

# Characterization of Multi-Antenna Systems in RIMP and Random-LOS Environments Using Probability of Detection of Different Bit Streams

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## Abstract

In this paper, we present characterizations of multi-antenna systems in two opposite edge environments, i.e., rich isotropic multipath (RIMP) and random line-of-sight (LOS) environments. We use the detection probability of the single or multiple bit streams (for diversity and multiplexing cases, respectively) over an ensemble of users as the characterizing quantity. The relationship between the detection probability and the throughput in RIMP is given. An wideband compact multi-port antenna is used as an example to show characterizations in both RIMP and random-LOS environment.

## 1. Introduction

Traditionally antenna system tests were made in the anechoic chamber (AC), where a pure line-of-sight (LOS) path exists between the wireless terminal under test and the base station. Consequently, most previous antenna-system characterizations were adapted to this method. Nevertheless, nowadays most of the modern wireless communication systems, especially the most popular multiple-input multiple-output (MIMO) systems, have been designed for use in multipath environments, where the incident waves come from many different directions. The multipath is attributed to reflections, diffraction, and scattering from the objects (e.g., buildings, trees, vehicles, etc.) around and in between the mobile terminal and the base station. The multipath causes a severer increase of the path loss, which is definitely a downside. However, thanks to the multipath, the user can have a wireless connection almost wherever and whenever he or she wants, regardless of whether there is a LOS path or not between the mobile terminal and the base station. Moreover, the wireless network can make use of the MIMO spatial multiplexing technique to transmit multiple streams in the spatial domain to enhance the transmission data rate by virtue of the multipath property. As a result, the AC-like pure-LOS environment is no longer an appropriate test environment for modern wireless communication systems; and that is why the multipath-emulating reverberation chamber (RC) now has become the leading test environment to characterize the wireless devices for communication systems that are adopted to work in multipath environment.

The RC emulates a rich isotropic multipath environment (RIMP) [1], provided it is well stirred. The RC was originally used for electromagnetic compatibility (EMC) tests [2]. Since year 2000, it has been developed to en efficient tool for characterizations of small antennas and wireless devices, e.g., antenna efficiency, diversity gain, MIMO capacity [3, 4], total radiated power (TRP), total isotropic sensitivity (TIS) [1], and the last few years, throughput of the 4G long term evolution (LTE) system [5, 6].

The RIMP environment is a unique multipath environment where the large amount of incident waves is uniformly distributed in the full-spherical angular domain. To complement this limiting edge environment, an opposite edge environment is proposed, referred to as random-LOS [1, 7]. Herein it is assumed that, due to user randomness (e.g., different orientations of the handheld terminals), the LOS becomes random both in polarization and angles of arrival (AoA) relative to the receiving antenna on the terminal. The real-life environment may be somewhere in between the two edge environments. It is assumed that if a wireless device is tested with good performance in both pure-LOS and RIMP

environments, it will also perform well in real-life environments and situations, in a statistical sense [7]. This statement is referred to as a real-life hypothesis.

## 2. PoD based Characterization

We use the probability of detection (PoD) [1] to characterize a wireless device both in RIMP and random-LOS. Based on the threshold receiver model [5], the PoD is related to the throughput (i.e., data rate) and the cumulative distribution function (CDF) of the received channel matrix after the built-in signal-processing due to error coding, OFDM and MIMO, according to [8]

$$PoD(P_{av}) = T_{put}(P_{av}) / T_{put,max} = (1 - CDF(P_t / P_{av})). \quad (1)$$

To illustrate this, we show in Fig. 1 the CDFs and PoDs of diversity antennas with different numbers of antenna ports when the channel matrix has independent and identically distributed (i.i.d.) channels, being identical to what is obtained during measurements in a RIMP environment if the MIMO antenna ports are uncoupled and have 100% embedded element efficiencies. We see that the CDF and PoD curves are the same except for the fact that the abscissa (in dB) and ordinate axes have been inverted. Note that we prefer to use a logarithmic ordinate axis for the diversity gain, but not for the PoD. The diversity gain in dBR (dB w.r.t. Raleigh) at 1% CDF level becomes identical to an improvement in dB of the PoD at 99% level, and similarly for other CDF and PoD levels.

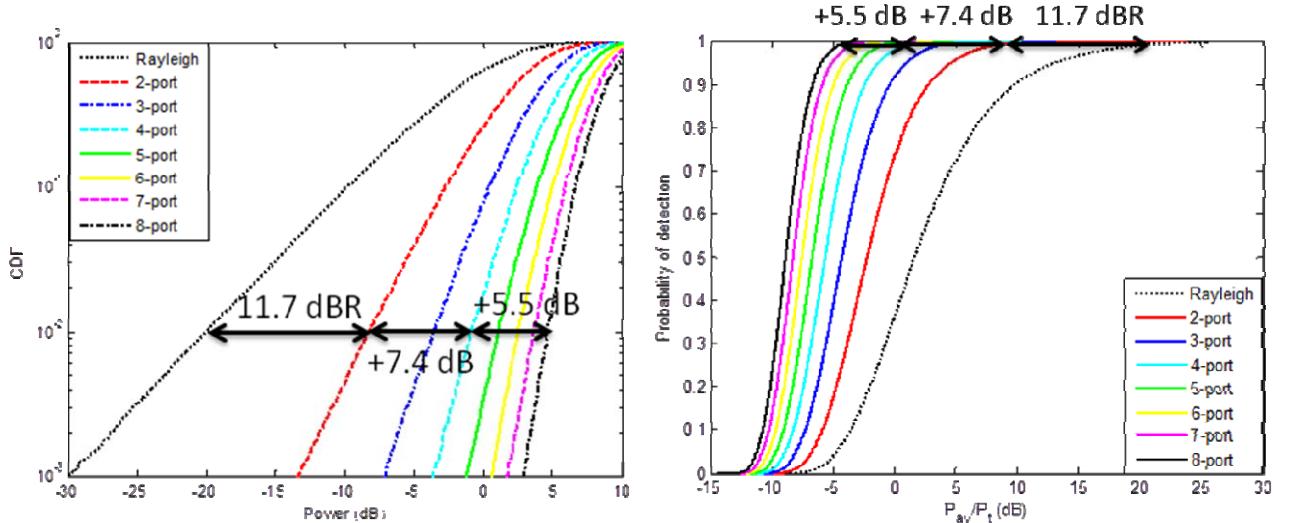


Fig. 1. CDFs (left) and PoDs (right) for a single bit stream for the i.i.d. RIMP case, corresponding to Rayleigh fading and what is emulated in RC when the antenna ports are uncoupled and have 100% total embedded element efficiency. The different curves show different maximum ratio combining (MRC) outputs of diversity antennas with different numbers of antenna ports.

To study the PoD of multiple streams, we assume open-loop MIMO systems (i.e., full channel information at the receiver but no channel information at the transmitter) with zero-forcing receivers [6]. Fig. 2 shows the PoD of ,  $2 \times 2$ ,  $4 \times 2$  and  $4 \times 4$  MIMO systems in RIMP. The power costs needed to achieve the 90% PoD level w.r.t. the SISO channel are marked in the same figure. It can be seen that, with only spatial multiplexing and no diversity, the power cost increases with the MIMO order: the  $2 \times 2$  MIMO system needs 4.8 dB more power to reach 90% PoD whereas the  $4 \times 4$  MIMO system needs 9.2 dB more power. On the other hand, when there are more receiving antennas than transmitting antennas, the MIMO system will also have a diversity gain. This is manifested by the fact that the  $4 \times 2$  MIMO system needs 6.1 dB less power to reach the 90% PoD level.

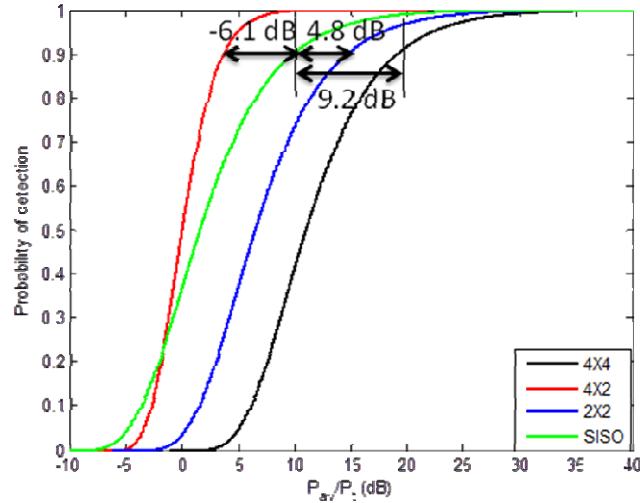


Fig. 2. PoD 1 stream, 2 streams and 4 streams in SISO, 2×2, 4×2 and 4×4 MIMO systems in RIMP, where the power cost of achieving higher order MIMO with respect to the SISO case is marked at 90% PoD level.

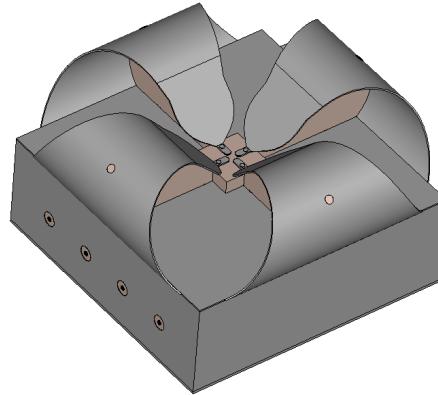


Fig. 3. Drawing of the 4-port bowtie antenna.

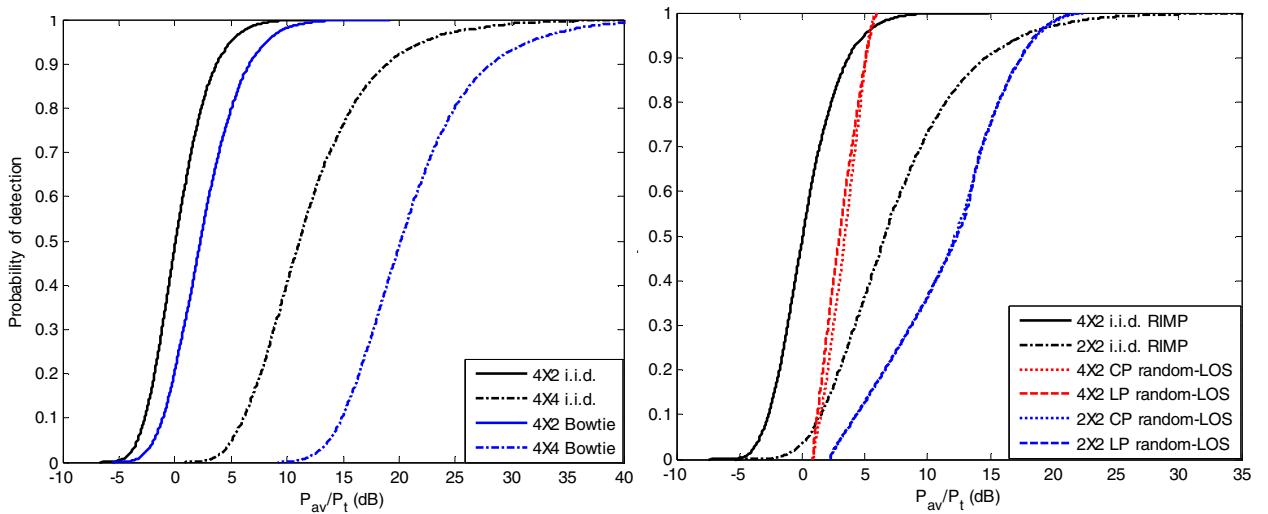


Fig. 4. PoDs of 2 and 4 streams of the 4-port bowtie antenna at 2.2 GHz in RIMP (left) and PoDs of 2 streams for the wall-mounted scenario in random-LOS (right). CP and LP stand for circular and linear polarizations for the random incident wave, respectively.

In order to demonstrate PoD characterization in random-LOS, we take the bowtie antenna [8] as an example. The bowtie antenna is a wideband compact 4-port antenna (see Fig. 3). It is designed to work in the wall-mounted scenario in random-LOS (i.e., the random-LOS arrives with equal probability from the half space that the bowtie antenna is facing). Once we know its radiation patterns (from either simulation or measurement), we can use the Virm-Lab [9] to calculate its PoD performance. Fig. 4 shows the PoDs of 2 and 4 streams of the bowtie antenna at 2.2 GHz in RIMP (left) and random-LOS (right). Note that due to the compactness, the bowtie antenna has a MIMO rank of 3 for most of the time in a  $4 \times 4$  MIMO system. As a result, it has good performance in for the 2-stream case and there is a power cost to detect all the 4 streams. Note that in random-LOS, one can transmit at most 2 streams by utilizing the orthogonal polarization. Also note that at higher frequencies, the bowtie antenna becomes electronically larger and therefore has better PoD performance.

## 5. Conclusion

We introduced PoD as a characterizing metric that can be used in RIMP, random-LOS environments, and real-life environments. PoD takes account of both the statistics of the environment and the user. The two reference environments RIMP and pure-LOS complement each other. Real-life environments are somewhere in between. It is believed that is a wireless terminal that works well in both RIMP and pure-LOS environments, it will also work in real-life environments.

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