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Performance Analysis of Empirical Radio Propagation Models in Wireless Cellular Networks

Rahul[1,*], Bajrang Bansal[2], Rajiv Kapoor[3]

[1]KIET Group of Institutions, Ghaziabad, India

[2]Jaypee Institute of Information Technology, Noida, India

[3]Delhi Technological University, Delhi, India

*E-mail address: rahul.ece@kiet.edu

ABSTRACT

This paper presents the performance analysis of different empirical radio propagation models used in wireless cellular networks. It particular, the parameters such as path loss and cell coverage area are studied for different cellular networks from second generation (2G) to fifth generation (5G). Accurate prediction of path loss and coverage area is highly desirable for planning of any wireless communication systems. Considering the urban terrain, the comparison is made between Hata model, Stanford University Interim (SUI) model, and modified SUI models. As a motivation for new millimeter wave (mm-wave) cellular systems, i.e., for 5G communication, the analysis is performed at 28 GHz. Considering -75 dBm as the desired minimum received power, it is observed that 2G communication (at 900 MHz using Hata model) experiences the lowest path loss and thus results into largest coverage area. The path loss is observed to be maximum for the future mm-wave systems (at 28 GHz using modified SUI model) that directly imply the smallest coverage area.

***Keywords*:** Path Loss, Cell Coverage, Radio Propagation Models, 2G, 3G, 4G, 5G Cellular Networks

1. INTRODUCTION

For efficient network planning, particularly for initial deployment of wireless network, radio propagation models are very important, as they describe the signal behavior while it is

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transmitted from the transmitter (Tx) antenna to the receiver (Rx) antenna [1] and the dependence of signal strength on many parameters [2]. In particular, empirical models which are measurement based [3], characterize the wave propagation in terms of distance between the transmitter (Tx) and receiver (Rx) antenna, operating frequency, antenna height, building heights, and etc. These empirical propagation models help in finding the important network parameters, like path loss and radio frequency (RF) coverage. The parameter, path loss is useful in finding the RF coverage distance and must be estimated for a deployment environment.

Using the -75 dBm Rx signal benchmark, we present the path loss and RF coverage simulations for existing microwave and future mm-wave networks. For second generation (2G) networks simulations are performed at 900 MHz using the Hata model [1, 4]. For third generation (3G) (at 2.1 GHz) and fourth generation (4G) (at 2.6 GHz) networks, Stanford University Interim (SUI) model is used [1]. While for future mm-wave systems (i.e., 5G communication), simulations are performed at 28 GHz using the modified SUI model [5]. Considering urban terrain, it has been observed that 2G networks show the smallest path loss and thus highest RF coverage area. The future cellular networks show the highest path loss which directly implies the smallest coverage area.

2. PATH LOSS AND RF COVERAGE FOR 2G/3G/4G/5G NETWORKS

Path loss is the attenuation in signal strength as it propagates from the Tx to the Rx and it dictates the RF coverage area for system deployment. The important path loss models include Okumura model, Hata model [1, 4], SUI model [1], and modified SUI model [5]. The path loss using the Hata model (used for 2G networks) is given as [1, 4]

$$PL_{Hata}(dB) = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_t - a(h_r) + (44.9 - 6.55\log_{10} h_t)\log_{10} d \tag{1}$$

where f_c is the carrier frequency, h_t and h_r are the Tx and Rx heights respectively and d is the separation between Tx and Rx antenna. The parameter $a(h_r)$ is the Rx antenna height correction factor (for Rx antenna) and is given as

$$a(h_r) = 3.2(\log_{10} 11.75 h_r)^2 - 4.97 \text{ dB} \tag{2}$$

The path loss using the SUI model (used for 3G and 4G networks) is given as [1]

$$PL_{SUI}(dB) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_{f_c} + X_{h_r} + S \tag{3}$$

where

$$PL(d_0) = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \tag{3a}$$

$$n = a - b.h_t + \frac{c}{h_t} \tag{3b}$$

$$X_{f_c} = 6\log_{10}\left(\frac{f_{MHz}}{2000}\right), f_c > 2GHz \tag{3c}$$

$$X_{h_r} = -10.8\log_{10}\left(\frac{h_r}{2}\right) \tag{3d}$$

with λ as the wavelength in meters. The parameter $PL(d_0)$ denotes the free space path loss in dB at a reference distance d_0 (the value of reference distance is 100 m). The parameters X_{f_c} and X_{h_r} are the correction factors for frequency and Rx heights with S as the shadowing variable such that $8.2 < S < 10.6$ dB. The parameters a, b, and c are constants used to model the terrain type [1].

The path loss using the modified SUI model (used for 5G networks) is given as [5]

$$PL_{SUI,Mod}(dB) = \alpha\left(PL_{SUI}(d) - PL_{SUI}(d_0)\right) + PL(d_0) + S \tag{4}$$

where $\alpha = 0.88$ is the slope correction factor. For 5G systems, we have performed the simulations at 28 GHz with reference distance $d_0 = 1$ m and $S = 9.2$ dB [5]. In the next Section, simulations are performed for path loss and RF coverage, for 2G/3G/4G/5G networks.

3. RESULTS AND DISCUSSION

The parameters of different networks used in simulations are shown in Table 1. With 43 dBm as the Tx power, the minimum acceptable value of Rx power is set to be -75 dBm [4, 5]. The parameter S used in (3) is 10.6 dB and the terrain used in (3b) is considered to be of type A [1] which represents the highly dense populated region.

Table 1. Simulation parameters for 2G/3G/4G/5G networks

Simulation Parameter	**2G**	**3G**	**4G**	**5G**
Frequency (in MHz)	900	2100	2600	28 GHz
Propagation Model	Hata	SUI	SUI	Modified SUI
Tx Antenna Height (m)	20	20	20	20
Rx Antenna Height (m)	2	2	2	2
Tx power (dBm)	43	43	43	43
Rx power (dBm)	-75	-75	-75	-75

Figs. 1 to 4 show the path loss for 2G, 3G, 4G, and 5G networks. At a particular frequency, it can be observed that the path loss increases with Tx-Rx separation and also for a particular Tx-Rx separation, path loss increases with operation frequency. Thus 2G networks experience the lowest path loss whereas the 5G networks experience the highest path loss. But it should be noted that mm-wave wireless communication will prove to be the backbone for 5G systems where the most likely band of operation is 28 GHz or 38 GHz [6, 7]. The demand for high data rate, low latency video and multimedia applications is the prime motivations for cellular providers to explore the mm-wave frequency spectrum for future 5G communication [6].

With -75 dBm as the minimum acceptable Rx power and $P_{rec}(d)[dB] = P_t(d)[dB] - PL(d)[dB]$ (P_t and P_t are the Tx and Rx power respectively with PL as the path loss), the RF coverage for different networks can be found out. For 2G systems, the path loss is found to be 118 dB corresponding to the considered Tx and Rx power. From Fig. 1, a cell radius of 536 m is obtained to maintain this path loss and minimum Rx power. This computed value of cell radius for 2G systems is in good agreement with the realistic cell size [5]. Similarly for the 3G and 4G networks, the computed cell sizes are 362 m and 325 m respectively which are in close agreement with the literature work [4, 5].

For finding the RF coverage in 5G systems, it is required to subtract the 49.5 dBi from the value simulated using (4) and then look for Tx-Rx separation corresponding to 118 dB. This 49.5 dBi is obtained using the 39.5 dBi antenna gains (Table 1, [5]) and 10 dB SNR requirement for reliable detecting level [6]. So the RF coverage for 5G systems is found to be 248 m which is in good agreement to the measured value [6] and simulated values [4, 5] in literature.

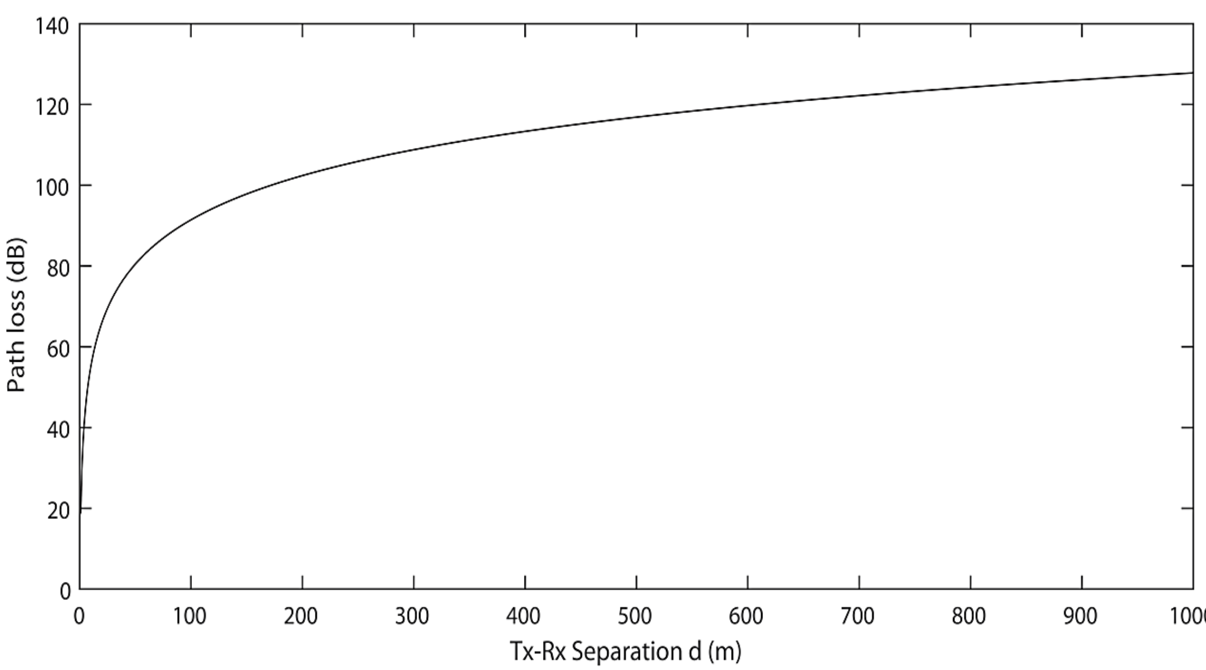

Fig. 1. Path loss simulation using Hata model at 900 MHz (for 2G networks)

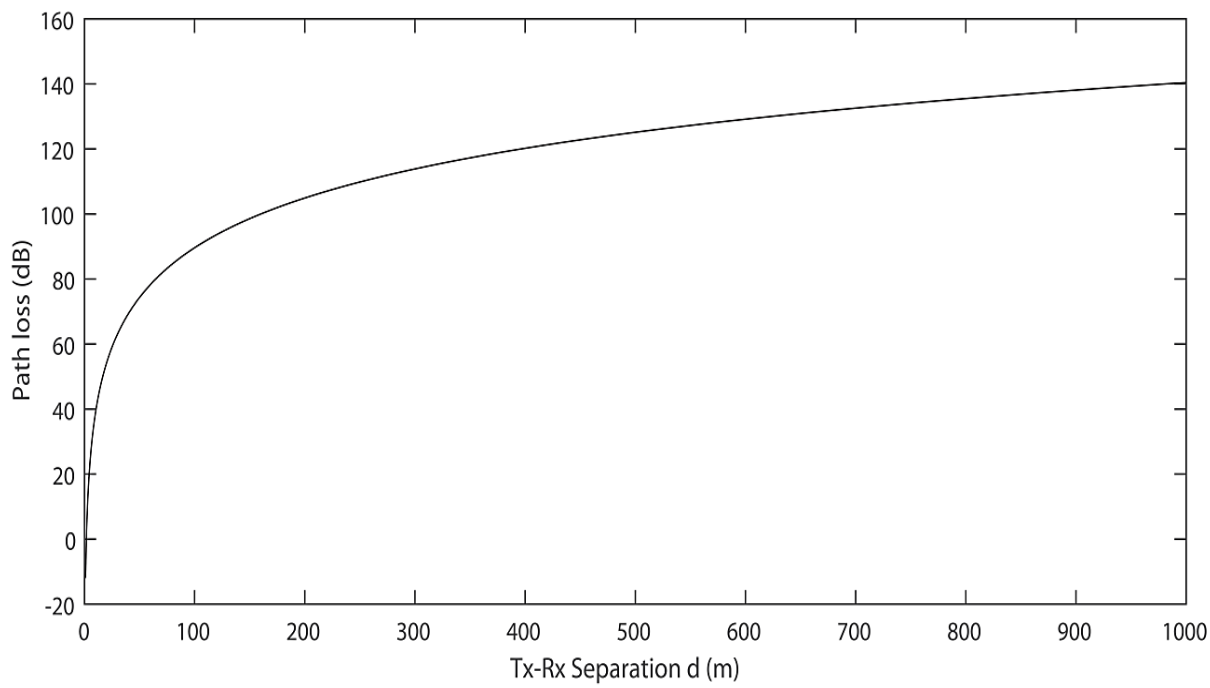

Fig. 2. Path loss simulation using SUI model at 2.1 GHz (for 3G networks)

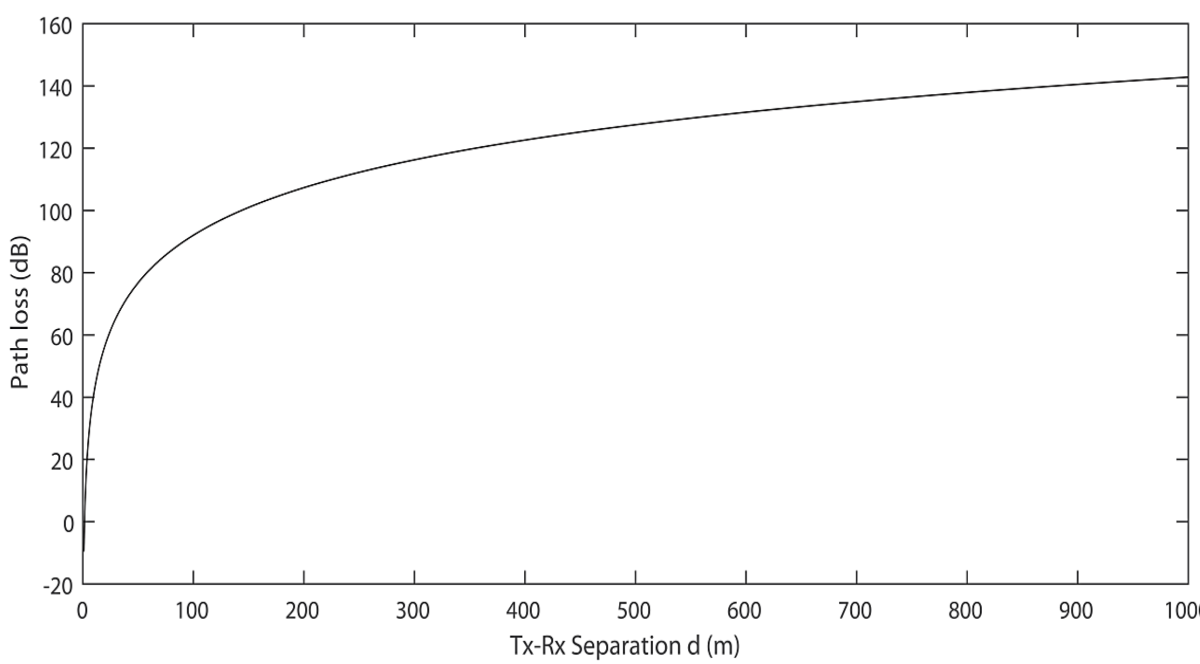

Fig. 3. Path loss simulation using SUI model at 2.6 GHz (for 4G networks)

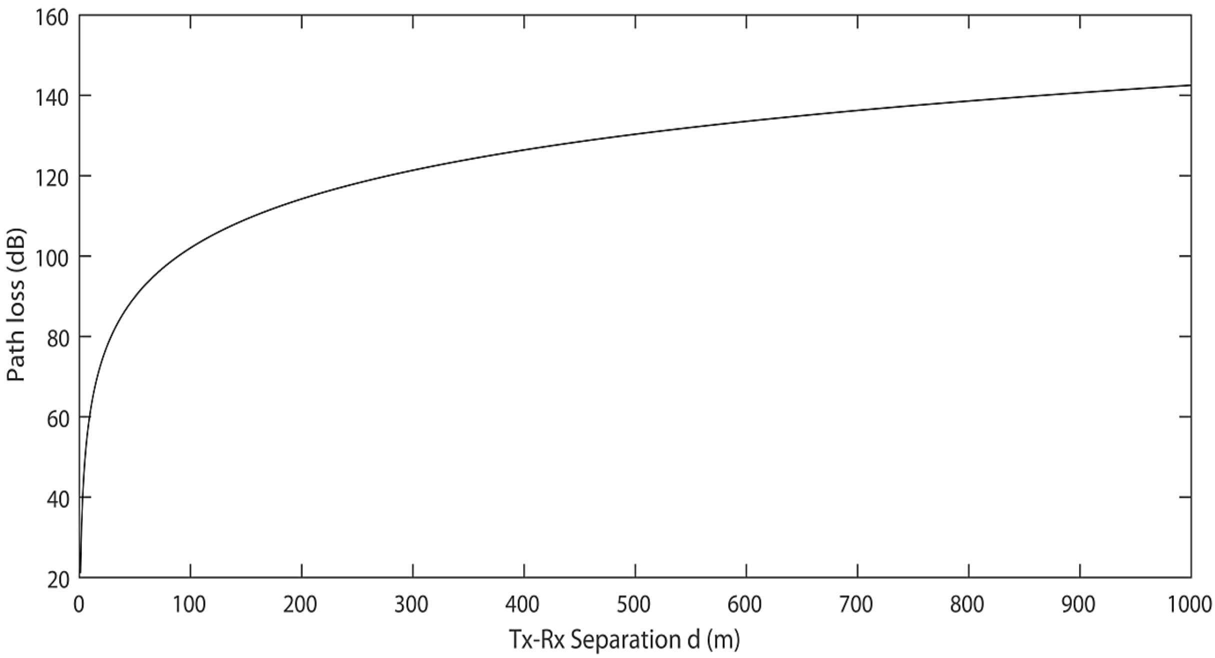

Fig. 4. Path loss simulation using modified SUI model at 28 GHz (for 5G networks)

Confirming the accuracy of different models, it can be concluded that (1), (3), and (4) can be used for finding the path loss and RF coverage for 2G, 3G, 4G, and 5G networks. The accuracy of simulated cell radius (248 m) for 5G communication is also confirmed by the fact that the future cell sizes in urban environments are on the order of 200 m [6].

4. CONCLUSIONS

In this paper, the performance of different propagation models used for cellular networks has been analyzed. The simulations for path loss and RF coverage have been performed where it is observed that at a particular Tx-Rx separation, 2G networks experience the lowest path loss and 5G networks experience the highest path loss. The cell sizes obtained for different networks are in good agreement with the realistic values obtained in literature. For future mobile communication, the cell radius of 248 m is obtained which is in agreement with the today's cell sizes of urban environment. Though smallest coverage area, but 5G communication at mm-wave frequency bands (simulated at 28 GHz here) will prove to be very useful for future mobile communication because of their advantages like high data rate, low latency video, and many multimedia applications.

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