A Detailed Large-Scale Radio Propagation Characteristics: Approaches with Time and Spatial Ratio

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***Abstract*—The 3.5GHz band was determined as the mobile communication frequency in IMT-2020. Basically, TD-LTE in small cell environment and supplementary downlink in hotspot area will be used in 3.5GHz band. In addition, the frequency resources are becoming insufficient over time due to the explosive increase in the radio equipment. If we use frequency resources in a time and space based sharing manner, it is expected that we will be able to efficiently use the scarce frequency resources. According to recent trends, the channel sounder for the 3.5GHz band consists of a universal device such as NI equipment for baseband and transceiver and its own modules which are high power amplifier, RF switch, timing module and antenna. In this paper, we introduce the channel sounder and have verified various measurement parameters such as path loss, delay spread, K-factor and channel capacity for actual radio measurements through this channel sounder in urban and suburban areas in the 3.5GHz band. Additionally, we show the result of the path loss modelling with time and space rate using this system.**

***Keyword*—Channel sounder, Radio propagation, Time and spatial ratio, Frequency sharing**

I. INTRODUCTION

RESEARCH on radio wave propagation characteristics and development of propagation models has become an indispensable research area for the design, introduction, performance analysis and verification of new radio communication systems. The studies on the propagation characteristics and modeling for the sub-6GHz band have been continuously studied for stable positioning of the new communication system in major countries [1]-[3]. The international standards organizations such as ITU, IEEE, 3GPP, and WINNER propose standard analysis methods and modeling results. In recent years, major domestic and international standards organizations are examining 5G wireless communication systems operating in various sub-6GHz bands such as 400MHz, 700MHz, 4GHz and 5GHz. From the viewpoint of radio propagation characteristics, radio wave characterization and the development of new radio models, the consensus and dedication of major international standards organizations is more important than individual countries. The reason is that the acquisition and use of the spectrum and its impacts are not merely affecting individual countries. We will now explain why the 3.5GHz band is important for radio measurement. First, the 3400-3600MHz band was selected as the mobile communication frequency in IMT-2020 along with the 1427-1518MHz band [4]. The second is that major companies such as Qualcomm are claiming to use the 3.5GHz band for small cell TD-LTE services [5]. Finally, the 3.5GHz band is likely to be used as a downlink supplemental link due to the explosion of frequency resources [6]. Because of these many reasons, the 3.5 GHz band is considered to be an important frequency resource for future mobile communication environments. When many communication devices and systems are going to use the 3.5 GHz band, the best and most efficient way is to share frequency resources in space and time. If a particular frequency band is not always used temporally or spatially, then each communication device and system will be able to share frequency resources. Therefore, in this paper, we introduce the 3.5GHz band radio propagation measurement system and analyze the measurement result of the corresponding band using this system to confirm the temporal or spatial propagation characteristics according to frequency sharing.

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II. SYSTEM SPECIFICATION

In this section, we introduce the specification of our developed radio measurement system. As shown in Fig. 1 below, our radio measurement system consists of five main components: baseband digital signal processing module, RF transceiver module, timing module, antenna, monitoring panel and storage module.

Fig. 1. System Total Shape

TABLE I
IMPLEMENTATION PARAMETERS FOR RADIO MEASUREMENT SYSTEM

Parameters	Specification
Frequency	400MHz-4GHz
Bandwidth	5MHz-130MHz
Channel Impulse Response	68dB (below 10ns resolution, above 65dB)
Transmit Power	Max 7dBm
Receive Auto Gain Control (AGC)	Min -70dBm
File Save and Replay	Receive data save and replay possible
Transmit and Reception Filter	0.1-1 (SRRC Filter, roll-off factor variable)

A. Baseband Digital Signal Processing Module

The baseband digital signal processing module is basically developed using universal NI PXI modules and the output signal is generated as direct sequence spread spectrum(DSSS) BPSK with 100Mcps. In baseband digital signal processing module, it consists of PXI 8135 for the computing function, NI 5792 for the receiving adapter module, NI 5793 for the transmitting adapter module and PXIe 7966 for the FPGA module.

B. RF Transceiver Module

The RF transceiver module is also made up of NI universal modules which are Tx/Rx IF modules and RF up/down converter. The RF upconverter raises the signal with the variable IF frequency below 3GHz to the RF frequency of 5GHz. And the RF downconverter serves to lower the signal having an RF frequency of 5GHz to an IF frequency of 3GHz. And the high power amplifier(HPA) utilizes RFHIC RUM43020 commercial product with output powers of up to 20 watts.

C. Timing Module (TIMU)

To produce the synchronized timing signal on the RF module and baseband, a rubidium oscillator with a 10MHz reference signal is utilized. To keep the time synchronization between the transmitter and the receiver of the radio measurement system, an RF cable is connected between the transmitter's TIMU and the receiver's TIMU. The clock signal is also inserted to the RF and baseband modules from the TIMU.

D. Antenna

The antennas used in the radio measurement system are developed to operate in the band between 3.5GHz and 3.7GHz. The antenna spacing is lambda(=85.7mm@3.5GHz) and the antenna gain is designed around 4-5dBi to obtain additional HPA output. The horizontal antenna pattern of the antenna is omni-directional, and the vertical antenna gain is designed to be distributed within the upper and lower 45 degrees.

E. Monitoring Panel and Storage Module

In the monitoring panel, key measurement data such as power level, spectrum mask, I/Q data and channel impulse response(CIR) are displayed. As shown in the Fig. 2-a below, the left side of the monitoring screen is configured to change the frequency, bandwidth, transmission power, receive auto gain control(AGC) and filter roll-off factor for operation of the radio wave measuring system. The measurement system operating parameters and current measurement status monitoring screens are implemented in NI LabVIEW and can be modified if functional modifications are required. Because measurement data is stored every second, a huge amount of measurement data accumulates on NI hard RAID system which is a massive storage device and a PCI express interface is built between NI PXI and NI hard RAID system for fast data storage and processing. The detailed parameters of our radio wave measurement system are shown in Table 1.

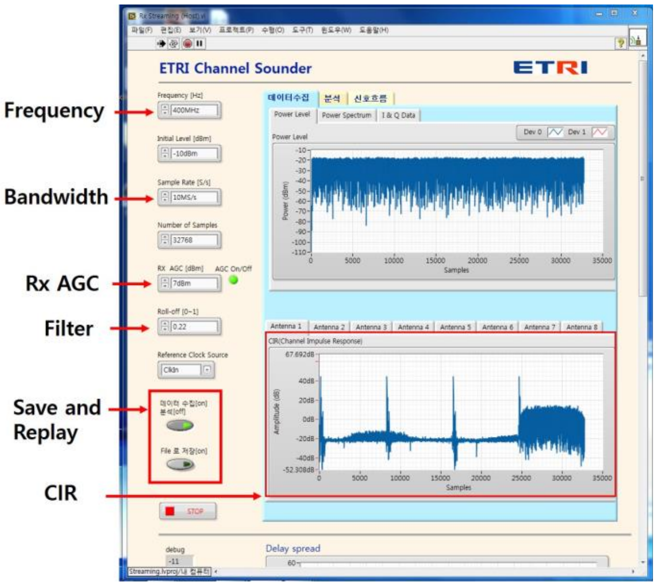

Fig. 2-a. Receiver Display

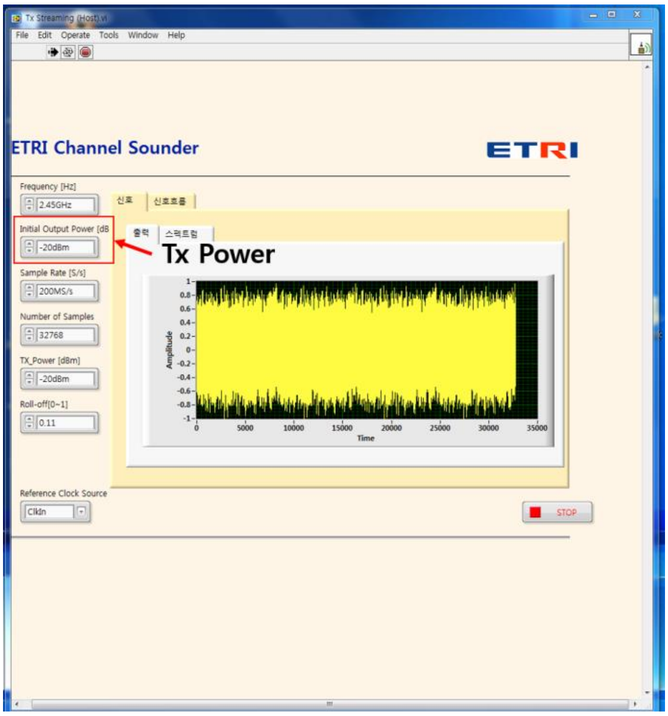

Fig. 2-b. Transmitter Display

F. Transmit Signal Generation and Receive Signal Processing Procedure

Fig. 3 shows the procedure for generating the transmit signal. The length of the PN sequence is 4096, and this sequence is oversampled twice using zero padding. To remove the adjacent signal from the transmitter, a squared root raised cosine filter with a roll-off factor 0.22 is used. The oversampled PN sequence is upconverted to IF frequency with a 200MHz sampling rate.

As shown in the Fig. 4, the received signal through the wireless channel performs A/D conversion at a sampling rate of 200MHz. After generating I/Q data, DC offset and I/Q phase offset should be removed. Next, the received signal is cross-correlated with a previously known PN sequence after processing the squared root raised cosine filter.

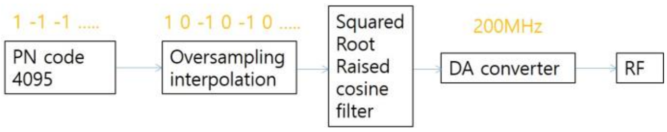

Fig. 3. Transmit Signal Generation Procedure

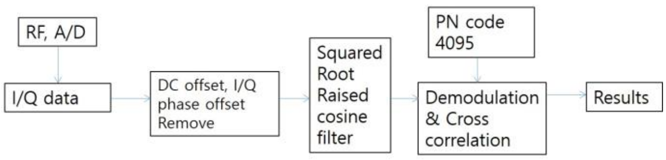

Fig. 4. Receive Signal Processing Procedure

III. Measurement

A. Synchronization

In order to perform cross-correlation between the received signal and the known PN sequence before measuring the propagation environment with the system introduced in this paper, time synchronization should be established between the transmitter and receiver. The magnitude and time delay of the received signal can be checked through cross-correlation between the received signal and the known PN sequence. The resolution of the time delay is closely related to the bandwidth of the signal. For example, a signal with a bandwidth of 100MHz has a time delay resolution of 10ns, so it can be detected up to 10ns in a multipath signal.

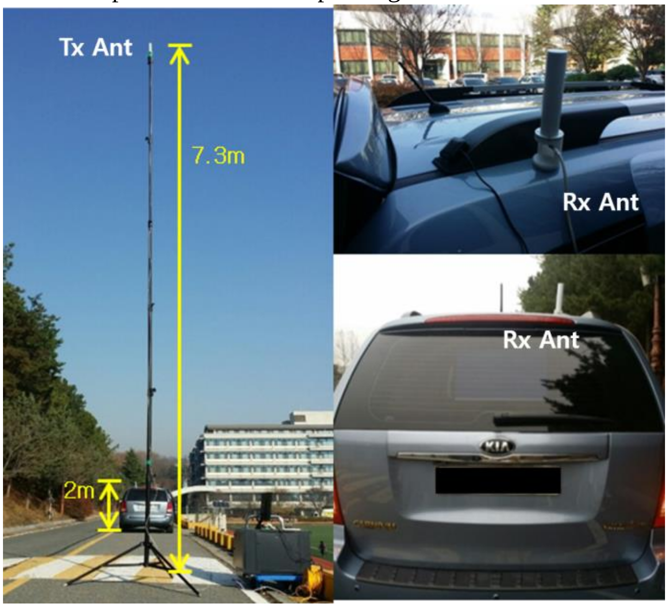

Fig. 5. Transmission and Receiving Antenna Configuration

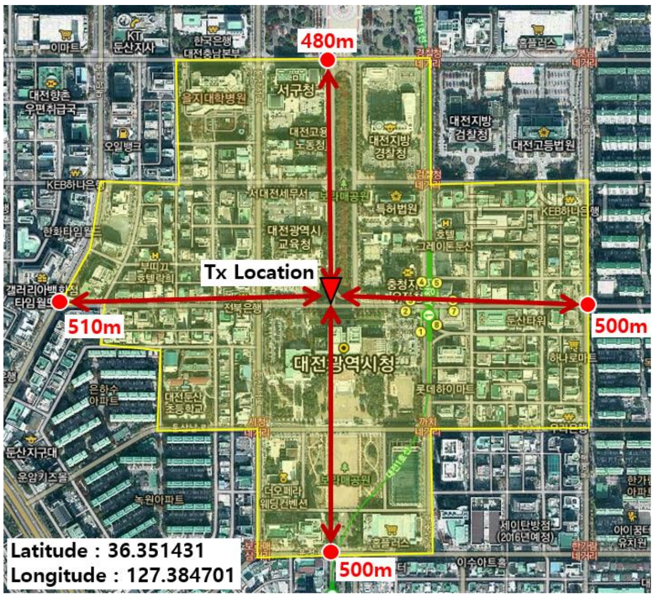

Fig. 6. Measurement Location and GPS Information of the Tx Location

B. Scenario

In this subsection, we briefly describe the measurement environment and scenarios. As shown in Fig. 5, the transmission antenna is installed on a pole with a height of 7.3m and the receiving antenna is installed on a vehicle with a height of 2m. Measurement are carried out near the Daejeon Metropolitan City Hall to analyze the propagation environment in the small cell urban environment. The location of the measurement area and the GPS information of the transmission point are shown in Fig. 6. The measurement scenario depends on the time and space rate measurement, and the detailed measurement contents according to the time and space rate will be described below.

1) Time Ratio Measurement Scenario:

Since the measurement of the radio wave according to the time rate is performed by fixing the position of the transmitter and receiver, the transceiver is arranged as shown in Fig. 7. The measurement time is conducted for seven and half hours from 11:30 a.m. to 19:00 p.m., considering lunch and work time.

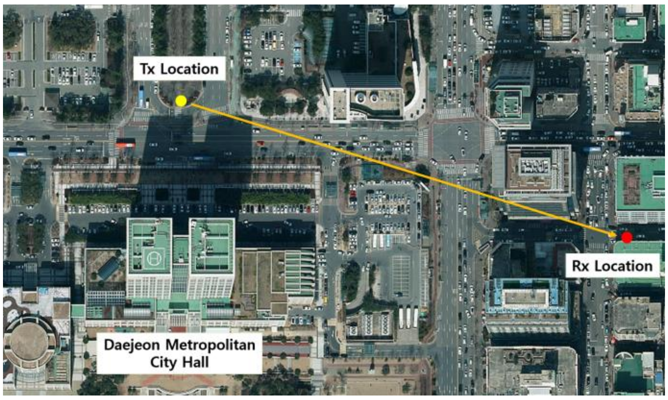

Fig. 7. Radio Measurement Map for Time Ratio

2) Spatial Ratio Measurement Scenario:

The radio wave measurement is carried out while driving near the Daejeon Metropolitan City Hall. The transmitter is placed in the same point as the time rate measurement, and the receiver is installed in a moving vehicle. Most of the measurement areas are high-rise buildings and large-scale transportation corridors. The measurement results are stored every one second while the vehicle carrying the receiver is travelling within an area of approximately 0.5km from the transmitter. The moving path of the receiver-equipped vehicle for the measurement of the space rate is shown in Fig. 8.

IV. PERFORMANCE RESULTS

As can be seen in Fig. 9, there are several steps to analyze the radio wave measurement results. In the transform measurement data step in Fig. 9, because our measurement and analysis program is based on MATLAB, we convert the files stored in the TDMS file format which is saved in NI HDD RAID system to the MAT file format that can be read by MATLAB. In manufacture analyzing data step after file transforming, among the measured PN sequences that are repeatedly stored four times, the first and fourth PN sequences that may have been contaminated at the receiving process are removed, and only the PN sequences at the second and third positions are selected to analyze. Through the measurement time, location from the GPS and the channel impulse response(CIR) stored in our radio measurement system, we can derive radio wave measurement parameters such as path loss and delay spread, etc.

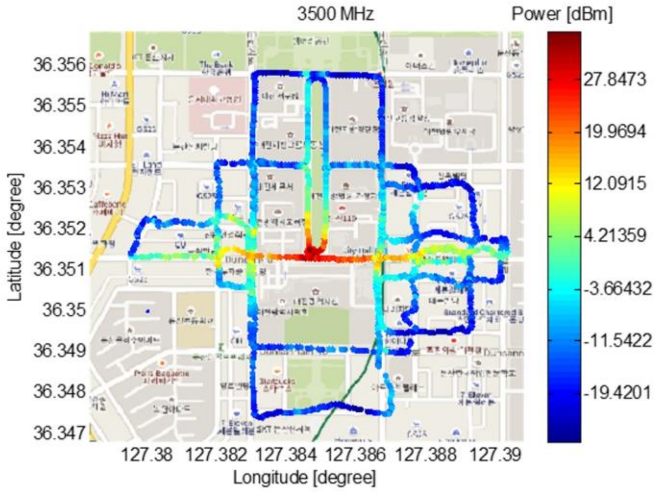

Fig. 8. Radio Measurement Map for Space Ratio

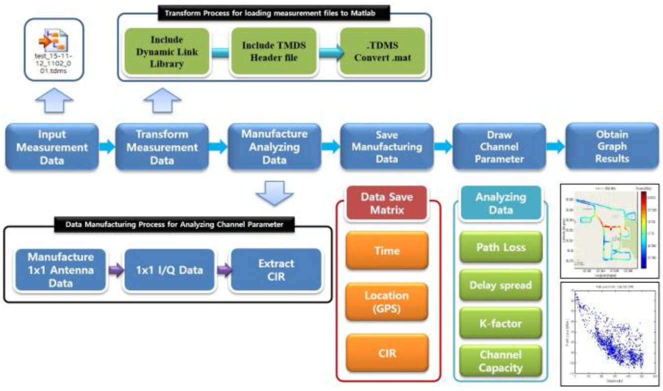

Fig. 9. Detailed Steps for Measurement Data Analysis

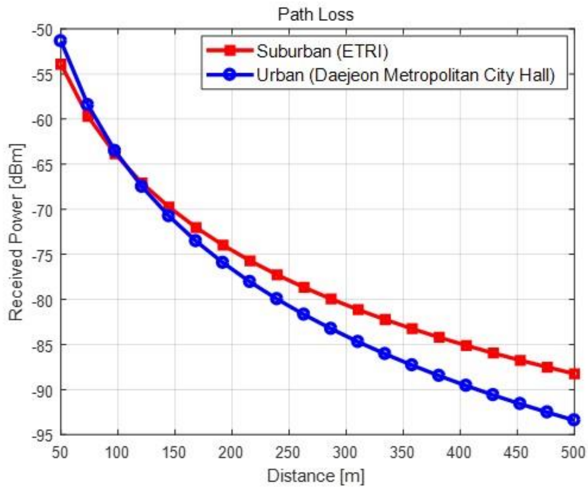

Fig. 10. Path Loss Result

A. Radio Wave Parameter Analysis

1) Path Loss:

We derive path loss results as shown in Fig. 10. This graph shows the results inside the ETRI which is a suburban area, and the results near the Daejeon Metropolitan City Hall area, which is an urban area. The path loss measured in the urban area near the Daejeon Metropolitan City Hall is larger than that in the suburban area as the distance increases. This is because there is a higher and denser building in the urban area. In (1), there are several variables to express the path loss formula. In urban area, L_0 is 20.06, n is 4.204 and X_σ is

8.91dB. In suburban area, L_0 is 4.367, n is 3.431 and X_σ is 11.26dB.

$$\text{Path Loss} = L_0 + 10n\log_{10}\left(d/d_{ref}\right) + X_\sigma \qquad (1)$$

2) Delay Spread:

Figure 11 shows the results of CDF in terms of time delay. The results in the blue graph, urban area, show a large distribution in the case of long time delay compared to the result in the red graph. Because there are a lot of high buildings in the urban area, many reflection waves are occurred. So, the large time delay results are relatively happened in the urban area. In (2), A is 0.0186 and B is 0.88 in suburban. In urban area, A is 0.3611 and B is 0.3593 in (2).

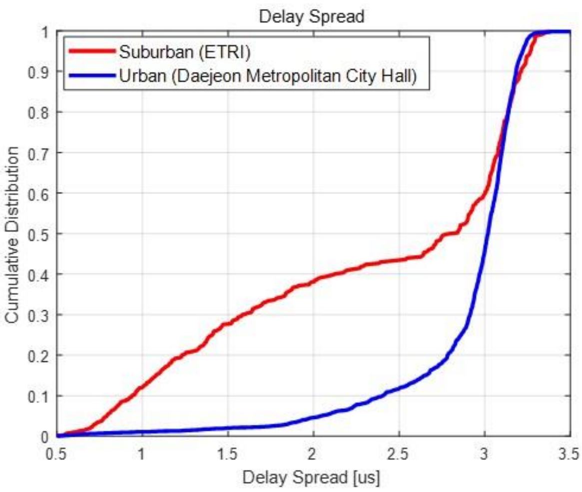

Fig. 11. Delay Spread Result

$$\text{Delay Spread} = A \cdot d^B \qquad (2)$$

B. Performance Results for Time Rate

The measurement results for the time rate are shown as below figures.

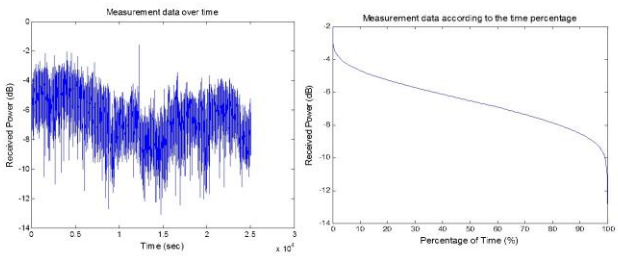

Fig. 12. Measurement Results for Time Ratio and Receiving Values according to Time Ratio

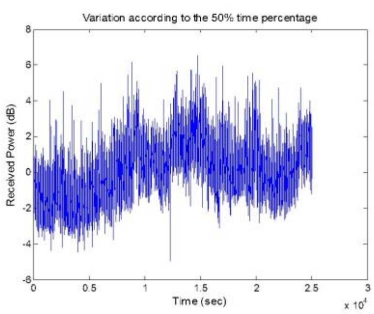

Fig. 13. The Variation Value for Signal according to the 50% Time Percentage

The time rate refers to the statistical properties of the field strength measured at a fixed location and indicates how much more than a few dB have been measured in the corresponding percentage of the total measurement time. The graph on the left side of Fig. 12 shows the strength of the received signal according to the total measurement time. As shown on the right graph of Fig. 12, the received signal strength values according to the 10%, 50% and 90%-time rate are -4.86dB, -6.19dB and -8.07dB, respectively. And Fig. 13 is a graph representing the magnitude of the received signal when the 50%-time ratio is assumed.

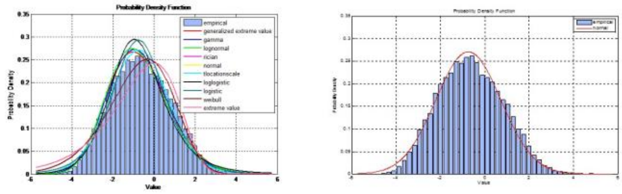

Fig. 14. The Variation Value for Signal according to the 50% Time Percentage

We show the probability distributed function (pdf) graph according to the strength of the received signal and search the distribution with similar tendency to the derived measurement result pdf graph. As shown in the right side of Fig. 14, a graph having similar distribution to the measurement results is derived, and its distribution is a normal distribution with a standard deviation of 1.47. Table 2 shows the path loss results according to the time rate application.

TABLE II
MEASUREMENT ENVIRONMENT CONSTANT VALUE

$PL(d) = L_0 + 10n\log_{10}(d/d_{ref}) + X_\sigma + \Delta T$(CORRELATION FACTOR)							
Measurement Condition			Path Loss			ΔT	Std
f	h_b	h_m	L_0	n	X_σ		
3.5	7	2	20.06	4.204	8.91	$N^{-1}(p)*\sigma$	1.47

C. The Performance Results for Spatial Ratio

The result of the path loss due to the mobile measurement is shown in Fig. 14 below.

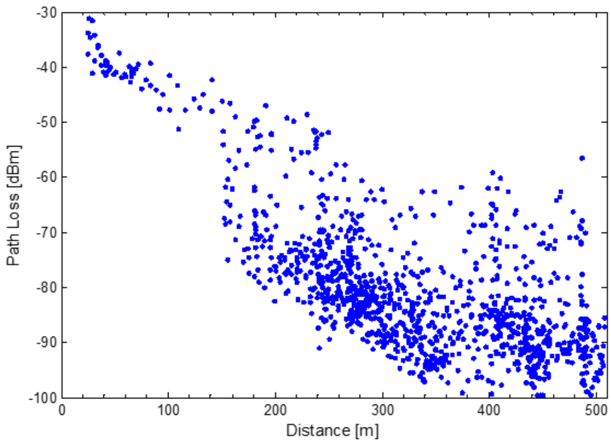

Fig. 15. Measurement Data with Mobile Vehicle

To analyze the measurement results related to the spatial rate, we should divide the results in Fig. 15 into the LOS and NLOS regions. The LOS signal distribution is shown in Fig. 16, and the curve fitting formula is expressed in (3).

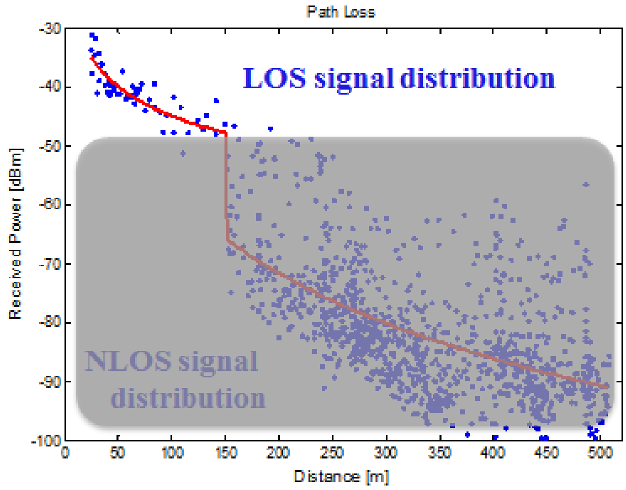

Fig. 16. LOS Signal Distribution for Spatial Ratio

$$L_{LOS} = 99.89 - 31.65\log_{10}\left(f\right) - 16.31\log_{10}\left(\frac{d}{d_{ref}}\right) \quad (3)$$

To verify the distribution of the signal with spatial rate, we obtain the difference of the LOS path loss model of equation (3) from the LOS actual measurement value. The distribution of the results is shown in Fig. 17.

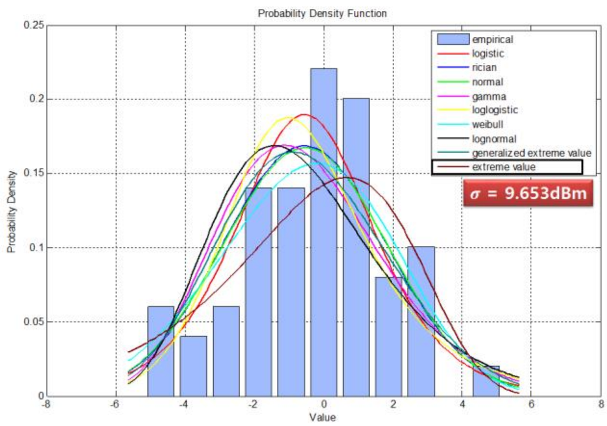

Fig. 17. Inference for LOS Signal Probability Distribution

From Fig. 17, we have obtained the LOS signal pdf and confirmed that extreme value distribution has the most similar distribution to our measurement results. The path loss model equation of NLOS is obtained from the actual measured data curve fitting, and the graph and equation are shown in Fig. 18 and formula (4). From Fig. 18 and equation (4), we confirm the pdf result and the most similar distribution function is t-location scale function as shown in Fig. 19. Based on the above results, we obtain path loss results according to the spatial rate as shown in Fig. 20. We can confirm the path loss value for 10%, 50% and 90% spatial ratio is -46dBm, -49dBm and -78dBm, respectively, when the distance between transmitter and receiver is about 200m. And we can check that the path loss is increased as the spatial rate increases from 10% and 90%.

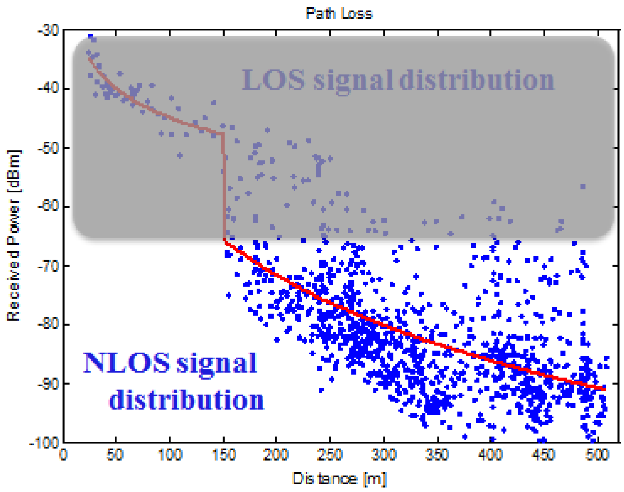

Fig. 18. NLOS Signal Distribution for Spatial Ratio

$$L_{LOS} = 20.55 + 5.109\log_{10}\left(f\right) - 47.93\log_{10}\left(\frac{d}{d_{ref}}\right) \quad (4)$$

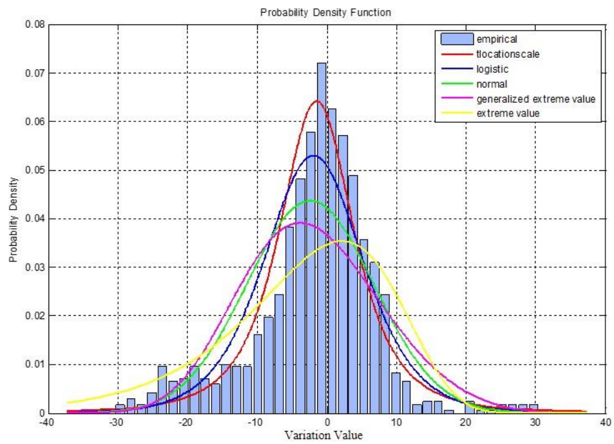

Fig. 19. Deduction for NLOS Signal Probability Distribution

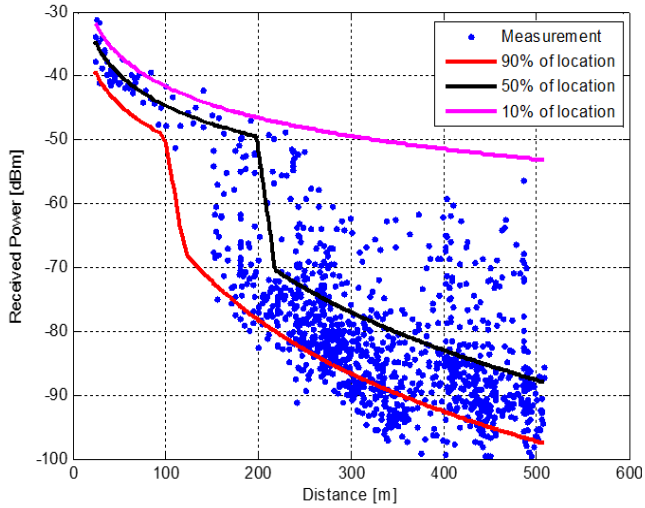

Fig. 20. Path Loss Results according to the Spatial Ratio

V. CONCLUSIONS

In this paper, we describe the results of measurement analysis in our radio measurement system and 3.5GHz band small cell environment. We measured the actual environment through the system we developed and derived a path loss model based on time and space ratio. Due to the short measurement period, the reliability of the analysis of measurement results may be somewhat insufficient. However, the tendency of analyzing the whole measurement result is well confirmed. In the future, we will try to get more accurate results by drawing sufficient measurement results.

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