Mathematical Analysis of Interference Issues and Study on Pathloss, Fading and Shadowing Effects on Cognitive Radio Networks

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Abstract—**Handling interference in wireless communication system is a challenging task. This paper aims about mathematical analysis of interference in general and also in cognitive radio networks. This paper concentrates on various sources of interferences such as pathloss, fading and shadowing. Interference system model was created by considering spatial distribution of nodes, wave propagation characteristics and mobility of the interferers. Interference from active set of nodes and aggregate interference was analyzed mathematically. Finally, interference in cognitive radio network was analyzed under different circumstances. Simulation results showed that the outage probability of secondary user to sense the transmission between primary transmitter and receiver with respect to pathloss, fading and shadowing.**

Index Terms—**Interference, pathloss, shadowing, fading, cognitive radio and mathematical model**

I. Introduction

In wireless communication environment, the major constraints which effects the performance of the system are

- Thermal noise
- Interference issues
- Propagation losses

A. Thermal noise

It is common phenomenon in most of the transmission lines and communication devices. Random electron motion is the main reason for thermal noise. It is also called as white noise and it will distribute uniformly along the full spectrum. For defined bandwidth, noise voltage is given as

$$V^2 = 4KT\int_{f_1}^{f_2} R\,dF \qquad (1)$$

R= Resistance
T= Temperature
f1 and f2= lower frequency and upper frequency of defined spectrum
V= Integrated RMS value between upper and lower frequencies.

B. Propagation losses

Losses occurred during the propagation of the signal is called as propagation loss. Attenuation and distance are inversely proportional to each other. As the propagation distance increased, radiated energy will spread and hence path loss will occur. The pathloss between two isotropic antennas can be represented as

$$L = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) \qquad (2)$$

Where d is the distance between transmitter and receiver, λ is wavelength and L is pathloss. Propagation losses will also occur due to the effects of Multipath fading, shadowing and etc…

C. Intereference issues

If one receiver accumulates the signal from not only defined transmitter but also other transmitters, interference problem will exists. Interference may disrupt the signal and sometimes it modifies the content of the original signal. It will reduce both coverage and capacity of the network. The following figure 1 shows various possibilities of interference sources. It explains about how the signals from other system will affect required system performance. Due to this effect overall Carrier to Interference ration (C/I) decreases.

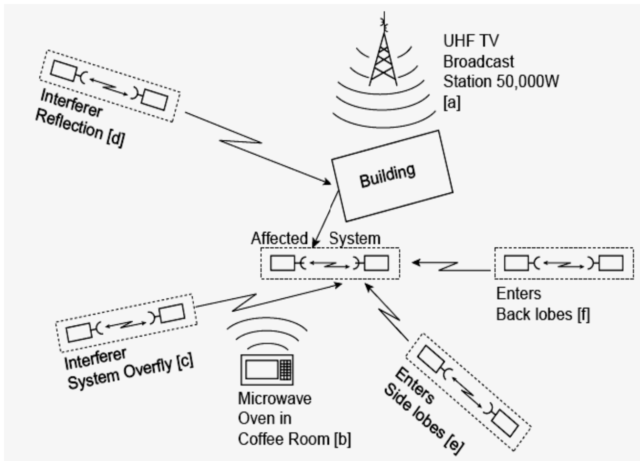

Figure 1.Possibilities of interferences

II. Interference sources

Main sources of interferences are classified into 3 broad categories.

1. Antenna parameters (Overlapping)
2. Out of band emitters
3. In band emitters

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A. Antenna parameters

ISM configured issues: Industrial, Scientific and Medical (ISM) fields will use unlicensed spectrum for their general applications. These bands were unlicensed and subjected to use under ISM fields. Hence, the users use these bands in their equipment's. These bands will create interference among themselves and also to the licensed spectrum.

Reflections: The complex building structures and other forms will create reflections. Signal reflection is main source for Multipath fading. Reflections from different surrounding will create different path lengths. These reflected signals will reach to the receiver and if they are in out of phase with each other, it leads to overlapping of signals. This is also one of the important reason for generation of interference.

B. Out of band emitters

Intermodulation: Nonlinear power amplifiers and other external components may create interference. Broadband power amplifiers are using in the final stage of communication system. The linear characteristics of those amplifiers are precise, any non-linearity will create cross reference signal which is near to original signal. The mixing of these two signals will lead to interference.

Desensitization: placement of receivers near high frequency transmitters or devices will also create interference. This only happens if the design of pre selection filter is not good. This effect will disturb linearity characteristics and creates nonlinear amplification nature. This will lead to intermodulation distortion and causes data errors.

C. In band emitters

The designers are also using Non-licensed spectrum for variety of applications. Frequency Hopping Spread Spectrum (FHSS) used by some wireless Local Area Networks (LAN) within this non licensed spectrum. This is close frequency band to in home applications such as microwave oven. Hence, these two operating in same environment will leads to interference.

III. MODELLING OF NETWORK INTERFERENCE

Modelling of network interference with respect to Ultra Wide Band (UWB) is always a challenging task. Impact of these UWB on narrowband applications such as GSM is a major focus in current research area. Andrew c et al proposed Finite Difference Time Domain method (FDTD) for interference modelling for indoor wireless applications.

The perfect interference model should concentrate on some physical parameters which effect interference. Some of them include propagation characteristics of channel, transmission characteristics of interferers and spatial distribution of interferers. There is no Unified network interference model which gives spectral efficiency, power spectral density, and throughput and bit error rate. This paper was proposed unifying model which can meet all above constraints.

System model - Physical scenario and distribution of nodes:

Consider two dimensional infinite plane (x, y). Place all nodes according to homogeneous point process method on plane. The probability of existence of node in defined particular region R over total area AR is given as

$$\text{P \{Number of nodes (n)in region R\}} = \left[\frac{(\lambda A_R)^n}{n!}\right] e^{-\lambda A_R}$$

Where, λ = spatial density of selected region R.

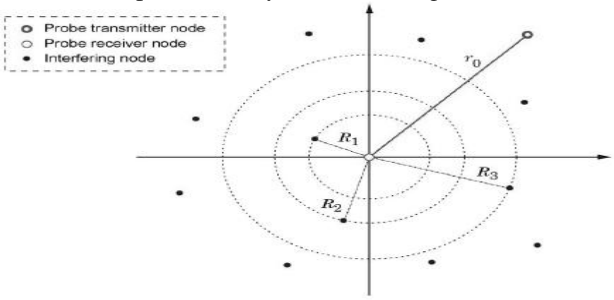

Figure 2. Distribution of Nodes

All nodes in defined area should operate in interested frequency band so that they act as interfere nodes. Density of interference nodes and the distance between interfering node and probe receiver mode will define the amount of interference. Network topology of these nodes has negligible effect on this process. From Fig.2, the distance between receiving node and actual transmitting node is r_0. By considering all other nodes as interference nodes, their distance from receiving node is shown as R1, R2 and R3.

Characteristics of wave propagation:

Transmitting node will send the signal to receiving node with transmitting power level of Pt. The receiver receives the signal with power Pr. the relationship between these two power levels is given by

$$P_r = (P_t \pi_k Z_k)/R^{2b} \quad (3)$$

Here we are considering Pt as average power measured from 1m away from transmitter, Z_k is other loss parameters which include shadowing and fading and b is amplitude loss component. The value of b is variable; it may range from 0.8-5. Depending on the traffic density, b value will change. If path loss component is 1, it will represent free space propagation. The proposed model considered all following situation to become unified model. They are

- Assuming there is no fading and only pathloss will exist
- Pathloss and fading is also existed (Nakagami fading)
- Pathloss and shadowing effect
- Pathloss, shadowing and fading effect

By taking time as an important and considerable factor, the relationship between transmitter and receiver can be represented in Equivalent Low Pass (ELP) representation. For received signal, expected ELP is given as

$$Y(t) = \left(\frac{\pi_k \sqrt{Z_k}}{R_b}\right) \int h(t,\tau) X(t-\tau) d\tau \quad (4)$$

X(t) is the transmitted signal and $h(t,\tau)$ is impulse response of channel.

Importance of movement of other nodes (interferers):

Obstructions in the path of both transmitter and receiver results fluctuations in power flow. These fluctuations cause the effect of shadowing on communication. Change in distance between interfere nodes and receiving node will also leads to effect of shadowing. It is assuming that the distance and shadowing effect is almost constant for

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particular duration of symbol [9]. Let ρ represents the shadowing and distance parameter. Here, there are two possibilities were existed i.e. slow varying and fast varying ρ.

In slow varying ρ, interfere nodes has long life time and in fast varying ρ, they has short life span. Measurement of outage metrics is possible in slow variation mode and average metrics are possible in fast variation mode.

IV. INTERFERENCE DISTRIBUTION

Let, real Random Vector (RV) which represents interference from all receivers is given byY = [y1, y2…yn]. Then the aggregate interference can be represented as

$$Y = \sum_{i=1}^{\infty}(Q_{i/R_i}\ )F_A(Q_i, R_i) \quad (5)$$

Here

$$F(Q_i, R_i) = \begin{cases} 1 & \text{when} \quad (Q,R) \in A \\ 0 & \text{when} \quad \text{otherwise} \end{cases}$$

Where QI represents associated with interferer i. In analysis of shadowing and fading, we can use variable. $F(Q_i, R_i)$ is the function which relates information about selection of nodes which are responsible for overall interference. A represents the set of elements (assuming that all elements are active). Now let us try to calculate the overall interference from number of elements which are in active set.Let R1, R2, R3… Rn are the distance between original node and active set elements. The general representation of these distances is $\{R_i\}$, i=1, 2… ∞.

The aggregate interference from all active elements is given by

$$Y = \sum_{i=1}^{\infty}(Q_{i/R_i}\ )F_A(Q_i, R_i) \quad (6)$$

Here η>1 and the characteristic function is given by $\emptyset_y(W, A)$ and is represented as

$$\emptyset_Y(W, A) = \exp\left(-2\pi\lambda \iint \left(1 - e^{\left(jw\frac{q}{R}\right).F(Q_i,R_i)}\right) f_Q(q)dq.dr\right. \quad (7)$$

Where $f_Q(q)$ is the probability distribition function of Q.

For above equation,

If A= {(q,r): r ∈ I ,

Then

$$\emptyset_Y(W, A) = \exp\left(-2\pi\lambda \int_I \left(1 - \emptyset_Q\left(\frac{W}{R}\right)\right) rdr\right. \quad (8)$$

From the above equation for η=b and I=[0, ∞), then it modify as

$$\emptyset_Y(W) = \exp\left(-2\pi\lambda \int_0^{\infty} \left(1 - \emptyset_Q\left(\frac{W}{R^b}\right)\right) rdr\right. \quad (9)$$

If the function is random variable, then the above equation can be modified as

$$\emptyset_Y(W, A) = \exp\left(-2\pi\lambda \int_0^{\infty} \left(1 - \emptyset_0\left(\mid \frac{W}{R} \mid\right)\right) rdr\right. \quad (10)$$

This is the modified characteristic function of aggregate of interference.

V. ANALYSIS OF COGNITIVE NETWORKS

Cellular and data traffic is increasing from day to day. All telecom operators were operating in their respective licensed spectrum. Now, spectrum became one of the scarce resources. To increase the usage efficiency of spectrum, cognitive radio concept was introduced.The concept of secondary user introduced in this technology. Secondary user can use the same licensed spectrum of primary user without making any interference. Spectrum sensing technique is the best example of cognitive behavior. Now, we will see the interference model set up in cognitive radio to avoid aggregate interference. If there is a transmission between primary transmitter and receiver, receiver will transmit beacon with power pr. This beacon will sense the secondary user to not to occupy the channel. But, the effects of shadowing and fading will disturb this beacon sometimes and make secondary user free environment (no transmission between primary transmitter and receiver).The probability that the second user can sense the transmission between primary transmitter and receiver is given as

$$p_d(r) = P_{\{z_k\}}\{(p_{pri}\pi_k Z_k)/R^{2b}\} \quad (11)$$

This is also called as threshold power or minimum power to sense by secondary user.

Calculation of interference by secondary users:

The generated power for particular secondary user is given as

$$I_{sec} = \sum_{i=1}^{\infty}(P_{sec}Z_i / R_i^{2b})F_A(Q, R) \quad (12)$$

From the expression of$\emptyset_y(W, A)$,

Put η =2b and$Q = P_{sec}Z$, it can be modified as

$$\emptyset_{I_{sec}}(w) = \exp\left(-2\pi\lambda_{sec} \int_0^{\infty} \int_0^{(p^* R^{2b}/P_{pri})} (1 - f_z(Z) rdzdr\right. \quad (13)$$

$f_z(Z)$ is the probability distribution function of Z_i

Analysis on propagation phenomenon:

To regulate the interference flow, it is essential to identify the beacon generated by the primary user. To control this phenomenon, propagation characteristics have to be studied under various circumstances.

- Pathloss
- Pathloss and Nakagami fading
- Pathloss and shadowing
- Pathloss, fading and shadowing

Pathloss:

It considers the radius of the primary receiver. The radius is given by $(\frac{P_{pri}}{p^*})^{1/2}$

Secondary node has to detect beacon whether it is inside the radius of primary receiver or not. Then, the probability characteristics can be modified as

$$P_d(r) = \begin{cases} 1 \ when \ 0 < r < (\frac{P_{pri}}{p^*})^{1/2} \\ 0 \ whenothercondition \end{cases} \quad (14)$$

Combination of pathloss and fading:

This fading is existed only when it crosses maximum radio diversity combining. This type of fading consideration is suitable for multipath scattering with large time delays. In this case, the probability that the second user can sense the transmission between primary transmitter and receiver is given as

$$P_d(r) = 1 - (1/\Gamma(m))\gamma_{inc}(m, \frac{p^* R^{2b}}{P_{pri}} m) \quad (15)$$

This equation is obtained from the Cumulative Distribution Function (CDF) of gamma. Gamma function is a continuous probability distribution function and also it follows maximum entropy probability distribution. Assuming that, for wireless communications, this distribution function is

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taken as ideal one. The function is an incomplete function. The modified probability that the second user can sense the original transmission with respect to m is given as

(16)

Here,

Combination of pathloss and shadowing:

The patterns like big obstacles or hills will produce shadowing effect. This shadowing may represented as log-normal distribution or log-distance path loss model. If we consider n number of individual events, the multiplicative product of all those independent variables were represented by log normal distribution. This condition is exactly suits for wireless environment and hence log normal distribution was used to represent shadowing effect.

Using Gaussian Q function the probability distribution of secondary user to detect transmission between primary transmitter and receiver is given as

(17)

VI. SIMULATION RESULTS

Let Pout is the probability of interference generated as an outcome of presence of second user. By considering conditions that $R/P_{sec} = 1$; b = 2; = 10, Pout was simulated and result is shown in following figure.

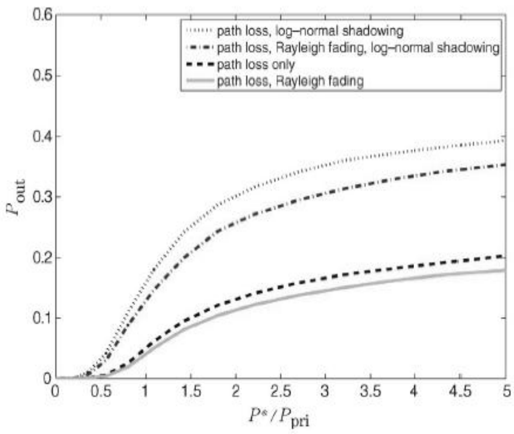

Figure 3.Pout vs for R/Psec = 1; b = 2; = 10

CONCLUSIONS

In this paper, Mathematical model of interference was investigated and simulated. By creating a physical scenario, aggregate interference generated by the all other nodes on primary receiver was developed and analyzed. The main parameters of interference viz. pathloss, fading and shadowing was also explained in detail. Interference handling in cognitive radio network was explained mathematically. Finally, the probability of sensing (between primary transmitter and receiver) was computed for different cases. Simulations carried on this paper only based on mathematical model. Simulations showed that the relationship between outage probability and. Still, perfection is needed in mathematical analysis to adopt to practical cases.

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