' considered at random position (x, y) and position of interfering SBS fixed at ($x_i$, $y_i$). Log normal shadowing is denoted by 'Ɛ' and path loss exponent by is denoted by 'β' is considered for the analysis. Let the power received at PU be 'P'.

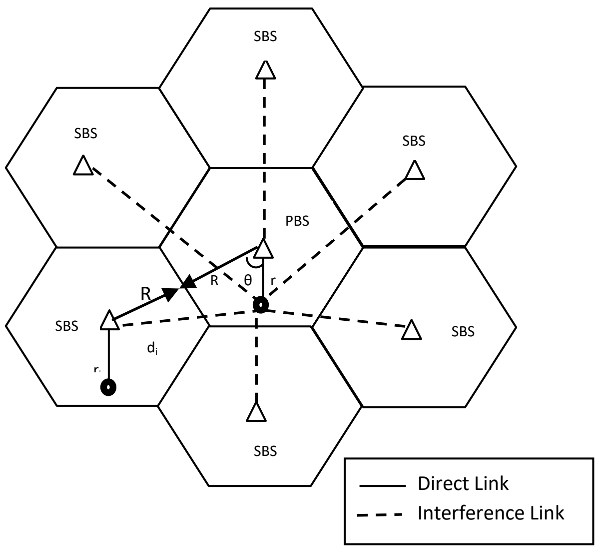


**Fig. 1. System Model**

Due to random position of PU in main cell, interference experienced by it from all six SBS will be random and correlated. Due to different locations of different PUs, interference experienced is different so all users will require different resources.

Therefore it is necessary to determine suitable resource allocation in multi user cooperative cognitive network. With the lack of resources, system experiences lower SIR. Outage probability is defined as the probability that the user is unable to establish successful communication if it's experienced SIR denoted by $\gamma_{exp}$ is less than the required SIR denoted by $\gamma_{req}$. So once the interference to signal power ratio is characterized outage probability can be determined.

## III. OUTAGE PROBABILITY ANALYSIS

We compute SIR for the system model illustrated in fig.1. Considering the log normal shadowing effect and interference from all six SBS, SIR at PU is given by

$$\gamma = \frac{P r^{-\beta} 10^{\varepsilon/10}}{\sum_{i=1}^{6} P d_i^{-\beta} 10^{\varepsilon_i/10}} \qquad (1)$$

where '$\varepsilon_i$' is log normal shadowing factor of $i^{th}$ SBS. Simplifying the equation of SIR as

$$\gamma = \frac{1}{\sum_{i=1}^{6} \left(\frac{d_i}{r}\right)^{-\beta} 10^{\varepsilon_i - \varepsilon/10}} = \frac{1}{\sum_{i=1}^{6} B_i C_i} \qquad (2)$$

where, $C_i = 10^{\varepsilon_i - \varepsilon/10}$ is the ratio of two log normal random variables that are correlated and

$$B_i = \left(\frac{d_i}{r}\right)^{-\beta} = \left[\frac{(x - x_i)^2 + (y - y_i)^2}{x^2 + y^2}\right]^{-\beta/2}$$

Since $d_i$ is dependent on random position of PU (x, y) and fixed position of interfering SBS ($x_i$, $y_i$). Therefore '$d_i$'s, are the correlated random variables.

$$E[I] = E\left[\sum_{i=1}^{6} B_i C_i\right] = E\,[B_i]\,E\,[C_i] \qquad (3)$$

We can assume E [$C_i$] = E [$C_j$] equal to some constant because Ɛ is independent of position of the user. So independent pair we can consider as (i, j). Therefore,

$$E[I] = E\,[\textstyle\sum_{i=1}^{6} B_i] E\,[C_i] \text{ and}$$

$$E[I^2] = E\left[\sum_{i=1}^{6} B_i^2\right] E\,[C_i^2] + E[C_i C_j]\left[E\left(\sum_{i=1}^{6} B_i\right)^2 - E\left(\sum_{i=1}^{6} B_i^2\right)\right]$$

Since distance between PU and $i^{th}$ interfering SBS are correlated, we can write

$$E\left[\sum_{i=1}^{6} B_i\right]^2 = \frac{2}{3\sqrt{3}} \iint_{xy\in z_o} \left[\sum_{i=1}^{6} \sqrt{\frac{(x-x_i)(y-y_i)}{x^2+y^2}}^{-\beta}\right]^2 d_x d_y$$

$$E\left[\sum_{i=1}^{6} B_i^2\right] = \sum_{i=1}^{6} \frac{2}{3\sqrt{3}} \iint_{xy\in z_o} \left[\frac{(x-x_i)^2+(y-y_i)^2}{x^2+y^2}\right]^{-\beta} d_x d_y$$

Now since we know E [I] and E [$I^2$], its distribution can be approximated by log normal parameters mean (μ) and standard deviation (σ).

$$E[I^K] = e^{\left[K\mu_I + \frac{K^2}{2}\sigma_I^2\right]}$$

For 1st moment, K = 1, $E[I] = e^{\left[\mu_I + \frac{1}{2}\sigma_I^2\right]}$

For 2nd moment, K = 2, $E[I^2] = e^{[2\mu_I + 2\sigma_I^2]}$

$\ln E[I^2] = 2\mu_I + 2\sigma_I^2$ and $2\ln E[I] = 2\mu_I + \sigma_I^2$

$$\sigma_I^2 = \ln E[I^2] - 2\ln E[I]$$

$$\mu_I = 2\ln E[I] - \frac{1}{2}\ln E[I^2]$$

CDF of interference to signal power ratio can be written as

$$F_I(x) = \emptyset\left[\frac{\ln(x) - \mu_I}{\sigma_I}\right] \qquad x > 0 \qquad (4)$$

Outage probability is written as

$$P_o = P_r\left[\gamma_{exp} \le \gamma_{req}\right]$$

where $\gamma_{exp}$ and $\gamma_{req}$ is the experienced SIR and required SIR respectively.

$$P_o = 1 - P_r\left[I \le \frac{1}{\gamma_{req}}\right]$$

$$= 1 - F_I\left(\frac{1}{\gamma_{req}}\right) \qquad (5)$$

Based on SIR experienced data rate achieved '$R_{ach}$' can be written as

$$R_{ach} = B\sum_{m=1}^{M}\log_2(1+\gamma_m) \qquad (6)$$

where 'B' is the bandwidth, 'M' is number of subcarriers required by a particular user to achieve required data rate for successful communication. '$\gamma_m$' is the experienced SIR for mth subcarrier by the user depending on its position from PBS.

Considering interference $I = 1/\gamma_m$, (6) can be used to determine the number of subcarriers required by a user as follows,

$$M = \frac{C}{\log_{10}\left(1+\frac{1}{I}\right)} \qquad (7)$$

where, $C = \frac{R_{ach}\log_{10} 2}{B}$

Let interference to signal power ratio is defined into 'N' levels. Corresponding to each level subcarrier requirement will be different. Based on this criterion different classes of users are defined. If a user experiences interference '$I_n$' corresponding to level n, where n = 1, 2, 3…….N, then number of subcarrier requirement for that particular level is given by '$M_n$'

$$M_n = \frac{C}{\log_{10}\left(1+\frac{1}{I_n}\right)} \qquad n = 1 \ldots N \qquad (8)$$

Probability that '$M_n$' numbers of subcarriers are required by user depending on the difference between (n+1)th and nth level of interference is given by

$$P[M_n = n] = P[I_n < I < I_{n+1}]$$

$$= F[I_{n+1}] - F[I_n] \qquad (9)$$

Here we define the class of a user as the number of subcarrier requirement. For example if a user requires two subcarriers then the class of user is two and so on.

## IV. RESULTS

This section provides simulation results of the OFDMA based CCRN system in which the characteristic of interference to signal power i.e. CDF, 1st and 2nd moments are computed. Once we know the characteristic of I, outage probability of the users for the system is determined.

The CDF of interference to signal power ratio for downlink of cognitive radio OFDMA based network is plotted in Fig. 2. The impact of shadowing deviations on the CDF of I has been observed. As shadowing deviation increases from 4 dB to 10 dB, the CDF of I increases.

The plot of variation in E [I] and E [$I^2$] with standard deviation of log normal shadowing is illustrated in fig. 3. As shadowing deviation increases, first and second moments of I increase. However, the variation in second moment, i.e. E [$I^2$] is large in comparison to E[I]. From these illustrations, one important observation is that higher the standard deviation of shadowing, the higher the first and second moments of I.

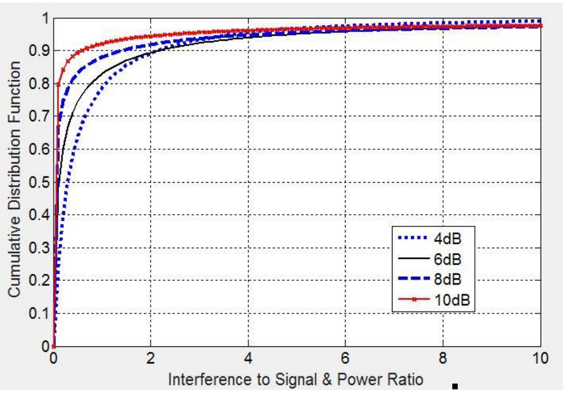


**Fig. 2. CDF of interference to signal power ratio for various shadowing.**

Retrieval Number: L26621081219/2019©BEIESP
DOI: 10.35940/ijitee.L2662.1081219
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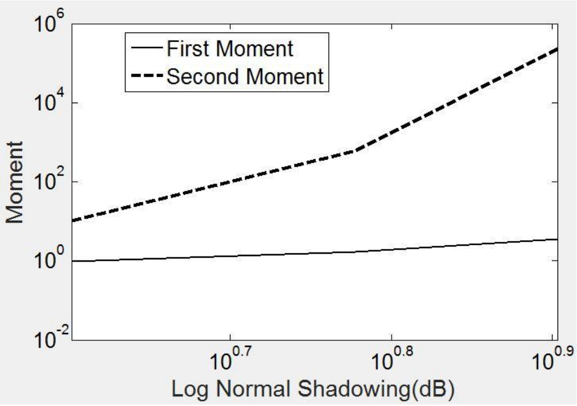


**Fig. 3. Variation of 1st and 2nd order Moments with log normal shadowing.**

Mean of interference to signal power ratio decreases and variance increases with the deviation of log normal shadowing as depicted in Fig. 4 and Fig. 5.

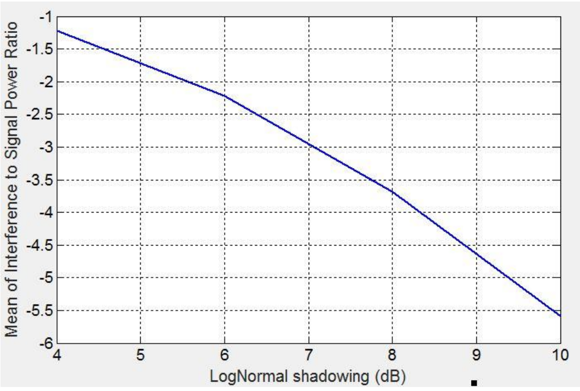


**Fig. 4. Mean of interference to signal power ratio for Log normal shadowing.**

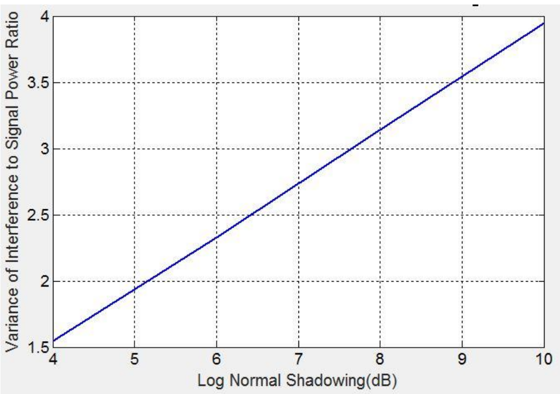


**Fig. 5. Variance of interference to signal power ratio for Log normal shadowing.**

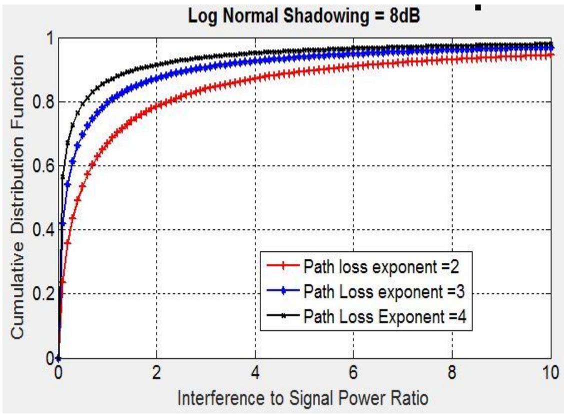


**Fig. 6. CDF versus signal to interference power ratio for different path loss exponent.**

Considering the cases of path loss exponent 2, 3, and 4 for a given standard deviation of shadowing of 8 dB, the impact of path loss exponent on the CDF of I is observed in Fig. 6. Figure illustrates that as path loss exponent increases, probability that interference experienced by the user increases.

Fig. 7 illustrates the impact of path loss exponent on outage probability for log normal shadowing of 8 dB. It is observed that as SIR requirement of user increases, the outage probability increases. For a given SIR requirement, as channel condition worsens outage probability increases. Values in table I indicates that the increase in path loss exponent increases CDF and outage probability.

Fig. 8 and 9 illustrate the probability of subcarrier requirement versus different class numbers for various data rate requirement of 64 Kbps to 1024 Kbps for subcarrier bandwidth of 15 KHz and 30 KHz respectively. Here class number denotes number of

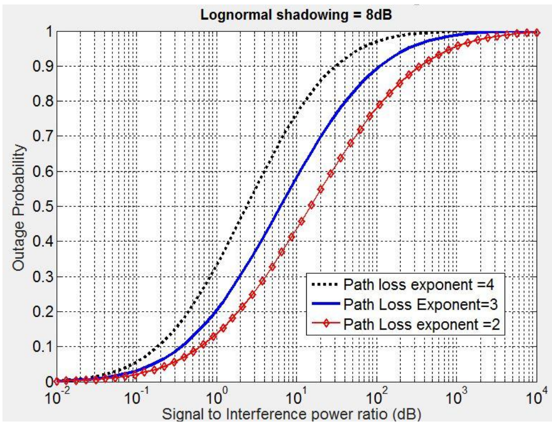


**Fig. 7. Outage probability versus signal to interference power ratio for different path loss exponent.**

**Table- I: Impact of Path Loss Exponent on CDF and Outage Probability**

| Path Loss Exponent | CDF | Outage Probability |
|---|---|---|
| 2 | 0.7 | 0.13 |
| 3 | 0.8 | 0.2 |
| 4 | 0.9 | 0.33 |

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

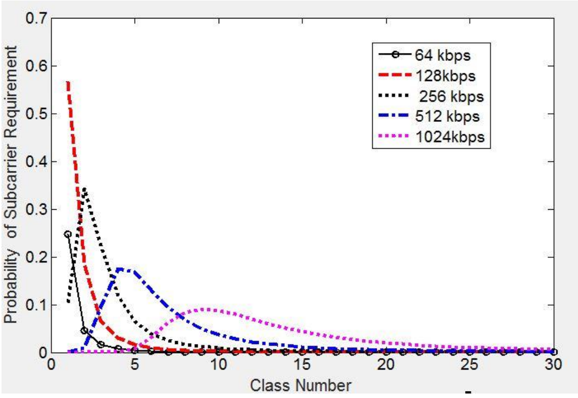


**Fig. 8. Probability of subcarrier requirement as per class number for different data rate requirement at 15 KHz subcarrier bandwidth.**

subcarriers required by a user for different data rate requirement and interference experienced. It is observed that more the data rate required user is assigned higher class number means more subcarriers are required by that user. For any specific data rate ex-512 Kbps, probability of subcarrier requirement goes on increasing till certain class number and then starts reducing again and later becomes zero once its requirement is fulfilled. The peak of probability of subcarrier requirement indicates suitable class number at which performance of the system will be at its best with required data rate. Suitable value of class number is 1 for 64 Kbps and 128 Kbps; it is 3 for 256 Kbps, 5 for 512 Kbps and 9 for 1024 Kbps.

Fig. 9 indicates probability of subcarrier requirement at 30 KHz of subcarrier bandwidth used. On comparison with both the results of Fig. 8 and Fig. 9, we find that the class number is reduced with increase in subcarrier bandwidth. With subcarrier bandwidth of

Table- II: Comparison of class number for Subcarrier bandwidth 15 KHz and 30 KHz.

| Data Rate (Kbps) | Class Number (Number of subcarriers) for 15KHz | Class Number (Number of subcarriers) for 30KHz |
|---|---|---|
| 64 | 1 | 1 |
| 128 | 1 | 1 |
| 256 | 3 | 1 |
| 512 | 5 | 3 |
| 1024 | 9 | 4 |

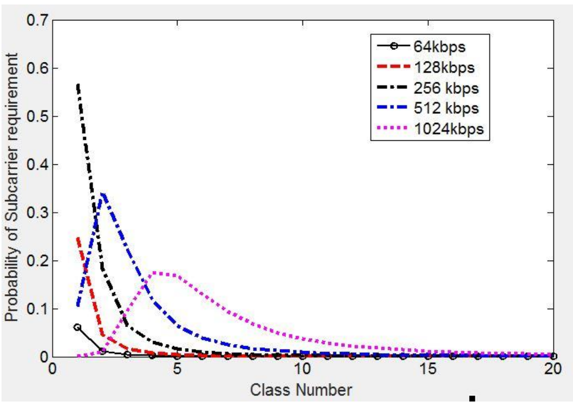


**Fig. 9. Probability of subcarrier requirement as per class number against different data rate requirement at 30 KHz subcarrier bandwidth.**

30 KHz, class number is 1 for 64 Kbps, 128 Kbps, and 256 Kbps, 3 for 512 Kbps and 4 for 1024 Kbps. Table II illustrates the number of subcarriers required for 15 KHz and 30 KHz of subcarrier bandwidth for achieving the required data rate. Less number of subcarriers are required for larger subcarrier bandwidth.

## V. CONCLUSION

In this paper, we determine resource requirement of a user irrespective of its position in OFDMA based CCRN system. First the characteristic of interference to signal power ratio using 1st and 2nd moments are computed. It is observed that as shadowing deviation and path loss exponent increases outage probability increases. Further depending upon SIR experienced users are allocated different classes. A user of class 'm' requires 'm' number of subcarriers.

It is also observed that subcarrier requirement increases with higher data rate requirement and so eventually the class number increases with it. We also performed the analysis for different subcarrier bandwidth. As the subcarrier bandwidth increases the class number decreases means less no of subcarriers will be required. This analysis is useful in efficient resource allocation to the users depending on SIR experienced irrespective of their position.

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