Ricean K-factor Analysis of Indoor Channel Measurements at 3.7 GHz

Jae-Joon Park, Myung-Don Kim, Hyun-Kyu Chung
Wireless Telecommunications Research Department
Electronics and Telecommunications Research Institute
Daejeon, Korea
E-mail: {jjpark, mdkim, hkchung}@etri.re.kr

Wonsop Kim
College of Engineering
Korea Advanced Institute of Science and Technology
Daejeon, Korea
Email: topsop@kaist.ac.kr

***Abstract*—This paper presents analysis results of the wideband MIMO channel based on indoor measurements. An accurate characterization of the *K*-factor is very important in design issues, especially for MIMO and broadband networks. We have performed measurement campaigns for the indoor wideband channel using the Band Exploration and Channel Sounding (BECS) system developed by ETRI at 3.7 GHz with 100 MHz RF bandwidth. Based on the measured data, we analyze the Ricean *K*-factor characteristics of the indoor channel.**

I. Introduction

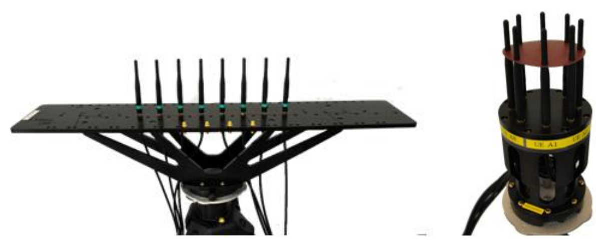
The use of multiple-input multiple-output (MIMO) antennas in wireless broadband communications promises high spectral efficiency and reliability. This leads to the fact that statistical characterization of the wideband MIMO channel is crucial for the design of wireless mobile broadband communication systems, especially upcoming IMT-Advanced system.

As for IMT-Advanced system, the carrier frequency and the bandwidth will be up to 3.6 GHz and 100 MHz, respectively. IMT-Advanced channel models were agreed in the ITU-R WP 5D in October 2008 [1]. The channel models are specified in the frequency range from 2 GHz to 6 GHz which are targeted for up to 100 MHz RF bandwidth. There are four test environments which are indoor, base coverage urban, microcelluar and high-speed test environments. For the indoor test environment, it focus on smallest cells and high user throughput in buildings.

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 [2]. 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 (VHT: very high throughput) using one or more of the following technologies: high order MIMO (above 4×4), 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 [3].

Unlike mobile channels, both ends of the link are classically static in indoor channels. It is well known that fading is usually Rayleigh distributed in mobile channels, especially in non-line-of-sight (NLOS) scenarios. However, the Rayleigh fading assumption is far from valid for indoor fixed or nomadic wireless access. Indeed, the receiver (Rx) and transmitter (Tx) are fixed during any typical communication, as are most scatterers. Therefore, temporal fading is only caused by the motion of some scatterers resulting in a Ricean fading distribution. The latter is typically characterized by the so-called Ricean *K*-factor [4]. An accurate characterization of the *K*-factor is thus very important in design issues, especially for MIMO and broadband networks, as a good indicator of the fading depths.

In this paper, we present the Ricean *K*-factor analysis results in terms of power delay profile (PDP) and power angular spectrum (PAS) based on the indoor measurement data. This paper organized as follows. In the section II, measurement environment is described. The Ricean *K*-factor analysis results are presented in the section III. Finally, the section IV gives conclusions.



(a) (b)

Fig. 1. 8-element array antennas were used at the Tx/Rx: (a) uniform linear array. (b) uniform circular array

II. Measurement Environment

A. Measurement System

The channel measurement campaigns were performed using the channel sounder BECS system [5] in ETRI, Korea. As a time division multiplexing (TDM) based wideband MIMO radio channel sounder, the BECS system is designed for MIMO channel sounding at carrier frequency of 3.7 GHz and 5.2 GHz with 100 MHz bandwidth and 2.3 GHz with

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20 MHz bandwidth using 8×8 array antennas. The BECS system uses pseudorandom noise (PN) sounding technique to sequentially transmit multiple PN signals. Multiple receivers then receive the transmitted signal sequentially. The complex channel impulse responses (CIRs) are extracted based on the cross-correlation properties between the received signals and the probing PN sequences.

Summary of the BECS system parameters are given in Table I. And Fig. 1 shows 8-element uniform linear array (ULA) antenna with separation of 0.5λ and uniform circular array (UCA) antenna with radius of 0.5λ. The ULA antenna was used at the Tx and Rx side for the K-factor and power delay profile (PDP) analysis. In the analysis of power angular spectrum (PAS), we used the UCA antenna at the Tx and Rx side.

Parameter	Value
Center frequency [GHz]	3.705
Bandwidth [MHz]	100
Tx Power [dBm]	19 or 24
Tx/Rx elements	8/8
Code length [chips]	4095
Chip rate [MHz]	100
Channel Sampling rate [MHz]	400

TABLE I
MEASUREMENT SYSTEM PARAMETERS

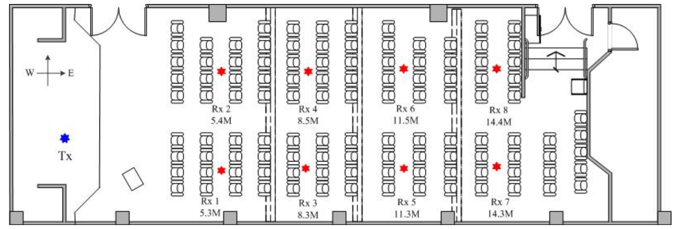


Fig. 2. Indoor Measurement Campaign - Lecture Room Scenario

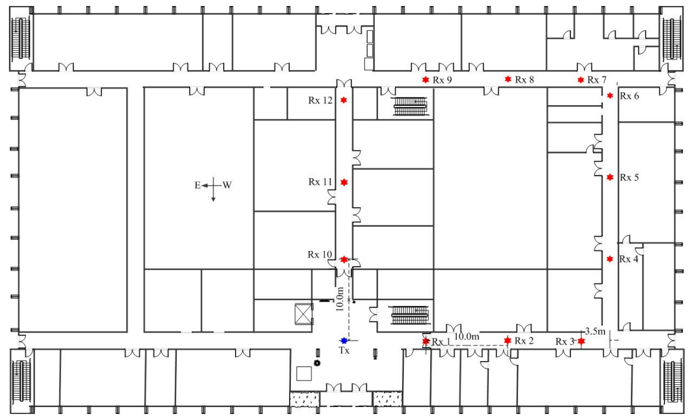


Fig. 3. Indoor Measurement Campaigns - Corridor Scenario

B. Measurement Scenarios

The indoor measurement campaigns were conducted in a lecture room and corridor of the ETRI, Korea. The site map and Tx and Rx locations are given in Fig. 2 and Fig. 3. In the figures, Tx is located at the blue point and Rx is located at the red point.

For the lecture room scenario, the dimensions are 21m×4m×2.6m (L×W×H). Tx antenna is 2.2m high with direct view to the Rx and Rx antenna is 1m high considering audiences. The outside walls of the building are largely glass, whereas the inside walls and ceilings are made of soundproof material and wood. We measured only LOS channel condition at 8 Rx positions in this scenario.

For the corridor measurement, the most of walls, ceiling and floor are made of reinforced concrete. However, the middle hallway walls of the building are made of metal material (LOS measurement locations at Rx10, Rx11, Rx12). The LOS and NLOS (Rx4∼Rx9) measurements were taken in the hallways on the first floor, which is lined by offices on both sides as shown in Fig. 3. The distance between each Rx position was approximately 10m. Tx antenna is 2m high and Rx antenna is 1.5m high from the ground considering pedestrian users.

In all scenarios, 20 snapshots of CIRs were recorded for the analysis at each Rx location. During the measurement campaigns, the Tx and Rx were fixed stationary except but moving scatterers.

III. ANALYSIS RESULTS

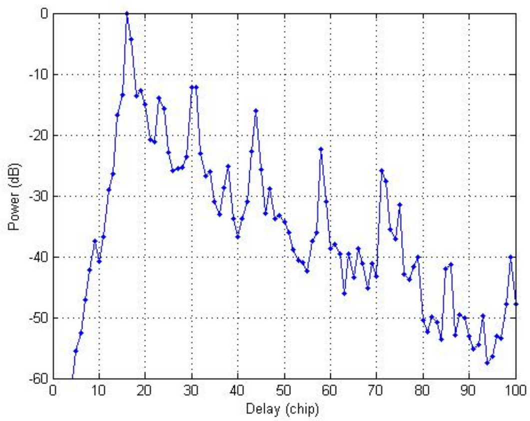
In this section, we present the Ricean K-factor analysis results based on the measurement data.

A. Power Delay Profile (PDP)

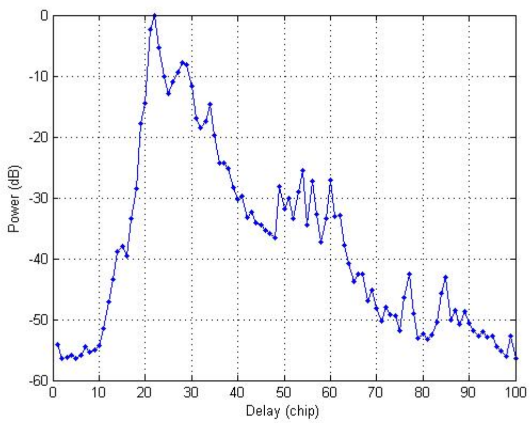
The BECS system consists of a baseband unit, a RF transceiver unit, a RF Front-end Unit and multiple antennas. The transmitting signals are filtered through a pulse shaping root-raised-cosine (RRC) filter in digital domain. A modulated intermediate frequency (IF) data is downloaded to the Tx digital baseband block and it is fed into high-speed D/A convertor to make analog IF signal. The IF signal is up-converted to RF frequency and then sequentially transmitted through the multiple antennas by selection of RF high power switch. At the receiver side, data is sequentially acquired through whole antenna elements. The RF input is filtered and amplified and feed to high-speed A/D convertor. Down-converted and demodulated I-Q data is saved in Rx digital baseband block of baseband unit.

The overall system impulse response (SIR) of the BECS system can be measured by taking a measurement via directly connecting a cable between the RF ports of Tx/Rx. Before the measurement campaigns, we measured the SIR for the calibration. After the SIR calibration, we analyzed the PDP, PAS and K-factor channel parameters using the measured CIR.

Fig. 4-5 and Fig. 6 show the PDP results of the corridor scenario and the lecture room scenario, respectively. Comparing to LOS and NLOS results, we observed that received signal power of the LOS conditions is larger than that of the NLOS conditions. However, there is a lot of multi-path in the LOS conditions, which is due to waveguide and long tunnel effect by the corridor and end-fire orientation of Rx. In the lecture room scenario, we can find from the PDP results that all the

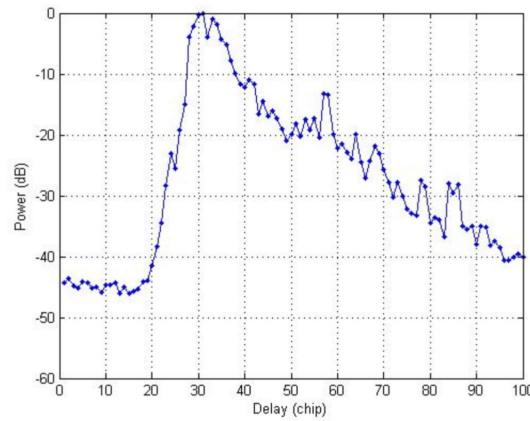


(a) LOS-Rx2

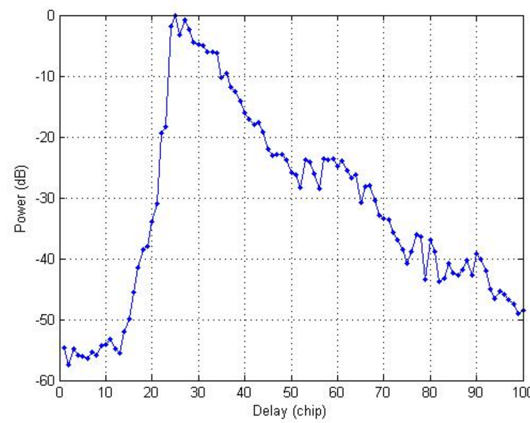


(b) LOS-Rx12

Fig. 4. PDP at the LOS position of the corridor scenario



(a) NLOS-Rx5



(b) NLOS-Rx9

Fig. 5. PDP at the NLOS position of the corridor scenario

Rx locations are clearly LOS channel condition.

B. Power Angular Spectrum (PAS)

For the PAS analysis, we also have conducted the same measurement campaigns with 8-element dipole uniform circular array antenna. Fig. 7-8 and Fig. 9 show the PAS results of the corridor and lecture room scenario, respectively. From these results, we can observe the same trend as in the PDP analysis.

C. K-factor

Under LOS channel conditions, the channels have a non-zero mean due to the presence of a direct component. For such channels, the envelope of the channel gains is well modeled by a Ricean distribution [6]. The Ricean *K*-factor, characterizes the Ricean distribution and is the ratio between the average powers of the deterministic and the random components of the channel. Fig. 10 shows an exemplary case where the envelop of the channel coefficients, in a measured LOS condition, exhibit a Ricean distribution.

Using the channel samples collected, we estimate the *K*-factor for each narrowband received power. We use a simple moment-based method to estimate the Ricean *K*-factor, which has been shown to yield good results [7],

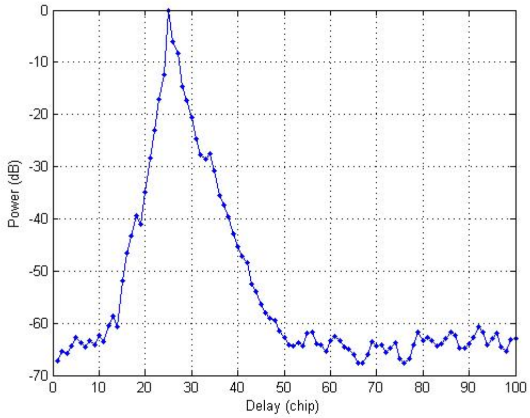
$$K = \frac{\sqrt{1-\gamma}}{1-\sqrt{1-\gamma}}$$

where $\gamma = \frac{\sigma^2}{P^2}$, and σ^2 is the variance of the received signal power P.

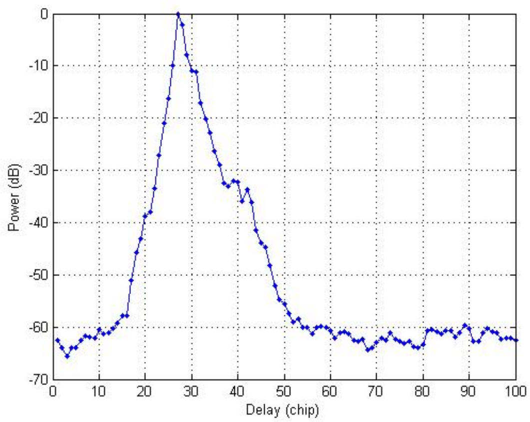
The narrowband *K*-factor for all snapshots were computed at each array antenna for all measurement runs. In the corridor scenario, the measured *K*-factor is 4.8 dB. Although counter-intuitive, we can observe from the PDP and PAS results why it has such relatively low *K*-factor. In previous measurements in the hallway environment [8], [9], we can also observe the same trend. And the measured *K*-factor of the lecture room scenario is 7.9 dB. Comparing to the mean *K*-factor, 7 dB, of the indoor IMT-Advanced channel model it has been shown to yield good consistency.

IV. Conclusions

The carrier frequency and the bandwidth will be up to 3.6 GHz and 100 MHz for the IMT-Advanced system. And interest

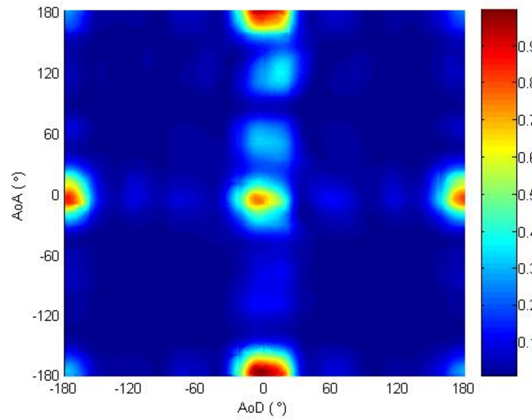


(a) Rx1

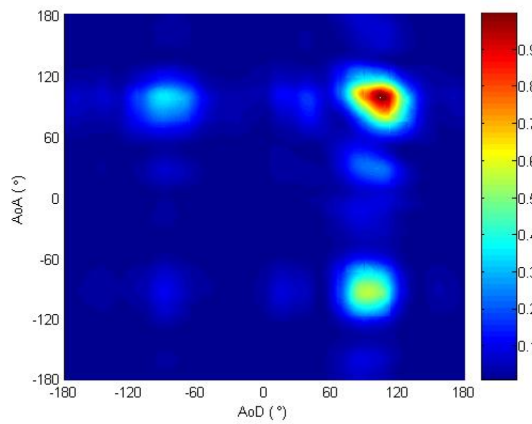


(b) Rx8

Fig. 6. PDP at the LOS position of the lecture room scenario



(a) LOS-Rx2



(b) LOS-Rx12

Fig. 7. PAS at the LOS position of the corridor scenario

of the indoor broadband channel model has been increased recently. In addition, an accurate characterization of the *K*-factor is very important in design issues, especially for MIMO and broadband networks. Therefore we have performed measurement campaigns for the indoor wideband channel using the BECS system at 3.7 GHz with 100 MHz RF bandwidth.

In this paper, we present analysis results of the wideband MIMO channel especially for the Ricean *K*-factor from the indoor measurements data. In the corridor scenario, the measured *K*-factor is 4.8 dB for the LOS conditions. And the measured *K*-factors are 7.9 dB for the lecture room scenario. Comparing to the mean *K*-factor, 7 dB, of the indoor IMT-Advanced channel model, it seems to be consistent at even 3.7 GHz.

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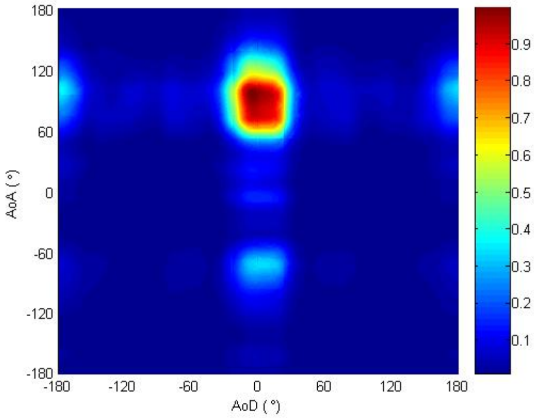
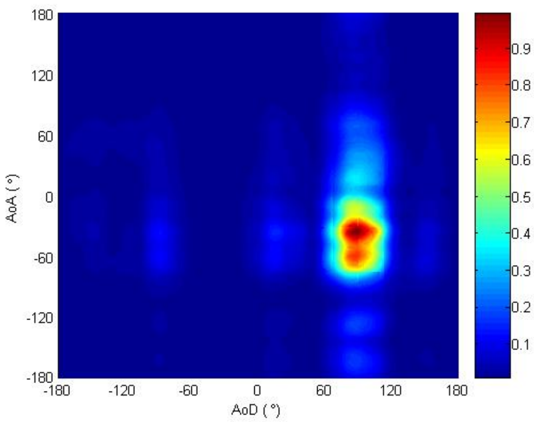


(a) NLOS-Rx5

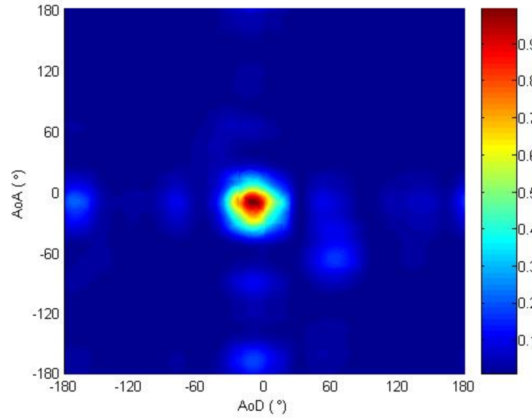


(b) NLOS-Rx9

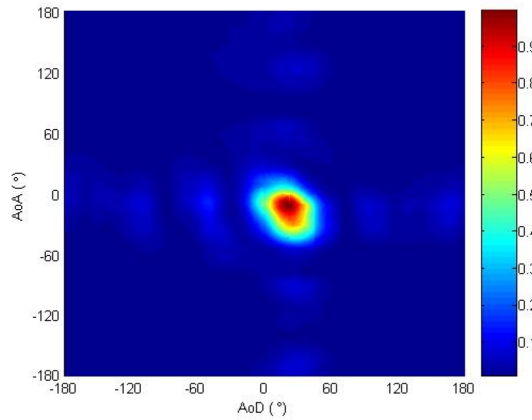
Fig. 8. PAS at the NLOS position of the corridor scenario

Position	K-factor [dB]	
	Corridor Scenario	Lecture Room Scenario
Rx1	7.7	10.0
Rx2	2.7	10.1
Rx3	2.3	8.0
Rx4	-	10.9
Rx5	-	5.8
Rx6	-	5.3
Rx7	-	6.2
Rx8	-	6.8
Rx9	-	-
Rx10	4.0	-
Rx11	7.7	-
Rx12	4.2	-
Mean	4.8	7.9
Variance	5.6	4.7

TABLE II
K-FACTOR RESULTS



(a) Rx1



(b) Rx8

Fig. 9. PAS of the lecture room scenario

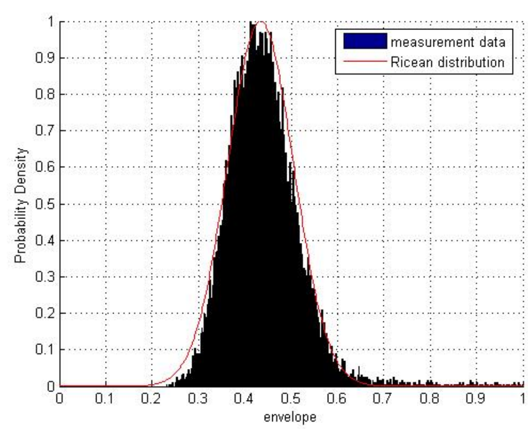


Fig. 10. Empirical PDF of the envelope of Rx5 in the lecture room scenario