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Abstract

It is often claimed that Rician fading must also be included for Over-The-Air (OTA) testing of mobile devices with Multiple-input Multiple-output (MIMO) capabilities. However, the Line-Of-Sight (LOS) component varies with orientation and location of the mobile device. Therefore, we study Rician channels with random LOS to determine its significance.

Keywords: Over-The-Air, MIMO, Propagation

1. Introduction

Today MIMO antenna systems have found several applications. With the advent of Long Term Evolution (LTE) wireless technology, MIMO antenna systems have a very promising future especially in mobile wireless devices. MIMO systems make use of antenna diversity in order to mitigate the effects of multipath fading. There are many articles already published on the characterization of MIMO terminals but the effect of user statistics i.e. user position and orientation has often been neglected. These user statistics will cause a random Line-Of-Sight (LOS) effect. Therefore, we will study the effect of random LOS in Rician fading channels to determine the significance of including the Rician environments in Over-The-Air (OTA) testing procedures for LTE devices. OTA tests are needed in order to include the performance of multiport antennas in complete wireless system tests. This is in contrast to conductive tests where channel emulators are directly connected to the RF ports of the wireless devices instead of the antennas.

In previous studies [1]-[3] the rich isotropic environment was proposed as a reference for OTA testing of wireless devices. The rich isotropic environment assumes no LOS and a large number of independent incoming waves. The independency means that the amplitude, phase, polarization and Angle-of-Arrival (AoA) of the incoming waves are randomly generated. The reverberation chamber is a multi-mode metal cavity that emulates rich isotropic multipath environment when stirred e.g. by moving metal plates inside it. It has been used for measuring performance of active and passive antenna systems for more than 10 years, and in particular to characterize MIMO performance [4],[5]. The amplitude of the voltage samples measured on each antenna port in such a well-stirred chamber shows Rayleigh distribution (i.e. both the real and imaginary parts of the complex voltages at each antenna port are Gaussian distributed with zero mean), which can be considered as a proof of pure NLOS environment [6]. There are published papers also on emulating Rician distributed channels in reverberation chamber [7], but unfortunately such Rician distribution causes measurement uncertainty [8]. Therefore, it is of particular interest to determine the significance of the Rician distribution for testing mobile devices, and in particular when the user statistics are taken into account. The latter is studied in the present paper simply by assuming random LOS voltages, at the antenna port, with complex Gaussian probability distribution. The validity of this assumption can be found in [9].

The reverberation chamber is known to give ergodic capacity for MIMO systems that is in agreement with other prediction methods e.g. based on measurements of efficiency and far-field function in anechoic chambers [10].

2. Random LOS Channel

A Rician fading environment is specified by Rician K-factor of the channel, defined by the ratio between the power of LOS contribution and the average power of the multipath contribution to the channel. The LOS contribution to the channel voltage corresponds to the mean of the complex port voltage, and the multipath contribution corresponds to the statistical variations around the mean. To handle a statistically varying LOS contribution, we introduce an average Rician K-factor K_{av}, being the ratio of the average power of the LOS contribution and the average power of the multipath contribution to the port voltage. We also introduce an integer parameter T which allows the LOS contribution to fade slower than the multipath contribution. We assume that the LOS contribution remains constant for T samples (i.e. no change in the user position and orientation during T samples), and thereafter it changes randomly to another value which remains constant for another T samples, and so on. Thus, T is a relative fading period. This channel model having a random LOS contribution together with a random multipath contribution is named as 'isotropically random Rician fading' model in a different study presented in [11].

3. Rayleigh Lab

This study has been carried out using MATLAB based simulation tool called 'Rayleigh Lab' [2]. It is also called a multipath response simulator since it provides a theoretical response of a multipath environment on each port of a multiport antenna system. Rayleigh Lab outputs the performance of MIMO antennas in Rayleigh fading, Rician fading, and Rician fading with random LOS. At first, Rayleigh Lab generates channels by using arrays of random numbers in MATLAB representing complex voltage samples received at the antenna ports. The user provides values for efficiencies of the antennas and correlation among them, and from these values Rayleigh Lab calculates the diversity gain and the ergodic capacity of the antenna system, by using the generated channels. The key terms such as samples, realizations, etc. used to present Rayleigh Lab results are explained in our previous studies [2], [12].

4. Simulation Results

Following are the results from Rayleigh lab showing Cumulative Distribution Function (CDF) for an ideal 4×4 MIMO system, i.e. with no correlation and 0 dB embedded element efficiency on all ports, using 10,000 channel samples at each port of the multiport antenna system. For the generation of the CDFs each voltage sample in each realization is normalized by the square root of the average received power on the port. The figures show CDFs of four different realizations of the 4x4 MIMO system, each realization with a different colour. So, there are 16 CDF curves of each colour in the graphs, in addition to 16 curves showing selection combined CDF, 4 curves for each realization.

The CDF curves of Rayleigh fading and Rician fading with a fixed K-factor shown in Figure 1 are as expected. The 16 curves show some spread around the theoretical curve because we use a limited number of samples. The CDFs for Rician fading with random LOS that has the same fading period T = 1 as the random multipath contribution are shown in Figure 2 for two values of K_{av}. We can observe that the CDFs are Gaussian with the same spread as in Figure 1. Thus, the sum of two Gaussian contributions is a Gaussian as well, which is not surprizing at all. The same CDFs are plotted in Figure 3 when the fading period is T = 100 times slower for the random LOS. We can see that the spread of these CDF curves are larger than in Figures 2, meaning that they have not converged so well as in Figures 2. The reason is that the number of independent samples in the LOS contribution is not sufficiently large. The number of uncorrelated samples is only 100 when the total number of samples is 10,000 and T = 100 samples, whereas we need at least 1000 uncorrelated samples to see convergence at 1% CDF level.

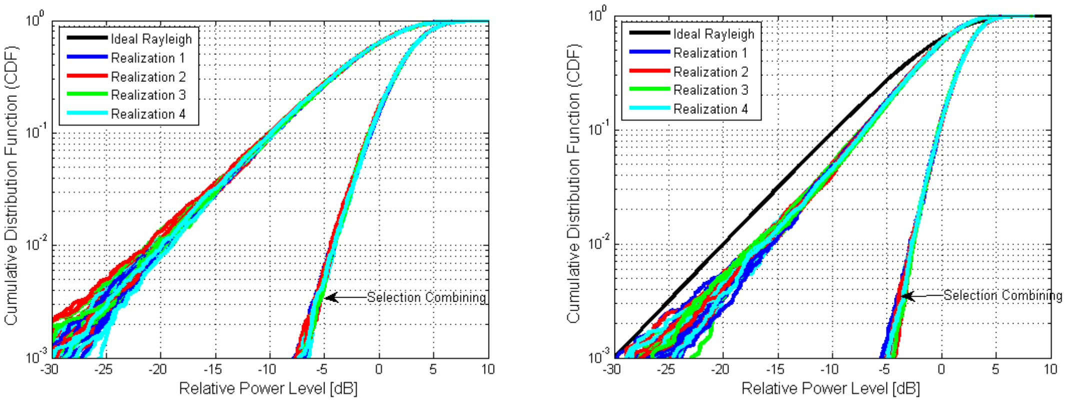

Figure 1: CDFs of pure Rayleigh fading (left) and Rician fading (right) with K = 3 dB.

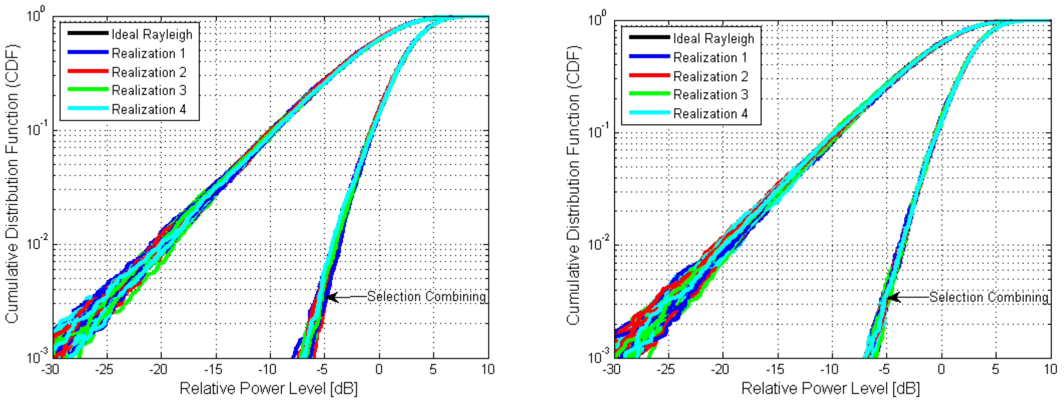

Figure 2: CDFs of Rician fading with random LOS, T = 1 sample, K_{av} = 3 dB (left) and 10 dB (right).

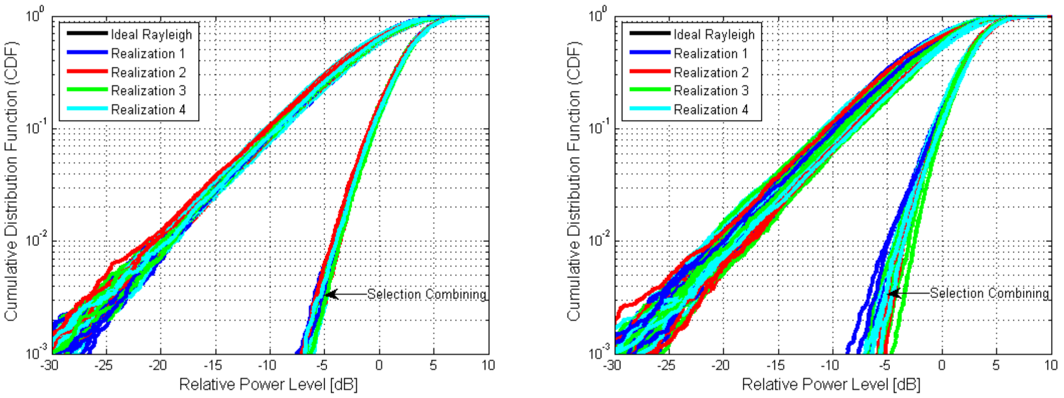

Figure 3: CDFs of Rician fading with random LOS, T = 100 samples, K_{av} = 3 dB (left) and 10 dB (right).

5. Conclusion

Arbitrary user positions and orientations will create an effect of ‘random LOS’, i.e. Rician fading environment with random Rician K-factor. We have shown that if this random LOS has a complex Gaussian distribution, the CDF of Rician fading with random LOS converges to the same

CDF as ideal Rayleigh fading with no LOS. Therefore, under these conditions there remains no need to emulate Rician fading environments for OTA testing of wireless mobile devices; they can equally well be tested under Rayleigh fading only.

References

[1] J. Carlsson, U. Carlberg, A. Hussain, and P-S. Kildal, “About measurements in reverberation chamber and isotropic reference environment”, 20th International Conference on Applied Electromagnetics and Communications ICECOM 2010, Dubrovnik, 20-23 September 2010.

[2] P-S. Kildal, A. Hussain, U. Carlberg, J. Carlsson, “On using isotropic multipath as reference environment for OTA performance: Uncertainty due to convergence of statistical expectation when estimating ergodic capacity and diversity gain”, European Cooperation in the field of Scientific and Technical Research - COST2100, Alborg, 2-4 April 2010.

[3] P.-S. Kildal, “Over-The-Air measurements of wireless stations in reverberation chamber versus anechoic chamber: from accuracy models to testing of MIMO systems”, 2010 International Workshop on Antenna Technology (iWAT), 1-3 March 2010, Lisbon, Portugal.

[4] K. Rosengren and P-S. Kildal, “Radiation efficiency, correlation, diversity gain and capacity of a six monopole antenna array for a MIMO System: theory, simulation and measurement in reverberation chamber,” in Proc. IEE, Microwaves, Optics and Antennas, pp. 7-16, Vol.152, No.1, Feb 2005. See also Erratum published in August 2006.

[5] P.-S. Kildal and K. Rosengren, “Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency and diversity gain of their antennas: Simulations and measurements in reverberation chamber”, IEEE Communications Magazine, vol. 42, no. 12, pp. 102-112, Dec. 2004.

[6] H. Hashemi, “The indoor radio propagation channel,” Proc. IEEE, vol. 81, pp. 943–968, July 1993.

[7] C.L. Holloway, D.A. Hill, J.M. Ladbury, P.F. Wilson, G. Koepke, J. Coder, "On the Use of Reverberation Chambers to Simulate a Rician Radio Environment for the Testing of Wireless Devices", IEEE Transactions Antennas Propagat., vol.54, no.11, pp.3167-3177, Nov. 2006.

[8] P.-S. Kildal, Sz-Hau Lai, and X. Chen, “Direct coupling as a residual error contribution during OTA measurements of wireless devices in reverberation chamber”, IEEE AP-S International Symposium on Antennas and Propagation, Charleston, USA, June 1-5, 2009

[9] U. Carlberg, P.-S. Kildal, J. Carlsson, “Study of random Line-of-Sight saused by arbitrary user positions and orientations with application to MIMO OTA measurements of wireless devices”, submitted to Internat. Symp. on Antennas and Propagation ISAP 2011, Jeju Korea Oct. 2011.

[10] X. Chen, P.-S. Kildal, J. Carlsson, J. Yang, “Comparison of Ergodic Capacities from Wideband MIMO Antenna Measurements in Reverberation Chamber and Anechoic Chamber", accepted for publication in Antennas and Wireless Propagation Letters, May 2011.

[11] M. Godavarti, T.L. Marzetta, S.S. Shitz, "Capacity of a mobile multiple-antenna wireless link with isotropically random Rician fading," Information Theory, 2001. Proceedings. 2001 IEEE International Symposium on , vol., no., pp.323, 2001.

[12] A. Hussain, U. Carlberg, J. Carlsson, P-S. Kildal, “Analysis of statistical uncertainties involved in estimating ergodic MIMO capacity and diversity gain in Rayleigh fading environment”, 20th International Conference on Applied Electromagnetics and Communications ICECOM 2010, Dubrovnik, 20-23 September 2010.

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