A method of controlling the base station correlation for MIMO-OTA based on Jakes model

Kazuhiro Honda\(^{a)}\) and Kun Li

Graduate School of Engineering, Toyama University,
3190 Gofuku, Toyama-shi, Toyama 930–8555, Japan
\(^{a)}\) hondak@eng.u-toyama.ac.jp

Abstract: This paper presents a methodology of controlling the spatial correlation of BS (base station) antenna realized by a bilateral fading emulator for MIMO-OTA (Over-The-Air) testing. On the basis of Jakes theory, the base station correlation is controlled by setting the initial phases of scatterers in a two-dimensional fading emulator. The experimental results show that the designed correlation coefficient of an uplink channel using the proposed method agrees well with the theoretical value. Further, it is confirmed that the channel capacity of uplink channel can be controlled when the base station and mobile terminal correlations are changed simultaneously.

Keywords: base station antenna correlation, Jakes model, MIMO-OTA, fading emulator, channel capacity

Classification: Antennas and Propagation

References


1 Introduction

Multiple-input multiple-output (MIMO) is a key technique to the success of forthcoming ultra-high-speed cellular systems [1]. To evaluate the performance of a MIMO device, Over-The-Air (OTA) testing is a widely approved method. In the previous study [2], the channel capacity of a MIMO antenna is evaluated using a two-dimensional fading emulator in downlink channel. However, the evaluation of the channel capacity of uplink channel was not clarified.

In future MIMO systems, a large capacity of uploading data from a handset to base station is anticipated, which means that the channel capacity needs to be evaluated not only in downlink but also in uplink channel. Since the correlation of a base station antenna is known to possess a relatively high value even in the case of the array spacing of several wavelengths in a small cell environment [3], it is important to consider a base station correlation when the evaluation of the channel capacity of a MIMO antenna in uplink channel is conducted.

This paper presents a methodology of controlling the spatial correlation of base station antenna realized by a bilateral fading emulator for MIMO-OTA testing [4]. On the basis of the Jakes theory, a method of achieving the spatial correlation of a base station antenna is introduced by setting the initial phases of scatterers in a two-dimensional channel model. Further, the channel capacity of uplink channel is evaluated when the base station correlation and terminal correlation are varied simultaneously.

2 A method of controlling the uplink correlation

We are developing a bilateral MIMO-OTA evaluation apparatus for measuring the channel capacity of uplink as well as downlink channels [5]. When the channel capacity of uplink channel is measured, RF signals radiated from a DUT MIMO antenna are received by each probe antenna and then the phase of the received signals is controlled by a circuit. Since the base station antenna with a separation of 5\(\lambda\) at 2 GHz is known to have a high correlation [3], it is important to consider a high base station correlation in uplink channel.

We have attempted to control the base station correlation using the initial phase of scatterers. Fig. 1 shows the implementation model for realizing the base station correlation. In Fig. 1, \(h_{ij}\) is the channel response from DUT \#j to Rx \#i. The fading emulator is created based on a two-dimensional channel model [2].

As shown in Fig. 1, RF signals radiated from a DUT MIMO antenna located at the center of the emulator are transmitted to the scatterers and then arrive at the base station (Rx1, Rx2). The different paths are realized by combining different initial phase matrices \(\Phi_1\) and \(\Phi_2\).
In general, the correlation in the uplink channel involves the characteristics of a radio wave propagation represented by multipath waves and a base station antenna. In this paper, the sum of the abovementioned two effects is attributed to the characteristics of the multipath waves. Therefore, the initial phase matrices $\Phi_1$ and $\Phi_2$ have the correlation characteristics that include the combined effects of both the multipath waves and base station antenna in an uplink channel. Based on this concept, the base station correlation characteristics can be controlled by setting the initial phases of scatterers using the Jakes model, as mentioned in the following way.

Although Jakes model is a theory for reception in downlink channel, it can also be applied to the uplink channel for the sake of bilateral nature in the radio wave propagation [6]. When a MIMO antenna placed at the center of the two-dimensional channel model is moved in a distance $d$, the geometrical phase difference $\alpha_i$ between the antenna and each scatterer can be calculated by Eq. (1) using the geometry shown in Fig. 1.

$$\alpha_i = kd \cos \phi_i$$

where $k = 2\pi/\lambda$ denotes the wave number.

The autocorrelation function between the received signal of Rx1 radiated from the initial position (origin) and that of Rx2 radiated from the position moved in a distance of $d$ is obtained as the Bessel function, $J_0(kd)$, from the Jakes model, as shown by the black curve in Fig. 2. The antenna separation $d$ is determined by a least-mean-square (LMS) function using the designed correlation coefficient $\rho_{BS}$, as shown by the red curve. The LMS function is given by Eq. (2).

$$d(\rho) = -0.46\rho^3 + 0.55\rho^2 - 0.45\rho + 0.39$$

Using this antenna separation $d$, the geometrical phase difference $\alpha_i$ is calculated by Eq. (1). Using this phase difference, the initial phase matrix $\Phi_2$ of the base station 2 (Rx2) can be calculated as the summation of the initial phase matrix $\Phi_1$ of the base station 1 (Rx1) and the geometrical phase difference matrix $A$, as expressed by Eq. (3).

$$\Phi_2 = \Phi_1 + A$$

$$= [\phi_1 \quad \phi_2 \quad \ldots \quad \phi_n] + [\alpha_1 \quad \alpha_2 \quad \ldots \quad \alpha_n]$$

$$= [\phi_1 + \alpha_1 \quad \phi_2 + \alpha_2 \quad \ldots \quad \phi_n + \alpha_n]$$

![Fig. 1. Implementation model for realizing the base station correlation.](image-url)
In Eq. (3), the initial phase matrix $\Phi_1$ indicates the uncorrelated initial phase generated by random numbers. Thus, the correlation between the signals of the two scattering groups forming the base stations 1 and 2 can be controlled in accordance with the designed base station correlation.

3 Experimental results

In order to confirm the validity of the proposed method, measurements have been carried out using a bilateral fading emulator for MIMO-OTA [5]. The DUT MIMO antenna is comprised of half-wavelength dipole antennas, which are constructed using a single dipole antenna placed at two different locations forming a quasi-array as shown in Fig. 3(a).

In this paper, the base station correlation $\rho_{BS}$ and terminal correlation $\rho_{MS}$ are defined using the channel responses, as expressed by the following equations.

$$\rho_{BS} = \frac{1}{2} \left( \frac{|h_{11}h_{21}|}{\sqrt{h_{11}^*h_{11}} \sqrt{h_{21}^*h_{21}}} + \frac{|h_{12}h_{22}|}{\sqrt{h_{12}^*h_{12}} \sqrt{h_{22}^*h_{22}}} \right)$$  \hspace{1cm} (4)

$$\rho_{MS} = \frac{1}{2} \left( \frac{|h_{11}h_{12}|}{\sqrt{h_{11}^*h_{11}} \sqrt{h_{12}^*h_{12}}} + \frac{|h_{21}h_{22}|}{\sqrt{h_{21}^*h_{21}} \sqrt{h_{22}^*h_{22}}} \right)$$  \hspace{1cm} (5)

where the asterisk (*) denotes the complex conjugate.

The correlation of a mobile terminal $\rho_{MS}$ can be controlled by setting the antenna separation using the Jakes model as shown in Fig. 2. The antenna separation of DUT array antenna $L$ is set to $0.29\lambda$, which means that $\rho_{MS}$ is designed as 0.3. Fig. 3(b) shows a photograph of the DUT antenna at the center of a fading emulator. The measurement frequency is set to 1.95 GHz which is the average frequency of uplink channel at 2 GHz band in Japan.

Fig. 3(c) shows the instantaneous channel response when the designed base station correlation $\rho_{BS}$ is set to 0.9 with a distance $d$ in Fig. 1 of $0.09\lambda$. The black curve indicates $h_{11}$ whereas the blue curve indicates $h_{21}$, respectively, when the transmitting dipole antenna Tx1 is placed at the center of the fading emulator. In this case, the correlation between the received signals of each base station antenna is found to be 0.91. Moreover, the red curve indicates $h_{12}$ whereas the pink curve indicates $h_{22}$, respectively, when the dipole antenna Tx2 is separated with a distance of $0.29\lambda$ away from the center of the fading emulator which allows $\rho_{MS}$ to be 0.3. Here, the correlation between the received signals of each base station antenna is
found to be 0.92. Therefore, when the location of the DUT antenna is moved, the correlation between the received signals of base station antennas agrees well with the designed base station correlation $\rho_{BS}$. This means that, using the proposed method, we can realize the same $\rho_{BS}$ values for the DUT antenna placed at different locations in the emulator.

Fig. 3(d) shows the measured results of the correlation coefficient for a $2 \times 2$ MIMO as a function of the designed base station correlation $\rho_{BS}$ when XPR is 50 dB. In Fig. 3(d), the symbols $\bullet$ show the measured results obtained from the fading emulator while the black curve indicates the analytical outcome calculated...
by the Monte Carlo simulation [7]. It can be seen that the designed base station correlation agrees well with the correlation analyzed by the Monte Carlo simulation. This fact confirms that the base station correlation can be controlled using the proposed method.

In our previous study [4], the impact of the base station correlation on the channel capacity is not investigated. In this paper, the MIMO channel capacity with regard to the different base station correlations is measured. Fig. 3(e) shows the measured and analytical results of $2 \times 2$ MIMO channel capacity with the designed base station correlation $\rho_{BS}$ varied from 0 to 0.95. $\rho_{MS}$ is set to 0.3 and 0.9. $XPR$ is 50 dB while $SNR$ of the incident wave is 30 dB. As can be seen in Fig. 3(e), the measured results agree well with the analytical outcomes. Further, the channel capacity is varied depending on $\rho_{MS}$. Therefore, using the proposed method, the combined evaluation of a handset MIMO antenna in consideration of both uplink and downlink channel properties can be realized.

### 4 Conclusion

This paper presents a method of controlling the base station correlation for the combined evaluation of a handset MIMO-OTA in consideration of both uplink and downlink channels. The results show that the measured correlation coefficient of uplink channel agrees well with the theoretical values, confirming the effectiveness of the proposed method. Further, the channel capacity of uplink channel is determined by changing not only the base station correlation but also the terminal correlation. Future studies include the derivation of the initial phase of scatterers in accordance with various $XPR$s.

### Acknowledgments

This work was entrusted by the MIC-SCOPE 2015.