Study of Random Line-of-Sight Caused by Arbitrary User Positions and Orientations with Application to MIMO OTA Measurements

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Abstract

We present the statistics of the simulated received voltages on diversity antennas in line-of-sight and rich isotropic multipath environments. The two environments are compared for receiving antennas with random positions and orientations, producing a random line-of-sight. The antennas are canonical small antenna types such as an ideally omni-directional antenna, and incremental electric dipoles, magnetic dipoles and Huygens sources.

Keywords: Multi-path environment, line-of-sight, Over-The-Air, MIMO

1. Introduction

A terminal such as a mobile phone will receive a statistical varying (faded) signal when moved around in a multipath propagation environment. The statistics of the multipath environment may be different indoor compared to outdoors, in a city centre compared to a rural area, and so on. On the other hand, it is also important to take into account the statistics of the user. Since a user will move the terminal around in the environment, the propagation environments must be studied for several random orientations and positions of the terminal. We assume that in practice, the distribution of the random orientation of the terminal is uniform over all directions.

In the present paper we compare a terminal in two well-defined and simple environments; the rich isotropic multipath environment and the pure line-of-sight (LOS) environment. The terminal is modelled by some simple analytical antennas such as hypothetical omni-directional radiators, incremental electric and magnetic dipoles, and Huygens sources. We consider a terminal with two antennas because then we may also calculate diversity gain and compare it for the two different environments.

The results of this study have implications on designing fair over-the-air (OTA) measurement techniques for multiple-input multiple-output (MIMO) devices. The purpose of such OTA testing should be to be able to differentiate between good and bad devices in a real-life environment, at least in an average sense when moving around in the environment, or when averaged over different users in the environment. The rich isotropic environment can be emulated by a reverberation chamber [1]. The testing of both active and passive multiport antenna systems based on channel measurements in reverberation chamber has been published [2] and successfully compared with testing based on channels simulated numerically by using efficiencies and radiation patterns measured in anechoic chambers [3]. The present simulations have been performed by ViRM-Lab, a ray-based simulation program initially described in [4]-[5].

2. Numerical Simulations

The rich isotropic environment we use in the present paper consists of twenty plane waves incident on the user from uniformly distributed random directions. Each wave has a uniform random phase, and a random polarization (balanced in average over any two linear orthogonal components). The amplitude is Rayleigh distributed.

The LOS environment consists of one plane wave with constant amplitude.

For both environments we gather 100,000 samples; by changing the orientation and position of the terminal model for the LOS case, and by generating a new set of twenty incoming plane waves for the isotropic environment.

Each of the 100,000 samples is calculated by multiplying the complex amplitude of the incident plane waves with the far-field function of the receiving antenna in the direction towards where the plane wave is coming from. The port of each antenna is assumed to be impedance matched, and mutual coupling between the antennas is not present for the chosen cases. In the isotropic environment the complex received voltage from twenty such waves are added together to one sample. The simulations correspond to rotating and moving the terminal model to arbitrary locations and orientations.

3. Results

In Figs. 1, 2, 3, and 4 we present the computed cumulative distribution functions (CDF) of the four different antenna configurations, respectively, in the two different environments, left and right graphs, respectively. All CDF curves are normalized to the received power average over the 100,000 samples, and the selection-combined curve is produced from two such normalized CDF curves.

We see in Fig. 1 that if we use ideally omni-directional antennas, in LOS environment, the appearance of low levels is smaller than in the theoretical Rayleigh distribution, but for the rich isotropic environment the CDF follows the theoretical distribution. For the LOS environment the statistical variations are coming from the arbitrary polarization due to the random orientation of the user. In Figs. 2, 3, and 4 it is clear that for the rich isotropic environment we have the same results as in Fig. 1. This is because we have chosen antennas that have uncoupled radiation field functions. For the random LOS environment the situation is different depending on which antennas are used, but the CDFs shown are actually not far from being Rayleigh distributed, except for the Huygens source antennas. The CDFs are different from in Fig. 1 because now the antennas contain nulls in certain directions and this will result in a higher probability of a received signal with low power level.

A receiver consisting of two directive antennas (with the beams directed in different directions) such as the Huygens sources shown in Fig. 4 will in the LOS environment have a very large probability of low signal levels in each beam. Therefore, these antennas will also have a large diversity gain after combining the two signals. This is because if one beam is not directed at the LOS component, the other beam may be directed there, and this gives then a very large diversity gain. However, in the rich isotropic environment, the diversity gain is more modest, since the likelihood that there will be very low signal on one port is much smaller. There will always be waves coming in the directions of the narrow beams when the environment is rich.

Even if the diversity gain of directive antennas in the LOS environment is large, it is not necessarily a desirable antenna system. Actually, it is the level of the combined CDF that is important, and for random LOS environments (i.e. a fixed LOS but a random user orientation) it is desirable to have antennas that together produce a full coverage of all directions of incidence. The two antennas should not have coinciding directions with low levels or nulls, like in our oppositely pointing Huygens source case. This will significantly reduce the probability to receive a low signal on the combined CDF, and therefore strongly improve the received power at the 1 % CDF level.

The relative quality of the four different antenna cases in the figures can readily be studied by comparing the selection combined CDFs. In the figures we have presented the improvement from the Rayleigh curve at 1 % CDF level. The selection combined CDF in the LOS environment is clearly better for the hypothetical isotropic radiators than for the other cases. It is also obvious, but not shown in the present paper, that the antennas should also produce low correlation if several antennas are used, both in the random LOS environment and the rich isotropic environments.

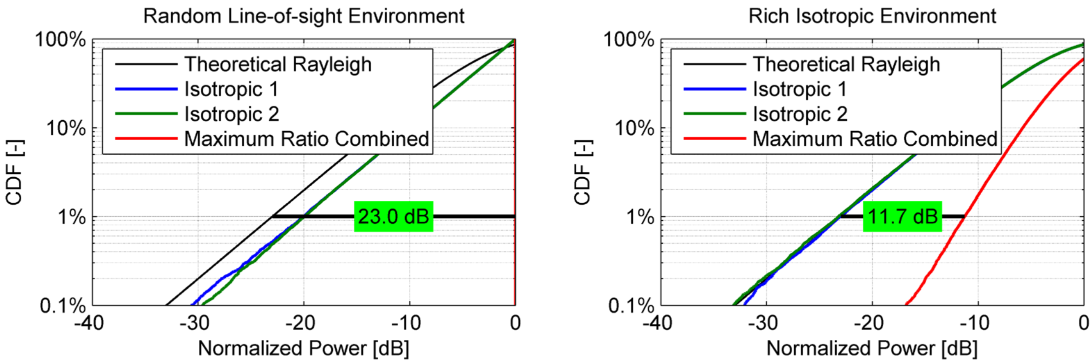

Figure 1: CDFs of received power from two ideally omni-directional antennas with orthogonal polarizations in all directions for the two environments (left and right plots).

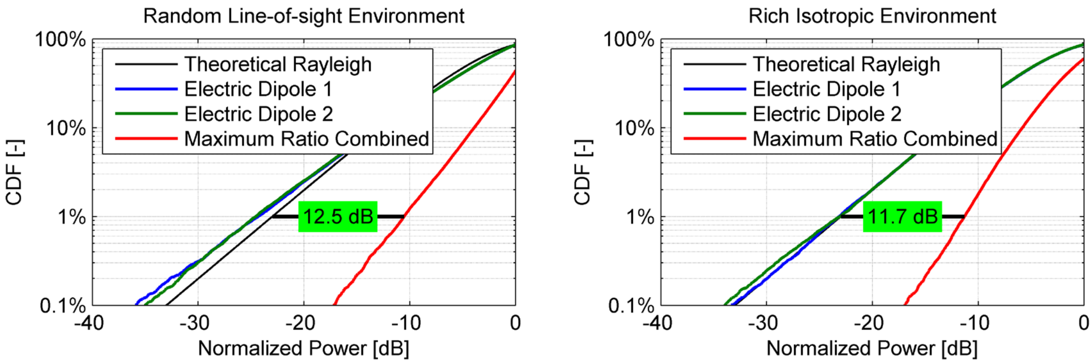

Figure 2: CDF curves of two orthogonal incremental electric dipoles.

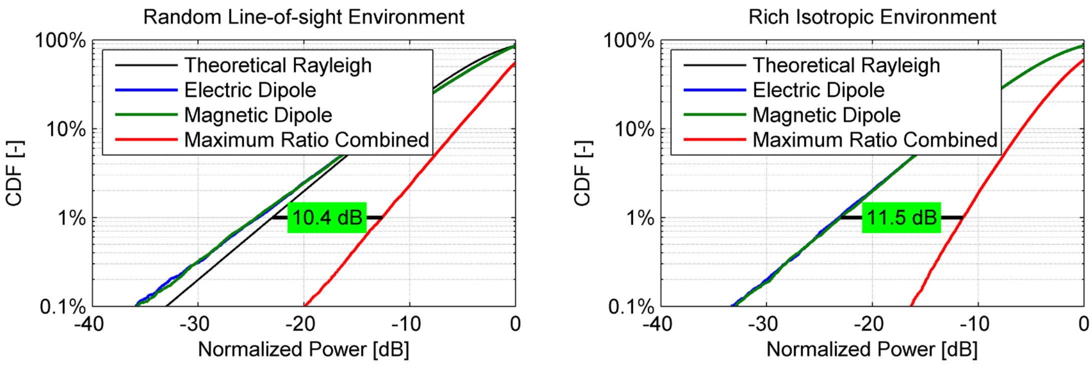

Figure 3: CDF curves of two antennas, an incremental electric dipole and an incremental magnetic dipole with orthogonal excitation currents.

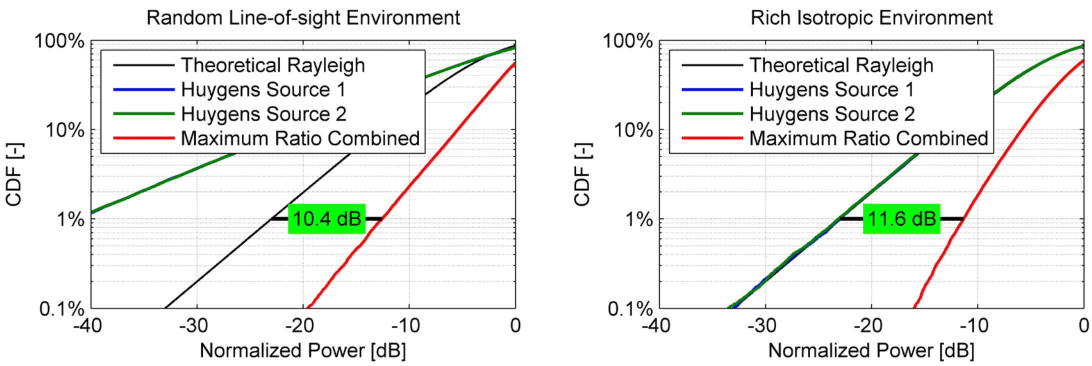

Figure 4: CDF curves of Huygens sources directed in opposite directions.

4. Conclusions

We have made a comparison between diversity antennas held by a random user in two very different environments; the pure LOS environment and the rich isotropic environment. When comparing these environments, a model of a receiving terminal with simple canonical antennas was used, and a uniform random distribution of the terminal's position and orientation was assumed. The hypothetical omni-directional antennas turned out to have CDFs in the random LOS environment that gives larger received power for a probability level of 1 % than the Rayleigh CDF in the rich isotropic multipath environment. When using dipoles as receive antennas the CDFs were quite similar to Rayleigh distribution in the LOS environment, and the selection combined CDFs are quite close to that of selection combined CDF in rich multipath. When using directive Huygens sources as antennas, the LOS environment gave a CDF with much higher probability of lower received power than the Rayleigh distribution. This makes the apparent diversity gain very large for the directive antennas. The oral presentation will also show results for ergodic capacity.

The simulations presented in the present paper suggest that the radiation patterns of antennas used in a statistical LOS environment should be as omni-directional as possible, i.e., they should contain as few nulls as possible, and antenna diversity should be achieved by orthogonal polarizations. When more antennas are used for diversity or MIMO their radiation field functions should together cover all directions in space, with as few nulls as possible. This is in contrast to antennas present in rich isotropic environments where the shape of the radiation patterns does not matter at all. Ideally, for a two-antenna system two ideally omni-directional antennas with orthogonal polarization in all directions should be used and will cause an ideal combined CDF curve with zero probability of a null.

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