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A Review on Path Loss Models of Spectrum Sensing in Cognitive Radio Networks

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***Abstract*— Cognitive Radio networks provide advancement to the wireless generations. Due to the fixed spectrum allocation policy, a wider portion of the spectrum is underutilized in many areas. Spectrum sensing adds intelligence to Cognitive Radios that dynamically identifies the spectrum holes. Many spectrum sensing algorithms are proposed in literature to sense the spectrum holes in a noisy environment. But, there are several challenges that are to be considered in simulating the algorithms in a real-time channel. In this paper, a review of various issues of spectrum sensing is discussed.**

Keywords—Co-operative spectrum sensing, path loss, fading, noise uncertainty.

I INTRODUCTION

The concept of cognitive radio was first introduced by Joseph Mitola III and Gerald Q. Maguire, Jr in 1999. The radio frequency spectrum contains electromagnetic radiation with frequencies between 3000 Hz and 300 GHz. The fixed spectrum allocation prevents frequencies that are rarely used by unlicensed users, even when their transmissions would not interfere at all with primary user's usage. Cognitive radio is the most intelligent means of facilitating effective usage of spectrum holes. This communication system senses its surrounding environment, and adapts itself to changes in the incoming RF stimuli by making suitable changes in carrier frequency, transmission power and other parameters.

Spectrum sensing is the primary function of Cognitive Radio[1]. This technique identifies the spectrum holes. The CR then performs spectrum management to select the most appropriate channel meeting with the secondary user requirements. The CR then calculates the spectrum mobility to predict how long the spectrum holes are likely to remain available for use to the secondary users. Finally, spectrum sharing is done to distribute the spectrum holes fairly among the secondary users in accordance with usage cost

A preemptory challenge in spectrum sensing is to sense in very low SNR regions. Several sensing techniques have been proposed in literature for enhanced utilization of the spectrum band. In paper [2] [3] and [4] some of the spectrum sensing techniques are-Energy detection technique, Matched filter Cyclo-stationary techniques. Energy detection technique[1] is a simple blind detection technique. It does not consider the structure of the signal. But its performance is susceptible to uncertainty in noise power Matched filtering [1] requires shorter detection time compared to Energy detection technique. It gives best results when secondary user has a prior knowledge of primary user signal. It maximizes output SNR for a given signal. But it fails in the scenario where the information from the primary user is unknown. Cyclo-stationary detection [1] is a method which utilizes the cyclic features of the signal. Cyclo-stationary signals exhibit the features of periodic statistics and spectral correlation, a characteristic which is not found in stationary noise and interference. Thus, cyclo-stationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. But this method uses high number of computations and longer sensing time.

A major drawback of the Energy Detection method is that it requires information on the noise power but experiences noise uncertainity. Covariance detection[5] does not require prior information about the signal and noise power as this detector exploits space-time signal co-relation. The signal and noise generally have different co-variances which can be used to estimate the presence of primary user. However, there is uncertainity in its performance under fading channels.

The presence of primary user can also be formulated with unknown noise levels. Entropy detection[6] is a simple technique in which the entropy of the received signal is compared to a suitable threshold value to determine the presence of a primary user. This method achieves a good performance in low SNR regions.

The other sections of the paper are organized as follows: Section II presents classification of spectrum sensing techniques. Section III emphasizes on challenges faced by Spectrum Sensing and finally section IV closes with conclusions.

II CLASSIFICATION OF SPECTRUM SENSING TECHNIQUES

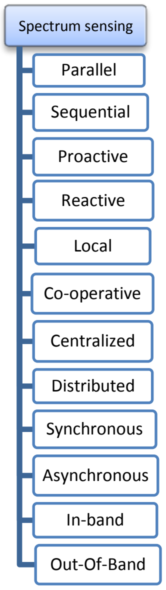

Fig 1: *Classification of Spectrum Sensing techniques*

Fig 1depicts the classification of various spectrum sensing techniques.
To begin with Parallel Sensing, If there are N frequency sensing channels, it senses all the N channels at the same time. It requires N sensing devices. Whereas, sequential sensing senses the N channels, one at a time. It might be difficult in finding an empty channel to carry out sequential sensing.

Another sensing technique is Proactive sensing where the CR performs sensing operation even though it does not transmit immediately. In comparison, reactive sensing technique is more energy efficient than proactive sensing. In this technique, CR performs the sensing operation only if it has to perform receive or transmit operation. However, the time taken to find an empty channel is higher than proactive sensing.

In Local Sensing, each CR senses on its own and uses its data to make a decision on channel state, whether idle or busy. But in Cooperative Sensing, CR shares its sensing information with others and utilizes the sensing results of others to make a decision. This method is a solution to hidden node or fading channel problem.

Centralized Sensing is a technique where a Central node or Fusion center collects the sensing information and then makes a decision on channel state on whether it is idle or busy. If the Central node fails, the whole system collapses .It is called Single Sensing Point of Failure. On the contrary, Distributed (Decentralized) technique is when each CR makes its own decision on the channel state. This technique is more efficient than Centralized sensing.

On the basis of clock schedule, sensing is divided into synchronous and asynchronous. In Synchronous sensing, all the CR's have a common time schedule to sense the channel. On the other hand, asynchronous sensing is performed when sensing is done to sense all the other channels other than the channel it is at present, to find an available channel in case of presence of a primary signal.

III. CHALLENGES OF SPECTRUM SENSING

The first part of this section elaborates few path loss models which explain the path loss which occurs during the propagation of the signal from the transmitter to the receiver.
The following models being:

- Friis Free Space propagation Model
- Log Distance Path Loss or Log Normal Shadowing Model
- Empirical models- Hata – Okumura Model, COST 231 Extension to Hata Model, COST 231-Walfish-Ikegami Model, Erceg Model

The second half emphasizes on signal fading. This phenomenon occurs on an encounter of a transmitted signal with an obstacle. Several important models of fading such as Rayleigh fading model, Rician fading model and Nakagami fading model are highlighted.

Path Loss

Path loss is used to estimate the signal loss between the transmitted and received signal when a clear path lies in between them.
It is also used to measure the attenuation loss due to various environmental factors between the received and transmitted signal. The commonly used models for path loss modeling are:

A. Path Loss Models

Friis Free Space Propagation Model

This model explains path loss in the channel. Propagation loss[7] is the loss which occurs during the transmission of the signal.

In this model, the received power decreases in the power of 2, when the distance from the transmitting antenna increases.

The received power is given by [7]:

$$P_r \propto 1/d^2 \qquad (1)$$

$$P_r(d) = P_t \frac{G_t G_r \lambda^2}{(4\prod d)^2 L} \qquad (2)$$

$P_r(d)$=Received signal power in Watts.

P_t= Transmitted signal power in Watts

G_t,G_r = Gains of transmitter & receiver antennas with respect to an isotropic antenna.

λ= Wavelength of carrier signal in meters.

L = Losses other than propagation losses like loss at the antenna, transmission line attenuation, filters etc.

This model is applicable only in the far-field of the transmitting antenna. Propagation loss is the difference between the transmitted and received power of the antenna. It is given by [7]

$$P_L(db) = -10\log_{10}\left(\frac{\lambda}{4\prod d}\right)^2 = +20\log_{10}\left(\frac{4\prod d}{\lambda}\right) \qquad (3)$$

If we substitute lambda =c/f, we see that the propagation loss is more when the frequency is more.

$$\lambda = c/f \qquad (4)$$

$$P_r(d) = P_t \frac{G_t G_r c^2}{(4\prod df)^2 L} \qquad (5)$$

It is seen that the received power decreases at the rate of 20dB for every increase in 10 λ .

Log Distance Path Loss or Log Normal Shadowing Model

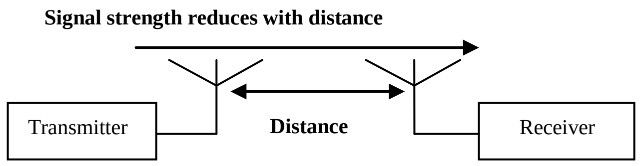

Fig 2: Log distance path loss model

Fig 2 is the log distance path loss model which explains path loss and shadowing. Unlike the traditional path loss model which is restricted to a clear path between the transmitter and the receiver, this model can measure a propagation loss for a wider environment[7].The loss in power while moving a distance d0 to any distance d is given by [7]:

$$PL_{do \rightarrow d}(db) = PL(d_o) + 10n\boldsymbol{log}\left(\frac{\boldsymbol{d}}{\boldsymbol{do}}\right) + \chi \qquad d_f \leq d_o \leq d \qquad (6)$$

PL(d 0) = Path Loss in dB at distance d0
PL (d>d0) = Path Loss in dB at a distance d
n = It is called the Path Loss exponent.

χ = A zero-mean Gaussian distributed random variable (in dB) which has the standard deviation – σ . This variable is used only if there is a shadowing effect. The log of this Normal (Gaussian)-variable is known as the“Log-Normal” fading.

If the shadowing effect is neglected, the Path Loss is a straight line When the shadowing effect is added, a standard deviation – σ is also added to the equation

Empirical models

➢ *Hata – Okumura Model*

The Okumura model is a universally used model. Almost all the propagation models are derived from this model. This model is useful for frequencies upto 3000 MHz. The maximum distance between transmitter and receiver is 100 km and the receiver height between 3 m and 10 m.

The path loss in Okumura model is given by [8]:

$$L50(db) = LF + Amu(f, d) - G(the) - G(hre) - G_{area} \qquad (7)$$

In this equation,

L50 is the median value of propagation loss

LF= path loss.

G(hte)- antenna gain factor

G(hre)-receiver gain factor.

hte and hre-heights of base station and the receiver.

Amu(f,d) -median attenuation factor.

➢ *COST 231 Extension to Hata Model*

This model functions as a radio propagation model. This model is an extension to Hata Model to 2GHz and is as follows [8]:

$$L = 46.3 + 33.9\log f - 13.82 \log h_B - a(h_R) + [44.9 - 6.55 \log h_B] \log d + C \qquad (8)$$

For rural environments

$$A(h_R) = (1.1 \log f - 0.7)\, h_R - (1.56 \log f - 0.8) \qquad (9)$$

$$C = \begin{cases} 3 \text{ db for rural and suburban areas} \\ \quad 0 \text{ db for metropolitan areas} \end{cases}$$

Where,

L(dB) is a measure of median path loss.

F(MHz) is the frequency of transmission signal.

H_B(m) is the antenna height in base station.

D(km) is the link distance.

H_R(m) is mobile station antenna height.

$A(h_R)$ is the antenna height correction factor of mobile station.

➢ *COST 231-Walfish-Ikegami Model*

This model is obtained from the combination of the models of J. Walfisch and F. Ikegami. It was later developed by the COST 231 model. It is now known as Empirical COST-Walfisch-Ikegami Model. The model takes into consideration, only the buildings in the vertical plane between the transmitter and the receiver. The accuracy of this empirical model is higher in urban environments because of the multiple diffractions over the roof-tops. The main parameters of the model are:

- Frequency f= 800-2000 MHz
- Transmitter height (h_{TX})= 4-50 m
- Receiver height (h_{RX}) =1-3 m
- The Distance between transmitter and receiver d= 20-5000 m
- Mean value of all the building heights= h_{ROOF}
- Mean value of street width= w
- Mean value of building separations =b

This model considers two situations: LOS-Line Of Sight and NLOS-Non Line-Of Sight.

LOS Situation This is similar to the free space loss condition and is given by [9]

$$l_p = 42.6 + 26 \log\left(\frac{d}{km}\right) + 20 \log\left(\frac{f}{MHz}\right) \qquad (10)$$

NLOS Situation The NLOS equations are more complicated. The loss is given below: Here, The free space loss=l_0

Multiple screen diffraction loss=l_{msd}

Rooftop-to-street diffraction loss=l_{rts}:

The free space loss is given by [9]:

$$l_0 = 32.44+20 \log \frac{f}{MHz} +20 \log \frac{d}{km} \quad (11)$$

The l_{rts} equation determines the loss which occurs on the wave coupling where the receiver is located.

$$l_{rts}= -16.9 - 10 \log \frac{w}{m} + 10 \log \frac{f}{MHz} +20 \log \frac{h_{roof} - h_{RX}}{m} +l_{ori} \quad (12)$$

With

$$lori = \begin{cases} -10 + 0.354 \frac{\varphi}{deg} \text{ for } 0 \le \varphi < 35° \\ 2.5 + 0.075 \left(\frac{\varphi}{deg} - 35\right) \text{ for } 35° \le \varphi < 35° \\ 4.0 - 0.114 \left(\frac{\varphi}{deg} - 35\right) \text{ for } 55° \le \varphi < 90° \end{cases} \quad (12)$$

The orientation loss l_{ori}[9] is the correction term determined from the calibration with measurements
COST 231 modified this equation for base station antenna heights below the rooftop level given by the following equations [9].

building separation= b

$$l_{msd}=l_{bsh}+ K_a + K_d \log \frac{d}{km} +K_f \lg\frac{f}{MHz} -9 \log \frac{b}{m} \quad (13)$$

$$K_a=\begin{cases} 54 & h_{TX} > h_{roof} \\ 54 - 0.8 \frac{h_{TX} - h_{roof}}{m} & d \ge 0.5km \text{ and } h_{TX} \le hroof \\ 54 - 0.8 \frac{h_{TX} - h_{roof}}{m} \frac{d/km}{0.5} & d < 0.5km \text{ and } h_{TX} \le hroof \end{cases} \quad (14)$$

$$K_d=\begin{cases} 18 & h_{TX} > h_{Roof} \\ 18 - 15 \frac{h_{TX} - h_{Roof}}{h_{Roof} - h_{RX}} & h_{TX} < h_{Roof} \end{cases} \quad (15)$$

$$K_f= -4+ \begin{cases} 0.7 \left(\frac{\frac{f}{MHz}}{925} - 1\right) \text{ for medium sized city and suburbs} \\ 1.5 \left(\frac{\frac{f}{MHz}}{925} - 1\right) \text{ for metropolitan areas} \end{cases}$$

(15)

The factors K_d and K_f balances the relation between the multi-screen diffraction loss vs distance/frequency.

- *Erceg Model*

This model was developed from the results of an experiment conducted by AT&T Wireless services in the United States in 95 macrocells at 1.9GHz. [9]

Here path loss P_L is given by [10]:

$$P_L(db)=20 \log_{10}(4\prod d_0/\lambda)+10\gamma\log_{10}(d/d) \quad \text{for } d>d_0 \quad (16)$$

Here,

λ = wavelength in meters

γ= is the path-loss exponent

$$\gamma=a-bh_b+d/h_b \quad (17)$$

h(m)=height of base station

The above model is valid for all frequencies up to 2 GHz and for receiver antenna heights up to 2 m. For frequencies and antenna heights which lies in the range of 2m to 10m, the following correction terms are as follows in [10]:

$$PL_{modified}= PL +\Delta PL_f +\Delta PL_h \quad (18)$$

$$\Delta PL_f=6\log_{10}(f/2000) \quad (19)$$

$$\Delta PL_h=-10.8\log_{10}(h/2) \text{ for categories A and B} \quad (20)$$

$$\Delta PL_h=-20\log_{10}(h/2) \text{ for C} \quad (21)$$

ΔPL_f = frequency

$\Delta PL_{h=}$ the receiver antenna height correction term.

Fading

If the transmitted signal encounters any obstruction in its propagating medium (for eg: buildings), it gets scattered, reflected, diffracted or undergoes absorption. This is called as slow fading/ long term fading.

Multipath Fading and time dispersal

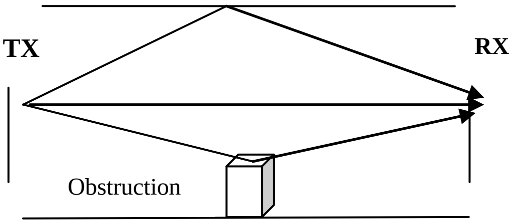

Fig 3: Transmission of signal via multiple paths

Fig 3 represents transmission of signal via multiple paths. in wireless communication networks. Sometimes uncertainties in received signal strength arises due to channel fading which may wrongly deduce that the primary system is located out of the secondary user's interference as the primary signal may be undergoing a deep fade or might be shadowed by obstacles. Therefore, cognitive radios are supposed to be more sensitive to distinguish a faded or shadowed primary signal from a white space. Since noise power is not constant, calculation of noise power is difficult

Noise Uncertainity

One of the important challenges in spectrum sensing is the impact of uncertainty in measurement of channel noise. The inaccurate estimation of noise power is terned as noise uncertainty. The signal to noise ratio gets severly degraded due to its presence. The detection of spread spectrum signals by a wideband energy detector becomes far more difficult because the SNR which is required for detection becomes dependent on noise uncertainty but independent of its observation interval. To overcome noise uncertainty, multiple antennas are used.. [11]. Noise uncertainity is given as follows [12]

$$\gamma_{min} = \frac{P_p L(D+R)}{N} \qquad (22)$$

Where

N= Noise power.

P_p =Transmitted power by the primary user.

D= Interference Range

R= Maximum distance between primary transmitter and its receiver

B.Fading Models

- *Rayleigh Fading*

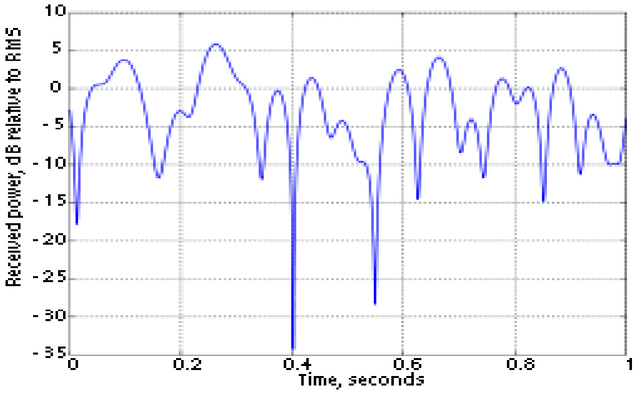

Fig 3: *Rayleigh plot of time Vs Received power in dB*

In Fig 3, deep fading appears in every half a wavelength.The phenomenon of Rayleigh Fading [13] arises as result of multi path fading. A moving antenna receives a large number of waves due to scattering and reflection. Due to wave cancellation effects, the received power as seen from the antenna becomes a variable dependent on the location of the antenna.

- *Rician Fading*

Rician fading model [14] is similar to that for Rayleigh fading. But in Rician fading, a strong dominant component is observed. This dominant component can for example, be the line-of-sight wave. Refined Rician models are explained as follows:

- The dominant wave can be considered as a phasor sum of two or more dominant signals, e.g. the line-of-sight and a ground reflection.
- The dominant wave can also undergo shadow attenuation. This is a supposition in the modelling of satellite channels.

In addition to the dominant component, the mobile antenna receives reflected and scattered waves.

- *Nakagami Fading*

Nakagami fading[15] does occur for multipath scattering having large delay-time spreads. In this model, the power density function of signal amplitude which is exposed to mobile fading is demonstrated .

- If the signal is Nakagami distributed, the instantaneous power of the signal is gamma distributed.

- The Nakagami parameter *m* is called the 'shape factor'.
- If *m* = 1, Rayleigh fading is recovered, the signal having an exponentially distributed instantaneous power
- For *m* > 1, the fluctuations in the strength of the signal reduce.

IV CONCLUSION

The broad classification of spectrum sensing techniques is presented. The detection performance of the spectrum sensing techniques can be improved by increasing the number of cognitive users in co-operative sensing. But there are several issues that are to be considered while simulating multi node sensing. The various path loss models for transmission between transmitter and receiver are also discussed .Finally, the fading channels and the effect of noise uncertainty are explored.

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