Feasibility Study of Emulating Extended Spatial Channel Models in a Multi-probe MIMO OTA Antenna Test Setup

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Abstract— In this paper we demonstrate the feasibility of a multi-probe based multiple-input multiple-output (MIMO) over-the-air (OTA) test method, where urban macro and microcellular scenarios of the spatial channel model — extended (SCME) are used as a target multipath channel. No work has reported the feasibility of the field synthesis aiming at emulation of the SCME using the plane-wave field synthesis (PWS) based on spherical wave theory so far. In this work we used this technique to emulate the reference channel inside the test area. The feasibility is tested by evaluating the emulated field in terms of four basic channel properties: power delay profile, temporal correlation function, spatial correlation function, and cross polarization ratio. The study shows that feasibility of the PWS technique to emulate all the basic parameters in a multi-probe based MIMO OTA test setup.

1. INTRODUCTION

Multiple input multiple output (MIMO) radios, which use multiple antennas in the two ends of the communication link, have been attracting attention because of their ability to meet the increased demand for higher data rate communications. However, the performance of MIMO links depends not only on the antenna performance but also on the propagation environment. Hence, accurate MIMO performance testing of mobile terminal devices needs to consider both the multiple terminal antennas as well as the propagation environment. Over-the-air (OTA) antenna test method has been widely used for legacy mobile devices equipped with only a single antenna, and its extension to the MIMO device has been actively investigated.

Standardization works for MIMO OTA testing have been intensively coordinated by Cellular Telecommunications Industry Association (CTIA) and 3rd Generation Partnership Project (3GPP), where several different MIMO OTA test methods have been proposed [1]. One mandatory requirement of any MIMO OTA test methods is to emulate an electromagnetic environment, which resembles the radio propagation scenario where the terminal operates. Geometry-based channel models such as the Spatial Channel Model (SCM), SCME, WINNER II or IMT-Advance constitute a good means to describe the propagation scenario, which is translated into the electromagnetic environment in the OTA testing. The use of such well-defined channel model in MIMO OTA testing makes the test methods realistic and hence well justified.

One of the proposed methods in the standardization of the MIMO OTA testing is the use of an anechoic chamber equipped with multiple probes that emulates the intended electromagnetic environment inside a confined area of the chamber, which is called a test zone. To emulate the spatial and temporal characteristics of the intended electromagnetic environment defined by the channel model, two techniques have been reported in the literature; one is the plane wave synthesis (PWS) [2–4] and another is the prefaded signal synthesis (PFS) [4, 5]. In this paper, we address the PWS technique based on the spherical wave theory, and prove its consistency with other MIMO OTA testing techniques such as the PFS.

The purpose of the paper is to demonstrate that the PWS technique is capable of emulating the intended electromagnetic environment in a multi-probe based MIMO OTA test system. In this study, we demonstrate the capability for the 3GPP SCME [1] as the intended electromagnetic environment, since no literature so far has made the demonstration. The accuracy of the emulation is evaluated in terms of power delay profile (PDP), temporal correlation function, spatial correlation, and cross-polarization ratio (XPR) as influential radio channel properties to the link data rate. Our results serve as an important reference when comparing the performance of the PWS technique with other MIMO OTA techniques such as the PFS.

The remainder of this paper is organized as follows. Section 2 describes the PWS emulation techniques. Section 3 presents the simulation set up. After Section 4 compares the emulated and intended fields to demonstrate the feasibility of the PWS technique for the SCME, Section 5 concludes the paper.

2. CHANNEL EMULATION TECHNIQUES

2.1. Configuration of the Multi-probe Anechoic Chamber

An illustration of a 2D multi-probe anechoic chamber based MIMO OTA test system is shown in Figure 1. The base station emulator feeds the downlink transmit signals to multichannel fading emulator. The output ports of the fading emulator are connected to the K probe antennas, which are equally spaced on the probe ring with radius r. Thus the radio frequency signals emitted from the probes to the air are controlled by the fading emulator to produce the intended electromagnetic environment inside a test zone. For the 2D test setup, the device under test (DUT) is at the center of the circular test zone with radius r_0. It is required that the intended electromagnetic environment should be accurately emulated over the test zone, and hence the DUT would experience the same propagation channels as it would be in the operation environment.

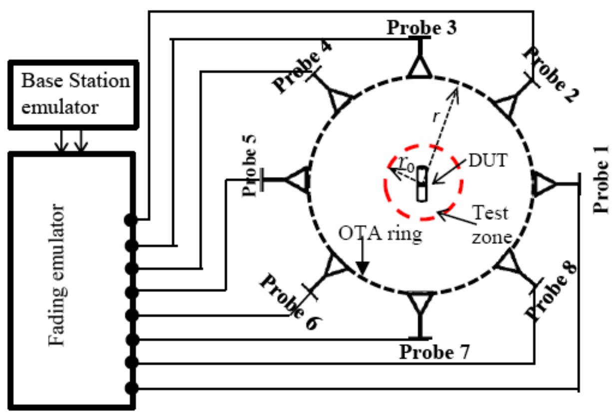

Figure 1: The 2D multi-probe based MIMO OTA test system with eight uniformly spaced probes on a ring.

2.2. Field Emulation Techniques

2.2.1. PFS Technique

The PFS technique is presented in [4, 5]. This technique focuses on clusters (i.e., groups of multipath components). The basic component of this technique is a single cluster with parameters like nominal Angle of arrival (AoA), angular spread of arrival (ASA), Doppler spectrum, and cross polarization ratio (XPR). The PFS technique emulates the intended electromagnetic environment by weighting the independent fading signals transmitted from multiple probes. The signal weighting is made so that the power angular spectrum (PAS) of the emulated field resembles that of the intended field as much as possible. This leads to accurate emulation of the spatial correlation characteristics inside the test zone.

2.2.2. PWS Technique

The PWS technique synthesizes the intended electromagnetic field inside the test zone by exciting the multiple probes with proper voltages, such that the total field from the probes resembles the intended field at a location in the test zone. This technique has a point of view in plane waves instead of clusters. The basic component generated by this technique is a plane wave with a specific AoA, Doppler shift and magnitude. The PWS reported in [2, 3] is based on the spherical wave theory [6], stating that any plane wave field in a test zone can be expressed by a finite sum of orthonormal wave modes. This spherical wave theory provides theoretical justification of the required number of probes as a result of its well-known cut-off properties of the orthonormal modes. In [2], the maximum relative error between the emulated and target field on the circumference of the test zone is evaluated.

3. CONFIGURATION OF THE SIMULATION SET-UP

A 2-D MIMO OTA test system is shown in Figure 1. The probe antennas are on a circle of radius r and are equally spaced over the circle on the horizontal plane. The antennas produce the far field towards the DUT located at the center of the test zone with the radius r_0.

One of the main issues addressed in the multi-probe OTA test method is the number of required of probe antennas. According to the PWS technique that uses the spherical wave theory, the required number of probes K for accurate emulation of the intended field is directly related to the size of the test zone. For synthesizing both vertically and horizontally polarized plane wave fields inside a test zone, K is given as [6]

$$K_{\min}^{2\text{-D}} = 4[kr_0 + n_1] + 2, \tag{1}$$

where k is the wave number, the unknown number n_1 is a constant that determines the accuracy of the field synthesis [6]. The values of n_1 for different relative error levels of the synthesized field have been reported in [7]. In this paper, $-15\,\text{dB}$ relative error is considered and then the required number of probes considering the vertical and horizontal polarizations in 2D case becomes [7]

$$K_{\min,-15\,\text{dB}}^{2\text{-D}} = 4\left[kr_0 + 0.74\sqrt[3]{kr_0}\right] + 2. \tag{2}$$

In this paper, the field synthesis targets the radio frequency of 806 MHz. The following setup of the OTA test system is considered: a 45° slanted dipole antenna at the base station, half-wavelength dipole and magnetic loop as antennas of DUT, 8 dual-polarized Vivaldi antennas as probes. The base station antenna is taken into account in the fading emulator when calculating an excitation voltage of each probe, and the probes are placed evenly on the OTA ring with the radius of $r = 1.75\,\text{m}$, and the test zone has a radius $r_0 = 0.15\,\text{m}$. The required number of probes is 16 (or 8 dual-polarized) in this case, according to (2), and hence, the number of probes considered in the OTA test system here is sufficient. The intended fields are defined by the urban macro and microcellular scenarios of the SCME, are reproduced according to the channel parameters presented in Tables 8.2-1 and 8.2-2 of [1].

4. SIMULATED CHANNEL MODEL VALIDATION RESULTS

Before starting any advanced testing activity, for example, throughput measurements, the emulated fields at the DUT antenna location need to be compared with the intended field defined by the selected channel model, in order to verify their agreement and address any anomaly in the emulation. Complete verification of the emulated field against the intended one is an extensive task since it needs to involve all the relevant dimensions of the propagation channel such as space, time, delay, power and polarization. In this paper, the verification is performed in terms of four basic properties of 3GPP SCME channel model: PDP, spatial correlation function, temporal correlation function, and XPR.

4.1. Power Delay Profile

Each scenario in the 3GPP SCME channel model produces propagation channels consisting of 6 spatio-temporal propagation paths and each path has 20 sub-paths [1]. Furthermore, 20 sub-paths per path have been split into three subsets, namely "mid-paths". Each path of the channel is associated with a delay and power. The objective of the PDP comparison is to find out the deviation between PDP in the emulated channels and in the reference channels.

The PDP is simulated with a vertically polarized half-wavelength dipole as a receiving antenna. In total 20,000 samples (i.e., a set of propagation paths) are simulated. The reference PDPs

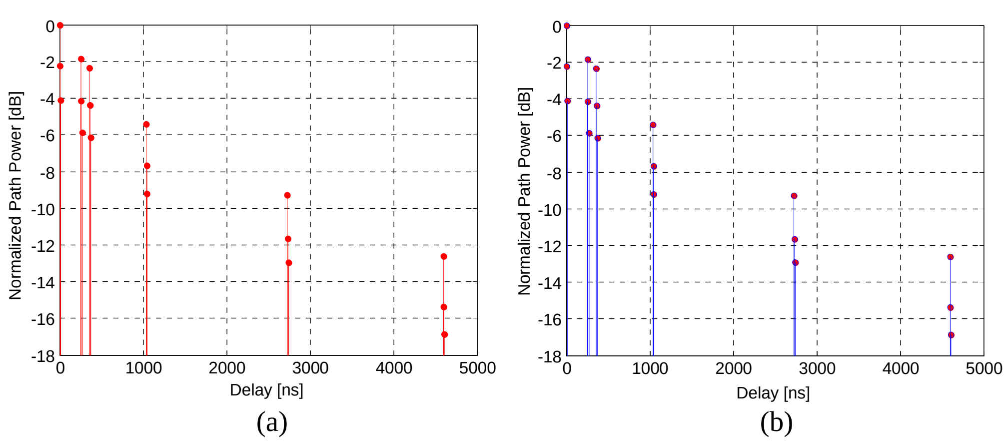

Figure 2: PDP of SCME urban macro model: (a) reference (red), and (b) emulated (blue).

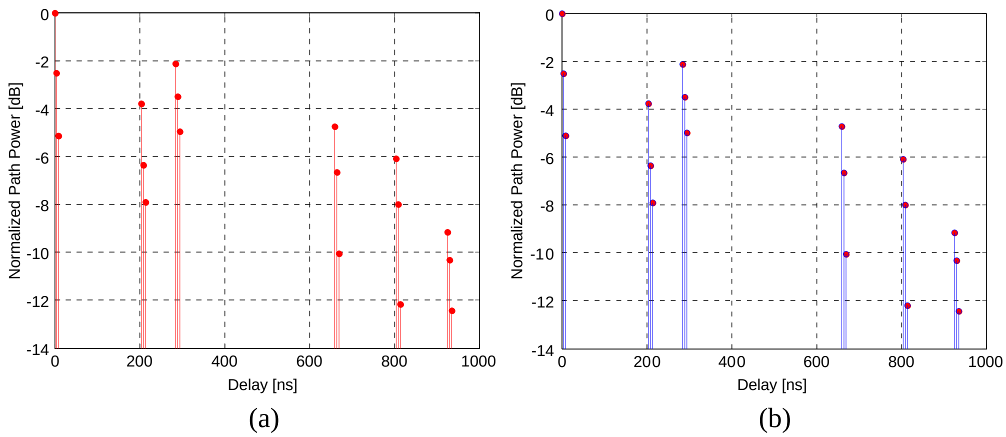

Figure 3: PDPs of SCME for the urban microcellular scenario: (a) reference (red), and (b) emulated (blue).

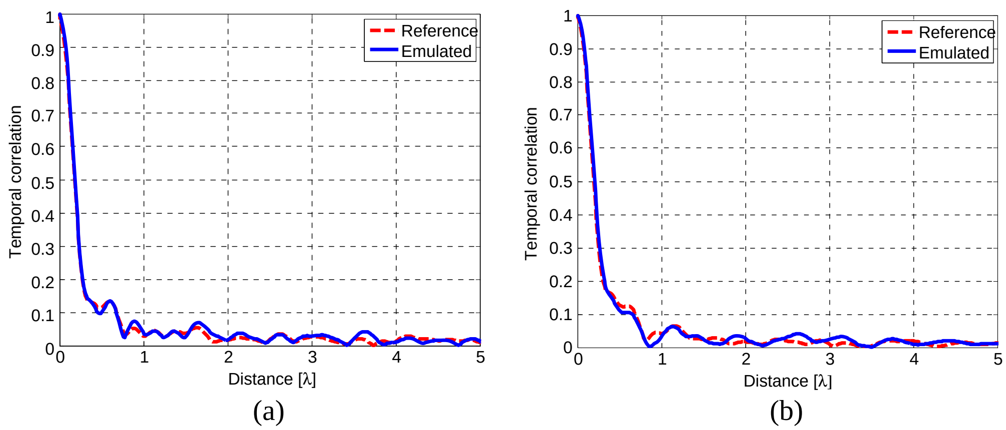

Figure 4: Reference and emulated temporal correlation: (a) SCME urban macro and (b) microcellular scenarios.

generated from the 3GPP SCME for urban macro and microcellular scenarios are presented in Figures 2(a) and 3(a), respectively, while the corresponding emulated PDPs are shown in Figures 2(b) and 3(b). Note that the figures illustrate the powers and delays associated with each mid-path of the six paths. The emulated PDP follows the reference one very well for both scenarios.

4.2. Temporal Correlation Function

The goal of comparing the temporal correlation is to see the accurately of the temporal behavior of the emulated channel in relation to those of the reference channel. Temporal correlation function is equivalent to the power Doppler spectrum (PDS) of the channel as they are Fourier pairs. Since it is difficult to compare the PDS because of their spiky shapes, temporal correlation is used in this paper for the comparison. A half-wavelength vertically polarized dipole as a DUT antenna is used in the simulation; 32 samples per half-wavelength and a total of 50,000 samples are used to make the temporal correlation function curves smooth. In Figure 4, with constant DUT velocity of 30 km/h, the red and blue curves show the reference and emulated temporal correlation function, respectively. It can be clearly seen from Figure 4 that the emulated and reference temporal correlation functions match well for both scenarios. Note that the values of temporal correlation function left from the maximum and after five wavelengths have been cut out.

4.3. Spatial Correlation Function

Accurate reproduction of the spatial correlation function is also an important goal of the MIMO OTA antenna testing. In comparing the emulated and reference spatial correlation defined by the SCME, two vertically polarized dipole antennas are used as DUT antennas. Only the separation between the antennas has been changed to estimate the variation of the spatial correlation, while other setups of the simulation remain the same as the previous ones. For each antenna separation distance, the reference and emulated spatial correlation coefficients are calculated from 20,000

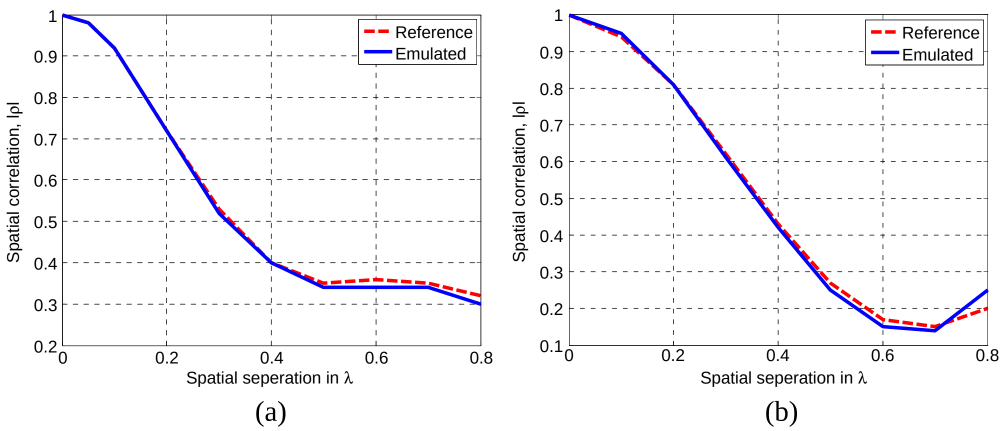

Figure 5: Reference and emulated spatial correlation: (a) SCME urban macro, and (b) microcellular scenarios.

Table 1: XPR values of the emulated and reference channels for the SCME urban macro and micro scenarios.

	Reference XPR [dB]	**Emulated XPR [dB]**	**Delta [dB]**
3GPP SCME urban macro	8.55	8.67	0.12
3GPP SCME microcellular	0.96	0.86	0.10

channel impulse responses. In Figure 5, red curve and blue curve show the reference and emulated spatial correlation function. The spatial correlation is one when the two antennas are collocated, while the correlation decreases as the separation increased up to 0.8λ. It is obvious from the figure that the emulated spatial correlation functions follow the reference one very well for both scenarios.

4.4. Cross-polarization Ratio

The polarization characteristic of the emulated channel is investigated by evaluating the XPR. In this paper, the XPR is defined as a difference of the received power by vertically and horizontally polarized antenna located at the center of the test zone. In particular, a vertically polarized half-wavelength dipole and a horizontally polarized magnetic loop were considered. Table 1 illustrates the emulated and reference XPR values for the urban macro and microcellular scenarios, estimated by 20,000 channel impulse responses generated by the SCME. The emulated XPR values deviates from the reference by 0.12 dB and 0.10 dB in the macro and microcellular scenarios, respectively. The slight deviations are likely from the difference of multipath power received at the DUT.

5. CONCLUSION

This paper presented a comparison of emulated and reference channels in a multi-probe based MIMO OTA test system. The field emulation inside the test zone was based on the PWS technique. The comparison has been performed in terms of four metrics of the radio channels that are influential to radio link performance: PDP, temporal correlation function, spatial correlation function, and XPR. A good agreement between the emulated and reference values has been achieved in all the investigated metrics. The minor deviation in the XPR values is likely introduced by slight difference of multipath profiles received at the DUT. Future work concerns the experimental validation of the emulation technique and further analysis of the MIMO performance metric, such as MIMO capacity and throughput.

ACKNOWLEDGMENT

The research was conducted in the framework of a research project, abbreviated MIMOTA-2, funded by the Finnish Funding Agency for Technology and Innovation (Tekes) and the companies Microsoft, Anite Oy, and ETS-Lindgren.

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