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Performance Evaluation of CognitiveRadio Network under different pathloss models using frequency range of 1900 and 2100 MHz

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Abstract—The correct detection of the presence of licensed user (Primary user) is the most essential requirement of Cognitive Radio Network (CRN). Otherwise the PU will face jamming signal from unlicensed user (Secondary User) and therefore will not be able to transmit. At the same time if a PU is not in transmitting mode but SU senses the presence of PU in transmitting mode then the SU will stop transmission even though the frequency band is free to use. In this situation, different path loss models incorporating with different fading channels have been proposed previously to measure the performance of CRN. Fading is generally a signal loss due to sudden alteration in channel response. In this paper, the aim is to evaluate the performance under different types of fading condition (such as Rayleigh, Nakagami-m, Weibull and Normal) with the incorporation of different types of path loss models such as Lee's path loss Model, COST-231 Walfisch Ikagami Model and ECC-33/ Hata Okumura Extended Model along with MRC and Selection combining Scheme under frequency ranges of 1900 MHz and 2100 MHz as this range is well suited for 4G technology.

Index Terms—Cognitive radio network, Lee's model, Cost-231 Walfisch-Ikagami model, ECC-33 model, Fading channel, Selection combining scheme, Maximal Ratio Combinig Scheme.

1 INTRODUCTION

Cognitive radio network represents a modern approach in wireless engineering where radios are designed with a unique level of intelligence and agility. A cognitive radio is a radio that employs model based reasoning to achieve a specified level of competence in radio-related domains. These radios are able to observe, sense, and identify the circumstances of their operating background, and dynamically reconfigure their own features to best match those circumstances. It enables radio devices to use spectrum in entirely innovative and sophisticated ways. The FCC studied that some frequency bands are heavily used in particular location and at particular time but most of the bands are only partly occupied [1]. For different radio frequency bands several spectrum management models have been introduced in the paper [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. There are four main functional parts of CR network [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 takes the decision of using the spectrum accordingly. There are two binary hypotheses in [4] 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. Spectrum management involves capturing the best available network among the free networks detected to meet the SUs communication requirement. As spectrum sensing is 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, spatial false alarm (SFA) problem has become a major point of attention. 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 no busy PU inside the sensing region is detected by a SU. To find the expression for the medium access probability by including the effect of the conventional false alarm (CFA) probability and the SFA probability a theory has been developed in [6]. 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. The medium access probability of CRN in 1900 and 2100 MHz is measured for only Lee's model in [10]. In [11] 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 standards

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(WiMAX). In [12] the experimental framework for cognitive radio enabled LTE is introduced. The secondary CR-enabled system has large influence on the primary Long Term Evolution OFDM that has been studied in [13].

Wireless access network has becoming vital tools in maintaining communications especially at home and workplaces due to communication models. Propagation models can be classified mainly into two extremes, i.e. fully empirical models and Deterministic models. There are some models which have the characteristics of both types. Those are known as Semi-empirical models. Empirical models are based on practically measured data. Since few parameters are used, these models are simple but not very accurate. The models are categorized as empirical model for macro cellular environment which include Hata model, Okumura model, COST-231 Hata model. On the other hand, deterministic models are very accurate. Some of the examples include Ray Tracing and Ikegami model. As mentioned earlier, semi-empirical models are based on both empirical data and deterministic aspects. Cost-231 Walfisch-Ikegami model is categorized as a semi empirical model. All these models estimate the mean path loss based on parameters such as antenna heights of the transmitter and Receiver, distance between them, etc. These models have been extensively validated for mobile networks. Most of these models are based on a systematic interpretation of measurement data obtained in the service area [14], [15], [16], [17], [18], [19], [20], [21], [22]. Hata-Okumura Extended model or ECC-33 model is one of the most widely used empirical models [23].

In this paper, we have enhance the work of [8], [9], [10] for the following fading channels: Nakagami-*m*, Rayleigh, Normal, Weibull, Rayleigh with Maximal Ratio Combining Scheme (MRC) and Rayleigh with Selection Combining Scheme considering Lee's path loss model under the frequency of 1900 and 2100 MHz and the work of [22], [23], [24] by considering COST 231 Walfisch-Ikagami model and ECC-33/Extended Okumura Hata model using the same frequency range as these frequency ranges are suitable for 4G wireless communication and finally their result will be compared to obtain the best performances amongst them.

2. System Model

2.1 Lee's Model

There are two predictions for Lee's model to determine the area-to-area path loss [10]. These are:

- A specific set of conditions for Path loss prediction
- 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} = 100 m

MS power at the antenna =50W

BS antenna gain, g_1 = 0 dB above dipole gain

MS antenna gain, g_2 = 12 dB above dipole gain

MS antenna height, h_{MS} = 5 m

The model requires two parameters:

Power at 1 mile interception, Pro in dB

Path loss exponent γ

In this model, received power:

$$P_r = P_{ro}\left(\frac{r}{r_0}\right)^{-r} \cdot \left(\frac{f}{f_0}\right)^{-n} .\alpha_0 \quad (1)$$

In (dB) the received power will be:

$$P_r = P_{ro} - \gamma 10\log\left(\frac{r}{r_0}\right) - n10\log\left(\frac{f}{f_0}\right) + \alpha_0 \quad (2)$$

Here n is a constant whose value can be in the ranges of 2 to 3 depends on the geographical location and operational frequency.

α_0 i\s the adjustment factor for different set of conditions expressed as:

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

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

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

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

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

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

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

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

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,

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

(7)

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

2.2 Cost-231 Walfisch-Ikagami Model

With the consideration of a number of parameters, Cost-231 Walfisch–Ikagami model allows an excellent path loss model to explain the characters of an urban area such as average height of buildings, widths of roads, building separation and road orientation with respect to the straight radio path. This model differentiated between line-of-sight (LOS) and non-line-of-sight (NLOS) circumstances. This model is appropriate for frequencies 800MHz to 2000 MHz and above where distance can be very small like 200m [22].

For the LOS case the prediction need only two parameters.

$$l_p = 42.6 + 20\log(d) + 20\log(f) \quad (3)$$

This LOS equation is similar to the free space loss equation, where d= distance in Km and f= frequency in MHz.

As NLOS equation is the sum of free space loss l_0, the multiple screen diffraction loss l_{msd} and the rooftop-to-street diffraction loss l_{rts}, so it is more problematical to calculate.

$$lp = \begin{cases} l_0 + l_{rts} + l_{msd} & l_{rts} + l_{msd} > 0 \\ l_0 & l_{rts} + l_{msd} <= 0 \end{cases} \quad (4)$$

Free space loss is

$$l_0 = 32.4 + 20\log(d) + 20\log(f_c);\ d \geq 20m \quad (5)$$

Roof top-to-street diffraction and scatter loss is

$$l_{rts} = -16.9 - 10\log(w) + 10\log(f_c) + 20\log(\Delta h_m) + l_{ori} \quad (6)$$

$$l_{ori} = -10 + 0.354(\phi) \quad 0 \leq \phi < 35^\circ$$

$$\Delta h_m = h_{roof} - h_m$$

h_m= Mobile antenna height

h_{roof} = Average roof height

w = street width

L_{ori} is the street orientation loss:

$$l_{ori}(\phi) = \begin{cases} -10 + 0.354\varphi;\ 0 \leq \varphi < 35^o \\ 2.5 + 0.075(\varphi - 35);\ 35^o \leq \varphi < 55^o \\ 4.0 - 0.114(\varphi - 55);\ 55^o \leq \varphi < 90^o \end{cases}$$

Where ϕ = road orientation with respect to the direction of radio propagation in degrees incident angle relative to the street.

Multi-screen diffraction loss is

$$l_{msd} = l_{bsh} + k_a + k_d\log(d) + k_f\log(f_c) - 9\log(b) \quad (7)$$

Where b = the mean value for building separation.

And

$$L_{bsh} = \begin{cases} -18\log(11) + (h_{BTS} - h_{roof}); & h_{BTS} > h_{roof} \\ 0; & h_{BTS} < h_{roof} \end{cases}$$

$$K_d = \begin{cases} 18; & h_{BTS} < h_{roof} \\ 18 - 15\dfrac{h_{BTS} - h_{roof}}{h_{roof} - h_{MS}}; & h_{BTS} > h_{roof} \end{cases}$$

h_{BTS} = Height of base station

h_{roof} = Height of roof-top

$$K_f = 4 + \begin{cases} 0.7\left(\dfrac{f}{925} - 1\right); & \text{medium city \& suburban centers} \\ 1.5\left(\dfrac{f}{925} - 1\right); & \text{urban centers} \end{cases}$$

$$K_a = \begin{cases} 54; & h_{BTS} > h_{roof} \\ 54 - 0.8(h_{BTS} - h_{roof});\ d \geq 0.5\text{Km and } h_{BTS} \leq h_{roof} \\ 54 - 1.6(h_{BTS} - h_{roof})d;\ d < 0.5\text{Km and } h_{BTS} \leq h_{roof} \end{cases}$$

$$\Delta h_{BTS} = h_{BTS} - h_{roof}$$

The parameter *Ka* increases the path loss in case the BTS is below the rooftop. The parameters K_d and K_f are for adjusting the correction between the distance and frequency with multi-screen diffraction.

2.3 ECC-33/Hata Okumura Extended Model

ECC-33/Hata-Okumura Extended Model is one of the most widely used empirical propagation model which is founded on the Okumura Model. In this model data speed doesn't exceed 3GHz. International Telecommunication Union (ITU) expanded this model up to 3.5GHz. This model is largely used for urban environment particularly in large and medium size cities. This model is developed by Electronic Communication Committee (ECC). The path loss of this model is defined by

[24],

$$PL = A_{fs} + A_{bm} - G_b - G_r$$

Where,

A_{fs} = Free space

A_{bm} = Basic median path loss

G_b = Transmitter antenna height gain factor

G_r = Receiver antenna height gain factor

They are individually defined as:

A_{fs} = 92.4 + 20log10 (d) + 20log10 (f)

A_{bm} = 20.41 + 9.83log10 (d) + 7.894log10 (f) + 9.56[log10 (f)]^2

G_b = log10 (hb÷200)[13.958 + 8(log10(d))^2]

For medium cities, Gr will be expressed in:

G_r = [42.57 + 13.7log10 (f)][log10(hr) – 0.585]

For large cities, G_r = 0.759hr – 1.862

2.4 Medium Access Probability of Cognitive Radio

To correct the functions of CRN we have to find correct expression for the medium access probability by including the effect of the conventional false alarm (CFA) probability and the spatial false alarm (SFA) probability in the case of different fading channel. SU senses no busy PU inside the sensing region using MAP. In cognitive radio network the objective of conventional senescing is to determine the real on-off status of a PU inside the SU's sensing range. Therefore there are two hypotheses: PU in off state that determines access opportunity is available for SU or PU in on state that determines access opportunity is unavailable is obtained by analyzing the received signal. There can be three possible states for a SU [10]:

$P(H_0^-)$→Probability of a primary user only at "on" sate within the sensing region.

$P(H_0^+)$→At the transmitting state, the probability of a primary user outside the sensing region.

$P(H_1)$→Probability of a primary user at transmitting mode inside the sensing region.

For these three possible states we have to maintain two correct decisions:

$$P_{C1} = P(H_0^-)\left\{1 - P(H_1 \mid H_0^-)\right\} \quad (8)$$

And $$P_{C2} = P(H_0^+)\{1 - P(H_1 \mid H_0^+)\} \quad (9)$$

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 P_{c1} and P_{c2} can be expressed as:

$$P_{c1} = (1-p)\left(1 - \int_{\varepsilon}^{\infty} \frac{m^m \gamma^{m-1}}{\gamma_{av}\Gamma(m)} e^{-m\gamma/\gamma_{av}} d\gamma\right) \text{ Where } P(H_0^+) = p \quad (10)$$

$$P_{c2} = p. \int_{r_s}^{r_s\sqrt{\frac{p}{1-H_0}}} \{1 - D(r)\} \frac{2r}{r_s^2 . \frac{p}{1-H_0}} dr \quad (11)$$

Where the average SNR γ_{av} depends on distance, r_s is the radius of sensing zone and ε is the threshold of detection. SNR $\gamma_{av}(r)$ depends on distance and large scale fading parameters. Medium Access Probability of Nakagami-*m*, Rayleigh, Normal and Weibull fading environment including MRC and Selection Combining schemes will be calculated here. Then we will compare the performance of these different fading environments for three different models at the frequency range 1900 MHz and 2100MHz.

3. Result and discussion

To determine the average SNR, we have considered three path loss models at the receiver end where γ_{av} is a function of path loss parameters. First of all for Lee's model we have observed that the profile of medium access probability *PMA* against the probability of the access opportunity $P(H_0)$ for Nakagami-*m*, Rayleigh, Normal and Weibull fading environment for both the case of carrier frequencies of 1900MHz and 2100MHz. In Lee's path loss model the parameters are: n = 2.7, r_0 = 1.609 Km, f_c = 900 MHz, h_{BS} =100 m, h_{MS} = 5m, g_1 = 0 dB, g_2 = 12dB and P_t = 45 W. The other parameters for different fading environment 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. The Probability of Medium Access is greater at 1900MHz than to 2100MHz for the corresponding fading cases. We can determine the visible comparison of the fading channels and combining scheme to analyze their performance.

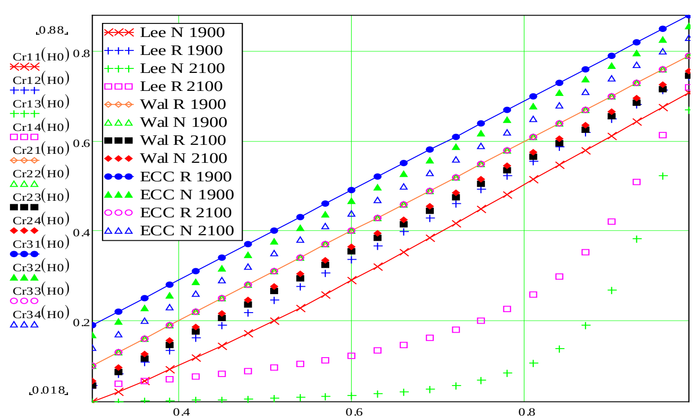

Fig1: Rayleigh and Nakagami channel performance

In case of Cost-231 Walfisch-Ikagami model we have chosen same parameter as we have considered in Lee's model. Here the graph remain different result from Lee's model under all distribution which indicate that the PMA increases exponentially and different fading are very close to each other and also follow linear distribution. Therefore Cost-231 Walfisch-Ikagami model provide better result in the urban area that compromise different types of environment and the receive signal is better for Weibull than other fading channels.

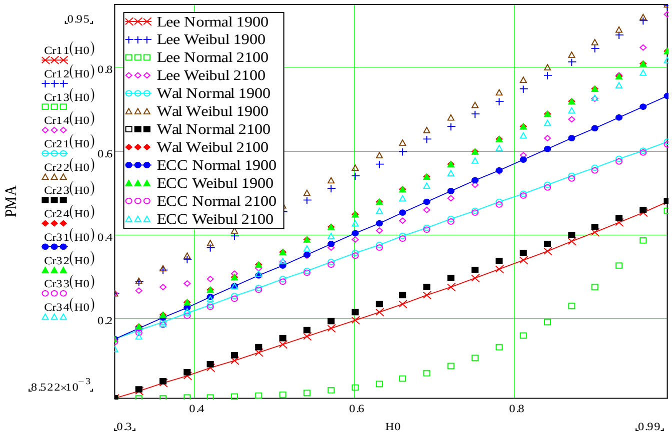

Fig2:Nornal and Weibull channel performance

In ECC-33/ Hata-Okumura Extended path loss model we have considered f=1900 and 2100 MHz, r= 1000km, h_r=5m, h_b=100m. All the other channel parameters are same as above. Here the fading

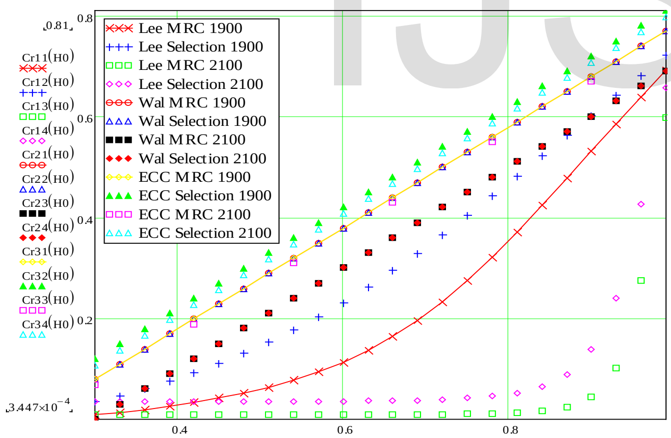

Fig3: MRC Rayleigh and Selection Combining Rayleigh performance

channels are increased exponentially and equally in 1900 MHz and 2100 MHz. PMA is found larger at 1900 MHz than the case of 2100 MHz because of larger path loss at higher frequency hence combining scheme is more appropriate at higher frequency. It is theoretically found that ECC-33/Hata-Okumura Extended model can work on 2100 MHz but practically the performance is degraded.

Fig.1 displays the comparison for Rayleigh and Nakagami fading at a particular carrier frequency for the mentioned three models. Here ECC-33 model shows the best performance for both Rayleigh and Nalagami fading channel at the frequency range 1900 MHz. In **Fig.2** Normal and Weibull fading channel's performance are compared where we get that cost-231 Walfisch-Ikagami model shows the best performance for these two fading channels at the frequency 1900 MHz. The impact of combining schemes (MRC and selection combining scheme) at receiver is shown in the **Fig.3** where *PMA* is found larger with incorporation of any type of combining scheme and ECC-33 shows the highest performance. For all the fig.1, fig.2 and fig.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 and among three models ECC-33 performs better than lee's and cost-231 Walfisch-Ikagami model.

4. Conclusion

In this paper, we have evaluated the performance of cognitive radio network based on medium access probability under Nakagami-*m*, Raileigh, Normal, Weibull fading environment. The impact of the number of antenna at receiving end and combining scheme (MRC) is also depicted explicitly. We worked specially in the frequency range of 1900 and 2100MHz since this range of frequency is destined for 4G network. We have extended the work incorporating three path loss models under different fading channels through the MATHCAD simulation and can also apply the concept of 2-hop wireless link for micro cell instead of femto or pico cell in future. The result of the simulation shows which fading channel will perform better under the path loss models in the specified frequency range. It will also be helpful for providing more accurate signal coverage of modern wireless networks.

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