

# Multipath Channel Parameters based on Indoor Hotspot Channel Measurements at 3.7GHz

Myung-Don Kim, Heon Kook Kwon, Bum Soo Park, Jae Joon Park and Hyun Kyu Chung

Wireless Telecommunications Research Department

Electronics and Telecommunications Research Institute

138, Gajeong-dong, Yuseong-gu, Daejeon, 305-700, Korea

E-mail: {mdkim, hkkwon, hyla114, jjpark, hkchung}@etri.re.kr

**Abstract**— Statistical characterization of the indoor hotspot radio channel is very important for the future MIMO system design. In this paper, we present multipath channel parameters acquiring from wideband MIMO channel measurement at 3.7GHz frequency band. The channel measurement campaign has been performed in the Incheon international airport, where is a representative indoor hotspot region in Korea. The measurement was carried out at peak time and at off-peak time, respectively. Each measurement scenario includes both line of sight (LoS) points and non-line of sight (NLoS) points. The numerical results of MIMO channel characteristics such as root mean square delay spread, maximum excess delay, angular spread of arrival and angular spread of departure are presented.

**Keywords**— MIMO, channel sounder, channel measurement, channel modelling

## I. INTRODUCTION

Recently, the use of multiple-input multiple-output (MIMO) antennas in wireless broadband communications promises high spectral efficiency and reliability. The IEEE 802.11n task group (TGn) has developed a comprehensive broadband channel model applicable to indoor MIMO wireless local area networks (WLAN) systems, with support for 40 MHz channelization and 4 antennas [1]. The model can be used for both 2 GHz and 5 GHz frequency bands. Recently, IEEE 802.11ac task group (TGac) is targeting above 1 Gbps throughput using one or more of the following technologies: high order MIMO (above 4x4), higher bandwidth (above 40 MHz), multi-user MIMO with above 4 access point (AP) antennas and OFDMA. They have modified the TGn channel models to enable their use for TGac [2].

Especially, high data rate services are required in hotspot areas such as airports, rail-way stations, conference halls and shopping malls with heavy traffic and high user density. Many important applications of MIMO system occur in indoor hotspot scenario where both transmitter and receiver are surrounded by local scatters. Statistical characterization of the indoor hotspot radio channel is very important for the future MIMO system designs. This statistical channel modelling can be obtained by conducting extensive measurements in the various environments and analyzing the measured data. It is still used frequently and has advantage that the reliable results

are expected because measurement is made in the real environments [3].

In this paper, a measurement campaign has been performed to find out wideband MIMO channel parameters of indoor hotspot environment at 3.7GHz carrier frequency. In Section II, we introduce a MIMO channel sounder which is developed by Electronics and Telecommunications Research Institute (ETRI) to measure wideband MIMO radio channel characteristics. The channel measurement campaign has been carried out in Incheon international airport terminal, where is one of representative indoor hotspot regions of Korea. In Section III, numerical results of channel measurement through the post data processing are presented. Finally, we conclude this paper.

## II. CHANNEL MEASUREMENT CAMPAIGN

### A. MIMO Channel Sounder

The Band Exploration and Channel Sounding system (BECS) is designed for wideband MIMO channel sounding using multiple antennas. This system applies antenna switching techniques based on a time multiplexing mode (TDM).

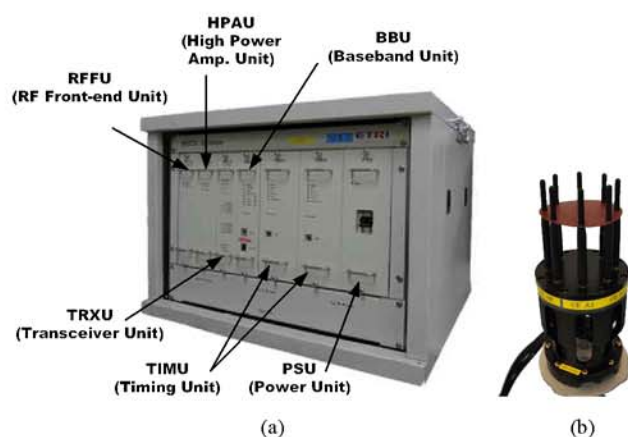


Figure 1. The BECS channel sounder (a) and UCA antenna (b)

This work was supported by the IT R&D program of MKE/KEIT of Korea. [KI002060, Wideband Wireless Channel Modeling based on IMT-Advanced]

As shown in Fig. 1(a), BECS channel sounder consists of a baseband unit (BBU), a transceiver unit (TRXU), a timing unit (TIMU), a high power amplifier (HPA), a RF front-end unit (RFFU) and a uniform circular array (UCA) antenna. The wideband sounding method is a pulse compression technique based on the periodic transmission of a PN sequence with a maximum chip rate of 400Mcps. The BBU generates consecutive PN sequences and transforms to a pulse shaped probing signal with a bandwidth of 100MHz. The output signal is up-converted to RF frequency by TRXU and then sequentially transmitted through the multiple antennas by selection of RF high power switch of RFFU.

TABLE 1. SPECIFICATION OF THE BECS SYSTEM

| Item                    | Specification                               |
|-------------------------|---------------------------------------------|
| Center Frequency        | 3.705 GHz                                   |
| Bandwidth               | Max. 100MHz                                 |
| Chip rate               | Max. 100Mcps                                |
| PN Length               | 31 ~ 4095 chips                             |
| Number of Antenna       | Tx : 8, Rx : 8                              |
| Rx ADC                  | Sampling : 400MSa/s<br>Resolution : 12 bits |
| Tx Output Power         | Max. +36dBm                                 |
| Tx/Rx attenuation range | 30dB (Tx), 60dB (Rx)                        |
| Receiver NF             | < 7dB                                       |
| Multipath resolution    | 10 nsec                                     |

At the receiver side, data acquisition is sequentially made in turn through whole antenna elements. The RF input signal is filtered and down-converted to IF signal. The A/D convertor performs the high speed sampling of 400Mps. The BBU stores the measured data to hard-disk for later analysis. The high precision rubidium oscillator of TIMU provides very exact reference clock within 1ns for synchronization between a transmitter and a receiver. Detailed descriptions of BECS

channel sounder is explained in [4][5]. Table 1 shows the specification of the BECS system.

As shown in Fig. 1(b), the uniform circular array (UCA) antenna having 8 omni-directional antenna elements was used in a transmitter (TX) and a receiver (RX) side. The space between elements is  $0.5\lambda$ . Due to the geometry of antenna array, both a direction of the radio path launched from the TX and a direction of incoming to the RX side can be estimated.

## B. Measurement Scenario

Channel measurement campaign was performed at inside of Incheon international airport building. This measurement area is the place that the hundreds of passengers are often crowded and wireless traffic is very high. Measurement has been carried out in big hall which is a departure platform located on third floor of terminal building. Whole hall's size is about 650m x 82m, and height between hall's bottom and ceiling is about 20m. Internal ceiling and wall of terminal building consist of steel frames and thick tempered glasses, and the ground of hall consists of steel-reinforced concrete. Many check-in booths, shops, chairs for passengers are surrounded in the floor, and steel pillars are at the hall. There were elevators, escalators and concrete stairs on side of hall. Fig. 2 displays a half part of departure platform where channel measurement campaign was carried out.

The BECS systems and UCA antennas are installed at the positions of TX and RX (as marked in the Fig. 2). The TX is located on the second floor in the hall (dashed line). As shown in Fig. 3(a), the position of TX is fixed, and the UCA antenna for transmission was installed at the place of about 7m height from bottom of the first floor. Fig. 3(b) shows that the RX is mounted on the trolley, and the height of RX antenna was 1.6 m. As shown in Fig. 2, the positions of RX are classified into line of sight (LoS) points and non-line of sight (NLoS) points.

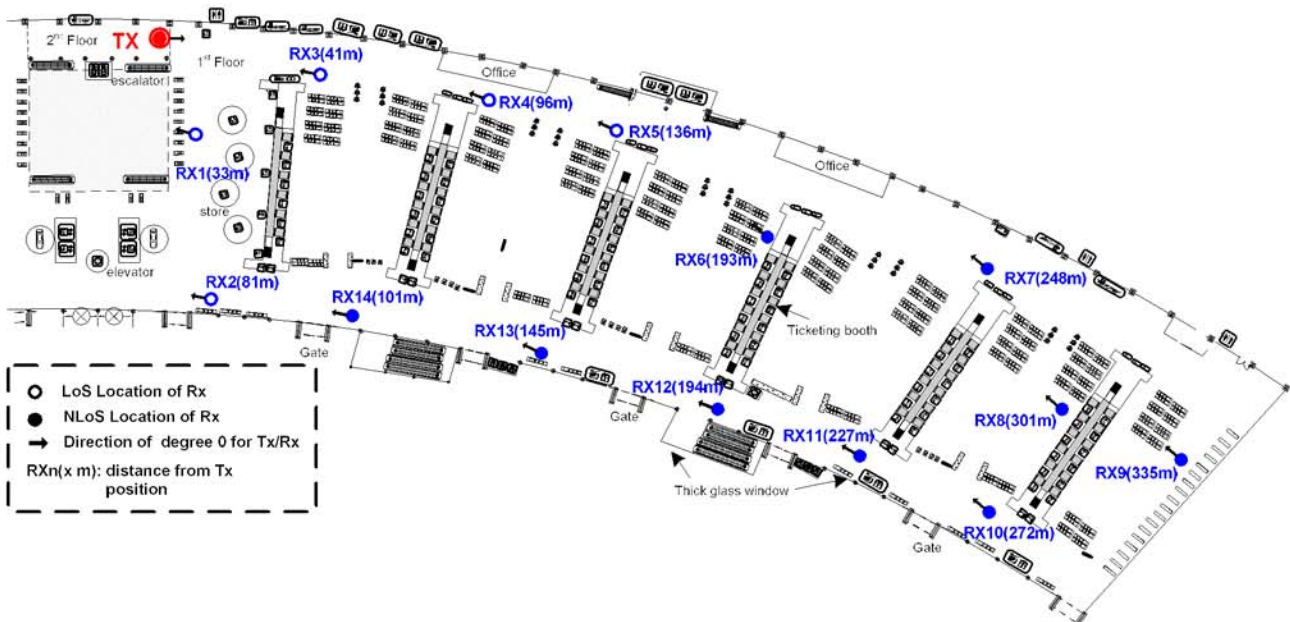


Figure 2. The architecture of the BECS channel sounder

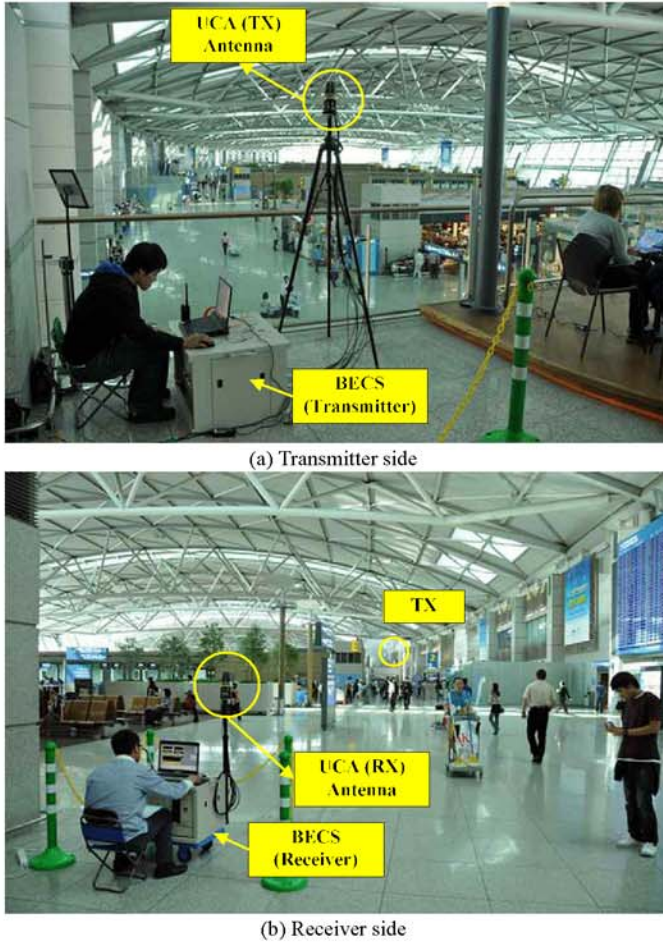


**Figure 3.** Channel measurement campaign using the BECS channel sounder and UCA antenna

Each measurement was performed at LoS positions which marked as RX1 to RX5, and at NLoS measurement positions from RX6 to RX14, respectively. Additionally, we divide time zones into a peak time and an off-peak time during a day, and carried out measurement campaign respectively in each time zone. At peak time, many people were moving around in the hall and passing by our channel sounder as shown in Fig. 3(b). In other side, at off-peak time, only a few people remained around measurement place.

In this measurement, the power of transmission for channel sounder was +30dBm. We collected 20 measured samples at each measurement points. One measured sample includes 64 radio channel information between Tx and Rx antenna pairs. Therefore, in this channel measurement campaign, we gathered total 560 (= 14 points x 20 samples x 2 time zones) measured samples.

### III. MEASUREMENT RESULTS AND ANALYSIS

#### A. Post Data Processing

Measured data which stored at each Rx measurement point are raw data including a characteristic system response of channel sounder and radio channel impulse responses  $h(\tau, t)$ .

$$h(\tau, t) = \sum_i h_i(t) \delta(\tau - \tau_i(t))$$

, where  $t$  and  $\tau$  denote the measurement time and delay, and  $h_i$  is the complex amplitude of a signal arriving via a discrete propagation path having an excess delay  $\tau_i$ .

Through the post data processing, we can remove a system response and get channel impulse responses (CIRs) from measured data. First, to remove a system response of channel sounder clearly, we have been performed a system calibration process through wired connection between Tx and Rx channel sounders. In this process, the effect of channel sounder such as delay and phase distortion which comes from RF module and cables of the system can be eliminated. Next, CIRs can be obtained through cyclic correlation with system response which was obtained from the calibration process [6].

In this paper, in order to estimate multiple propagation paths and extract the channel parameters from CIRs, the Space-Alternating Generalized Expectation-maximization (SAGE) algorithm [7] is used. Each estimated path has a set of channel parameters such as an angle of departure, an angle of arrival, a propagation delay, a doppler shift, and a complex weight, respectively. In the SAGE process, we extracted 40 multi-paths at each measurement point considering that measurement site is indoor environment. The resolutions of delay and angle were set by 1 degree and 1 ns respectively.

We conducted analysis about spatial channel characteristics such as delay spread, maximum excess delay, angular spread of arrival, angular spread of departure through process of preceding descriptions.

#### B. Delay Spread

The root mean square (r.m.s) delay spread (DS) is the standard deviation value of the delay of reflections, and it is weighted proportional to the energy in the reflected waves. As delay spread is large, frequency selectivity increases and coherent bandwidth decreases.

The r.m.s delay spread ( $\sigma_\tau$ ) is defined as

$$\sigma_\tau = \sqrt{\bar{\tau}^2 - (\bar{\tau})^2} \quad (1)$$

$$\bar{\tau}^2 = \frac{\sum_{k=1}^M P(\tau_k) \cdot \tau_k^2}{\sum_{k=1}^M P(\tau_k)}, \quad \bar{\tau} = \frac{\sum_{k=1}^M P(\tau_k) \cdot \tau_k}{\sum_{k=1}^M P(\tau_k)} \quad (2)$$

The maximum excess delay (MED) is defined as the length of the delay profile between two paths farthest apart for a given threshold.

#### C. Circular Angular Spread

We used circular angular spread (CAS) method that is described in the 3GPP spatial channel model (SCM) specification [8] to calculate angular spread of arrival (ASA) and angular spread of departure (ASD).

The CAS ( $\sigma_{AS}$ ) is defined as

$$\sigma_{AS} = \min_{\Delta} \sigma_{AS}(\Delta) = \sqrt{\frac{\sum_{k=1}^M (\theta_{k,\mu}(\Delta))^2 \cdot P_k}{\sum_{k=1}^M P_k}} \quad (3)$$

, where  $P_k$  is the energy of  $k^{\text{th}}$  path.  $\theta_{k,\mu}(\Delta)$  is defined as

$$\theta_{k,\mu}(\Delta) = \begin{cases} 2\pi + (\theta_k(\Delta) - \mu_\theta(\Delta)), & \text{if } (\theta_k(\Delta) - \mu_\theta(\Delta)) < -\pi \\ (\theta_k(\Delta) - \mu_\theta(\Delta)), & \text{if } |(\theta_k(\Delta) - \mu_\theta(\Delta))| \leq \pi \\ 2\pi - (\theta_k(\Delta) - \mu_\theta(\Delta)), & \text{if } (\theta_k(\Delta) - \mu_\theta(\Delta)) > \pi \end{cases} \quad (4)$$

$\mu_\theta(\Delta)$  is defined as

$$\mu_\theta(\Delta) = \frac{\sum_{k=1}^M \theta_{k,\mu}(\Delta) \cdot P_k}{\sum_{k=1}^M P_k} \quad (5)$$

$$\theta_k(\Delta) = \theta_k + \Delta \quad (6)$$

, where  $\theta_k$  is the angle of arrival (AoA) or angle of departure (AoD) of  $k^{\text{th}}$  path, and  $\Delta$  denotes the angle ranging from  $-\pi$  to  $\pi$ .

Fig. 4 displays examples of estimated results of multiple paths with AoD and AoA at points of RX4 and RX8. As shown in Fig. 4(a), we can observe that a dominant path having the largest power starts by angle of about  $-10^\circ$  and arrives at  $-10^\circ$  correctly. And other multiple path components are mostly gathered at 0 degree because of RX4 is LoS point. In Fig. 4(b), we can see that multipath components at NLoS point are dispersed because incoming rays are reflected by surrounding scatters.

Table 2 shows the numerical results of channel parameter obtained from this measurement. All values are classified respectively into LoS cases or NLoS cases. Furthermore, we divide measured time zones into a peak time and an off-peak time and compare each value.

At peak time, we can observe that the mean of DS and the mean of MED in NLoS (80 ns, 416 ns) are bigger than results in LoS (50.9 ns, 387 ns). These results are considered as natural because DS in NLoS is larger than in LoS. But, in case of RX8, RX12 and RX14, we observe that the results of delay spread are similar to the LoS scenarios instead of the NLoS.

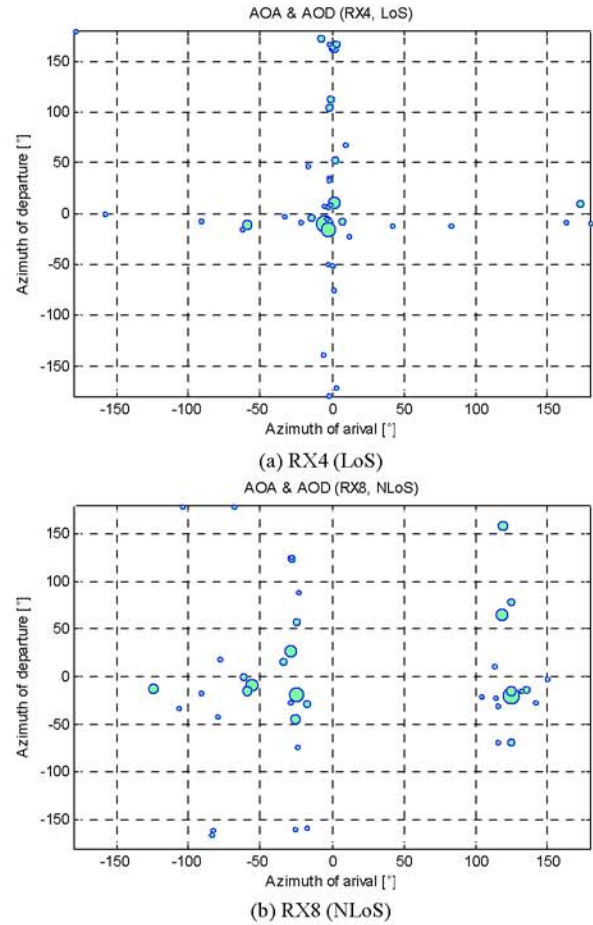


**Figure 4.** Estimated results of multiple path components with AoA and AoD at the position of RX1

**TABLE 2.** NUMERICAL RESULTS OF CHANNEL PARAMETERS FROM MEASUREMENTS

| parameters |      | Peak Time(A) |          |           |           | Off-peak Time(B) |          |           |           | $\Delta(B-A)$ |          |           |           |
|------------|------|--------------|----------|-----------|-----------|------------------|----------|-----------|-----------|---------------|----------|-----------|-----------|
|            |      | DS [ns]      | MED [ns] | ASA [deg] | ASD [deg] | DS [ns]          | MED [ns] | ASA [deg] | ASD [deg] | DS [ns]       | MED [ns] | ASA [deg] | ASD [deg] |
| LoS        | RX1  | 62.6         | 620.0    | 34.13     | 74.81     | 72.67            | 645.0    | 47.94     | 77.41     | 10.1          | 25.0     | 13.81     | 2.60      |
|            | RX2  | 38.5         | 255.0    | 50.57     | 97.39     | 25.41            | 238.0    | 59.64     | 99.96     | -13.1         | -17.0    | 9.07      | 2.57      |
|            | RX3  | 40.0         | 416.0    | 36.22     | 51.78     | 62.47            | 503.0    | 38.13     | 44.89     | 22.5          | 87.0     | 1.90      | -6.89     |
|            | RX4  | 53.3         | 317.0    | 36.64     | 73.30     | 46.76            | 321.0    | 33.23     | 55.32     | -6.5          | 4.0      | -3.41     | -17.97    |
|            | RX5  | 60.2         | 327.0    | 57.71     | 54.93     | 66.57            | 246.0    | 64.24     | 48.01     | 6.4           | -81.0    | 6.53      | -6.92     |
|            | Mean | 50.9         | 387.0    | 43.05     | 70.44     | 54.78            | 390.6    | 48.64     | 65.12     | 3.9           | 3.6      | 5.58      | -5.32     |
| NLoS       | RX6  | 67.3         | 283.0    | 66.10     | 72.06     | 74.01            | 406.0    | 66.58     | 67.09     | 6.7           | 123.0    | 0.47      | -4.97     |
|            | RX7  | 146.0        | 619.0    | 69.60     | 85.01     | 130.22           | 633.0    | 67.33     | 84.50     | -15.8         | 14.0     | -2.28     | -0.51     |
|            | RX8  | 57.4         | 293.0    | 93.08     | 66.15     | 78.34            | 524.0    | 77.82     | 57.24     | 20.9          | 231.0    | -15.26    | -8.91     |
|            | RX9  | 93.4         | 477.0    | 90.17     | 43.46     | 103.62           | 482.0    | 91.87     | 38.13     | 10.2          | 5.0      | 1.70      | -5.33     |
|            | RX10 | 105.6        | 342.0    | 79.16     | 82.34     | 111.69           | 346.0    | 86.80     | 74.51     | 6.1           | 4.0      | 7.64      | -7.83     |
|            | RX11 | 79.0         | 634.0    | 32.03     | 53.72     | 66.75            | 389.0    | 28.23     | 59.79     | -12.2         | -245.0   | -3.80     | 6.07      |
|            | RX12 | 49.0         | 271.0    | 53.66     | 65.85     | 69.87            | 397.0    | 55.63     | 68.44     | 20.9          | 126.0    | 1.97      | 2.59      |
|            | RX13 | 87.4         | 460.0    | 37.22     | 60.94     | 91.10            | 467.0    | 35.42     | 58.63     | 3.7           | 7.0      | -1.80     | -2.31     |
|            | RX14 | 35.2         | 367.0    | 46.65     | 57.72     | 68.31            | 332.0    | 61.94     | 65.36     | 33.1          | -35.0    | 15.29     | 7.64      |
|            | Mean | 80.0         | 416.2    | 63.07     | 65.25     | 88.21            | 441.8    | 63.51     | 63.74     | 8.2           | 25.6     | 0.44      | -1.51     |
| Total Mean |      | 69.6         | 405.8    | 55.92     | 67.10     | 76.27            | 423.5    | 58.20     | 64.23     | 6.6           | 17.7     | 2.27      | -2.87     |

We expect the reason that most of paths with high power are obstructed by scatters and the number of incoming paths is smaller than the other NLoS points. When we compared the results of angular spread, ASA ( $63.07^\circ$ ) in NLoS is larger than ASA ( $43.05^\circ$ ) in LoS. The reason is appeared that incoming paths at NLoS are more reflected and dispersed by scatters than at LoS point. We can see that this tendency is very similar to at off-peak time.

In table 2, we also compared result values between at peak time and at off-peak time. Both total mean value of DS and MED at peak time are smaller than the values at off-peak time. While total mean of ASA at peak time is smaller than at off-peak time, the result of ASD ( $67.10^\circ$ ) at peak time is larger than the value ( $64.23^\circ$ ) at off-peak time. In this result, we can expect that some incoming multiple path components from the TX became blocking by the people (passenger's body) especially at peak time. Besides, these results can be considered as very reasonable thing because the indoor hotspot area is richer scattering than the typical indoor environment.

#### IV. CONCLUSIONS

This paper presents the results of wideband channel measurements of indoor hotspot area at 3.7GHz. The channel measurement campaign has been performed in the Incheon international airport terminal. Our measurement was carried out at peak time and at off-peak time respectively and each measured scenario includes both LoS and NLoS measurement points. We analyzed the numerical results of the SAGE algorithm in the point of view of delay spread and angular spread. Through channel measurement and analysis process, we can get following conclusion. To get a more accurate channel model for indoor hotspot environment, it is proper to apply channel parameters obtained through real channel measurement especially at peak time. Also, it is better to get more samples at various measurement points to improve accuracy of statistic. These results are important for studies of indoor hotspot propagation characteristics and can be used for future MIMO system design and channel modelling.

#### REFERENCES

- [1] V. Erceg and et al., "TGn Channel Models," Doc. IEEE802.11-03/940r4, 2004.
- [2] G. Breit and et al., "TGac Channel Model Addendum," Doc.IEEE802.11-09/0308r10, 2010.
- [3] G. J. Foschini and M. J. Gans, "On limits of wireless personal communications in a fading environment when using multiple antennas," *Wireless Personal Communications*, vol. 6, no. 3, pp. 311 – 335, March 1998.
- [4] M. D. Kim, H. K. Kwon, W. S. Kim, J. J. Park, and H. K. Chung, "Performance Evaluation of Bi-directional MIMO channel Sounding System", *ICWN2008*, vol. 1, 2008, pp704-708.
- [5] H. Chung, N. Vloeberghs, H. K. Kwon, S. J. Lee, and K. C. Lee, "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.
- [6] Xin Nie, Jianhua Zhang, Yu Zhang, Guangyi Liu, Zemin Liu, "An Experimental Investigation of Wideband MIMO Channel Based on

- Indoor Hotspot NLOS Measurements at 2.35GHz", *IEEE GLOBECOM 2008*, pp1-5, Nov. 2008.
- [7] B. H. Fleury, M. Tschudin, R. Heddergott, D. Dahlhaus, and K. I. Pedersen, "Channel Parameter Estimation in Mobile Radio Environment Using the SAGE Algorithm", *IEEE Journal on Selected Areas in Communications*, vol. 17, No. 3, pp. 434-450, March 1999.
- [8] Spatial Channel Model for Multiple Input Multiple Output (MIMO) Simulations (3GPP TR25.996), v6.1.0, Sep. 2003, [www.3pp.org](http://www.3pp.org)