New Approach to OTA Testing: RIMP and pure-LOS as Extreme Environments & a Hypothesis

New Approach to OTA Testing: RIMP and pure-LOS Reference Environments & a Hypothesis

Per-Simon Kildal[1] and Jan Carlsson[1,2]

[1]Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden, per-simon.kildal@chalmers.se

[2]SP Research Institute of Sweden, Borås, Sweden, jan.carlsson@sp.se

***Abstract*—We propose a new systematic approach to OTA testing of wireless devices. This involves testing in the two opposite environments Rich Isotropic Multipath (RIMP) and pure-LOS (Line-of-Sight), being present in well-stirred reverberation chambers and traditional anechoic chambers, respectively. It is now well known how to test multipath-related functions such as MIMO and OFDM in the RIMP environment in reverberation chambers, and results are in excellent agreement with basic theories and algorithms. Herein, it is proposed how to test the effects of the users randomness in the pure-LOS in an anechoic chamber. The two tests complement each other to a full test procedure via a reasonable OTA hypothesis, which covers real-life situations. It is proposed to test the real-life OTA hypothesis by extensive simulations to determine its possible limitations.**

***Index Terms*—OTA testing; small antennas; MIMO; reverberation chamber; anechoic chamber**

I. INTRODUCTION

Organizations, such as CTIA and 3GPP, work with introducing standards for Over-The-Air (OTA) testing of wireless devices for modern communication systems with MIMO and OFDM. The proposed test schemes are in many cases very complex. The purpose of this paper is to propose a very simple approach, involving testing in both reverberation chamber and anechoic chamber. The testing in reverberation chambers are known to be statistical, because it emulates Rayleigh fading, and the signal variations on a receiver port (also called the channel) are described in terms of a Cumulative Distribution Function (CDF) accounting for the statistics of the received voltage due to all the interfering incoming waves. Here we also propose a statistical CDF-based method for testing user randomness in anechoic chambers.

The anechoic chamber is the traditional test chamber for antennas. However, it was traditionally only used for antennas with directive beams, and the antennas were supposed to be mounted with a known pointing direction of the beam. The problem is that modern wireless devices do NOT have a directive beam. They actually hardly have any main beam at all, but rather a number of arbitrarily oriented sidelobes. The radiation pattern is also strongly affected by the orientation of the user and how he holds the device. These effects cannot be characterized by standard measurement procedures in anechoic chambers. Therefore, new procedures must be developed, and these procedures must take the statistics of the user into account. It makes no sense to study a multiple of radiation patterns for many different orientations of the device and user without representing the statistical variations in some way. Therefore, we need to characterize even the performance measured in anechoic chambers in terms of CDFs, with the CDFs describing the statistical variations over many typical users. The anechoic chamber can more generically be referred to as a pure-LOS (Line Of Sight) environment, meaning that we have only one wave coming in on the receiving antenna. Modern multi-probe anechoic chambers are not of this kind, so we will here only consider traditional anechoic chambers with one transmit antennas, i.e. a pure-LOS environment.

The reverberation chamber has since year 2000 been developed to a very accurate tool for characterization of small antennas and wireless devices in Rich Isotropic Multipath (RIMP), where the term "rich" means many incoming waves, typically more than 100, and "isotropic" means that the Angles-of-Arrival (AoA) of the incoming waves are uniformly distributed over the unit sphere. The first developments were focused on improving measurement accuracy when measuring radiation efficiency, and to define and accurately measure diversity gains of multi-port antennas and the embedded element efficiencies on their ports [1, 2]. The measurement accuracy was further improved and is now supported by basic new theories [3] including small random LOS components in the chamber as error sources. A procedure for measuring receiver sensitivity during fading was developed, and later extended to measuring data rate throughput of LTE devices. These measurements are supported by simplified theoretical models [4] for throughput that really include with good accuracy both MIMO and OFDM functions when environments with different time delay spread are emulated.

The developments of the reverberation chamber for OTA measurements are summarized in a generic form in [5]. That paper also introduces the random pure-LOS, as another opposite environment. In the present paper we build on [5], but we have been able to additionally simplify the description, and a real-life OTA hypothesis is introduced, linking together pure-LOS and RIMP tests.

II. RIMP, PURE-LOS & A REAL-LIFE OTA HYPOTHESIS

The pure-LOS and RIMP environments are defined in the introduction. They are opposite and uttermost environments, which rarely are present in real-life. Real-life environments will be somewhere in between pure-LOS and RIMP. They may not be rich (too few incoming waves), and they may not be isotropic (AoA may not be uniformly distributed over unit sphere). This is illustrated in Figure 1 together with the characterizing antenna parameters of each environment.

The picture in Figure 1 is simple and makes it reasonable to introduce the following real-life OTA hypothesis:

"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."

We have discussed this simple hypothesis with many antenna, systems and propagation specialists, and they think it sounds reasonable. Still, it is necessary to test it, but we think this is most easily done by extensive computations. These computations should then involve all the different propagation environments that have been defined or could appear in practice, such as e.g. the previously defined Winner models. However, first we must agree on a good characterizing parameter related to the CDFs.

In the next two sections we describe such characterizing parameters in RIMP and pure-LOS.

Environment	Equivalent measurement method	Antenna quality measure	MIMO and diversity capability
Free space (pure-LOS)	Anechoic chamber	Deterministic case: Realized gain User-random case: Not known	To some degree
Real-life environments		No unique quality measure	Yes
Rich isotropic multipath (RIMP)	Reverberation chamber	Total radiation efficiency e_{rad}	Yes

Figure 1. Illustration of how the extreme pure-LOS and RIMP environments surround the real-life case. The two extreme environments have unique quality metrics, real-life environments have not. The presented real-life OTA hypothesis completes the picture.

III. HOW DIVERSIY GAIN AFFECTS THROUGHPUT – RELATION BETWEEN CDF, THROUGHPUT AND OUTAGE PROBABILITY IN RIMP ENVIRONMENT

The CDF describes the signal level variations on the port of an antenna in a dynamic rich multipath environment, and if the environment is isotropic, the average received power will be proportional to the embedded radiation efficiency on the port [2]. The threshold receiver model introduced in [4] gives a unique relation between the CDF and the shape of the throughput curve for LTE and related advanced digital communication systems. The reason is that in modern digital communication systems there are error correction codes that correct well for additive white Gaussian noise in a non-fading channel, except when the received power is below a

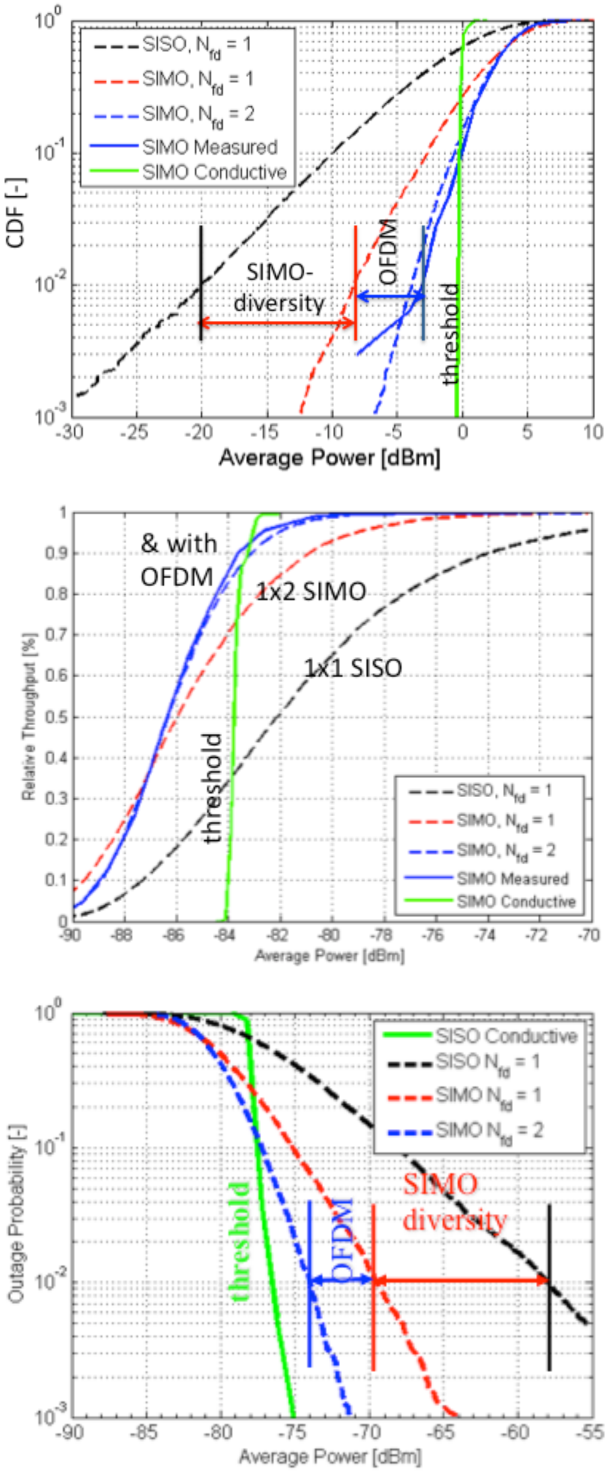

Figure 2. The same received signal plotted as CDF (upper), throughput (middle) and Outage (lower) by using the relation in (1) and a known threshold power of the digital receiver. The 1% diversity gains have a well defined meaning in the CDF and outage curves, and gets a similar important emaning at the 99% throughput level.

very well defined threshold power level, at which the digital receiver with the error correction codes breaks down. This threshold level P_t is therefore one of the parameters that enters the relation between the CDF and the throughput, and the other is the average received power P_{av} on a receiver port with 100% embedded radiation efficiency. The CDF itself is affected by the signal processing algorithms in the receiver, but we have shown in [4] can describe actual measured performance with very simple MIMO and OFDM algorithms based on Maximum ratio Combination of single channels. The relation between the CDF and the throughput gives also a unique relation between the CDF and the outage probability. The formulas are:

$$\begin{aligned} Tput(P_{av}) &= 1 - Outage(P_{av}) \\ &= Maxrate * \{1 - CDF(P_t / P_{av})\} \end{aligned} \quad (1)$$

The throughput, CDF and Outage probability are plotted in Figure 2 from the same data using (1), representing a SISO system, a 2x1 SIMO system, and a 2x1 SIMO system with additional diversity due to OFDM. In the middle graph we also see how the final result (dashed blue line) agrees with the measured throughput (solid blue line) after the CDF has been computed due to 2x1 SIMO, and OFDM. The agreement between measurements and theory has also been extensively studied for different system bandwidth and in environments with different time-delay spreads (or related coherence bandwidths) in a parallel paper at this conference [6].

The graphs tells us two important things:

1. The ideal threshold receiver model is very useful to relate CDF, threshold and outage.
2. The diversity gain defined for a passive measurement set-up [2] at 1% CDF has a very clear and direct influence in the form of a gain of the same amount on the throughput curve at the high level of 99%.
3. In a practical OTA test it may be convenient to define the diversity gain at a higher CDF level, such as e.g. 5%, in order to ensure better quality of the reading of the curves. The small bit errors require larger measurement time, and it is also difficult to achieve reliable error readings at these low levels due to imperfections in the measurement setup as well as in the wireless system itself.

The above diversity gains represent a clear quality improvement for moving users in a RIMP environment. The performance in RIMP does not depend on user and device orientations, because the shapes of the radiation patterns do not matter at all. The only quality metric is the embedded element efficiency on the port, and the mutual coupling between them. The latter must be low to ensure no correlation and maximum diversity gain. However, the mutual coupling has larger effect on the embedded element efficiency than on the correlation [2], opposite to what many take for granted.

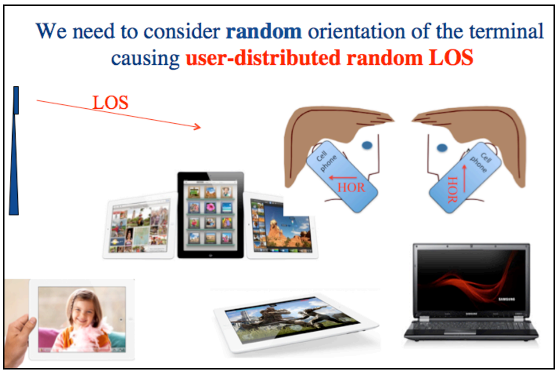

Figure 3. Illustration of random orientations of a wireless user device.

IV. QUALITY IN PURE-LOS WITH RANDOM USERS

The question is now how to measure quality in pure-LOS environment with a random received signal due to the random orientation of the user and his device, i.e. depending on how he holds or uses the wireless device. It is clear that this needs to be characterized in terms of a CDF, and that we should be able to define diversity gains in the same way as in RIMP environment.

In order to know the user statistics we need to gather user data. However, as a first approximation we have assumed a completely random orientation of the device in three dimensions (3-D). This can be justified by the way modern terminals are used, as shown in Figure 3. Thus, we should consider a CDF based on receiving an incoming LOS from an arbitrary 3-D direction. This CDF can therefore be obtained directly from the full 3-D radiation pattern in equally spaced points on the unit sphere, by arranging all values from the smallest to the largest.

We have done this for some example antennas, such as incremental dipoles and practical small antennas. The results show that the CDFs of practical small antennas actually are very close to a Rayleigh shape and in particular when they are located on a phone chassis or or held by a human hand. Antennas that have a clean radiation pattern like small dipoles or directive antennas, have CDFs very different from Rayleigh. This practical similarity with Rayleigh CDF is not an important point in itself, but it can be used to characterize the far field patterns of small antennas in 3-D random pure-LOS in terms of how much better they are compared to the CDF of a Rayleigh distribution. Therefore, we can define a quality in terms of their level at 1% relative to the theoretical Rayleigh curve. This can be done both or the single-port CDF, and for the diversity-combined dual-port CDF. The latter is the same way that we originally defined diversity gain of small multi-port antennas in RIMP environments. ***The levels of the CDFs at 1% are in this way quantified in dBR, i.e. dB relative to Rayleigh.***

Figure 4 shows an example. The CDF in 3-D random LOS is very similar to a theoretical Rayleigh, but this is not important in itself. The most important thing here is that we can measure its quality in terms of the gain compared to the

Rayleigh at 1% level. The random pure-LOS diversity gain will in principle be different for different polarization of the LOS, and, it is in principle different from the diversity gain in RIMP although for good antennas it may be similar. The example in Figure 4 shows a linearly-polarized LOS. On the other side, the RIMP environment is of course completely arbitrarily polarized.

From initial studies we are able to conclude already that in order to get high diversity gains, the radiation patterns on each port of the antenna should cover the whole space, i.e. all directions on the unit sphere. Thereafter, they should cover two orthogonal polarizations.

V. CONCLUSIONS

We have defined two extreme reference environments that are convenient for OTA tests, and we have defined a new quality measure for performance in pure-LOS environment. The latter is the CDF level at 1% relative to the level of a Rayleigh distribution, quantified as a level in dBR (dB relative to Rayleigh). The CDF in pure-LOS must be taken over a distribution of random users, and the gain represents the gain of the 1% worst users and user practices when they have implemented diversity in their devices. We have given examples for a 3-D random orientation of the device, but it is clear that we need statistical user data to determine more correct statistics.

The two reference environments RIMP and pure-LOS complement each other. Real-life environments are somewhere in between, and we have formulated a simple real-life OTA hypothesis that states how performance in real-life depends on performance in RIMP and pure-LOS. Testing must prove this hypothesis, and we believe that the best way to do this is by simulations using different published propagation models. However, to make good tests of the hypothesis we need statistical data of how wireless devices are used by different users.

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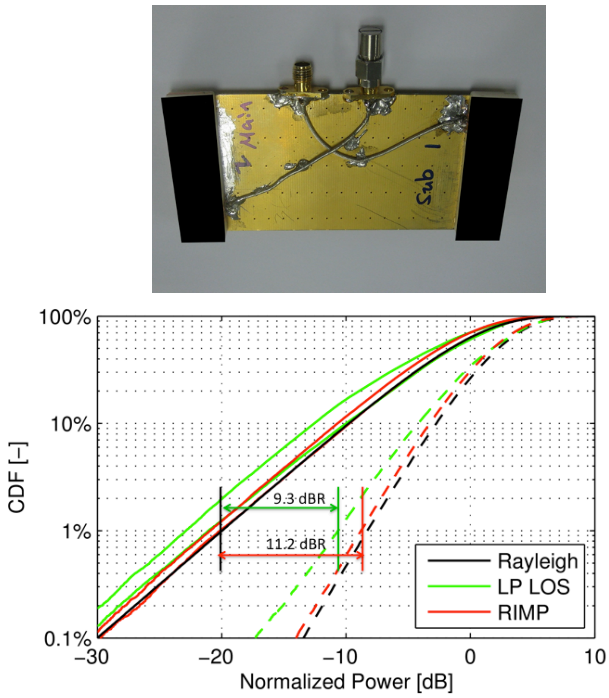

Figure 4. Mock-up of mobile phone with two antennas for MIMO diversity evaluation in a linearly-polarized LOS, i.e. LP LOS. The solid curves are CDFs on one port, and the dashed lines are the CDFs of two MRC-combined single-port CDFs. The corresponding RIMP CDFs are shown as well.