

An Enhanced Approach for a Prediction Method of the Propagation Characteristics in Korean Environments at 781 MHz

Myoung-Won Jung, Jong Ho Kim, Jae Ick Choi, Joo Seok Kim, Kyungseok Kim, and Jeong-Ki Pack

In high-speed wireless communications, an analysis of the propagation characteristics is an important process. Information on the propagation characteristics suitable for each environment significantly helps in the design of mobile communications. This paper presents the analysis results of radio propagation characteristics in outdoor environments for a new mobile wireless system at 781 MHz. To avoid the interference of Korean DTV broadcasting, we measure the channel characteristics in urban, suburban, and rural areas on Jeju Island, Republic of Korea, using a channel sounder and 4×4 antenna. The path loss (PL) measurement results differ from those of existing propagation models by more than 10 dB. To analyze the frequency characteristics for Korean propagation environments, we derive various propagation characteristic parameters: PL, delay spread, angular spread, and K-factor. Finally, we verify the validity of the measurement results by comparing them with the actual measurement results and 3D ray-tracing simulation results.

Keywords: Propagation characteristic, new mobile system, channel parameter, correlation, ray-tracing.

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Myoung-Won Jung (phone: +82 42 860 5904, mwjung@etri.re.kr), Jong Ho Kim (jonghkim@etri.re.kr), and Jae Ick Choi (jichoi@etri.re.kr) are with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Joo Seok Kim (kjs7205@naver.com) and Kyungseok Kim (kseokkim@cnu.ac.kr) are with the Department of Electrical Engineering, Chungbuk National University, Cheongju, Rep. of Korea.

Jeong-Ki Pack (jkpack@cnu.ac.kr) is with the Department of Electrical Engineering, Chungnam National University, Daejeon, Rep. of Korea.

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I. Introduction

These days, the IT paradigm is changing rapidly from Internet-centered technology to the technology of integrating human beings, objects, and computers. For this reason, the number of services required by wireless communication technologies has also increased. Over the last two decades, communication has become faster and less expensive, and communication systems have become portable, networked, and integrated. The existing 2G/3G communication technology has difficulty meeting the technical needs in the development of next-generation systems, so 4G communication technology that can accommodate qualitative changes in all related areas of mobile content, applications, services, terminals, and so on is required [1]-[3].

Although the UHF band is currently allocated for DTV (470 MHz to 862 MHz), a portion of this band (790 MHz to 862 MHz) will soon be assigned to the mobile communication frequency [4]. In the mobile communication areas, the wave propagations are reflected, penetrated, diffracted, and transmitted along the complicated multipath [5]-[9]. The path loss (PL) and delay during the multipath transmission affect the communication quality and transmission speed [10]. Therefore, predicting the PL and signal delay is an integral part in designing efficient communication networks [11]-[13]. In particular, the various elements of the surrounding environment have different electrical characteristics, which are the key variables when predicting the propagation characteristics [14].

However, the current Korean studies on the characteristics of wave propagations for mobile communications in the UHF

band are insufficient. Although worldwide studies on this issue have been quite active, it is difficult to apply such studies to Korean environments, as the study results are based on their own particular environments. This is because the propagation characteristics vary according to the type and amount of buildings and forests located in each region.

In this paper, we measure the propagation characteristics of various environments on Jeju Island at 781 MHz and analyze various channel parameters. We analyze the PL for cell planning and delay spread (DS) to choose the frequency bandwidth. The angular spread (AS), K-factor, and other elements are also analyzed to study the propagation characteristics [15]. We perform a ray-tracing simulation to validate the analysis results. All of the main structures, such as buildings, roads, and forests, are modeled, and the electric properties of the structural materials are measured [16].

Four typical environments are chosen to develop a site-general model for the measurement environments. For each environment, several different structures are numerically implemented, and the PL and delay characteristics are statistically modeled for each environment.

II. Existing Propagation Model

In this paper, we study a number of PL models to predict the propagation loss for a new mobile system frequency. In Fig. 1, there exist nine models. First, we compare the frequency band of our model with their frequency bands. There are six existing models (Okumura, Hata, M.F. Ibrahim, Sakahmi, COST WI, WINNER+) within the same frequency band. The symbol “○” means it is suitable, and “×” means it is unsuitable.

Next, we compare analyzed environments in our model with those of the six existing models classified in Fig. 1. We consider urban, suburban, and rural environments. In Fig. 2, two existing models (Okumura and Hata) have the same environment. We analyze the COST WI and WINNER models. Even though they do not have a rural environment, they can be analyzed regarding urban and suburban environments. The symbol “△” means that a portion of the model is suitable. The model by M.F. Ibrahim and J.D. Parsons and the model by Sakagmi and Kuboi are not suitable to compare with our model because they proposed an urban scenario analysis. Thus, four models are used for the comparison, but the Okumura model is not mentioned because a formula was not provided [17]. Table 1 reflects the environments of our proposed model and the existing three models, which are used for the analysis.

1. Hata Model

Developed based on field test results of the Okumura model, the Hata model predicts various equations for a PL with

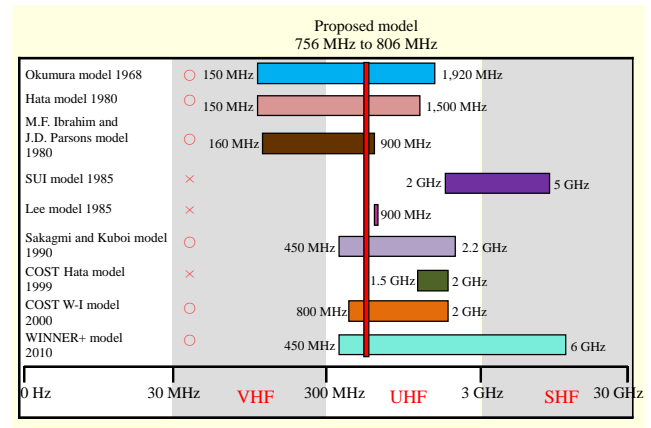


Fig. 1. Applicable range of existing propagation models (frequency).

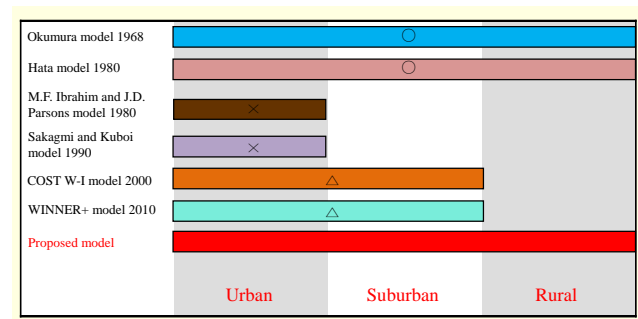


Fig. 2. Applicable range of existing propagation models (environment).

Table 1. Summary of existing models and proposed model.

Model	Frequency (MHz)	Distance (km)	Scenario
Hata	150 to 1,500	1 to 20	Urban/suburban/rural
COST W.I.	800 to 2,000	0.02 to 5	Urban/suburban
WINNER+	450 to 6,000	0.003 to 8	Urban/suburban
Proposed	756 to 806	0.05 to 2	Urban/suburban/rural

different types of clutter. The Hata model's limit is owing to the range of test results from a carrier frequency of 150 MHz to 1,500 MHz. Representative mathematical PL models for each of the urban, suburban, and rural environments are illustrated in (1)/(2), (3), and (4), respectively.

$$PL_{\text{urban}} = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_{\text{BS}}) - a(h_{\text{MS}}) + (44.9 - 6.55 \log(h_{\text{BS}})) \log(d) \quad [\text{dB}], (1)$$

$$a(h_{\text{MS}}) = (1.1 \log(f_c) - 0.7) h_{\text{MS}} - (1.56 \log(f_c) - 0.8) \quad [\text{dB}], (2)$$

$$PL_{\text{suburban}} = PL_{\text{urban}} - 2 \{ \log(f_c / 28) \}^2 - 5.4 \quad [\text{dB}], (3)$$

$$PL_{\text{rural}} = PL_{\text{urban}} - 4.78 \{ \log(f_c) \}^2 + 18.33 \log(f_c) - 40.94 \quad [\text{dB}]. (4)$$

In the Hata model, d is the distance (km) between the base station (BS) and the mobile station (MS), h_{BS} is the height (m) of the transmitter, h_{MS} is the height (m) of the receiver, and f_c is the center frequency (GHz) of the wireless system.

2. COST 231 Walfisch-Ikegami Model

The PL of the COST 231 Walfisch-Ikegami model is composed of free-space loss, L_0 , multiple screen diffraction loss, L_{msd} , and rooftop-to-street diffraction and scatter loss, L_{rts} (Fig. 3):

$$PL_{urban} = L_0 + L_{rts} + L_{msd}. \quad (5)$$

The free-space loss is given by

$$L_0 = 32.44 + 20 \log f_c + 20 \log d. \quad (6)$$

The L_{rts} term describes the coupling of the wave propagation along a multiple-screen path into the street where the MS is located.

$$L_{rts} = -16.89 - 10 \log w + 10 \log f_c + 20 \log (h_{Roof} - h_{MS}). \quad (7)$$

The heights of the buildings and their spatial separations along the direct radio path are modeled using absorbing screens for the determination of L_{msd} .

$$L_{msd_urban} = -18(1 + h_{BS} - h_{Roof}) + 54 + 18 \log d + \left(-4 + 1.5 \left(\frac{f_c}{925} - 1 \right) \right) \log f_c - 9 \log b, \quad (8)$$

$$L_{msd_suburban} = -18(1 + h_{BS} - h_{Roof}) + 54 + 18 \log d + \left(-4 + 0.7 \left(\frac{f_c}{925} - 1 \right) \right) \log f_c - 9 \log b. \quad (9)$$

In the COST 231 model, d is the distance (km) between the BS and the MS, w is the distance (m) between outer walls of the building and the adjacent building, b is the distance (m) between centers of the building and the adjacent building, h_{BS} is the height (m) of the transmitter, h_{MS} is the height (m) of the receiver, and f_c is the center frequency (MHz).

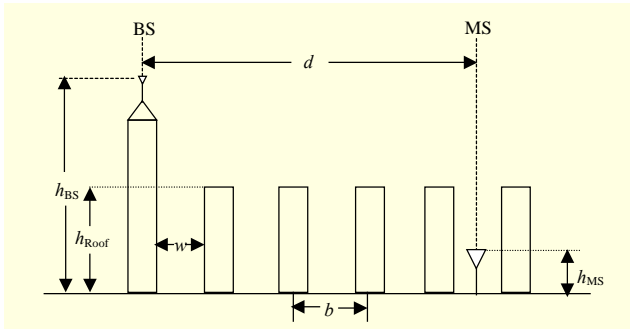


Fig. 3. 2D scenario for COST 231 Walfisch-Ikegami model.

3. WINNER+ Model

The PL characteristic of the WINNER+ model uses the following equation [4].

$$PL_{urban} = 40.0 \log_{10}(d) + 9.27 - 14.0 \log_{10}(h_{BS}) - 14.0 \log_{10}(h_{MS}) + 6.0 \log_{10}(f_c) \quad [\text{dB}], \quad (10)$$

$$PL_{suburban} = 40.0 \log_{10}(d) + 9.0 - 16.2 \log_{10}(h_{BS}) - 16.2 \log_{10}(h_{MS}) + 3.8 \log_{10}(f_c) \quad [\text{dB}]. \quad (11)$$

In the WINNER+ model, d is the distance (m) between the BS and the MS, h_{BS} is the height (m) of the transmitter, h_{MS} is the height (m) of the receiver, and f_c is the center frequency (GHz) of the wireless system.

III. Difference Between Existing Propagation Model and Measurement Data

1. Measurement Environments

The goal of this study is to analyze the propagation characteristics of multiple antennas at the 781 MHz frequency band in various Korean environments. We focus on basic channel characteristics, which are important for the development and validation of realistic channel models. Hence, we construct a measurement system for analyzing the propagation characteristics. To avoid interference from Korean DTV broadcasting, we take measurements on Jeju Island using a 4×4 antenna and a channel sounder from the Electronics and Telecommunications Research Institute (ETRI) of Korea. The measurement scenario consists of four different Tx locations and Rx routes. The Tx location is fixed at each site, and the Rx is driven along the measurement routes. Figure 4 shows an aerial map of the measurement area.

In the transmitter and receiver equipment, the number of antennas is four, respectively. The BS is located in the middle of the vehicle rooftop with an antenna height of 5 m. The antenna of the MS with an antenna height of 1.5 m is set on the end of the rooftop of another vehicle, as we are able to ignore the reflection since an absorber is installed at the rear of the vehicle. In addition, we measure the radio channel characteristics with a channel sounder. The base-band module of the transmitter generates an IF signal with a 50-MHz bandwidth. The RF module has four switching signals, and the adjacent high power amplifier (HPA) module that follows has a maximum power of up to 40 dBm. The samples stored by the sounder are I and Q data forms. The measured I and Q data is converted into a power delay profile for an analysis of the propagation characteristics. In the analysis, paths more than 20 dB below the maximum are discarded, as are taps of less than 3 dB above the noise level [18], [19].

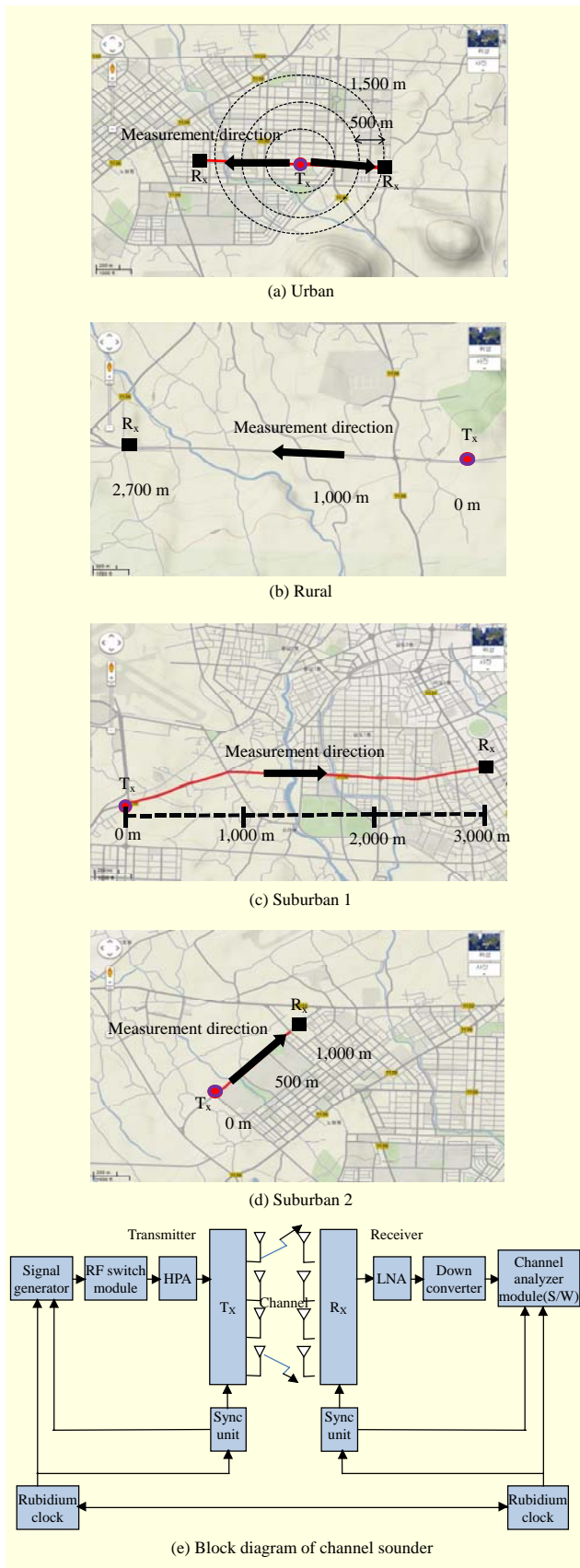


Fig. 4. Measurement scenario and system.

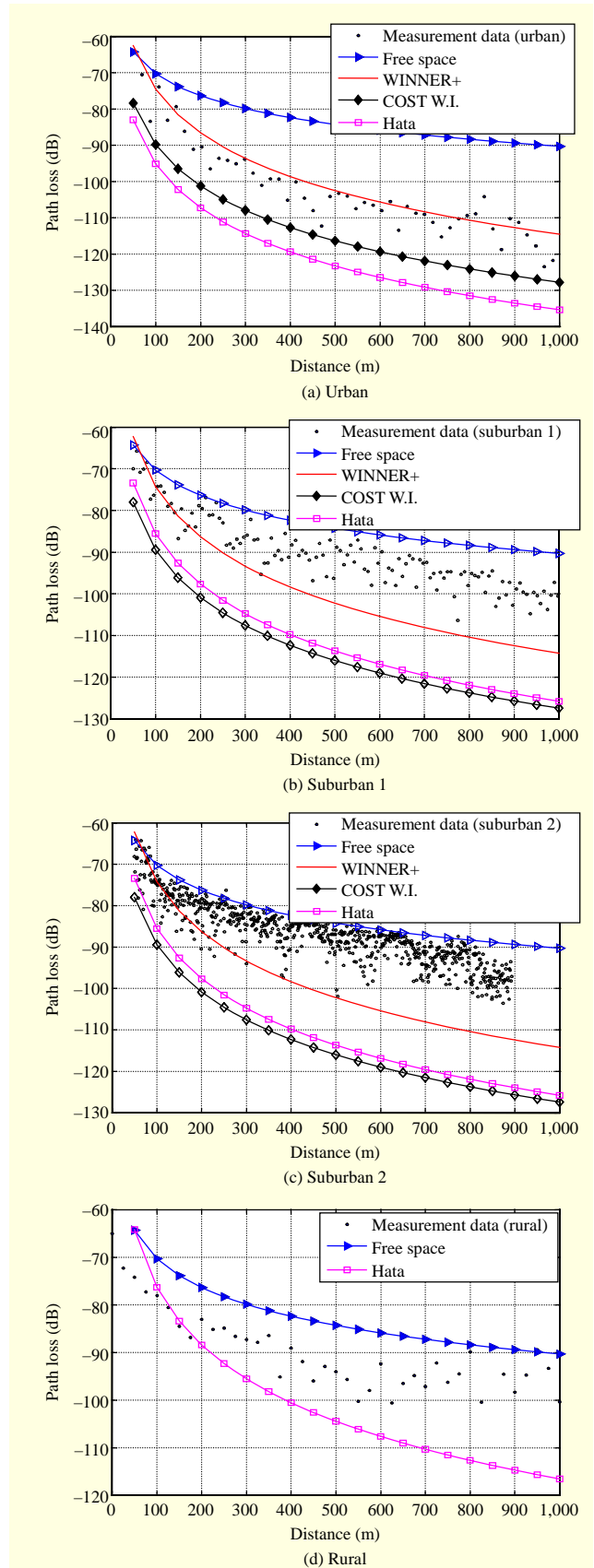


Fig. 5. Comparison results with existing propagation model.

2. Difference Analysis Between the Measurement Data and Existing Propagation Models

Existing propagation models offer general values according to the surrounding environment, frequency, antenna height, and so on. However, the actual measurement results can be different from the results of the existing propagation models. Propagation characteristics of multiple-input multiple-output systems in this paper can also be different from existing single-input single-output systems. An analysis of the propagation characteristics for the measurement environment and system is needed, as the actual measurement environment can be different from the environments of existing propagation models.

To analyze the difference between the actual environment and those of the general propagation models, we measure the received power level in various environments. The distance between the transmitter and receiver is from 50 m to 1,000 m, and the number of measurements is from 50 to 700 points. The PL values are derived by excluding the gain of the transmitter and receiver in terms of received power level and are compared with the values of the existing propagation models in Fig. 5.

As seen in Fig. 5, the general propagation models have different values in the same environment. The attenuation value of the free-space model is the lowest, as it is an ideal environment without any obstacles. The attenuation value of each of the following models is greater in ascending order: WINNER+, COST WI, and HATA. Despite having the same environment and frequency, each PL value is different. In the urban environment in Fig. 5(a), the measurement data is similar to that for the WINNER+ model, but the measurement data in other environments in Figs. 5(b) through 5(d) differs from the data for the existing propagation models. This means that the topographic characteristics, buildings, population density, and so on in the Korean environment are different from those in the existing propagation models. In Fig. 5(d), the WINNER+ and COST WI models are excluded because these models do not consider a rural environment at the 781 MHz frequency band. Thus, the propagation characteristics for the Korean environment must be analyzed through a comparison with the measurement results and the results for the existing propagation models. Therefore, a PL analysis suitable for a domestic environment is needed. To analyze the exact envelope of the PL, we apply a moving average method in the next section and analyze the DS, AS, K-factor, and so on for the frequency characteristics in a Korean environment.

IV. Channel Characteristics Analysis

1. Path Loss

A PL is a major component in the analysis and design of the

link budget of a telecommunication system. In this subsection, we fit the measured data in various environments into a formula and analyze the data statistically through a deterministic channel analysis [20].

A PL is a parameter dependant on the distance and is given as

$$P_L(d) = L_0 - 10n \log_{10} \left(\frac{d}{d_{\text{ref}}} \right) + X_\sigma, \quad [\text{dB}], \quad (12)$$

where L_0 is the initial value at the reference distance d_{ref} , n is the PL index, and X_σ is the standard deviation (STD). Here, L_0 and n are estimated by a regression analysis of the measured reception data. These parameters show the propagation characteristics of our model. The PL results are shown along

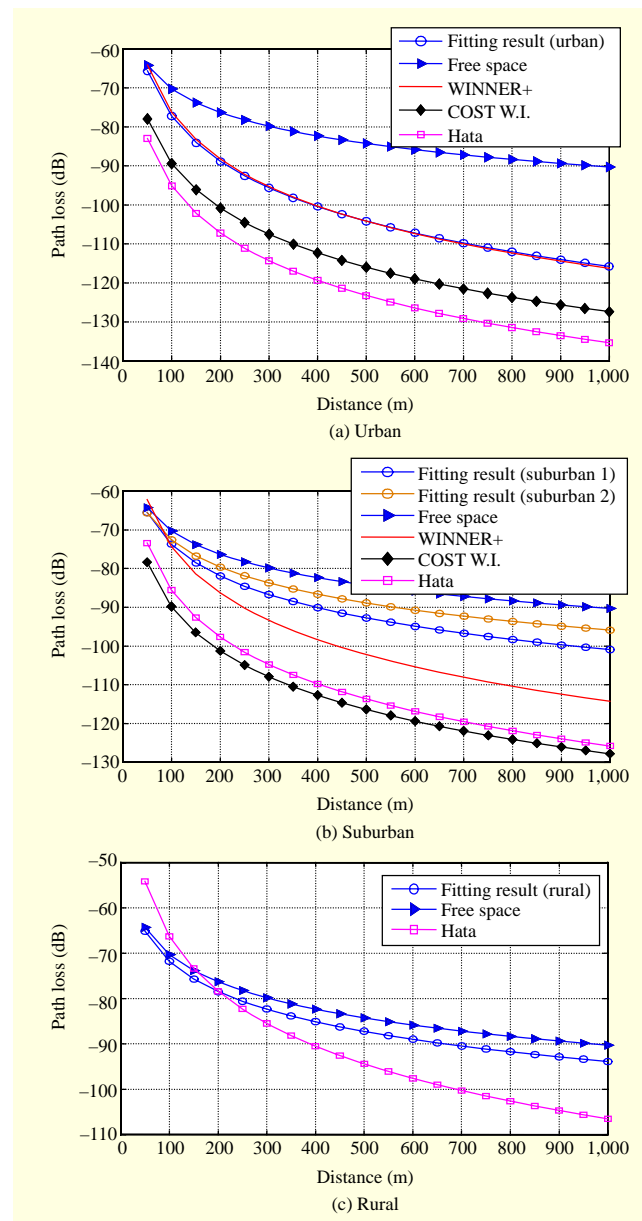


Fig. 6. PL graph of various measurement environments.

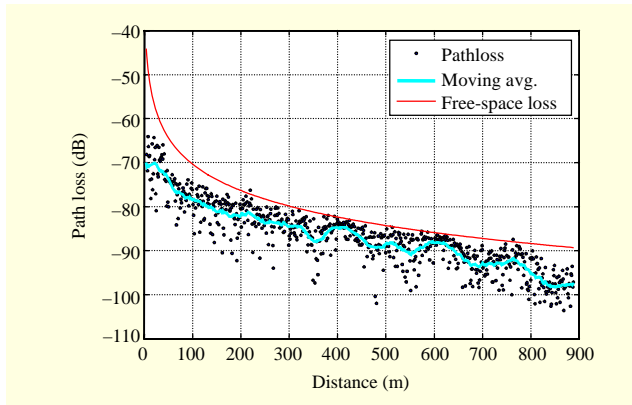


Fig. 7. Moving average analysis in suburban 2 case.

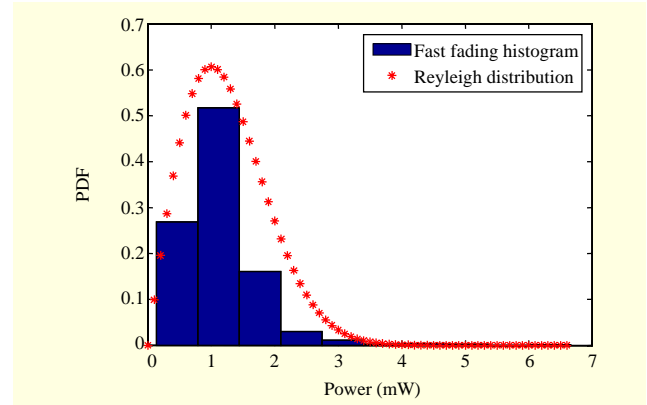


Fig. 9. Probability distribution in suburban 2 case.

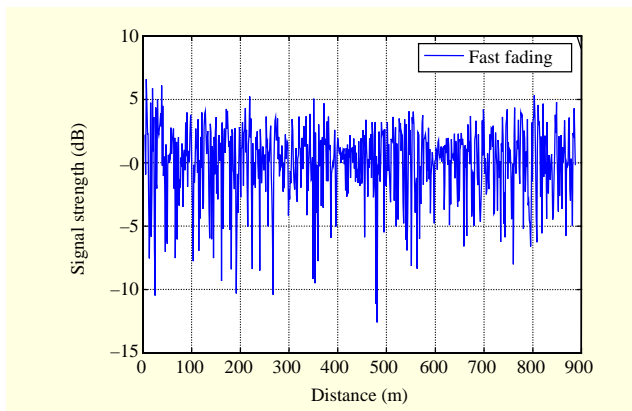


Fig. 8. Fast fading in suburban 2 case.

with the fitting results in Fig. 6. We consider the simple moving average. A data point is given by the statistical mean value over the last n measurements (Fig. 7). The parameter n determines the smoothness of the resulting curve. In addition, fast fading is derived from the difference between the measured data and moving average result. Figure 8 shows a fast fading range of about -13 dB to 5 dB. Figure 9 shows a probability distribution function graph for fast fading. The urban, suburban 1, and suburban 2 environments follow a Rayleigh distribution, and the rural environment follows a Rician distribution.

As mentioned in section III, our measured data differs from that of the existing models regarding suburban and rural environments in the 781-MHz frequency band. Therefore, in analyzing the proposed model and the existing models with adjacent frequencies in suburban and rural environments, we compare the PL values. Figure 10 shows the PL values at adjacent frequencies for each propagation model in the suburban environments. Results in the rural environment are similar to those in the suburban cases. The comparison shows that the PL results have about a 10-dB difference at the adjacent frequencies. Therefore, a frequency characteristic analysis is needed.

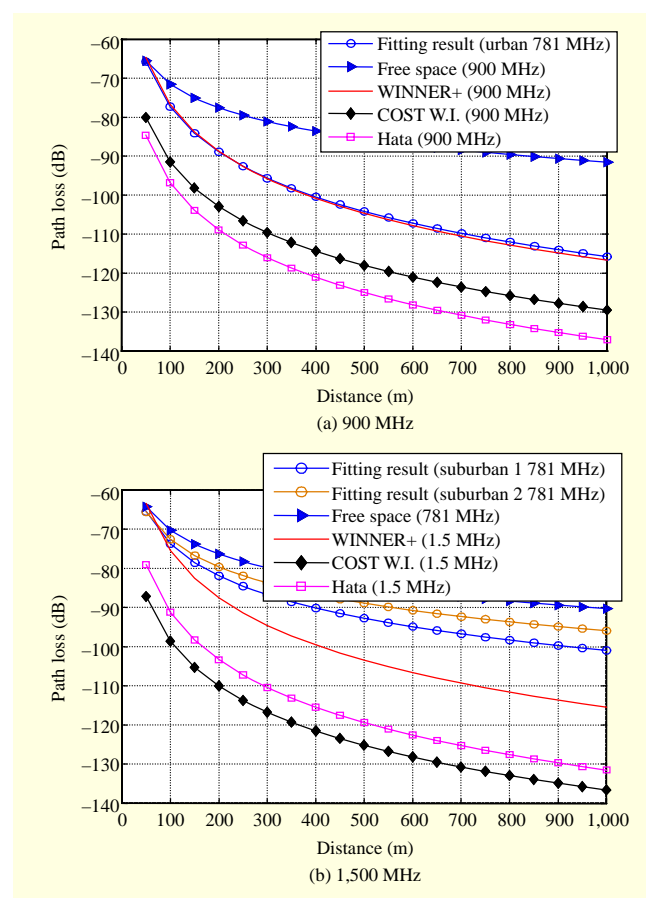


Fig. 10. PL of each model at adjacent frequencies.

2. Delay Spread

The power delay profile (PDP) is computed for all measured data by averaging the squared magnitudes of the channel impulse response over all spatial channels. Figure 11(a) shows the results of the PDP being measured repeatedly while moving over a distance of 1 km. DS values calculated through the PDP are shown in Fig. 11(b). Figure 11(c) shows the

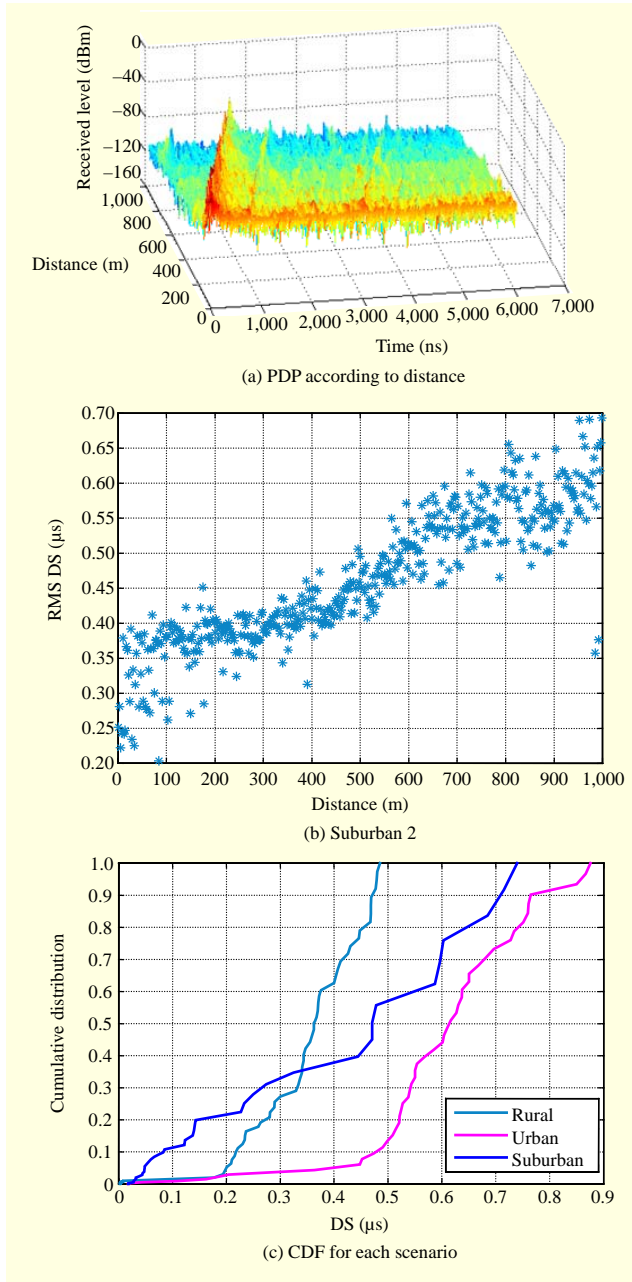


Fig. 11. Measured DS.

cumulative distribution function (CDF) results of the measured DSs. Figure 12 plots the fitting results of the measured DS data, that is, the mean of the root mean square (RMS) and the STD of the RMS. As expected, the largest DSs are found in the urban environment, mostly because of its high density of clusters. Moreover, the rural environment shows a smaller DS, possibly owing to smaller inter-vehicle distances and little cluster scattering.

3. Angular Spread

The AS is a measure of how multipath components arrive

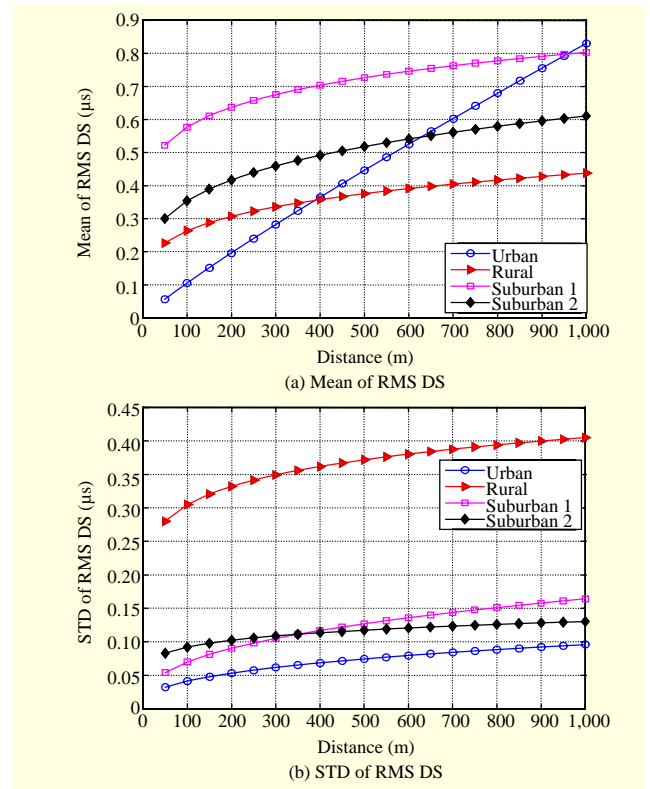


Fig. 12. Fitting results for RMS DS.

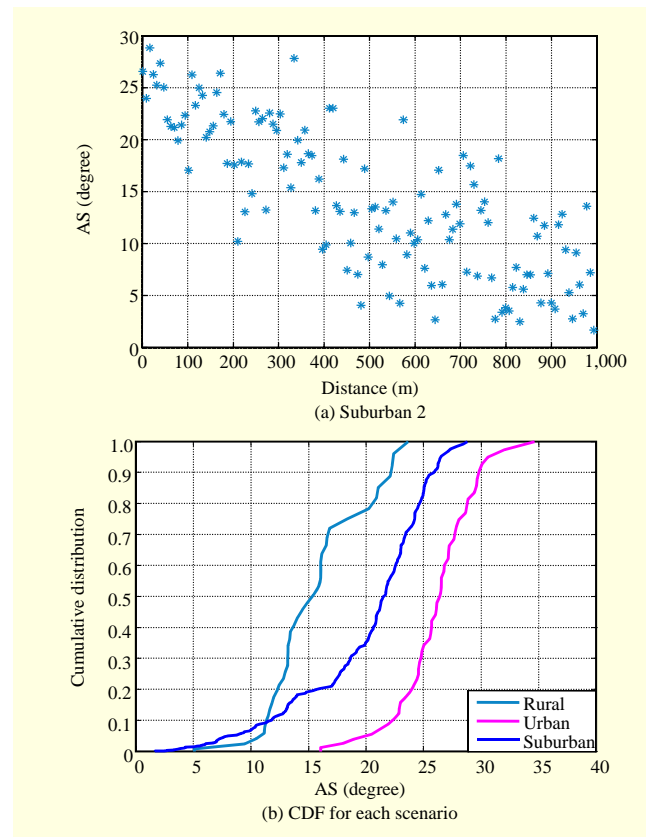


Fig. 13. Measured AS.

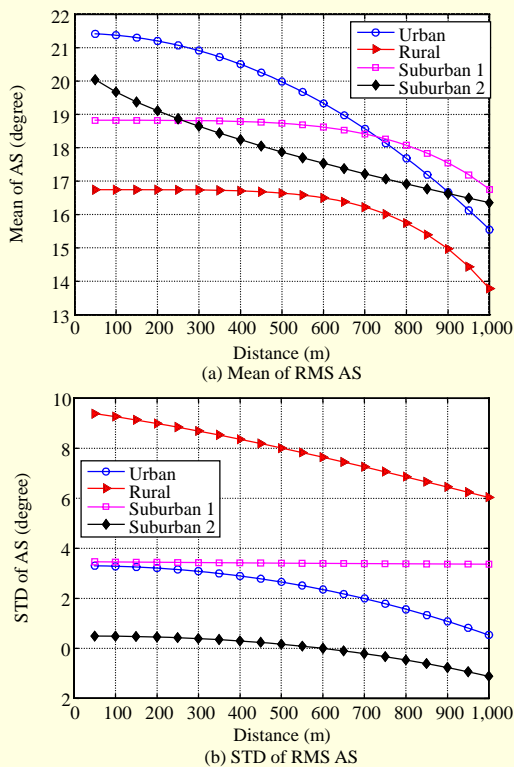


Fig. 14. Fitting results for RMS AS.

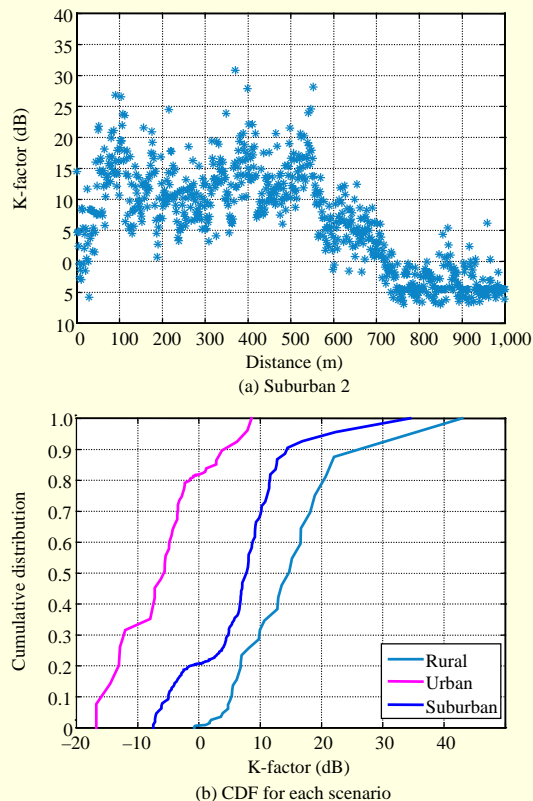


Fig. 15. Measured K-factor.

relative to the mean angle of arrival. The spread is commonly measured in degrees and describes the width of the sector from which most of the received signal power arrives. The measured AS data and fitting results are shown in Figs. 13 and 14.

4. K-Factor

In many radio environments, the complex path gain consists of a fixed component plus a zero-mean fluctuating component. Often, this fluctuation is complex Gaussian. Thus, the time-varying envelope of the composite gain has a Rician distribution. The ratio of the fixed and fluctuating power components is defined as the K-factor [21]. The measured K-factor data is shown in Fig. 15.

5. Correlation Between Channel Parameters

The correlations of parameters observed in the measured data are reflected in the joint power or probability distributions. Generally, the DS shows a positive correlation, and the PL, the AS, and the K-factor show negative correlations according to the distance. The highest correlation between the DS and distance is found in the urban environment, mostly owing to its high density of cluster scattering. A reduction in the overall power explains the negative correlation between the PL and distance. In addition, the AS shows why a negative correlation exists when the Rx is far from the Tx, as the Rx receives a relatively small angle of the signal. The reduction of the line-of-sight signal explains the negative correlation between the K-factor and distance. The strongest correlation between the PL and the distance is observed in the urban scenario. Because the urban environment is most complicated, attenuation of the received signal according to the increase of distance is greater. Tables 2 through 4 show correlation coefficients between individual parameters.

V. Verification of Measurement Results Using Ray-Tracing Method

To verify the validity of the measurement results, we create a simulation condition based on a geographic information system map in real environments. The simulation environment consists of buildings and forest information similar to a real environment. A 3D simulation is carried out after adding information to the real propagation: diffraction, reflection, scattering, and so on. We increase the reliability of the simulation by applying different values for the roads, buildings, forests, and so forth.

In Fig. 16, the picture on the left is the ray-tracing simulation screen based on the real urban environment that is shown in the

Table 2. Correlation coefficients (urban).

	Distance	PL	DS	AS	K-factor
Distance	1.0	-0.90	0.24	-0.57	-0.10
PL	-0.90	1.0	-0.18	0.46	0.02
DS	0.24	-0.18	1.0	-0.39	0.07
AS	-0.57	0.46	-0.39	1.0	0.49
K-factor	-0.10	0.02	0.07	0.49	1.0

Table 3. Correlation coefficients (suburban).

	Distance	PL	DS	AS	K-factor
Distance	1.0	-0.87	0.90	-0.09	-0.71
PL	-0.87	1.0	-0.78	0.04	0.51
DS	0.90	-0.78	1.0	-0.04	-0.65
AS	-0.09	0.04	-0.04	1.0	0.21
K-factor	-0.71	0.51	-0.65	0.21	1.0

Table 4. Correlation coefficients (rural).

	Distance	PL	DS	AS	K-factor
Distance	1.0	-0.75	0.88	-0.79	0.54
PL	-0.75	1.0	-0.42	0.63	0.29
DS	0.88	-0.42	1.0	-0.56	-0.47
AS	-0.79	0.63	-0.56	1.0	0.40
K-factor	-0.51	0.29	-0.47	0.40	1.0

photograph on the right. We compare the measurement results with the ray-tracing results in Fig. 17. The ray-tracing results are slightly different from the measurement results, but their tendencies are similar, with a difference of within 10 dB, which is quite slight when considering the overall tendency for decrease. Therefore, the measurement data of this paper can be determined to be reliable.

In an urban environment, the number of buildings is greater and the density of the structures is higher than in other environments. Additionally, there is a large floating population and a significant amount of parked cars. Therefore, the PL attenuation in an urban environment is greater than it is in other environments.

The suburban 2 environment has wide roads and less traffic, and one side of the road is an open area, as shown in Fig. 18. Therefore, its reflection and diffraction are less than they are in the urban and suburban 1 areas. In short, the PL attenuation is less than it is in the urban and suburban 1 environments, as shown in Fig. 19.

A rural environment consists of forests and hills, as shown in Fig. 20. As there are few buildings, the PL attenuation is less



Fig. 16. Ray-tracing simulation and photograph of real street in urban environment.

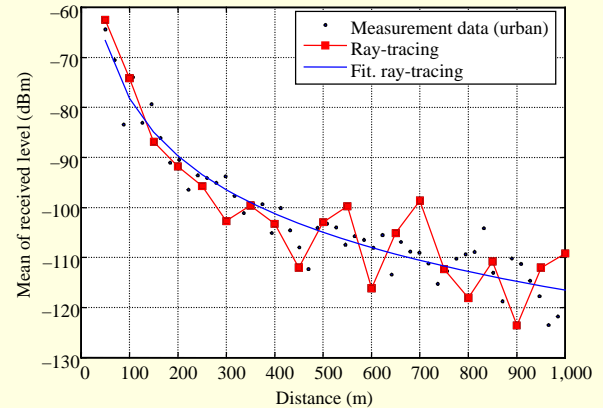


Fig. 17. Comparison of measurement results with the ray-tracing results in urban environment.



Fig. 18. Ray-tracing simulation and photograph of real street in suburban 2 environment.

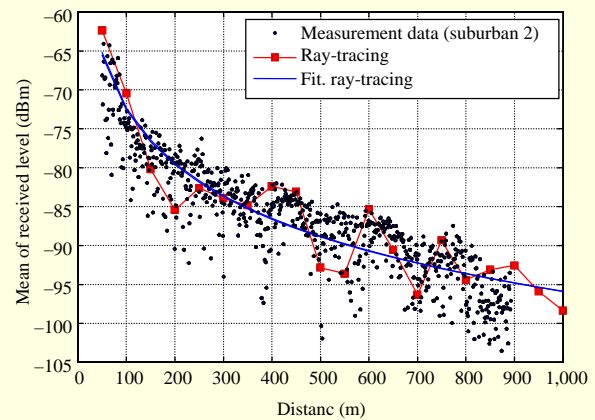


Fig. 19. Comparison of measurement results with ray-tracing results in suburban 2 environment.

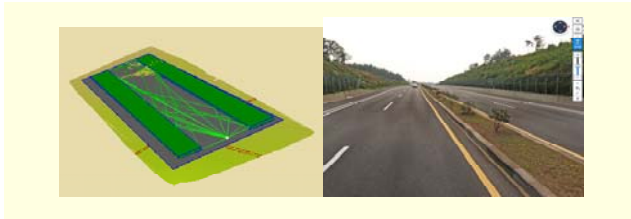


Fig. 20. Ray-tracing simulation and photograph of real street in rural environment.

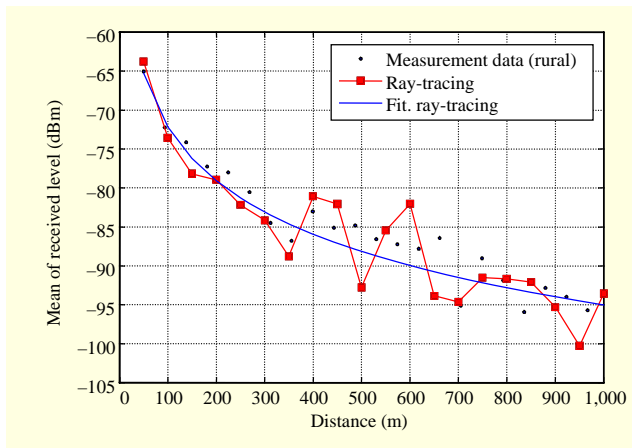


Fig. 21. Comparison of measurement results with ray-tracing results in rural environment.

than it is in the other environments, as shown in Fig. 21. However, like the other results, the ray-tracing results tend to be similar to the measurement results.

VI. Conclusion

Recently, it has become necessary to verify propagation channel system implementation to optimize the development of next-generation mobile communication systems, owing to the rapidly increasing needs of wireless communication and the explosion of mobile communication services. For this reason, we performed various analyses on the measurement of a propagation channel on Jeju Island, Republic of Korea. First, to verify the propagation channel system used in next-generation mobile communication in the 700 MHz band, we studied a general propagation model in different regions and frequency bands. After that, we compared our measurement results with the results of existing propagation models in similar frequency bands and environments. The PL value in the analysis results showed a difference of more than 10 dB. Therefore, a frequency characteristic analysis is needed for Korean environments. In this paper, we analyzed the propagation characteristics in detail using the deterministic method as well as one of the existing analysis methods. According to the analysis results, the values of the DS and the AS were highest

in an urban environment, whereas the K-factor was the highest in a rural environment. We also verified the validity of the measurement results through a comparison of the actual measurement results and the 3D ray-tracing simulation results. We increased the reliability of the simulation by applying a simulation environment similar to that of the actual measurements. In conclusion, our study will help in the cell planning of next-generation mobile communication services through detailed channel modeling at 781 MHz. In the future, we will compare this data to the local propagation characteristics of other places in Korea and other countries, provided this frequency band has been allocated in Korea.

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Myoung-Won Jung received his BS and MS in electronic engineering from Chungnam National University, Daejeon, Rep. of Korea, in 2006 and 2008, respectively. Since 2009, he has been working for ETRI, Daejeon, Rep. of Korea, where he is a senior member of the engineering staff of the Radio Technology Department. His main interests are radio propagation study for mobile communication and millimeter wave propagation study in indoor and outdoor environments.



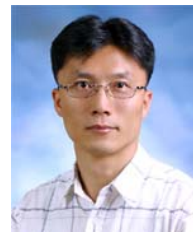
Jong Ho Kim received his BS, MS, and PhD in electronic engineering from Chungnam National University, Daejeon, Rep. of Korea, in 1986, 1988, and 2006, respectively. Since 1989, he has been working for ETRI, Daejeon, Rep. of Korea, where he is a principal member of the engineering staff of the Radio Technology Department. His main interests are radio propagation and spectrum engineering.



Jae Ick Choi received his BS, MS, and PhD from Korea University, Seoul, Rep. of Korea, in 1981, 1983, and 1995, respectively. Since 1983, he has been with ETRI, Daejeon, Rep. of Korea. He was involved in the RF/antenna development of the earth station, specifically the SCPC and VSAT system, the TT&C ground station (of the Arirang satellite), the IMT2000 system, and digital DBS, among others. He was in charge of electromagnetic environment research and development with relation to EMI/EMC technologies and EMF exposure assessment from 2004 to 2005. Currently, he is researching and developing metamaterials and their application technologies for antenna/RF sensors, RF components, radio transmission technologies, and so on.



Joo Seok Kim received his BS in information and communication engineering and his MS in wireless communication engineering from Chungbuk National University, Cheongju, Rep. of Korea, in 2007 and 2009, respectively. He is currently working toward his PhD with the School of Wireless Communication Engineering of Chungbuk National University. His research interests include cognitive radio, digital radio, and MIMO wireless channel.



Kyungseok Kim received his PhD in electrical and electronics engineering from Surrey University, Guildford, England, UK, in 2002. He worked for ETRI, Daejeon, Rep. of Korea, from 1989 to 1998 and from 2002 to 2004. He is currently working as a professor at Chungbuk National University, Cheongju, Rep. of Korea. His research interests include SDR, cognitive radio, power line communication, digital radio, and MIMO wireless channels.



Jeong-Ki Pack received his BS in electronics engineering from Seoul National University, Seoul, Rep. of Korea, in 1978. He received his MS and PhD in electrical engineering from Virginia Tech, Blacksburg, VA, USA, in 1985 and 1988, respectively. From 1978 to 1983, he was a research engineer in the Agency for Defense Development. From 1988 to 1989, he worked at ETRI, Daejeon, Rep. of Korea, as a senior research engineer. He was an associate professor in the Department of Electronics Engineering at Dong-A University for six years, beginning in 1989, and he thereafter moved to Chungnam National University. He has served the Korea Institute of Electromagnetic Engineering & Science as a member of the board of directors, Vice President, President, and Honorary President since 2002 and has been a board member of the Bioelectromagnetics Society. His research is focused on wave propagation and bioelectromagnetics.