Medium Access Probability of Cognitive Radio Network at 1900 MHz and 2100 MHz

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ABSTRACT
Conventionally fading analysis of wireless LAN or MAN means small scale fading i.e. wide fluctuation of received signal with small variation of time and distance. In analysis of fading channel we consider the received signal in power, voltage or SNR as a random variable then statistical probability density function (pdf) like Rayleigh, Rician or Nakagami-*m* is used to get the probability of different phenomena. Most of the pdf is governed by two parameters: mean and variance of the random variable. In recent literature the mean value is taken constant but in this paper we consider the mean value as a slowly varying random variable and depend on the parameters of large scale fading. In this paper the concept of large and small scale fading is combined, in analysis of performance of cognitive radio network in context of medium access probability specially at 1900MHz and 2100MHz.

Keywords
Blocking probability; path loss model; fading channel; MRC; spatial false alarm.

1. INTRODUCTION
A cognitive radio is a radio that intelligently monitor any spectrum, can sense the presence or absence of a licensed user, called primary user (PU) in that spectrum and can make a decision based on the sensing result. As the demand for the wireless communication is growing significantly fast, higher data rate services are required in the wireless communication. Therefore, there is a need for more spectrum for wireless communication but most of the available spectrum has already been allocated to different agencies and only small parts of it can be licensed to new wireless applications. A study by the FCC has showed that some frequency bands are heavily used in particular location and at particular time but most of the bands are only partly occupied [1]. Different spectrum management models have been introduced in the literature for different radio frequency bands [2] to improve this scenario and among all the proposed models cognitive radio network has got highest importance because of its intelligent way of sensing the network and act accordingly. The basic idea behind CR technique is to find the frequency bands in a licensed spectrum that are not being used by their licensed user, called primary user (PU) and provide an unlicensed user, called secondary user (SU) opportunity to use that frequency without causing any harm to the PU. A Secondary user can use the frequency band as long as it does not create any harmful interference with the primary user. CR technology introduces a way to improve the spectrum utilization by discovering spectrum opportunities in both licensed and unlicensed spectrum bands. The main functions of CR network is divided into four parts [3]: spectrum sensing, spectrum management, spectrum mobility and spectrum sharing. In spectrum sensing the SU detects the presence or absence of PU in the sensing region and take the decision of using the spectrum accordingly. There are two binary hypothesis in spectrum sensing: H_1: the PU is present and in transmitting mode, H_0: the PU is absent; so that SU can use the spectrum [4]. Spectrum management involves capturing the best available network among the free networks detected to meet the SUs communication requirement. Spectrum mobility defines as the process when a SU change its frequency. Spectrum sharing involves the method of fair spectrum schedule. As spectrum sensing the major challenge in CRN, a fully distributed and scalable cooperative spectrum sensing scheme is proposed in [5] based on recent advances in consensus algorithm; where the SUs can maintain coordination based on only local information exchange without a centralized common receiver.

Recently, special attention is given on spatial false alarm (SFA) problem where a busy PU outside the sensing region can be detected by a SU as in transmitting mode inside the sensing region. Therefore, the SU misinterprets it and hereby loses the opportunity to utilize the unused channel. To solve the SFA problem, in [6] the authors shows the cause of this sensing problem using both stochastic geometry and the statistical signal processing principle and proposed a reliable performance evaluation method to improve its negative impact.

Medium Access Probability (MAP) is the probability that a SU detects no busy PU inside the sensing region. A theory has been developed in [6] to find the expression for the medium access probability by including the effect of the conventional false alarm (CFA) probability and the SFA probability. In this paper the authors explicitly discusses the probability of correct decision only for the case of received signal under Normal distribution of the fading channel. The work of [7] has been enhanced in [8] for three small scale fading channels: Rayleigh, Rician and Nakagami-*m* fading channels to get the real scenario of CR network in an urban area. The work of [8] is further enhanced in [9], where the fading channels are considered under two popular path loss models (Lee's and Okumura-Hata path loss model) and two dimensional traffic models are used to evaluate the performance of CR network.

Again the increasing demand for mobile Internet and related services has increased the need for huge bandwidth along with high speed data rate. Therefore the 4G technology is becoming the customers' demand in every country as 4G mobile devices are IP-based and able to provide data speeds of up to 100 Megabits per second (Mbps) when the device is being used while moving and up to 1 Gigabit per second (Gbps) when stationary. In the current scenario when the available spectrum is limited and the allocated spectrum is heavily underutilized, 4G technology with CR network will bring a revolutionary change in the world of wireless communication. Two standards are widely used with 4G technologies: WiMAX and Long Term Evaluation (LTE). In [10] the role of CR network in fourth generation wireless communication is reviewed. In this paper, the authors discuss the benefit of using CR network over 4G technology based in 802.16 standard (WiMAX).

For mobile cellular networks, such as Third Generation Partnership Project (3GPP) Long Term Evolution – Advanced (LTE-A), CR may be incorporated as a technique for carrier aggregation that combines together disparate bands for wider channels, but allow for higher spectrum utilization. Theoretical study has been done on [11] and [12] analyzing the scope of CR-enabled LTE system, such as LTE operations on TV white space (TVWS). In [11] the experimental framework for cognitive radio enabled LTE is introduced. The impact of a secondary CR-enabled system on the primary LTE OFDM has been studied in [13] and it is found that the coexistence of OFDM-based LTE and GFDM is possible and in some cases GFDM is more suitable than OFDM as a next generation CR waveform to access the frequency holes in an LTE cellular system.

In the present paper, the work of Han et. al. [7] is enhanced for the following small scale fading channels: Nakagami-m, Rayleigh, Normal, Weibull, Rayleigh with maximal ratio combining (MRC) and Rayleigh with Selection Combining Distribution considering Lee's path loss model under the frequency of 1900 and 2100 MHz as these frequency ranges are suitable for 4G wireless communication.

The rest of the paper is organized as follows: section II deals with mathematical analysis of medium access probability and Lee's path loss model; section III provides the result that are pertinent to the theoretical analysis of section II and section IV concludes the paper.

2. SYSTEM MODEL

2.1 Medium Access Probability of Cognitive Radio

A SU has sensing territory where it has to detect presence of a PU. The PU may be in idle mode (on state but not transmitting) or in transmitting mode inside or outside the sensing zone. To ensure the situation for a SU we consider three probabilities of occurrences like:

$P(H_0^-) \rightarrow$ Probability of a PU in idle mode inside the sensing territory,

$P(H_0^+) \rightarrow$ Probability of a PU in transmitting mode outside the sensing territory, and $P(H_1) \rightarrow$ Probability of a PU in transmitting mode inside the sensing territory.

Using above probability we have to maintain two correct decisions:

$$P_{C1} = P(H_0^-)\left\{1 - P(H_1 \mid H_0^-)\right\} \quad (1)$$

and

$$P_{C2} = P(H_0^+)\{1 - P(H_1 \mid H_0^+)\} \quad (2)$$

The sum of above two correct decisions is called the MAP (medium access probability) expressed as:

$$P_C = P_{C1} + P_{C2}$$

For Nakagami-*m* fading case Pc1 and Pc2 can be expressed as [9]:

$$P_{c1} = (1-p)\left(1 - \int_{\varepsilon}^{\infty} \frac{m^m \gamma^{m-1}}{\gamma_{av}\Gamma(m)} e^{-m\gamma/\gamma_{av}} d\gamma\right) \quad (3)$$

;where

$$P(H_0^+) = P = p$$

$$P_{c2} = p. \int_{r_s}^{r_s\sqrt{\frac{p}{1-H_0}}} \{1 - D(r)\} \frac{2r}{r_s^2 . \frac{p}{1-H_0}} dr \quad (4)$$

and

$$D(r) = \int_{\varepsilon}^{\infty} \frac{m^m \gamma^{m-1}}{\gamma_{av}(r)\Gamma(m)} e^{-m\gamma/\gamma_{av}(r)} d\gamma$$

Here the average SNR γ_{av} depends on distance.

The Medium Access Probability for Nakagami-m, Rayleigh, Normal and Weibull fading environment including MRC and Selection Combining schemes will be determined in this paper. The relative performance at 1900 MHz and 2100MHz will also be observed.

2.2 Lee's Path Loss Model

Lee's model can be used to predict area-to-area path loss. The model consists of two parts:

a) Path loss prediction for a specific set of conditions.
b) Adjustment factors for a set of conditions different from the specified one.

The parameters under specified condition are:

Carrier frequency, f_c = 900MHz
BS antenna height, h_{BS} = 30.48 m (100ft)
MS power at the antenna =10W
BS antenna gain, g_1 = 6dB above dipole gain
MS antenna gain, g_2 = 0dB above dipole gain
MS antenna height, h_{MS} = 3 m (10ft)
The model requires two parameters:
Power at 1 mile interception, P_{ro} in dB
Path loss exponent γ
In this model, the received power:

$$P_r = P_{ro}\left(\frac{r}{r_0}\right)^{-r} . \left(\frac{f}{f_0}\right)^{-n} . \alpha_0 \quad (5)$$

In (dB) the received power will be:

$$P_r = P_{ro} - \gamma 10\log\left(\frac{r}{r_0}\right) - n10\log\left(\frac{f}{f_0}\right) + \alpha_0 \quad (6)$$

;where *n* is a constant whose value lies in the ranges of 2 to 3 depends on the geographical location and operational frequency.

The parameter α_0 is the adjustment factor for different set of conditions expressed as:

$$\alpha_0 = \sum_{i=1}^{5} \alpha_i$$

$$\alpha_1 = \left(\frac{\text{New base station antenna height (m)}}{30.48\,(\text{m})} \right)^2$$

$$= \left(\frac{\text{New base station antenna height (ft)}}{100(\,ft)} \right)^2$$

$$\alpha_2 = \left(\frac{\text{New MS antenna height (m)}}{3} \right)^v$$

$$= \left(\frac{\text{New MS antenna height (ft)}}{10} \right)^v$$

$$\alpha_3 = \left(\frac{\text{New transmitt power (watts)}}{10\,(\text{watts})} \right)$$

$$\alpha_4 = \left(\frac{\text{New base station antena gain w.r.t dipole antena } \lambda/2}{4} \right)$$

$$\alpha_5 = \left(\frac{\text{antena gain correction factor at MS}}{1} \right)$$

$$\alpha_5 = \left(\frac{\text{antena gain correction factor at MS}}{1} \right)$$

Incorporating all the parameters the final expression of α_0 becomes,

$$\alpha_0 = 20\log(h_{BS}) + 10\log(P_t) + g_1 + g_2 + 10\log(h_{MS}) - 64$$

The variation of average SNR with distance,

$$\gamma_{av}(r) = \left(\frac{r}{r_0} \right)^{-n} \left(\frac{f}{f_0} \right)^{-3.84} .\alpha_{01} \qquad (7)$$

Where, $\alpha_{01} = 10^{\frac{\alpha_0}{10}}$

Correction factor to determine v in α_2

v = 2, for new mobile-unit antenna height > 10 m

v = 1, for new mobile-unit antenna height < 3 m

Typical parameters of Lee's path loss model are shown in table-1.

Table-1 Path loss parameters

Terrain	**P_{ro}(dBm)**	***n***
Free space	-45	2
Open area	-49	4.35
Suburban area	-61.7	3.84
Urban area(New York)	-64	4.31
Urban area(Tokyo)	-84	3.05

Using the path loss parameters of table-1 the variation of path loss in dB against distance in Km is shown in fig.1 for sub-urban, urban and rural areas. Path loss is highest in a dense urban area and lowest in rural or open area because of density of obstacle since EM wave is absorbed, scattered, reflected and refracted by big obstructions.

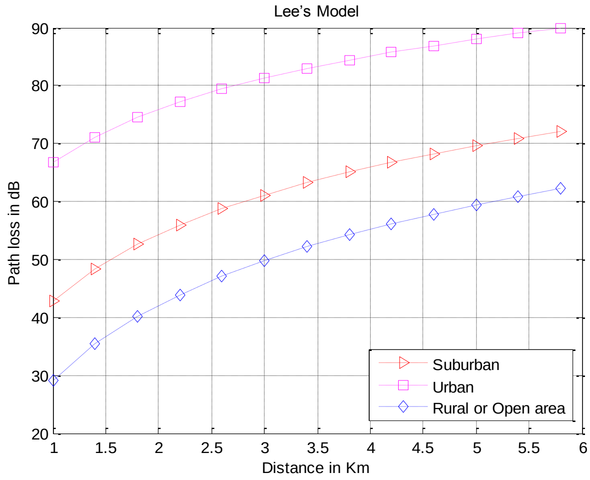

Fig.1 Comparison of large scale path loss

3. RESULT

In this paper, Lee's path loss model has been considered to evaluate the average SNR at the receiver i.e γ_{av} is a function of large scale path loss parameters. First of all the profile of medium access probability P_{MA} against the probability of the access opportunity $P(H_0)$ for Nakagami-*m*, Rayleigh, Normal and Weibull fading environment has been observed. Two carrier frequencies: 1900MHz and 2100MHz destined for 3G and 4G mobile are considered here. In Lee's path loss model we used the typical parameters as: n = 2.7, r_0 = 1.609Km, f_0 = 900 MHz, h_{BS} = 100 m h_{MS} = 5m, g_1 = 0 dB, g_2 = 12dB and P_t = 45 W. Again the parameters for different pdf are: Normal distribution, σ = 0.42 and mean signal strength μ is function of path loss parameters; Weibull fading channel, β = 0.25 and α is function of path loss parameters; Nakagami-*m* fading case m = 2 and γ_{av} is a function of path loss parameters; and Rayleigh fading case the only parameter γ_{av} is a function of path loss parameters.

The PMA is found larger at 1900MHz compared to 2100MHz for the corresponding fading cases. If we compare all the four fading at a particular carrier frequency the PMA in ascending order are: Normal, Nakagami-*m*, Rayleigh and Weibull visualized from fig.2.

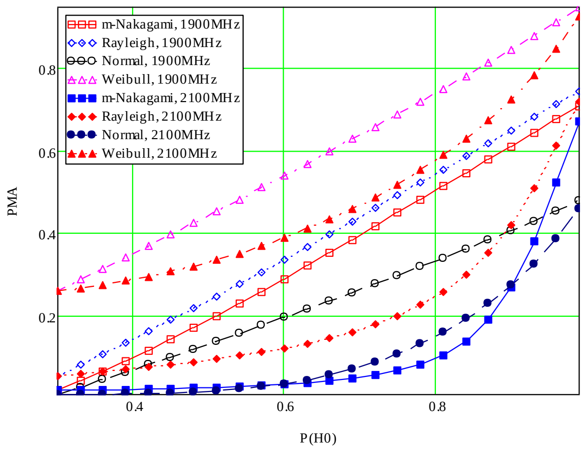

Fig. 2 Comparison of P_{MA} under different fading cases at 1900 and 2100MHz

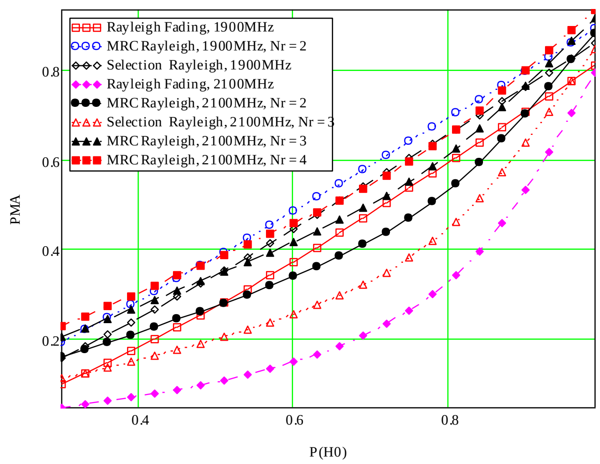

Fig. 3 Comparison of P_{MA} under two combining schemes at 1900 and 2100MHz

The impact of combining schemes (MRC and selection combining scheme) at receiver is shown in fig.3 where PMA is found larger with incorporation of any type of combining scheme. In this case the receiver becomes highly sensitive to the spectrum hence only the one state of the PU vicinity to the SU will be treated as transmitting state of the PU hence a free channel becomes unutilized. Therefore the throughput of the network will be reduced, which violates the conventional idea of combining scheme. To maximize the throughput optimum sensitivity of the SU receiver has been ensured so that it can detect the exact condition of the PU. For both the fig.2 and 3 PMA is found larger at 1900MHz than the case of 2100MHz because of larger path loss at higher frequency hence combining scheme is more appropriate at higher frequency.

4. CONCLUSION

In this paper, the performance of cognitive radio network based on medium access probability under Nakagami-*m*, Rayleigh, Normal, Weibull fading environment has been evaluated. The impact of the number of antenna at receiving end and combining scheme (MRC) is also depicted explicitly. Special focus has been given for the frequencies of 1900 and 2100MHz to include both 3G and 4G networks. The entire work can be extended incorporating other path loss models and also applying the concept of 2-hop wireless link for micro cell instead of femto or pico cell.

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