Multipath Channel Characteristics for Propagation between Mobile Terminals in Urban Street Canyon Environments

Myung-Don KIM, Juyul LEE, Jinyi LIANG, Jinup KIM

Electronics and Telecommunications Research Institute (ETRI)

218, Gajeongno, Yuseong-gu, Daejeon, 305-700, Korea

mdkim@etri.re.kr, juyul@etri.re.kr, liangjinyi@etri.re.kr, jukim@etri.re.kr

***Abstract*—In this paper, we focus on multipath channel characteristics of low–height antenna links for mobile to mobile communications in urban street canyon environments. We present a wideband MIMO channel sounder and antennas used to measure multipath channel characteristics in the 3.7GHz frequency band and the result of calibration test to evaluate a system performance before field measurement. We carried out channel measurement campaigns in typical urban street canyon environments in Seoul, Korea. The root mean square (r.m.s.) delay spread and angular spread characteristics are analyzed with results of their distribution and cumulative density function (CDF) in line of sight (LoS) and non-LoS (NLoS) case respectively.**

***Keyword*—Mobile-to-Mobile, multipath characteristics, channel model, channel measurements, channel sounder**

I. INTRODUCTION

MOBILE-TO-MOBILE direct communications services, commonly known as D2D (device-to-device), are now being actively discussed in various standardization bodies, e.g., "ProSe" for the LTE-Advanced system [1]. Unlike typical rooftop cellular networks, both transmitters and receivers are generally found near street levels, since direct communication links are established between mobile terminals. Consequently, conventional propagation models are limited in their ability to predict specific channel environments and those characteristics for development of the direct communication system using a system or link level channel simulation.

Recently, new prediction methods and channel characteristics for propagation between mobile terminals based on field measurement in various outdoor environments are reported widely. Lu et al [2] developed simplified site-specific path loss formulas for street grids. They assumed that surrounding buildings are infinitely high so that "vertical plane" effects can be ignored. Considering reflection and diffraction along with the horizontal plane, they developed path loss formula based on two-ray models, which can account for up to two-turn NLoS links. M. Sasaki [3] proposed a new path loss model for propagation between terminals located below roof-top in residential environments. J. Lee et al [4] investigated the effects of surrounding building heights on path loss characteristics, especially in urban street grid environments in Korea. From the comparison results of the ITU-R propagation models such as ITU-R Recommendation P.1411 [5] and Report M.2135 [6], it is noted that conventional channel models are overestimated and the path loss characteristics can be affected by surrounding building heights. Furthermore, from the aspect of radio propagation between low-antenna terminals in high-rise environment, reflected waves at corners in horizontal plane seem to play a dominant role. Most of these researches are relevant to the path loss characteristics for mobile to mobile direct communications. However, when we consider direct communications between terminals using MIMO antennas, the study of multipath characteristics (i.e. delay spread, angular spread, etc.) is also very important.

This paper investigates multipath channel characteristics for propagation between mobile terminals based on channel measurements in Seoul, Korea. Section II presents a wideband MIMO channel sounder used to measure multipath channel characteristics, and the result of calibration measurement to evaluate a system performance before field measurement. In Section III and Section IV, the field measurement campaign and analysis results of multipath characteristics such as delay spread and angular spread are described. Finally, to wrap up the work, conclusions are given in Section V.

Manuscript received September 8, 2014. This work was supported in part by the MSIP (Ministry of Science, ICT & Future Planning), Korea in the ICT R&D Program 2014, "Development of core technologies to improve spectral efficiency for mobile big-bang (14-000-01-002)". (Corresponding author: +82-42-860-6178; fax: +82-42-860-6732; e-mail: mdkim@etri.re.kr)

Myung-Don Kim is Principal Researcher with the Electronics and Telecommunications Research Institute, Daejeon, Korea (+82-42-860-6178; fax: +82-42-860-6732; e-mail: mdkim@etri.re.kr).

Juyul Lee is Senior Researcher with the Electronics and Telecommunications Research Institute, Daejeon, Korea (+82-42-860-5503; fax: +82-42-860-6789; e-mail: juyul@etri.re.kr).

Jinyi Liang is Researcher with the Electronics and Telecommunications Research Institute, Daejeon, Korea (+82-42-860-5289; fax: +82-42-860-6732; e-mail: liangjinyi@etri.re.kr).

Jinup Kim is Principal Researcher with the Electronics and Telecommunications Research Institute, Daejeon, Korea (+82-42-860-5423; fax: +82-42-860-6789; e-mail: jukim@etri.re.kr).

II. Measurement System and Calibration of System Performance Before Measurement

A. *Wideband MIMO Channel Sounder*

Measurement campaigns were conducted with the wideband MIMO channel sounder system developed at Electronics and Telecommunications Research Institute (ETRI), which can measure multipath characteristics in the 3.7 GHz frequency with 100 MHz bandwidth [7][8]. Table I represents a detailed specification of the channel sounder which can measure the channels received from multiple antenna elements and estimate multipath components with a time delay resolution of 10 ns.

TABLE I
SPECIFICATION OF CHANNEL SOUNDER AND MEASUREMENT CONFIGURATIONS

Items	Specifications
Frequency	3.7 GHz
Channel bandwidth	100 MHz
PN code length	2047 chips
Maximum Tx power	36 dBm
Multipath Resolution	10 ns (3m)
Frequency stability	10^{-11}
Number of Antenna elements	TX: 8 UCA, RX:8 UCA

For the measurement campaign, we installed a transmitter (TX) and a receiver (RX) channel sounder in separate vehicles respectively as shown in Fig. 1. A uniform circular array (UCA) antenna which has eight vertically polarized elements aligned circularly with a spacing of 0.5 λ is mounted on the rooftop of each vehicle with the height of 1.9 meters.

Fig. 1. Installation of channel sounder system and antennas (mounted on the rooftop of vehicle) for channel measurement campaign

B. *System Calibration Measurement and Results*

Before measurement campaign, we have conducted a system calibration measurement at ETRI playground (open space) with channel sounders (a transmitter and a receiver) and antenna arrays. For this measurement, full radiation patterns of all the elements of each array antenna were measured in the anechoic chamber in advance. The azimuth plane radiation pattern with two polarizations (vertically and horizontally from -180° to +180°) and the elevation plane (from -45° to +45°) have been obtained enabling the estimation of the spatial channel characteristics. Fig. 2 depicts a configuration of this test. The position of a transmitter (TX) was fixed, and a receiver (RX) was located at 9 m away. The UCA8 array antennas for both TX and RX were installed on the ground with a height of 1.5 m. We measured a channel from TX to RX, and changed the position of the RX and collected measured samples of total 8 points with different angles (θ = 0°, 45°, 90°, 135°, 180°, -45°, -90°, -135°).

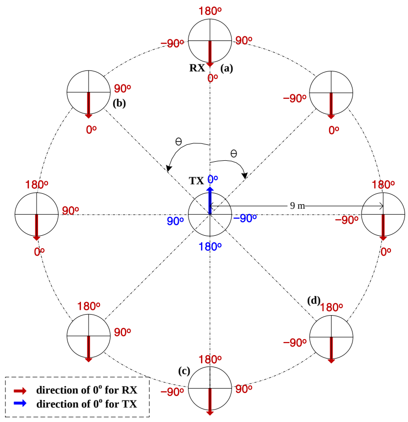


Fig. 2. Configuration of calibration measurement for channel sounders (TX-RX) and antennas

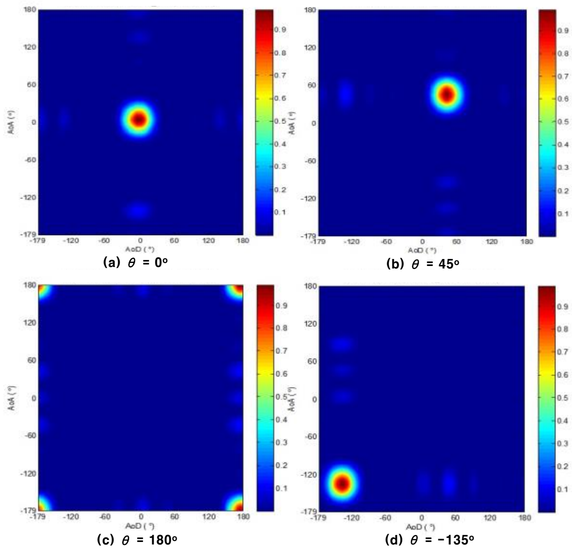


Fig. 3. Estimated result of AoA and AoD at the position of θ

In this paper, we observed the estimated results of an angle of departure (AoD) and an angle of arrival (AoA) by using a Barlett beam-forming method [9]. Fig. 3 shows estimated results of AoA and AoD at each point of θ. We can see that a dominant path component having the strongest channel power (red part) starts from each angle of 0°, 45°, 180° and -135° and correctly arrives at each angle of 0°, 45°, 180° and -135° in Fig. 3(a)-(d). From this measurement results, the performance of our channel sounders was evaluated, and we confirmed the ability to estimate time and spatial characteristics of multipath channels through field measurement campaign.

III. Measurement Campaign

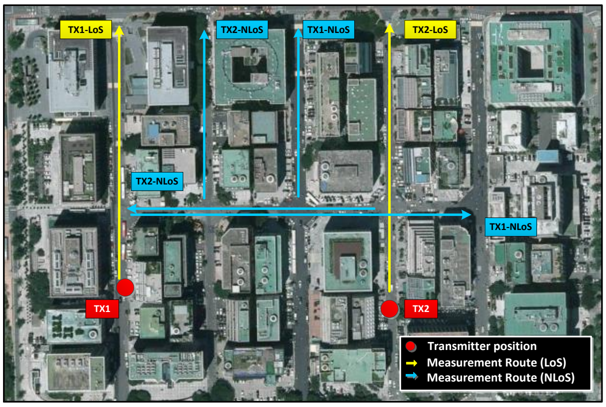
To obtain multipath characteristics in urban street canyon environments, we conducted a measurement campaign at 3 sites which are carefully selected places among typical urban low-rise, high-rise, and very high-rise environments in Korea. All sites are composed of rectilinear flat street grids, but their average building heights are different, as specified in Table II.

Fig. 4 shows the measurement routes and surrounding environment of each area. The measurement campaigns were performed along the planned routes in three different sites respectively. Each site has two TX points i.e. TX1 and TX2, and all RX positions for LoS and NLoS scenario assigned along the road as shown in the map.

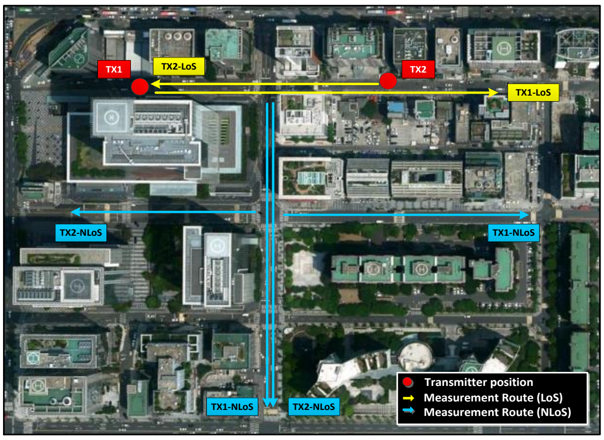
TABLE II
MEASUREMENT SITES AND ENVIRONMENTS

Sites	Class	Location	Feature
Site 1	Urban low-rise	Ilsan, Seoul	Low-rise buildings (3-5 story, 11-14m height) are located at both side of 2 lanes road (avg. 18 m wide)
Site 2	Urban high-rise	Yeouido, Seoul	A commercial area where high-rise buildings (10-15 story, 35-45m height) are located at both side of 2 lanes road (avg. 24 m wide)
Site 3	Urban very high-rise	Gangnam, Seoul	A downtown area with skyscrapers where very high-rise buildings (50-195m height) are located at both side of 2-4 lanes road (avg. 26 m wide)

(a) Site 1



(b) Site 2



(c) Site 3

Fig. 4. Measurement routes and environments of each site ((a) Site 1: Ilsan area, (b) Site 2: Yeouido area, (c) Site 3: Gangnam area)

The measurement campaigns were taken during daytime and outside of normal rush hours, when few people are on sidewalks and vehicle traffic running at about 30km/h. During measurement, we held the TX vehicle at a stationary position and moved the RX vehicle at a speed under 10 km/h along measurement routes. The RX channel sounder collected measured data including channel impulse responses and GPS information.

IV. MEASUREMENT RESULTS AND ANALYSIS

We analyzed multipath channel characteristics such as r.m.s delay spread and angular spread of arrival from measured results.

A. r.m.s delay spread

The r.m.s delay spread (DS) is the standard deviation value of the delay of multiple paths, and it is weighted proportional to the energy in the reflected waves. To obtain delay spread from measured data, we estimate the multipath components from power delay profile (PDP) from measured channel impulse responses (CIRs). CIRs can be obtained from the auto/cross-correlation function between an original PN sequence and a received signal as follows:

$$h_{mn}(\tau)=\frac{R_{xy}(\tau)}{R_{xx}(0)}=\frac{\mathcal{F}^{-1}(-X(f)^{*}\cdot Y(f))}{\sum_{i}\left|x(\tau_i)\right|^2} \quad (1)$$

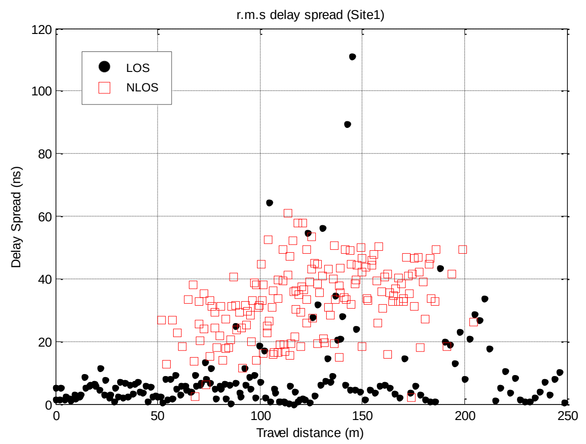
, where $Y(f)$ is a Fourier transform of the received signal $y(\tau)$, $x(\tau)$ is a sequence for transmission, R_{xx} means an auto-correlation to remove a system impairment [9], and $R_{xy}(\tau)$ means a cross-correlation of $x(\tau)$ and $y(\tau)$.

The power delay profile (PDP) can be calculated by:

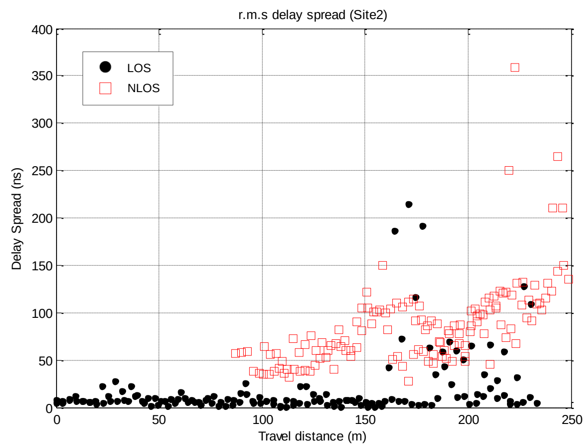
$$PDP(\tau)=\sum_{n=1}^{N}\sum_{m=1}^{M}\left|h_{mn}(\tau)\right|^2 \quad (2)$$

, where $h_{mn}(\tau)$ has an N × M matrix (*n* and *m* are the index of Rx and Tx antennas respectively). To extract multipath components, we set a threshold (20 dB below the peak level in this paper) considering the dynamic range of channel impulse responses [11], and then pick the multipath components $h(\tau_l)$ with a related delay τ_l, $l=1:L$. L is a total number of multipath components founded within threshold. Finally, delay spread can be calculated by the same method in [11].

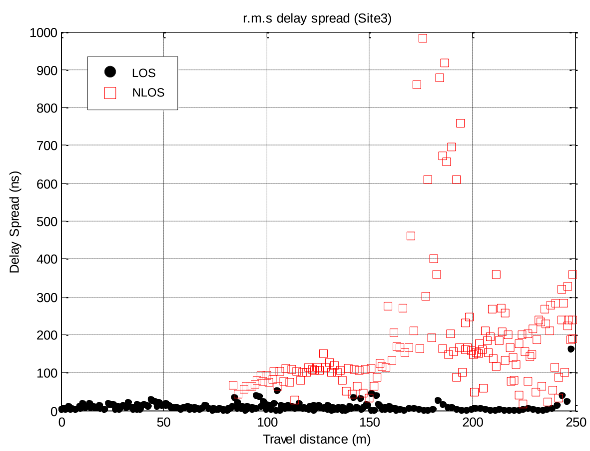
Fig. 5 shows the distribution of r.m.s. DS values corresponding to travel distance between the TX station and RX station for each scenario (LoS and NLoS) and environments (urban low-rise, urban high-rise and urban very high-rise). From the measurement results, we can see that distributed DS values of the NLoS are much larger than the LoS for all sites. Furthermore, in case of NLoS, we can observe that the DS values are gradually increased proportion to the distance. In addition, the cumulative distribution functions (CDF) of the delay spread for LoS and NLoS cases are plotted in Fig. 6.



(a) Site 1



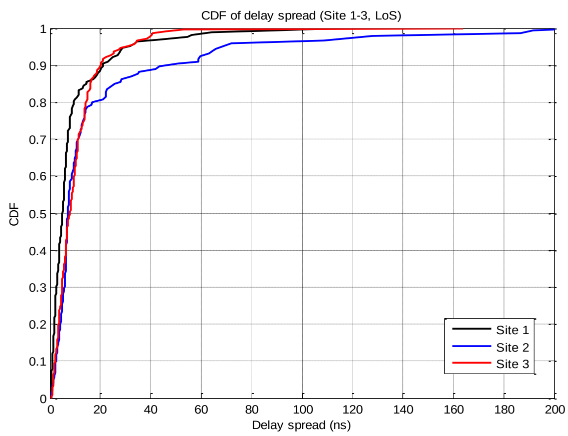
(b) Site 2



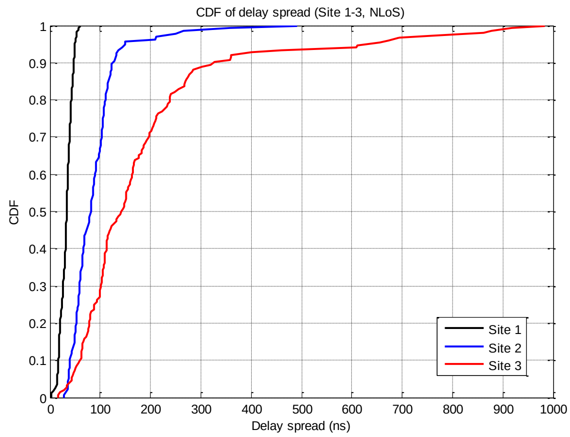
(c) Site 3

Fig. 5. Measurement results of r.m.s. delay spread corresponding to Tx-Rx distance ((a) Site 1: urban low-rise environment, (b) Site 2: urban high-rise environment, (c) Site 3: urban very high-rise environment)

We summarize the measured r.m.s. delay spread for the different cases with cumulative probability of 10%, 50% and 95% as shown in Table III. When we compared median values (50% of CDF) of r.m.s. delay spread in Table III, Site 3 (urban very high-rise environment) has the largest value, Site 2 (urban high-rise environment) has a medium, and Site 1 (urban low-rise environment) has the smallest value. From this result, we can understand that the higher buildings around the TX or the RX station, the more multipath components can be generated.



(a) LoS cases



(b) NLoS cases

Fig. 6. CDF of delay spread for LoS and NLoS scenarios (site 1 to 3)

TABLE III
MEASUREMENT RESULTS OF R.M.S DELAY SPREAD

Sites	Class	Scenario	r.m.s. delay spread (ns)		
			10%	50%	95%
Site 1	Urban low-rise	LoS	0.9	5	31.9
		NLoS	16.7	33.1	50
Site 2	Urban high-rise	LoS	2.2	7.1	69
		NLoS	40.5	81.3	149.4
Site 3	Urban very high-rise	LoS	2	8.1	31
		NLoS	58	142	610.5

B. *r.m.s angular spread*

The r.m.s. angular spread is the power-weighted standard deviation of the direction of arrival and departure, and it is given by the second moment of the power angular profile [11]. We calculate the power azimuth spectrum (PAS) corresponding to the only founded multipath components. The PAS calculation function is based on Bartlett beam-forming theory [9], which is written as follows:

$$PAS_i(\varphi_{\mathrm{AOA}}) = \left|\Omega_{\mathrm{RX}}(\varphi_{\mathrm{AOA}}) \cdot h_{mn}(\tau_{\mathrm{i}})\right|^2 \qquad (3)$$

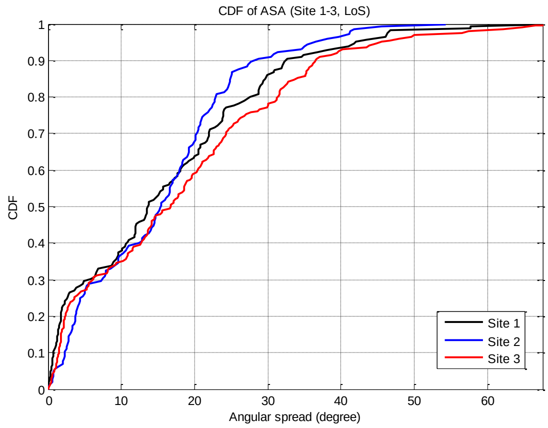
, where Ω_{RX} is a radiation pattern of RX antennas (360 x N matrix), and φ_{AOA} is an angle of arrival.

Then, to overcome the limitation of angular resolution for estimation of direction of arrival using a small number of antenna elements [12], we find the peak angle φ_l from the result of PAS as below:

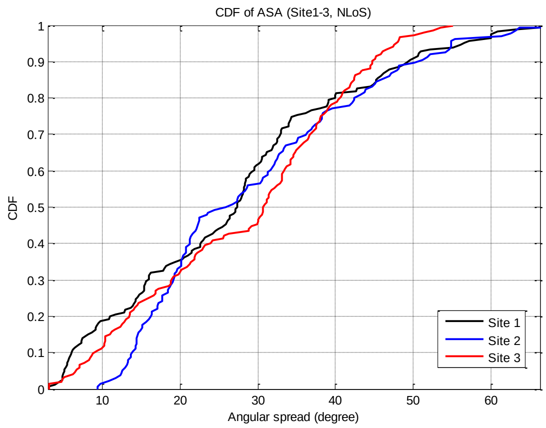
$$\varphi_l = arg\max_{\varphi}\{\mathrm{PAS}_l(\varphi_{\mathrm{AOA}})\} \quad (4)$$

After all, we obtained the r.m.s. angular spread of arrival from extracted coefficients such as arrival angle φ_l and related power for each multipath components.

Fig. 7 depicts the CDF curves of the angular spread of arrival (ASA) for LoS and NLoS case, respectively. When we observed the distribution of ASA values, they are not increased or decreased depending on the distance, but the case of NLoS is highly distributed than the LoS for all environments.



(a) LoS cases



(b) NLoS cases

Fig. 7. CDF of angular spread of arrival for LoS and NLoS scenarios

TABLE IV
MEASUREMENT RESULTS OF R.M.S ANGULAR SPREAD

Sites	Class	Scenario	r.m.s. angular spread (degree)		
			10%	50%	95%
Site 1	Urban low-rise	LoS	0.7	13.6	42
		NLoS	6.1	27.3	56.6
Site 2	Urban high-rise	LoS	2.3	15.4	36.5
		NLoS	13.9	25.9	54.9
Site 3	Urban very high-rise	LoS	1.5	16.7	45.6
		NLoS	8.7	30.7	47.5

Table IV summarizes the measured results of r.m.s. angular spread with the probability of 10%, 50% and 95% for the different environments and scenarios. We can observe that the median values (50% of CDF) of r.m.s. angular spread in NLoS cases are higher than the LoS cases for all environments. Furthermore, the height of surrounding building seems to affect the angular spread characteristics at 50%, but not much at other probabilities.

V. CONCLUSION

In this paper, we investigated the multipath channel characteristics between mobile terminals with low-height antennas considering for mobile-to-mobile communication scenarios. We carried out channel measurement campaigns in the 3.7GHz frequency band in three different urban street canyon environments. In our measured results, r.m.s delay spread values of the NLoS case are much larger than the LoS for all sites. Furthermore, especially in case of NLoS, we can observe that the DS values are gradually increased proportion to the distance. On the other hand, r.m.s. angular spread values are not looked increase or decrease depending on the distance in those circumstances. The ASA values in case of NLoS are highly distributed than LoS case for all environments. The height of surrounding building, in particular at 50% of CDF, seems to slightly affect the angular spread characteristics. This issue should be further studied on the basis of more measurement data. The statistical angular characteristics of departure (ASD) are expected to similar with those of arrival based on reciprocity if two mobile terminals are located at the same environment and scenario.

REFERENCES

[1] 3GPP TR 22.803, Feasibility study for Proximity Services (ProSe), Mar. 2013.
[2] J. S. Lu, H. L. Bertoni, C. Chrysanthou, and J. Boksiner, “Simplified path gain model for mobile-to-mobile communications in an urban high-rise environment,” in Proc. IEEE Sarnoff Symp., Princeton, NJ, Apr. 2010.
[3] Motoharu Sasaki, Wataru Yamada, Naoki Kita, Takatoshi Sugiyama, “Path Loss Model with Low Antenna Height for Microwave Bands in Residential Areas”, IEICE Transactions 96-B(7), pp1930-1944, 2013
[4] J. Lee, H. K. Chung and M. D. Kim, "Building Height Effects on Path Loss for Low Antenna Links in Urban Street Grid Environments", IEEE Asia Pacific Wireless Communication Symposium, Aug. 2013.
[5] Rec. ITU-R P.1411, Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz, Feb. 2012.
[6] Rep. ITU-R M.2135-1, Guidelines for evaluation of radio interface technologies for IMT-Advanced, Dec. 2009.
[7] J.-J. Park, M.-D. Kim, H.-K. Kwon, H.-K. Chung, X. Yin, and Y. Fu, “Measurement-Based Stochastic Cross-Correlation Models of a Multilink Channel in Cooperative Communication Environments,” ETRI Journal, vol. 34, pp. 858–868, Dec. 2012.
[8] M. D. Kim, J. J. Park, H. K. Kwon, and H. K. Chung, “Performance Evaluation of Wideband MIMO Relay Channel Sounder for 3.7 GHz,” IEEE Asia Pacific Wireless Communication Symposium, Aug. 2011.
[9] M. Barlett, “Smoothing periodograms from time series with continuous spectra,” Nature (London), vol. 161, no. 8, pp. 686–687, 1948.
[10] H. Chung, et al., “MIMO channel sounder implementation and effects of sounder impairment on statistics of multipath delay spread,” Proc. IEEE VTC, vol. 1, pp. 349–353, Sep. 2005.
[11] Rec. ITU-R P.1407, "Multipath propagation and parameterization of its characteristics", Oct. 2009.
[12] Gerd Sommerkorn, et.al. "Performance Evaluation of Real Antenna Arrays for High-Resolution DoA Estimation in Channel Sounding", COST 273 TD(03)196, Sept. 2003.

Myung-Don Kim (BS'93–MS'95) is a Principal Researcher in the Advanced Communications Research Laboratory at Electronics and Telecommunications Research Institute (ETRI). He joined ETRI, Daejeon, Rep. of Korea, in 1995, and he worked on the development of mobile test-beds for CDMA, IMT-2000 and WCDMA systems. Since 2006, he has been involved in the development of wideband MIMO channel measuring system, measurement and channel estimation of MIMO channels. His research interests include MIMO, channel measurement and channel modeling for next generation mobile communications

Juyul Lee (BS'96-MS'98-PhD'10) is a Senior Researcher in the Advanced Communications Research Laboratory at Electronics and Telecommunications Research Institute (ETRI) since 2000. Prior joining with ETRI, he was a Research Engineer with the Agency for Defense Development (ADD) from 1998 to 2000. His research spans the fields of information theory and wireless communications, with special interests in multiple-antenna/multiple-user/multi-cell resource allocations, device-to-device communications, and wireless propagation channel measurements and modeling.

Jinyi Liang (BS'04–MS'13) is a Researcher in the Advanced Communications Research Laboratory at Electronics and Telecommunications Research Institute (ETRI). He is Chinese and joined ETRI, Daejeon, Rep. of Korea, in July 2013, and he's working on the project 'Wireless Channel and Frequency Characterization based on Field Measurements for Broadband Mobile Hot-Spot Applications'. His research interests include MIMO, channel measurement and channel modeling for next generation mobile communications.

Jinup Kim (BS'85-MS'87-PhD'96) has been with Electronics and Telecommunication Research Institute since 1987. And also he has been a professor of University of Science and Technology in the field of Wireless communications since 2005. He has researched in the field of the wireless communication system. He is recently interested in the Digital RF, channel modeling, Software Defined Radio and Cognitive Radio technologies, etc.