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ANALYSIS OF PATH LOSS PROPAGATION MODELS IN MOBILE COMMUNICATION

SIRIAKSORN JAKBORVORNPHAN

Department of Engineering, Thai-Nichi Institute of Technology, Thailand

E-mail: siriaksorn@tni.ac.th

ABSTRACT

The trend of exchanging information data will continuously increase due to the rapid development of mobile communication networks. The new fifth-generation (5G) technology is designed to support the ever increasing demand for internet traffic volume over wide coverage ranges. This paper focuses on the studies of empirical path loss prediction models for network planning of 5G mobile communication systems. The relationship between path loss and other wireless propagation parameters such as transmitter-receiver antennas separation distance, antenna heights, operating frequency are presented to improve the performance optimisation of wireless networks. The data provided in this paper was analysed in MATLAB computer program to predict signal path loss; estimate radio coverage; avoid interferences; and determine received power level. The results based on the studied model showed that the propagation path loss decreases in accordance with the increase in base station tower antenna height. Okumura model is the most suitable model for short-haul applications in 5G radio network communication.

Keywords: *Path Loss Propagation, Free Space Propagation, Outdoor Propagation Model, Line-Of-Sight Signal, Wireless Communication*

1. INTRODUCTION

Nowadays, mobile phone and internet usage plays an important role in daily life, work and in business dealings. An extraordinary increase in the demand of internet usage has led to the high speed of mobile communication network. One of the most important elements in radio planning in communication systems is the prediction of signal propagation over a desired distance. Also, the installation of high-quality mobile signal generators throughout coverage areas has become a major necessity [1]. It should also reduce radio network latency as well as support the increasing use of digital equipment.

To a large extent, in order to deploy the new communication systems in the most cost effective and efficient way, it is beneficial to understand how the received signal strength performs in different environments. We see in Figure 1 that the signal strength decreases with the propagation distances. Moreover, it is typically advisable to use an appropriate model that provides reliable predictions of the signal strength. The system designers are therefore assured that the service area is adequately covered [1, 2].

Path loss propagation models are used to predict the probability of the amount of radio received signal strength over the entire coverage in a region with less interference to the nearby cell sites. In addition, the received path losses were determined with respect to propagation distance for various path loss models that can be adopted to improve the quality of signal.

In this work, we study a path loss prediction model of the received signal strength at a specified environmental area. Some useful guidance on how to choose the model which would be most appropriate in different environments was presented. Besides, various path loss propagation models such as Free Space Propagation, Okumura, Okumura-Hata, COST-231 models were used to predict the signal coverage and characteristics of mobile radio channel over different locations. The behavior of the wireless channel over different path loss propagation models was investigated through various key input parameters.

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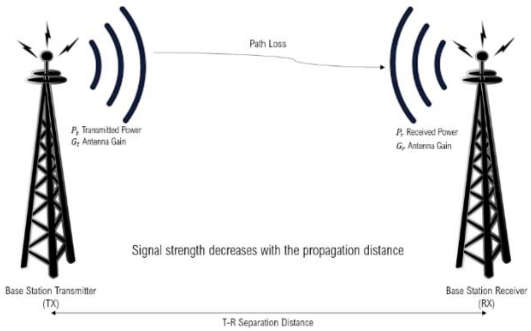

Figure 1: Illustrates Path Loss Between the Transmitter and A Receiver.

2. LITERATURE REVIEW

2.1 Radio Received Signal Strength

The Received Signal Strength (RSS) of transmitted signal is a measure of the received power presented at the receiving end for radio network planning and optimisation. In order to maintain the quality of the signal, the measured RSS should be greater than that of the threshold value. On the other hand, the signal strength should not be too high because it will cause interference with another cell (i.e. the cell that uses the same set of frequency range), located in another cluster at the desired distance away, as depicted in Figure 2, so as to minimise the co-channel interference [3, 4].

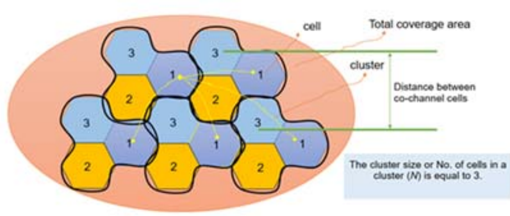

Figure 2: Illustration of Frequency Reuse Concept Between the Co-Channel Cells [2]

The determination of signal strength is necessary because the mobile connection must transfer an ongoing active call or data session from one cell/channel to a nearby cell/channel if and only if the received signal strength drops below the threshold value. This phenomenon is known as handoff or handover in a cellular network (see Figure 3).

It should be note that the occurrences of handover are relatively proportional to the size of the cell. This means the smaller the size of the cell, the greater the number of handovers in the system. The position of the different regions causes the distance between the user and the signal generator to be different.

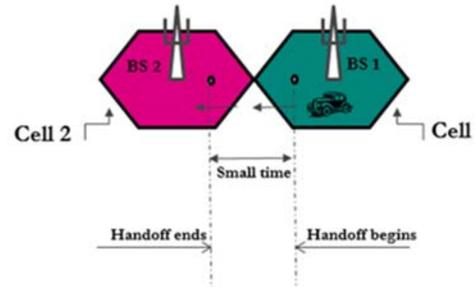

Figure 3: Handover Strategy Occurred at Boundary Between Two Adjacent Cells [2]

This results in the different signal quality received in each area. However, in order to design the construction of signal networks, it is important to know signal strength at different locations. The required minimum field intensity and the signal-to-interference ratio, hence the reliability of the communication must be maintained throughout the entire service area [5].

2.2 Frii Free Space Propagation Model

The Free Space Propagation model states that the received amount of power decays exponentially as the mobile station moves further away from the base station, i.e. as a function of Transmitter-Receiver (T-R) separation distance. This means that the received power falls with the transmission distance at a rate of 20 dB/decade. The free space received power can be expressed by:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (1)$$

where P_t is the transmitted power, G_t and G_r are the gain of the transmitter and receiver antenna, respectively, L is the system loss factor usually and it is usual equivalent to 1 (assume that no loss generated in the system), d is the T-R separation distance between radiating transmitted antenna and received antenna in the unit of meter, and λ is the wavelength and it relates to the carrier frequency which can be defined by

$$\lambda = \frac{c}{f} = \frac{2\pi c}{w_c} \qquad (2)$$

where the relationship between the angular frequency, w_c, and the carrier frequency is that

$w_c = 2\pi f$ [5-7]. It should be noted that in an ideal isotropic antenna, the free space path loss model is typically expressed as

$$L_p = \frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (3)$$

We see in Figure 1 that the free space path loss increases proportionally with the propagation distances. An exponentially increasing of path loss in normal unit and in dB unit over the communication distances (in km) are shown in Figure 4(a) and Figure 4(b), respectively, at the operating frequency of 2.1 GHz.

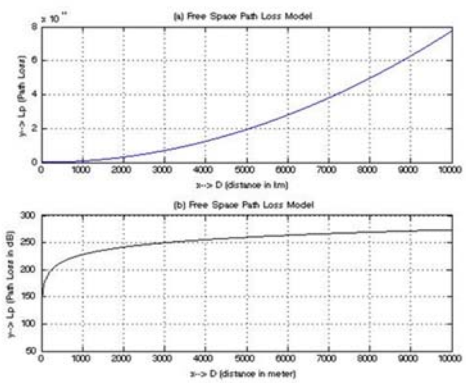

Figure 4: An Increasing of Free Space Path Loss Over the Communication Distances; (a) Path Loss Shown in Normal Unit and (b) Path Loss Shown in dB Unit.

The free space received power in eq. (1) can be reduced to

$$P_r(d) = \frac{P_t G_t G_r}{L_p L} \quad (4)$$

Thus, the received power levels in eq. (6) can be calculated in terms of dB unit as

$$P_r(dB) = 10\log P_t + 10\log G_t + 10\log G_r - 10\log L_p \quad (5)$$

2.3 Okumura Model

The most used model in mobile radio planning is Okumura. The model provides signal strength prediction graphs for bands based at 150, 450, 900, and 1500 MHz for several terrains, such as dense urban, suburban and open areas [4]. The total mean path loss for Okumura's model at distance T-R separation distance can be calculated from

$$L_{50}(dB) = L_p + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \quad (6)$$

where $A_{mu}(f,d)$ is the median attenuation relative to free space, G_{AREA} is the gain due to the type of environment, $G(h_{te})$ is the base station height gain factor and $G(h_{re})$ is mobile height gain factor and can be determined from the condition stated in Table 1.

Table 1: Conditions for base station Height gain and mobile receiver antenna gain [1]

$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right)$	1000 meters > h_{te} ≥ 30 meters
$G(h_{te}) = 10\log\left(\frac{h_{te}}{200}\right)$	h_{te} < 30 meters
$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right)$	10 meters > h_{te} > 3 meters
$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right)$	h_{te} ≤ 3 meters

2.4 Okumura-Hata Model

The Okumura-Hata model provides mathematical formulae that approximate the original Okumura curves. The Okumura-Hata model is a widely used planning tool for land mobile radio systems because of its simplicity. The model introduces restrictions on the acceptable frequency range from 150 to 1500 MHz. The measured distance from the transmitter site from 1 km to 20 km and transmitter antenna heights of the values between 30 and 200 meters above the surrounding terrain.

However, this model is suitable to the design the terrestrial land mobile systems rather than cellular systems due to the limitation of travelled distance [5]. It may also be noted that there are only four main parameters required for the determine the path loss: frequency, height of received mobile antenna, height of base station, and the propagation distance between base station and received antenna in Okumura-Hata model. The standard formula for median path loss in urban areas is given by

$$L_{50,urban}(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_{te}) - a(h_{re}) + (44.9 - 6.55\log h_{te})\log(d) \quad (7)$$

The standard formula for median path loss in suburban areas is given by

$$L_{50,suburban}(dB) = L_{50,urban} - 2\left[\log\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \quad (8)$$

The standard formula for median path loss in open rural areas is given by

$$L_{50,rural}(dB) = L_{50,urban} - 4.78[\log(f_c)]^2 - 18.33\log(f_c) - 40.98 \quad (9)$$

where f_c is the frequency in (MHz) ranging from 150 MHz to 1500 MHz, h_{te} is the effective transmitter base station antenna height ranging

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from 30 m. to 200 m., h_{re} is the effective receiver antenna height ranging from 1 m. to 10 m., d is the T-R separation distance (in the unit of km.), and $a(h_{re})$ is the correction factor for an effective mobile antenna height. It is a function of the size of the coverage area which can be determined from the following conditions:

$$a(h_{re})dB = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8) \quad (10)$$

for small to medium city and

$$a(h_{re})dB = 8.29(\log 1.54h_{re})^2 - 1.1 \qquad for\ 150 \le f_c \le 200MHz$$
$$a(h_{re})dB = 3.2(\log 11.75h_{re})^2 - 4.97 \qquad for\ 200 < f_c \le 1500MHz \quad (11)$$

for large city.

2.5 COST-231 Hata Model

The Co-operative for Scientific and Technical Research (COST-231) model is an extended Okumura-Hata model and used to determine the propagation path loss for the Personal Communication System (PCS) applications, operating at the frequency ranging from 1800 to 2000 MHz. The propagation path loss is predicted by

$$L_{50,urban}(dB) = 46.3 + 33.9\log(f_c) - 13.82\log(h_{te}) - a(h_{re}) + (44.9 - 6.55\log h_{te})\log(d) + C_M \quad (12)$$

where $a(h_{re})$ is defined in the equation (10) and (11) for small to medium city size and large city size, respectively, and $C_M = 0\,dB$ for medium sized city and suburban areas and $C_M = 3\,dB$ for metropolitan centres [1, 2].

3. RESULTS AND DISCUSSION

The transmission of radiowaves is analysed based on actual models that are used to predict the signal strength of all possible paths. The path loss in signal strength when signal waves propagate around obstacles between the base station and mobile unit at different carrier frequencies was calculated and the simulated results is shown in Figure 5. It shows that the system shows the good performance at the operating frequency of 900 MHz, comparing to that of the higher frequency bands at further distances. The reason for this is because the propagation path loss increases with distance as well as the operating frequency [4, 5].

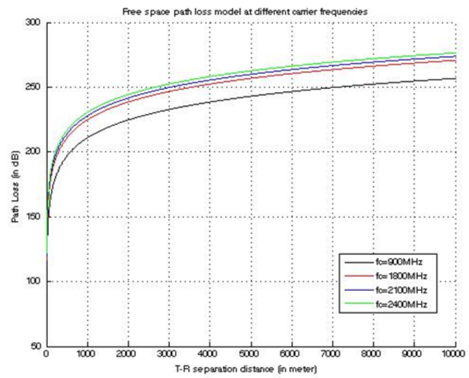

Figure 5: The Free Space Path Loss Propagation at Different Carrier Frequencies Over the T-R Separation Distances.

The path loss propagation for the Okumura-Hata model was analysed at three different base station height in various environments, operating at the operating frequency of 1000 MHz. The comparison in Figure 6 demonstrates that the path loss values measured at the same receiver antenna height was highest in urban area compared to that of the suburban and rural areas. This can be explained by the fact that Okumura-Hata model generally provides better prediction of path loss in rural area due to the lower traffic congestion [6].

In addition, high signaling losses occur in areas where the height of the signal transmission towers is low. The path loss will decrease with increasing height of the receiving antenna. The reason loss reduces when the height of a receiver is increased is because channel fading is typically reduced because the increase in height of the receiving antenna enables the propagating LOS signal to avoid more obstacles and travel further, reaching the receiver with higher power. This means an increase in the ratio of the power received at the receiver unit [8-11]. The key parameters used in the demonstration of Okumura-Hata model was shown in Table 2.

Table 2: Key Parameters of the Determination of Path Loss in Okumura-Hata Model

Parameters (Unit)	Minimum Value	Maximum Value
Base Station Height (m)	30	200
Mobile Station Height (m)	1	10
Carrier Frequency (MHz)	150	1500
T-R Separation Distance (km)	1	20

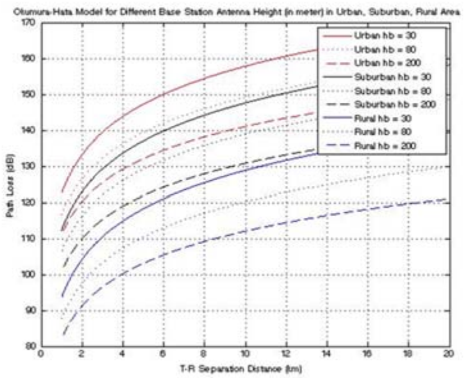

Figure 6: The Okumura-Hata Path Loss Propagation Model for Three Different Base Station Height in Various Environments with the Operating Frequency of 1000 MHz.

The simulation results in Figure 7 (a), (b), and (c) shows the predicted path loss in accordance with distance. It was performed using Okumura-Hata model at different carrier frequencies in urban, suburban, and rural areas, respectively. It can be seen that the determined path loss in were attained at the values of 111 dB, 115 dB, and 118 dB at the operating frequency of 0.9, 1.8, and 2.1 GHz, respectively in rural area with the base station height of 200 meters at the T-R separation distance of 10 km.

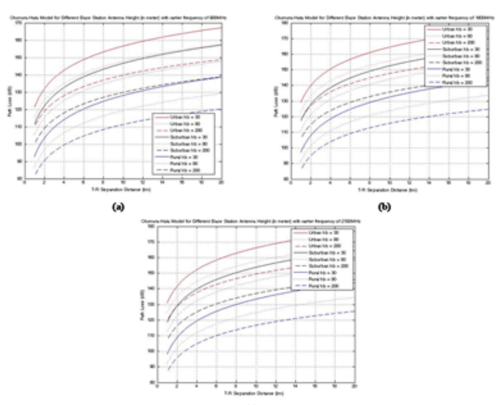

Figure 7: Okumura-Hata Model for Different Base Station Height (in Meters) at (a) Frequency of 900 MHz (b) Frequency of 1800 MHz and c) Frequency of 2100 MHz

Interestingly, at the same base station height, the simulated path losses in an urban area were 140 dB, 148 dB, and 150dB when we operated with frequency of 0.9, 1.8, and 2.1 GHz, respectively. On the other hand, the increased path losses were realised on the values of 158 dB, 165 dB, and 168 dB in urban areas at the base station height of 30 meters with a 10 km separation distances. The results in Figure 7 revealed that the reduced path loss can be found in a rural area rather than the urban and suburban areas [12]. Correspondingly, it is confirmed that increase the base station height would minimise the value of path loss.

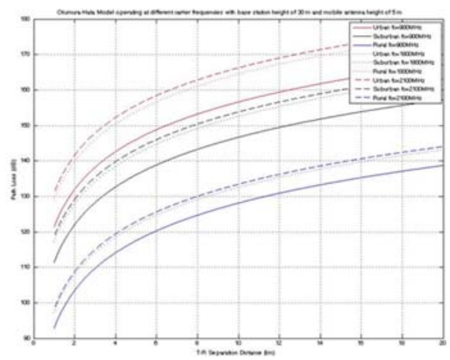

Figure 8: Okumura-Hata Model Operating at Various Carrier Frequencies in Urban, Suburban, and Rural Areas with the Base Station Height of 30 Meters and the Receiver Antenna Height of 5 Meters.

The determination of received path loss between the base station height of 30 meters and mobile station height on the value of 5 meters were analysed on various environmental areas at three different operating frequencies, as shown in Figure 8. The results exposed that the worst path loss performance can be found in the system operated at higher frequency region. This is the reason why faster data transmission was realised in 2.1 GHz rather than a lower frequency band. Thus, the higher frequency band is appropriate short-haul applications [13].

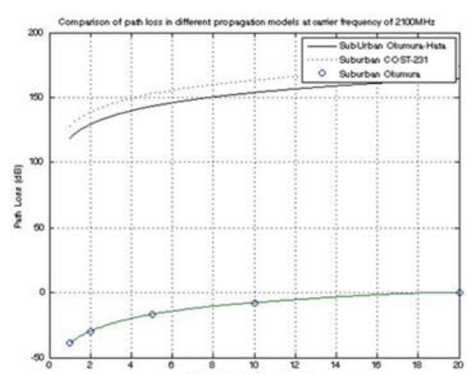

Figure 9: Comparison of Path Loss Analysis in Different Propagation Models at Carrier Frequency of 2100 MHz.

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The demonstration in Figure 9 shows the received path loss in accordance with distance using Okumura, Okumura-Hata, and COST-231 models in suburban area. We experiment these path loss models for suburban environments. It was observed that the Okumura path loss model has an improved coverage performance compared to the Okumura-Hata and COST-231 path loss models, respectively. The maximum path loss for received antenna was 154 dB in COST-231 models and maximum path loss for Okumura-Hata model was 151 dB at carrier frequency of 2.1 GHz. However, the analysis could generally be adjusted for other propagation environments.

4. CONCLUSION

Signal propagation models were used extensively in network planning, particularly for conducting feasibility studies. In this paper, a consideration of commonly used path loss propagation models was presented. The analyses and simulation were done to find out the path loss by varying the BTS antenna height, MS antenna height, and the T-R separation. The propagation path loss decreases due to the increase in BTS antenna height for all the models. These interpretations evidently revealed the effect of path loss on wireless networks. The models chosen for the simulation were the Free space, Okumura, Okumura-Hata, and COST-231 path loss models in suburban area. This is to confirm that the use of new higher frequency bands, especially at mm-wave spectrum, is suitable for short distance applications, i.e. IoTs devices communication, because the higher the frequency is, the greater the path loss will be. It was evidently confirmed from the demonstrations that Okumura model shows better performance than that of Okumura-Hata and COST-231 in terms of path loss reduction. Okumura model could be utilised for the study of 5G radio network planning in wireless communication.

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REFERENCES:

[1] Vijay K. Garg, *Wireless Communications and Networking* (Elsevier, 2007).

[2] S. Jakborvornphan, *Cellular Communication System* (Thai-Nichi Institute of Technology, 2019)

[3] Y. Zakaria and L. IVANEK, "Propagation Modelling of Path Loss Models for Wireless Communication in Urban and Rural Environments at 1800 GSM Frequency Band", *Information and Communication Technologies and Services, Vol. 14* (2), June 2016, pp. 139-144.

[4] Y. Okumura *et al.*, "Field strength and its variability in VHF and UHF land mobile radio service", *Rev. Elec. Comm. Lab., Vol. 16* (9-10), 1968, pp. 825-873.

[5] M. Hata, "Empirical formula for propagation loss in land mobile services", *IEEE Trans. Veh. Tech., Vol. 29* (3), 1980, pp. 317-325.

[6] P. Rani, V. Chauhan, S. Kumar and D. Sharma, "A Review on Wireless Propagation Models," *International Journal of Engineering and Innovative Technology, Vol. 3* (11), 2014, pp. 256–261.

[7] H, Ruisi *et al*., "An Emperical Path Loss Model and Fading Analysis for High Speed Railway Viaduct Scenarios," *IEEE Antennas and Wireless Propagation Letters, Vol.10*, 2011, pp. 808-812.

[8] H.K. Hoomod *et al.*, "Analyzing Study of Path Loss Propagation Models in Wireless Communications at 0.8 GHz" , *IHSCICONF2017 IOP Publishing IOP Conf. Series: Journal of Physics: Conf. Series 1003, 2018.*

[9] A. Bhuvaneshwari, R. Hemalatha, T. Satyasavithri, "Semi Deterministic Hybrid model for Path Loss prediction improvement", *2nd ICCC-2016*, pp-336–344.

[10] M. Kumar, V. Kumar, and S. Malik, "Performance and Analysis of Propagation Models for Predicting RSS for Efficient Handoff", *International Journal of Advanced Scientific and Technical Research, Vol. 1* (2), 2012, pp. 61-70.

[11] Armoogum.V, Soyjaudah.K.M.S, Fogarty.T and Mohamudally. N, "Comparative Study of Path Loss using Existing Models for Digital Television Broadcasting for Summer Season in the North of Mauritius", *Proceedings of Third Advanced IEEE International Conference on Telecommunication, Mauritius Vol. 4*, pp 34-38, May 2007.

[12] A. Valcarce and J. Zhang, "Empirical indoor-to-outdoor propagation model for residential areas at 0.9–3.5 GHz", *IEEE Antennas Wireless Propag. Lett., Vol. 9*, pp. 682–685, 2010.

[13] G.S. Latta, A.J. Plantinga and M. R. Sloggy, "The Effects of Internet Use on Glibal Demand for Paper Products", *Journal of Forestry*, Vol. 114 (4), 2016, pp.433-440.