OPTIMIZATION OF RF PROPAGATION MODELS FOR COGNITIVE RADIO

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Abstract - *Radio propagation models mainly focus on realization of path loss. Radio propagation models are empirical in nature and developed based on large collection of data for the specific scenario. The aim of this paper is to study of different path loss propagation models in radio communication at different frequency band. Like Log normal shadowing model SUI model, Hata model, Okumura model, COST-231 model and which is best suited for the Cognitive radio based on which it can analyze the available Spectrum in the licensed spectrum band. Here we also try to find the correction factor for Log normal shadowing model as it does not directly depend on frequency parameter.*

Key Words: **Cognitive cycle [2], Dynamic spectrum Access, Empirical path loss propagation models, Free space path loss models, Spectrum sensing.**

1.INTRODUCTION

Cognitive radio (CR)[1][2] is the enabling technology for supporting dynamic spectrum access: it addresses the spectrum scarcity problem that is faced in many countries. A cognitive radio is an intelligent radio that can be reprogrammed and reconfigured dynamically. A cognitive radio is designed to use the best available wireless channels in its surroundings. Its transceiver can automatically detect available channels in wireless spectrum and can change its transmission and reception parameters accordingly to allow more concurrent wireless communication in a given wireless band for a particular instant of time for a particular place. Such spectrum allocation is known as dynamic spectrum management (DSA) [1] [2]. The cognitive engine is capable of configuring radio-system parameters automatically, in response to the operator's commands. These parameters include "waveform, protocol, operating frequency, and networking". A CR "monitors its own performance continuously", in addition to "reading the radio's outputs"; it then uses this information to "determine the RF environment, channel conditions, link performance, etc.", and adjusts the "radio's settings to deliver the required quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints". This process is called as Cognitive Cycle [1] [2]. The main aim of cognitive radio [3] is to improve spectrum utilization in wireless communication system while accommodating the increasing number of services and applications in wireless environment. Now Radio propagation models are an empirical formulation for characterize the radio wave propagation as a function of distance between transmitter and receiver antenna, function of frequency and function of other condition. RF Propagation models [9] are used in network planning, particularly for conducting feasibility studies & during initial deployment. So in Cognitive radio RF propagation models [6] are so important that's help to find proper transmission channel depending on the various factors like path loss, scattering, refraction, absorption due to obstacles etc.

2. DIFFERENT TYPES OF PROPAGATION MODEL

2.1 RSSI-BASED RANGING MODEL (FRIIS EQUATION)

RSSI propagation models in wireless sensor networks include free-space model, ground bidirectional reflectance model and log-normal shadow model.
Free-space model is applicable to the following occasions:
1) The transmission distance is much larger than the antenna size and the carrier wavelength λ;
2) There are no obstacles between the transmitters and the receivers.
The **Friis transmission equation** [9] is used in telecommunications engineering, and gives the power received by one antenna under idealized conditions given another antenna some distance away transmitting a known amount of power.

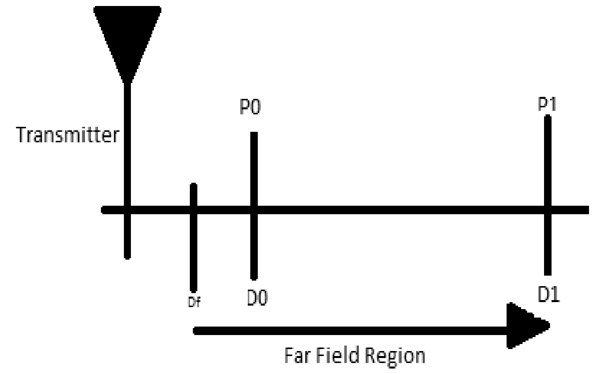
Simple Form of Friis Equation

$$P_r / P_t = G_t * G_r * (\lambda / 4\pi R)^2 \text{ --------------(1)}$$

- P_r: Power at the receiving antenna
- P_t: output power of transmitting antenna
- G_t and G_r: gain of the transmitting and receiving antenna, respectively
- λ: wavelength
- R: distance between the antennas

2.2 LOG NORMAL SHADOWING MODEL

Log distance path loss model [9] is a generic model and an extension to Friis Free space model. It is used to predict the propagation loss for a wide range of environments, whereas, the Friis Free space model is restricted to unobstructed clear path between the transmitter & the receiver.



In the far field region of the transmitter ($d \geq d_f$), if $PL(d_0)$ is the path loss measured in dB at a distance d_0 from the transmitter, then the path loss (the loss in signal power measure in dB when moving from distance d_0 to d) at an arbitrary distance $d>d_0$ is given by

$$PL_{d_0 \to d}(dB) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + \chi \qquad d_f \leq d_0 \leq d$$

--------(2)

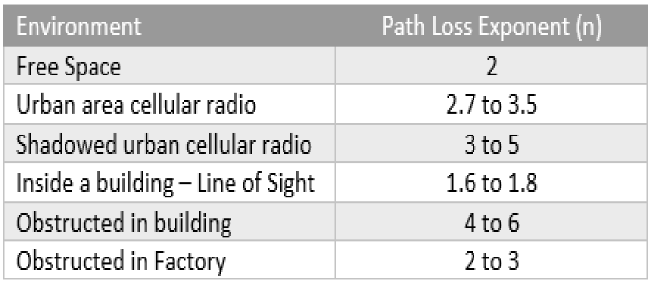
$PL(d_0)$ = Path Loss in dB at a distance d_0

$PL_d>d_0$ = Path Loss in dB at an arbitrary distance d

n = Path Loss exponent.

χ = A zero-mean Gaussian distributed random variable (in dB) with standard deviation – σ.

This variable is used only when there is a shadowing effect. If there is no shadowing effect, then this variable is zero. Taking log of the normal variable results in the name "Log-Normal" fading. See the table below that gives the path loss exponent for various environments.



Environment	Path Loss Exponent (n)
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
Inside a building – Line of Sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in Factory	2 to 3

Usually to model real environments the shadowing effects cannot be neglected. If the shadowing effect is neglected, the Path Loss is simply a straight line. To add shadowing effect a zero-mean Gaussian random variable with standard deviation – σ is added to the equation. The actual path loss may still vary due to other factors. Thus the path loss exponent (modelling the slope) and the standard deviation of the random variable should be known precisely for a better modelling. The Path Loss Exponent (PLE) table given above is for reference only. It may or may not fit the actual environment we are trying to model. PLE is an important parameter and it affects the system performance drastically. Usually PLE is considered to be known a-priori but mostly that is not the case. Care must be taken to estimate the PLE for the given environment before design & modelling. PLE estimation is done by equating the observed (empirical) values over several time instants to the established theoretical values.

2.3 OKUMURA-HATA MODEL

In wireless communication, the **Hata model for urban areas**, also known as the *Okumura–Hata model* [8] for being a developed version of the Okumura model. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. This model is suited for both point-to-point and broadcast transmissions and it is based on extensive empirical measurements taken.

The Hata model for urban areas is formulated as following:

$$L=69.55+26.16\log(f)-13.02\log(h_b)-C_H+[44.9-6.55\log(h_b)]\log(d) \text{ ----------------(3)}$$

For small or medium-sized city,

$$C_H=0.8+(1.1\log(f)-0.7)h_M-1.56\log(f) \text{ ---------(4)}$$

And for large cities,

$$C_H = \begin{cases} 8.29(\log(1.54h_M))^2 - 1.1\,, & if\ 150 \leq f \leq 200 \\ 3.2(\log(11.75h_M))^2 - 4.97\,, & if\ 200 \leq f \leq 1500 \end{cases}$$

-----------(5)

Where

- L= Path loss in urban areas. Unit: decibel (dB)
- h_b = Height of base station antenna. Unit: meter (m)
- h_M = Height of mobile station antenna. Unit: meter (m)
- f =Frequency of transmission in Megahertz (MHz).

- C_H = Antenna height correction factor
- d = Distance between the base and mobile stations. Unit: kilometer (km).

The parameters range for the above equation are:

- Frequency (f): 150–1500 MHz
- Mobile Station Antenna Height (h_M): 1–10 m
- Base station Antenna Height (h_b): 30–200 m
- Link distance (d): 1–10 km

Though based on the Okumura model, the Hata model does not provide coverage to the whole range of frequencies covered by Okumura model. Hata model does not go beyond 1500 MHz while Okumura provides support for up to 1920 MHz

2.4 COST 231-HATA MODEL

The **COST Hata model** [8] is a radio propagation model that extends the urban Hata model (which in turn is based on the Okumura model) to cover a more elaborated range of frequencies. COST **(COopération européenne dans le domaine de la recherche Scientifique et Technique)** is a European Union Forum for cooperative scientific research which has developed this model accordingly to various experiments and researches. This model is applicable to urban areas.

The COST Hata [8] model is formulated as,

$$PL = 46.3 + 33.9\log(f) - 13.82\log(h_b) - a(h_r) + [44.9 - 6.55\log(h_b)]\log(d) + c \text{ -----------------(6)}$$

For urban environments:

$$a(h_r) = 3.2(\log(11.75h_r))^2 - 4.97 \text{ --------------(7)}$$

For suburban or rural environments:

$$a(h_r) = (1.1\log(f) - 0.7)h_r - (1.58\log(f) - 0.8) \text{ ---------------(8)}$$

And the constant factor is given as

$$C = \begin{cases} 0 \text{ for Rural and Suburban areas} \\ 3 \text{ for Metropolitan or urban areas} \end{cases}$$

Where,

- L = Median path loss. Unit: decibel (dB)
- f=Frequency of Transmission in megahertz (MHz)
- h_b = Base station antenna effective height. Unit: meter (m)
- d = Link distance. Unit: Kilometer (km)
- h_R = Mobile station antenna effective height. Unit: meter (m)
- $a(h_R)$ = Mobile station antenna height correction factor as described in the Hata model for urban areas.

The European Co-operative for Scientific and Technical research (EUROCOST) formed the COST-231[8] working committee to develop an extended version of the Hata model. COST-231 proposed the following formula to extend Hata's model to 2 GHz.

2.5 STANFORD UNIVERSITY INTERIM MODEL

The 802.16 IEEE group [5], jointly with the Stanford University, carried out an extensive work with the aim to develop a channel model for WiMAX applications in suburban environments. One of the most important results obtained was the SUI (*Stanford University Interim*) propagation loss model [5], which is an extension of an early work carried out by AT&T Wireless. To calculate the median path loss using the SUI model, the environment is categorized in three different groups with their own characteristics:

- **Category A**: hilly terrain with moderate-to-heavy tree densities, which results in the maximum path loss.
- **Category B**: hilly environment but rare vegetation, or high vegetation but flat terrain. Intermediate path loss condition is typically of this category.
- **Category C**: mostly flat terrain with light tree densities. It corresponds to minimum path loss conditions.

Typically, for the three previous categories, the general scenario is as follows:

- Cells are < 10 km in radius.
- Receiver antenna height in the range of 2 to 10 m.
- Base station antenna height between 15 to 40m.
- High cell coverage requirement (80-90%)

In the following section, the SUI model and some variations including correction factors [5][7] are described.

The path loss in SUI model can be described as-

$$PL = A + 10\,\gamma \log(d/d_0) + X_f + X_h + S \text{--------(9)}$$

where

- PL= Path Loss in dB,
- d = the distance between the transmitter and receiver, do= the reference distance (Here its value is 100),
- Xf= the frequency correction factor,
- Xh= the Correction factor for Base station height,
- S= shadowing and
- γ= the path loss component and it is described as-

$$\gamma = a - bh_b + ch_b \text{ --------------------(10)}$$

Where

h_b= the height of the base station and

a, b and c represent the terrain for which the values are selected from the below table.

Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4	3.6
b(1/m)	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

Table: Different terrain and their parameters

The free space path loss, A is given as-

$$A = 20 \log \left(\frac{4\pi d_0}{\lambda}\right) \text{ .... (11)}$$

where

- d0= the distance between T_x and R_x and
- λ= the wavelength,

The correction factor for frequency and base station height [5] are as follows:

$$Xf = 6 \log 10 \left(\frac{f}{2000}\right) \text{ .... (12)}$$

$$X_h = -10.8 \log \left(\frac{h_r}{2000}\right) \text{ .... (13)}$$

Where

- f= the frequency in MHz,
- hr= the height of the receiver antenna.

This expression is used for terrain type A and B. For terrain C, the below expression is used-

$$X_h = -20 \log \left(\frac{h_r}{2000}\right) \text{ ------------------(14)}$$

$$S = 0.65(\log f)^2 - 1.3\log (f) + \alpha \text{ .... (15)}$$

Here α is 5.2 dB for rural and suburban environments (Terrain A & B) and 6.6 dB for urban environment (Terrain C) [5].

3. SIMULATION RESULTS

Path loss in communication is the difference between the transmitted power and the received power. Due to various environment parameters, the received signal power gets drastically reduced. Considering simple lognormal shadowing model, we find the path loss is quite low but in lognormal model the frequency factor is not included. So to find out proper solution and to consider the frequency factor we have worked on other three existing propagation models namely Cost Hata model or Cost 231 model, Okumura–Hata model and Stanford university interim model.

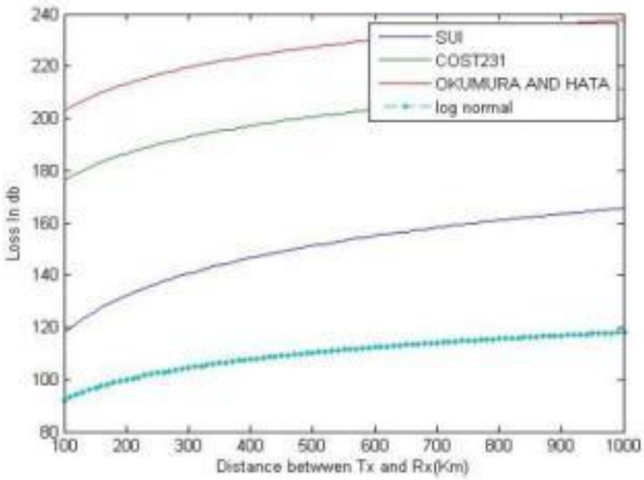


Fig: Path loss variations on various propagation models including lognormal model

we find that lognormal gives the best communication result but it didn't consider the frequency factor which is a major drawback. Now leaving the lognormal model if we concentrate the other three models mentioned above than the SUI path loss image we will get the SUI model is better than the other models overlooking the lognormal model.

We have found that the SUI model is the best propagation model so far in communication in cognitive environment considering same constants, frequency, antenna height of transmitter and receiver and various other parameters.

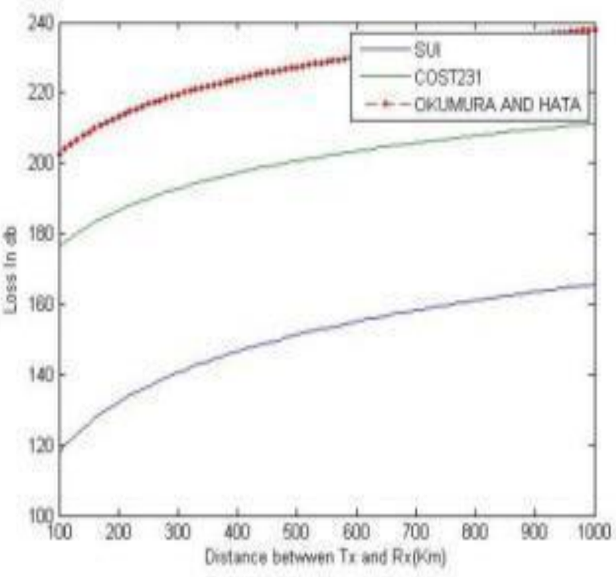


Fig: Comparison of SUI model with other three models

In simulation task it is been found that the SUI model provides the better path loss figure, further simulation operation we carried out on this propagation model to find the path loss in various terrain models of SUI model. As mentioned in the SUI model description three various terrain models.

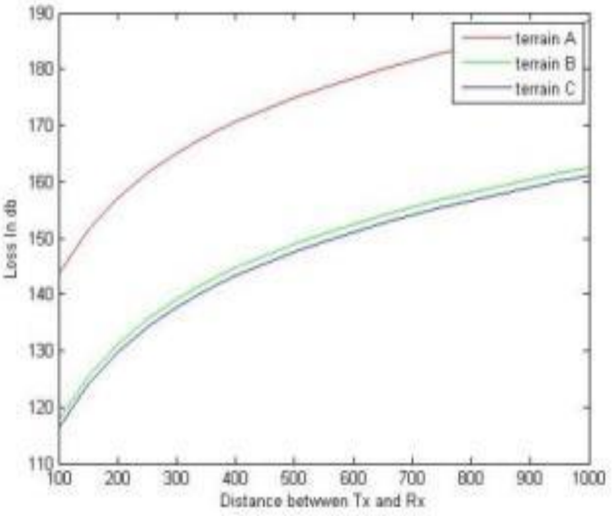


Fig: Path loss in various terrain model of SUI model

As terrain A is for urban area, the densely populated area, terrain B is suburban areas and terrain C is the rural area or less populated zone. The highly populated area has higher path loss but it is to accept that we get better reach because of scattering and diffraction of the signals. Above the graphical overview of path loss in various terrain model of SUI model and it shows higher path loss in terrain A.

3.1 CORRECTION FACTORS

Lognormal shadowing model is the base for any propagation models. In lognormal model the path loss is calculated based on the reference distance path loss value. In our work we have tried to find some correction factor for lognormal shadowing model. In our simulation work we have calculated the path loss of lognormal model and other propagation model on various frequencies. And the difference between their path loss is been considered as the correction factor for lognormal model.

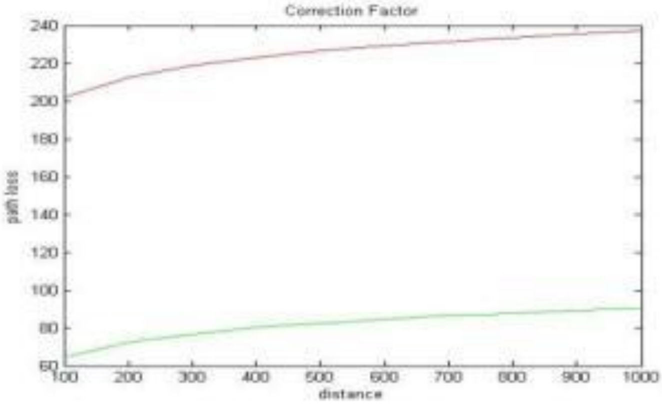


Fig: Calculation of correction factor for lognormal model based on COST 231

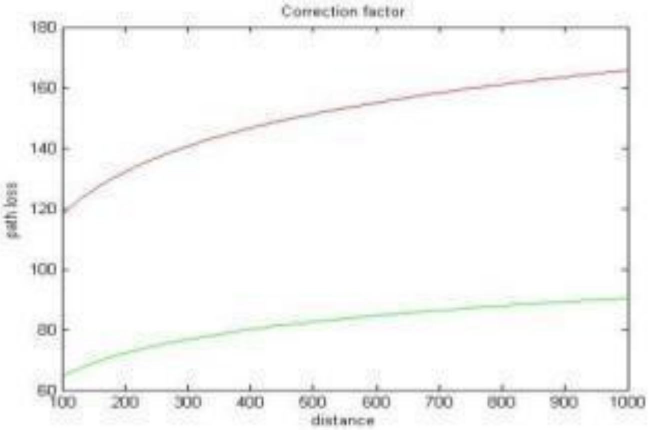


Fig: Calculation of correction factor for lognormal model based on SUI propagation model

Distance	*SUI Model (dB)*	*COST-231 HATA model (dB)*
100 meter	137.3810	53.3494
200 meter	140.1580	59.9570
300 meter	141.7824	63.4991

400 meter	142.9349	65.0154
500 meter	143.8289	67.0298
600 meter	144.5593	69.0657
700 meter	145.1769	70.4299
800 meter	145.7119	72.0346
900 meter	146.1838	74.1885
1000 meter	146.6059	75.2994

Table: Correction Factor table for Log normal model based on SUI model and COST231 HATA model

4. CONCLUSIONS

We know empirical models are not always accurate enough. Those models can use only over parameter ranges including in the original measurement set.

Here in this paper we reviewed the current state of the art in wireless channel models. There are two key aspects of this topic: best path loss model for cognitive radio environment and find correction factor for lognormal model. We have provided a summary of models for both aspects and references for the model parameters. Most of all, we have attempted to relate the various properties of wireless path loss models used in the design of CRs. This is certainly a topic that bears further thought and research.

We found that STANDFORD UNIVERSITY INTERIM model has shown better path loss figure in all the terrain such as urban, suburban and rural for 1900 MHz frequency. So, we found SUI as a better path loss models for cognitive radio environment.

In other hand, as lognormal model does not include frequency in operation directly so we tried to find correction factor for this model. We find the correction factor as 146.60 dB at a distance of 1km when compared this model with COST 231 model and 75.29 dB at a distance of 1 km as correction factor when compared with SUI model.

Thus, approximately 75 dB will be the correction factor for lognormal model for a distance of 1 km, considering SUI model as a better path loss propagation model among other path loss models.

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