

Comparative analysis of radio propagation models for LTE network on the sky train

Arif DATAESATU*, Pornpawit BOONSRIMUANG**, Kazuo MORI***, and Pisit BOONSRIMUANG*

* Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, 10520 Thailand.

** Faculty of Industrial Technology, Suan Sunandha Rajabhat University, Thailand, 10300 Thailand.

*** Electrical and Electronic Engineering, Graduate School of Engineering, Mie University, Tsu-shi, 514-8507 Japan.

60601211@kmitl.ac.th, pornpawit.bo@ssru.ac.th, kmori@elec.mie-u.ac.jp, kbpisit@kmitl.ac.th

Abstract— The usage of smartphones and computer for the data communications have become a more integrated part of everyday life for a large majority of the population. One important mode of transportation is the sky train, and users increasingly expect to be able to communicate satisfyingly while traveling on the train: MRT (Mass Rapid Transit Authority of Thailand). However, the radio conditions inside a train are very complex. A possibly large number of users that use at the same time, moving at high speed and a special environment on elevated guideways (height 20 m) are created big challenges for the data communication in LTE network. The accuracy of the path loss model is a very important tool to design the coverage areas and improve the performance in LTE network. This paper that studies and improve the accuracy of the path loss model, which use to design the coverage area of the LTE network under the sky train environment. Normally the radio propagation models under the urban area are designed on the ground approximately 1-3 meters in height but are not suitable for the user in the sky train, which is 20 meters high. we propose the Ericsson urban model in the special environment as sky train by the new values for a_0 from 36.2 to 47.2 and a_1 from 30.2 to 14.2. The proposed new coefficient for Ericsson urban model shows the most accurate path loss under the sky train with the urban area. The filed measurement is used by the smartphone-based measurement for low cost and practical usage.

Keywords— LTE, Path loss, Ericsson model and Sky train MRT.

I. INTRODUCTION

Providing a good Quality-of-Experience for a large number of users inside a sky train: MRT (Mass Rapid Transit Authority of Thailand) puts considerable demands on the density of cell tower placement along the train track. Instead of dimensioning the cellular network to handle a large and fast-moving group of users, an alternative approach is to analyze the radio propagation model on MRT can be categorized as followings:

A. Long Term Evolution (LTE)

Long-term evolution (LTE) is one of the technologies that represent fourth-generation mobile networks (4G). The term LTE was originally the radio access network (RAN) part of the greater system architecture evolution (SAE). But it became very popular, so it was later announced as the commercial name for the system. It is now even used as 4G, while some sources claim that LTE does not meet the criteria for 4G, but a later version, LTE Advance does so [1]; in our work, both are

covered. In LTE, depending on the country and service provider, different frequency bands are being used [2]. In Europe, 2100 MHz is common.

B. Path Loss

The selection of a proper radio propagation model is very important for good planning of communication networks to improve the quality of service (QoS). A radio propagation model has defined the behavior of the signal while it is transmitted from the transmitter to the receiver. The models depend on the distance between the transmitter and receiver, operating, frequency, transmitter and receiver antennas' height, and environment specific dependency. There are several propagation models have been proposed to predict path loss exponent from base to mobile [3].

C. Sky train: MRT (Mass Rapid Transit)

The MRT (Mass Rapid Transit Authority of Thailand) Purple Line is an elevated sky train transit system. The section starts from Bang Yai to Bang Sue. The total distance of this route is 23 kilometers long and has 16 elevated stations with along the route. The height of elevated the MRT is approximately 20 meters Figure 1 presents a view of the MRT on elevated guideways [4].

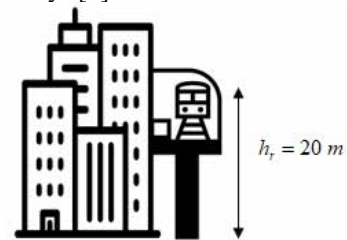


Figure 1. MRT on elevated guideways

The paper is organized by II reviews the propagation path loss models. Section III provides the results of the field measurements comparison with prediction propagation path loss models. Finally, conclusions are presented in Section IV.

II. PROPAGATION PATH LOSS MODELS

A. Stanford University Interim (SUI) Model

The Stanford University Interim (SUI) model is developed for IEEE 802.16 by Stanford University [5], [6]. In this propagation model, there are three different types of terrains or areas are called as terrain A, B, and C. Terrain A can be represented by an area with highest path loss, it can be a very densely populated area which describes the urban environment. Terrain B has an area with medium path loss as the suburban environment. Terrain C has the least path loss as rural or flat area. In Table 1, these different parameters used in SUI model are defined in the following table.

TABLE 1. NUMERICAL VALUES FOR THE SUI MODEL PARAMETERS

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b (1/m)	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

SUI model is defined by the path loss equation as shown below;

$$PL = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + S \quad \text{for } d > d_0 \quad (1)$$

where PL represents Path Loss in dBs, d is the distance between the transmitter and receiver, d_0 is the reference distance (Here its value is 100), X_f is the frequency correction factor, X_h is the Correction factor for transmitter height, S is shadowing & γ is the path loss component and it is described as;

$$\gamma = a - bh_b + \frac{c}{h_b} \quad (2)$$

where h_b represents the height of the base station. The a , b , and c parameters represent the territory for which the values are selected from table 1.

$$A = 20 \log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \quad (3)$$

where A is free space path loss, d_0 is the distance between the transmitter (Tx) and receiver (Rx) and PL is the wavelength. The correction factor for frequency and base station height can be expressed as:

$$X_f = 6.0 \log_{10}\left(\frac{f}{2000}\right) \quad (4)$$

$$X_h = -10.8 \log_{10}\left(\frac{h_r}{2000}\right) \quad (5)$$

where f is the frequency in MHz and h_r is the height of the receiver antenna. This expression is defined for terrain type A and B. For terrain C is used as:

$$X_h = -20.0 \log_{10}\left(\frac{h_r}{2000}\right) \quad (6)$$

$$S = 0.65(\log_{10} f)^2 - 1.3 \log_{10}(f) + \alpha \quad (7)$$

where $\alpha = 5.2$ dB for suburban and rural environments (Terrain A and B) while 6.6 dB for urban environment (Terrain C).

B. COST-231 Hata Model

COST-231 Hata model or COST Hata model has been proposed that It is the expansion of the Hata model [7]. The explanation for median path loss, PLU, in urban areas is given by

$$PL = 46.3 + 33.9 \log_{10}(f) - 13.82 \log_{10}(h_b) \quad (8)$$

$$-ah_m + (44.9 - 6.55 \log_{10}(h_b)) \log_{10}(d) + c_m$$

Here, f is the frequency in MHz, d is the distance between the transmitter and receiver h_b & h_r , which are the correction factors for the mobile base station height and receiver height, respectively. The parameter c_m is defined by 0 for suburban and rural environments and 3 for an urban area. The function ah_m for an urban area is defined as:

$$ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.97 \quad (9)$$

and for rural & suburban areas it is as follows:

$$ah_m = (1.1 \log_{10}(f) - 0.7)h_r - (1.56 \log_{10}(f) - 0.8) \quad (10)$$

C. Ericsson Model

As specified in the name, Ericsson path loss model is developed by Ericsson Inc. to predict the path loss under the network planning software. The model stands on the modified Hata-Okumura model to allow changes on the parameters according to the propagation environment. Path loss for this model can be estimated as follows [8]:

$$PL = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_b) + a_3 \log_{10}(h_b) \log_{10}(d) - 3.2(\log_{10}(11.75h_r))^2 + g(f) \quad (11)$$

where, f – is the envisioned frequency band, transmitter antenna height as a h_b , h_r – is the receiver antenna height and the following $g(f)$ can be expressed as [9],

$$g(f) = 44.49 \log_{10}(f) - 4.78 (\log_{10}(f))^2 \quad (12)$$

Coefficient values for a_0 , a_1 , a_2 and a_3 are presented in Table 2 for the different terrains.

TABLE 2. THE PARAMETER VALUES OF DIFFERENT TERRAIN FOR ERICSSON MODEL

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.60	12.0	0.1

The coefficient values of parameters a_0 and a_1 for the rural and suburban area are based on the Least Square (LS) method [9].

D. ECC-33 Model

ECC-33 path loss model is developed by Electronic Communication Committee (ECC). The original measurements by Okumura and modified its assumptions [10]. In this path loss model equation is used as,

$$PL = A_{fs} + A_{bm} - G_b - G_r \quad (13)$$

where A_{fs} , A_{bm} , G_b and G_r are the free space attenuation, the basic median path loss, the transmitter height gain factor and the receiver height gain factor. They are individually defined as,

$$A_{fs} = 92.4 + 20 \log_{10}(d) + 20 \log_{10}(f) \quad (14)$$

$$A_{bm} = 20.41 + 9.83 \log_{10}(d) + 7.894 \log_{10}(f) + 9.56 [\log_{10}(f)]^2 \quad (15)$$

$$G_b = \log_{10} \left(\frac{h_b}{200} \right) \{13.958 + 5.8 \log_{10}(d)\}^2 \quad (16)$$

$$G_r = 0.759 h_r - 1.862 \quad (17)$$

and for medium city environments,

$$G_r = [42.57 + 13.7 \log_{10}(f)] [\log_{10}(h_r) - 0.585] \quad (18)$$

III. COMPARATIVE ANALYSIS BETWEEN PROPAGATION MODELS AND FIELD MEASUREMENTS

This section explains the detail of using smartphone-based measurement (Sony Xperia X Performance) with Azenqos application software. This application software was developed in the Android phone system, which measures the radio signal level, location, and velocity and parameters in the LTE system as shown in figure 2. The position of the smartphone at the middle of MRT and the posture of the smartphone when doing measurement which a vertical like general use then the measurement setup is illustrated in Figure 3. We experimental measure the route of MRT from Bang Yai to Bang Sue stations,

which show in figure 4. The measurement was taken the several time and calculate the average value for each point as shown in figure 5 and 6. Path loss and distance are calculated from the radio signal level and location of mobile, respectively. The sky train was performed at elevated guideways approximately 20 meters height (h_r), and the route which measured path loss are shown in figure 4. The remaining parameters in this calculation were described in Table 3.

TABLE 3. CALCULATION PARAMETERS

Parameters	Values
Base station height	33 m
Receiver height (smartphone and sky train)	21.5 m
Operating frequency	2100 MHz
Train average velocity	33-42 km/h
Train Dimension (width x height)	3 m x 4 m
Distance between Tx & Rx	0.1-1.2 km

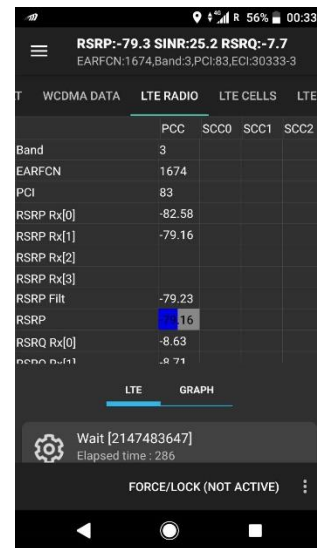


Figure 2. Example of smartphone-based measurement for LTE radio signal.

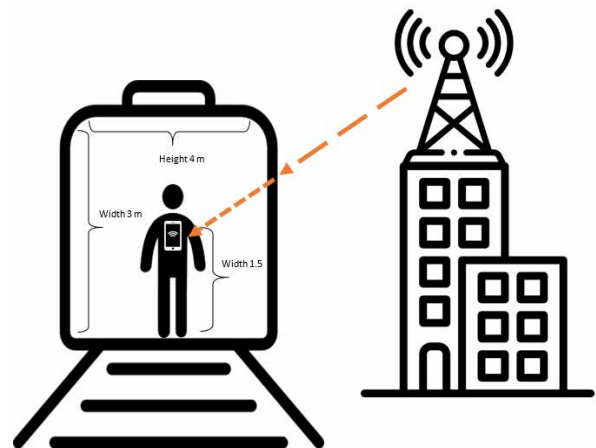


Figure 3. Measurement setup of UE positioned at the middle of MRT

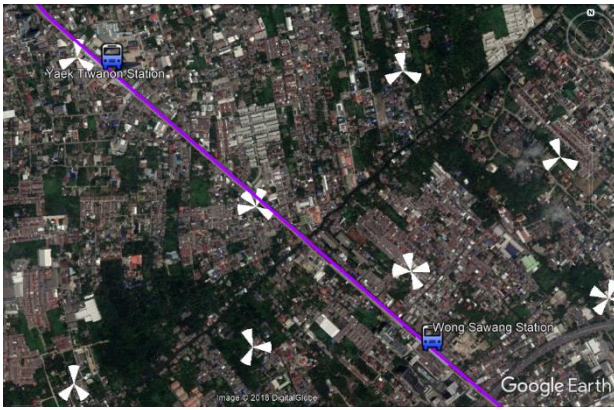


Figure 4. MRT route for the experiment.

The comparison of measurement results in figure 5 shows the difference between the models and the measurement signal level. The h_r was taken by the 20 meters for all the models when calculating the path loss from models for fairness. The average radio measurement signal was approximated by using the curve fitting, which shows the path loss similar to the Ericsson urban model. The best models from above mention were verified by the root means square error (RMSE). The RMSE and the standard deviation of the error between the measured and predicted values were calculated using the formula below:

$$RSME = \sqrt{\frac{\sum_{i=1}^n (x_{m,i} - x_{p,i})^2}{n}} \quad (19)$$

where $x_{m,i}$, $x_{p,i}$ are i^{th} measured and predicted values, respectively. These RMSE values are summarized in Table 4; it clearly shows that Ericsson urban model is the lowest error but still have a big error for path loss estimation.

TABLE 4. RMSE FOR DIFFERENT PATH LOSS MODELS

Path Loss Model	RMSE
COST231(urban)	21.8116
COST231(suburban)	65.1508
COST231(rural)	65.1508
ECC Hata (medium)	46.0193
ECC Hata (Large)	26.0971
Ericsson (urban)	16.8636
Ericsson (suburban)	26.7228
Ericsson (rural)	38.3512
SUI (urban)	56.4290
SUI (suburban)	59.2712
SUI (rural)	41.6802

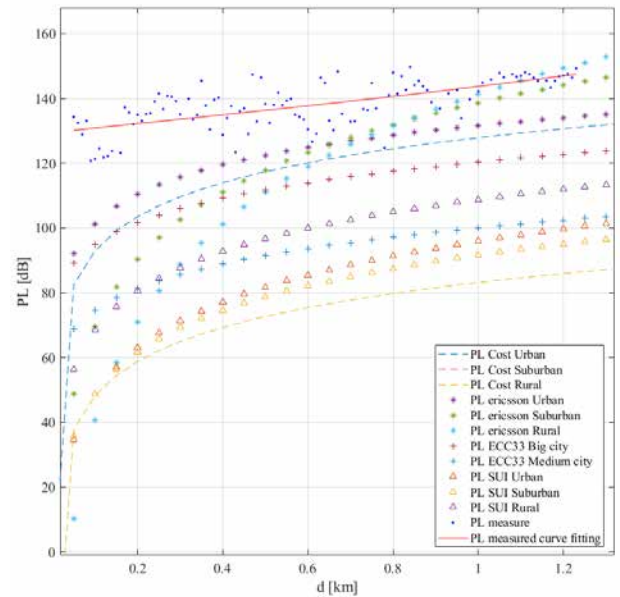


Figure 5. Comparison of measurements with path loss models

As shown in Table 2, these three Ericsson models different defined between urban, suburban and rural areas by the coefficient a_1 , a_2 , a_3 and a_4 , respectively. The coefficient in table 2 is not fit to sky train environment at MRT, Bangkok, Thailand. The special environment can be categorized as followings,

1. The vehicular penetration loss (VPL) [11]
2. The receiver height (sky train)
3. The train velocity

The received signal strength in the sky train takes addition path loss above mention in equation (11). The a_0 is additionally calculated from conventional Ericsson urban model by VPL [11] when we received LTE signal inside the sky train and the urban attenuations. The a_1 is calculated from the free space loss of Ericsson urban model by the distance between receiver height and transmitter height (base station) with train velocity in the Bangkok urban. Following these reasons, the experimental, analysis and calculation can get the new values for a_0 from 36.20 to 47.2 and a_1 from 30.20 to 14.2. The modification of the Ericsson model equation for sky train in an urban area can be expressed by;

$$PL = 47.2 + 14.2 \log_{10}(d) + 12 \log_{10}(h_b) + 0.1 \log_{10}(h_b) \log_{10}(d) - 3.2 (\log_{10}(11.75 h_r))^2 + g(f) \quad (20)$$

The Ericsson model with proposed new coefficient in equation (20) and conventional Ericsson model in question (11) with coefficient in table 2 are compared in figure 6. From figure 6 show the Ericsson model with a proposed new coefficient close to the measurement signal than conventional Ericsson

model. From this results, it can observe that path loss a_0 is increased when compared with conventional Ericsson model because of the VPL and obstruct of railway of sky train. But the path loss a_1 is decreasing when compared with conventional Ericsson model because of the absolute distance between mobile and base station is decreased. We recalculate the RMSE values to compare between the proposed new coefficient and conventional in Ericsson urban model. We can confirm the proposed new coefficient in Ericsson urban model shows lower error estimation in table 5.

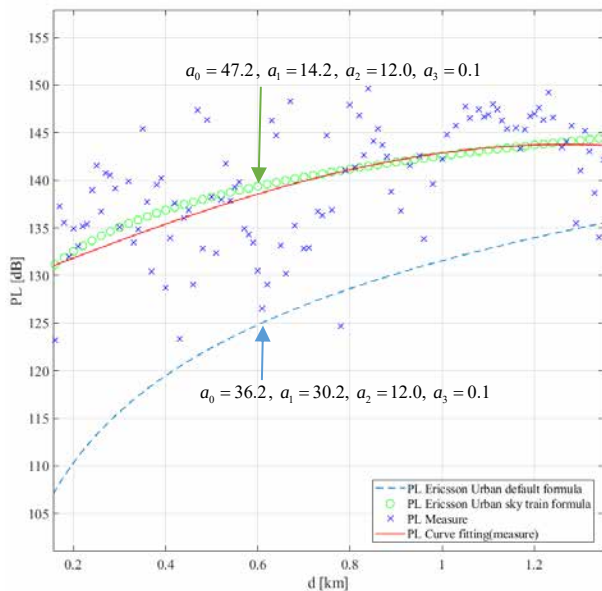


Figure 6. Comparison of measurements with difference Ericsson urban models' formula

TABLE 5. RMSE FOR DIFFERENCE ERICSSON URBAN MODELS' FORMULA

Path Loss Model	RMSE
Ericsson urban default	16.8636
Ericsson urban with a proposed new coefficient	5.4603

IV. CONCLUSION

This paper presents the comparative analysis of radio propagation models for LTE network on the sky train environment, Bangkok, Thailand. We study a large set of field measurements of LTE network operating at 2100 MHz on the sky train (MRT Thailand), which offers a special environment on elevated guideways (height 20 m). The smartphone-based measurements are used to measure the LTE signal for the common practical usage and low cost for simultaneous measurement in the many parameters. The analysis of smartphone-based measurement results shows that the Ericsson model for urban is the most accurate model when the new coefficient is taken by for a_0 from 36.2 to 47.2 and a_1 from 30.2 to 14.2, respectively because of the VPL and obstruction of the railway are large than conventional coefficient. The proposed new coefficient for Ericsson urban model shows that the trend

graph of path loss estimation is much close the practical measurement. RMSE is used to verify the accuracy of the proposed new efficiency for the Ericsson urban model. We can use this new efficiency for the design of the coverage area in the LTE network with the special environment as MRT, Bangkok, Thailand.

REFERENCES

- [1] T. Nakamura, (2009, Oct.). "Proposal for candidate radio interface technologies for IMT-advanced based on LTE release 10 and Beyond (LTE-Advanced)".[Online].Available: http://www.3gpp.org/IMG/pdf/2009_10_3gpp_IMT.pdf
- [2] LTE; E-UTRA; User Equipment (UE) Radio Transmission and Reception, 3GPP TS 36.101 version 12.5.0 Release 12, Nov. 2014.
- [3] Noman Shabbir, Muhammad T. Sadiq, Hasnain Kashif, Rizwan Ullah, "Comparison Of Radio Propagation Models For Long Term Evolution (LTE) Network," International Journal of Next-Generation Networks (IJNGN) Vol.3, No.3, September 2011.
- [4] The M.R.T. Chalong Ratchadham. Retrieved October 01, 2018, from <https://www.mrta.co.th/en/projectelectrictrain/purpleline/>
- [5] Josip Milanovic, Rimac-Drlje S, Bejuk K, "Comparison of propagation model accuracy for WiMAX on 3.5GHz," 14th IEEE International conference on electronic circuits and systems, Morocco, pp. 111-114. 2007.
- [6] V.S. Abhayawardhana, I.J. Wassel, D. Crosby, M.P. Sellers, M.G. Brown, "Comparison of empirical propagation path loss models for fixed wireless access systems," 61st IEEE Technology Conference, Stockholm, pp. 73-77, 2005
- [7] COST Action 231, "Digital mobile radio towards future generation systems, final report," tech. rep., European Communities, EUR 18957, 1999.
- [8] M. D. Alam and M. R. H. Khan, "Comparative Study of Path Loss Models of WiMAX at 2.5 GHz Frequency Band."
- [9] N. Shabbir, M. T. Sadiq, H. Kashif, and R. Ullah, "Comparison of radio propagation models for long-term evolution (LTE) network," arXiv preprint arXiv:1110.1519, 2011.
- [10] V. Erceg, and K.V.S. Hari, "Channel models for fixed wireless applications," tech. rep., IEEE 802.16. Broadband Wireless Access Working Group. January 2001.
- [11] T. Berisha, G. Artner, B. Krasniqi, B. Duriqi, M. Mućaj, S. Berisha, P. Svoboda and C. F. Mecklenbräuker, "Measurement and analysis of LTE coverage for vehicular use cases in live networks," 2017 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), pp. 260-263, 2017.



Arif DATAESATU received the B.Eng. degree in Telecommunication Engineering from King Mongkut's Institute of Technology Ladkrabang (KMUTL), Bangkok, Thailand, in 2017. He is studying the M.Eng. degree in Telecommunication Engineering from King Mongkut's Institute of Technology Ladkrabang (KMUTL), Bangkok, Thailand. He has been joining the Azenqos in 2018, he has worked on deep radio measurement parameters and layer-3 message signaling on android, and has also planned report and tested scenario for drive test solution for LTE, WCDMA & GSM.



Pornpawit Boonsrimuang received the B.Eng. and M.Eng degrees in telecommunication engineering from King Mongkut's Institute of Technology Ladkrabang (KMUTL), Thailand, in 2003, 2007 and Doctor degrees in Telecommunications Engineering at the Mie University, Japan in 2013. He is currently an assistant professor at the faculty of industrial technology, Suan Sunandha Rajabhat University,

Thailand. His research interests include digital communications for next generation of satellite, mobile, and wireless LAN systems.



Kazuo MORI received the B.Eng. degree in Computer Engineering from Nagoya Institute of Technology, Japan, in 1986 and received the Ph.D. degree in Information Electronics Engineering from Nagoya University, Japan in 2000. In 1986, He joined the Hyper-media Research Center, SANYO Electric Co., Ltd. and was engaged in research and development on Telecommunications Systems. From 1995 to 2000, he was a research

engineer at YRP Mobile Telecommunications Key Technology Research Laboratories Co., Ltd., where he was engaged in research on mobile communication systems. Since 2000, he has been an Associate Professor of the Department of Electrical and Electronic Engineering at Mie University, Japan. From 2005 to 2006, he was a Visiting Research Fellow at King's College London, UK. His research interests include mobile communication systems, CDMA schemes, radio packet communications, and tele traffic evaluation. Dr. Mori received the Excellent Paper Award from IEICE, Japan in 2002.



Pisit BOONSRIMUANG received the B.Eng, M.Eng, and Doctor degrees in Telecommunications Engineering, in 1997, and 2000, and 2007, respectively. He is currently an associate professor at King Mongkut's Institute of Technology Ladkrabang (KMUTL), Thailand. His research interests include transmission techniques for future multimedia wireless LAN systems and

next generation of mobile communication systems. He received the Student Award of Young Researches Encouragement Award from IEICE Tokai branch and Doctor Thesis Award for information technology from Nation Research Council of Thailand (NRCT) in 2005 and 2008, respectively. Since 2012, he has been an Associate Professor of KMUTL. His current research interests include mobile communication and broadband.