A Critical Review of MIMO OTA Test Concepts - Lessons learned from Actual Measurements

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Abstract

Multiple Input – Multiple Output (MIMO) Over-The-Air (OTA) performance testing of User Equipment (UE) has become an important issue in connection with the roll-out of Long Term Evolution (LTE). Its purpose is to assure that UE will provide satisfactory user experience and will not compromise network efficiency. Intended to become part of a commercial certification process, low complexity, high reproducibility and a coherent interpretation of results are mandatory. This contribution attempts a critical review of some of the essential concepts underlying proposals for MIMO OTA testing which have been made and are under discussion in 3GPP RAN4, CTIA and COST2100 SWG2.2.

1 Introduction

Since 2008, when the discussion about MIMO OTA test methods was opened [1], various approaches have been investigated. An overview of candidate methods and references can be found in [2] and the upcoming "Final COST2100 Book". Results from actual measurements have been gathered in the 2010 COST2100 Round Robin Measurement Campaign [3] and in the ongoing LTE MIMO OTA Measurement Campaign within 3GPP RAN4 [2]. When reviewing the concepts behind MIMO OTA test method proposals one can identify two different main paradigms. A first group of proposals follows the "realistic channel" paradigm. It is guided by the concept to recreate "real-life" propagation scenarios in an Anechoic Chamber (AC) or Reverberation Chamber (RC) by emulating in as much detail as possible simultaneously all spatial and temporal features of the 3GPP Spatial Channel Model Extended (SCME) [4, 5, 6, 7, 8]. The respective proposals make extensive use of fading emulators and require for a large number of probes. A second group of proposals follows the paradigm of "device characterization". It favours simple "synthetic" OTA test cases with the intent to isolate device performance and to minimize the impact of the OTA test scenario on the results [9, 10, 11, 12, 13]. Maximum reuse of existing CTIA chambers, use of a minimum number of probes in an AC and minimization of complexity are declared goals of this second group of proposals. A further approach which does not immediately fit into one of the above two categories may be associated with the "analytic paradigm". It aims at a separate characterization of the compound MIMO antenna pattern by support and feedback from the UE itself in a specific "MIMO test mode" [14, 15]. The approach is now sometimes referred to as "virtual OTA" or "non-intrusive pattern measurement". Since some manufacturers support such functionality it may find its place for gathering supplemental information which may speed up measurements. The ongoing discussion about MIMO OTA test methods suffers, to the author's opinion, from the fact that the essential concepts underlying different approaches and in particular the relative importance of different aspects of a "realistic channel" and their interplay with features of the LTE standard, as well as the definition of the final performance metric do not receive sufficient attention. With respect to MIMO OTA metrics the authors have recently made the argument for *statistical metrics*, i.e. for outage probabilities of a performance parameter (throughput, Block-Error-Rate (BLER), sensitivity) in a given test case as well defined and practically relevant metrics. The present contribution is devoted to a critical review of some of the essential aspects and concepts which are to be considered in the specification of a MIMO OTA test plan. For purposes of this discussion it is helpful to introduce the notion of a *constellation* which may equally describe a real world or a test scenario. With view on the latter, by constellation we refer to a given arrangement of multiple probes on the surface of a sphere which surrounds the Device Under Test (DUT) (and phantom). A constellation of K probes is specified by K triplets of angles $\{(\vartheta_k, \varphi_k, \tau_k) : k = 1, \ldots, K\}$ describing Angles of Arrival (AOA) and respective polarizations.

2 Essential Aspects of MIMO OTA test design

Handling of Adaptivity. The LTE Downlink (DL) features 7 basic transmission modes including e.g. Transmit Diversity (TD) and Open / Closed Loop Spatial Multiplexing (SM). There are in addition 16 different Modulation and Coding Schemes (MCSs). In reality, transmission mode, MCS and Resource Block (RB) allocation are adaptively selected by the evolved Node-B (eNB), taking into account or not, at its own discretion, Channel State Information (CSI) feedback from the UE. The question, how to deal with the built-in adaptivity of the standard in MIMO OTA

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testing amounts to a relevant conceptual decision but is widely dismissed. If adaptation is included in MIMO OTA testing, it must be supported by the eNB emulator. Its algorithms and time response then enter into the measurement results. A “standard eNB” would therefore have to be defined as part of a MIMO OTA test specification. This would assure that meaningful measurement results are obtained irrespective of the propagation scenario (including “realistic” scenarios) which is presented to the UE. From a standardization point of view, however, and also with view on the still limited support of adaptation by test equipment it may turn out a major endeavour. Whether adaptive selection of transmission mode and MCS is in line with the requirement of “coherent interpretation of results” may also be questioned. A much simpler alternative (which has in fact been followed in previously reported measurements) is the use of Fixed Reference Channels (FRCs). This approach is well established in conformance testing. But MIMO OTA concepts have to be chosen accordingly. If a set of propagation scenarios is presented to the UE it will most likely include cases where the MCS is too “high” for the actual channel (→ high BLER) or too “low” (possible throughput not reached). In some cases the rank of the channel may be deficient and the chosen transmission mode inappropriate for the actual propagation scenario. Combining FRCs with “realistic” propagation scenarios must therefore be rated as unrealistic with respect to the results. It is in particular not justified to consider average values of e.g. throughput taken over a set of “realistic” propagation scenarios under conditions of a FRC as representative of “real-life” performance.

Faded vs. MIMO-favourable scenario. The application of a faded channel is central to the “realistic channel” paradigm. Apart from the above mentioned problem with FRCs and additional cost and complexity (calibration and reproducibility) it is to be asked whether application of faded channels amounts to gain or loss of information about the DUT. It should first be noted that the DUT’s antenna system is transparent with respect to any applied Power-Delay Profile (PDP). Any possible effect on observed throughput is due to the baseband receiver algorithms. The spatial and temporal characteristics of the channel are “orthogonal” aspects with respect to device performance. Multiple OTA constellations are necessary to characterize the spatial properties of a DUT’s MIMO antenna system. The receiver’s response to delay spread and Doppler shift, however, can be tested with a single properly chosen constellation, by conducted measurements or simple coupler arrangements. It is not necessary to intermingle spatial and temporal channel aspects in OTA measurements. Furthermore, the value of the alleged gain in realism by application of faded channels is to be questioned. For illustration throughput vs. power curves of three commercial HSPA devices are reproduced in Fig. 1 [12]. Both subfigures show throughput under conditions of a FRC averaged over 312 constellations of two probes in the azimuthal plane of the DUTs (different combinations of polarization / angular probe offsets and rotation of the DUT, see [12] for details). Fig. 1a gives the results for two phase decorrelated but unfaded downlink signals. In Fig. 1b the downlink signals are individually faded according to a two cluster SCM model. The abscissa values correspond to average power per stream. Performance comparison between the three DUTs may be made in terms of the relative shift of the three curves (red,green,blue) along the abscissa at a fixed throughput level. It should be well noted, however, that the throughput values which can be read from Figs. 1a,b are by now way indicative of what would be observed in reality with adaptive MCS. Let us now compare the information which is contained in Figs. 1a and b, respectively. Fig. 1a represents essentially the convolution of the step-function like throughput vs. power relation for the selected MCS with the empirical Probability Density Function (PDF) of power received by the UE antenna system over the 312 constellations. The result of Fig. 1b in turn is essentially that of Fig. 1a after convolution with the PDF of power in the fading channel. The slope of the curves in Fig. 1b is therefore reduced. Hence Fig. 1a represents properties of the DUT whereas in Fig. 1b these are disguised by the faded channel what amounts to a loss of information. The effect is stronger in multi-probe setups (due to additional in-situ fading) [16] and becomes dominant when measurements are taken in a RC due to increased spread of received power [17].

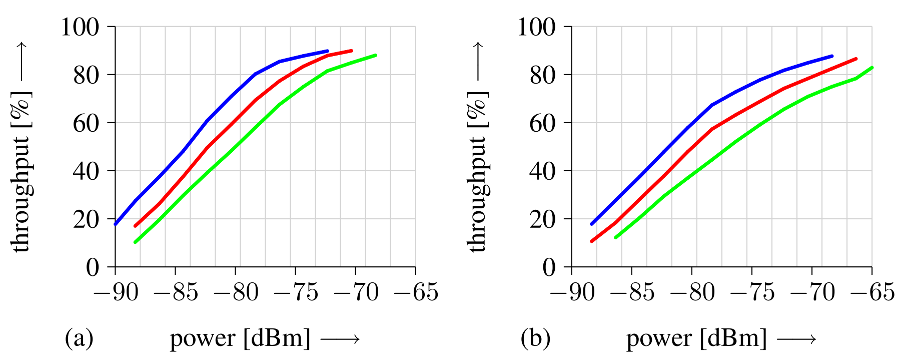

Fig. 1: Throughput vs. power for 3 different HSPA devices, averaged over 312 OTA constellations: (a) two unfaded (but decorrelated) DL streams, (b) two faded DL streams (two cluster SCM model) [12]

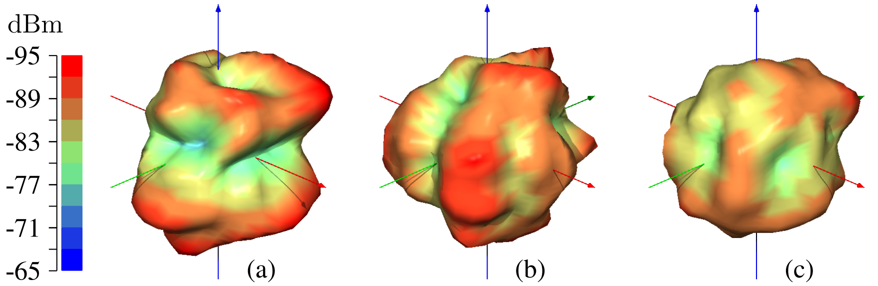

Fig. 2: 3D sensitivity pattern of a HSPA dongle: (a) vertical polarization only, (b) horizontal polarization only, (c) combined (polarization diversity with half power per polarization) [12]

Number of probes. Also with the intent to emulate “realistic” MIMO channels, OTA setups with 8, 16 or even 31 probes, arranged in a concentric circle around the DUT in its azimuthal plane have been proposed. Under cost restrictions a large number of probes implies severe tradeoffs to be made elsewhere (see below). It is therefore indicated to ask what number of probes is necessary and desirable. The rank of the channel which can eventually be realized in a MIMO OTA test setup can not exceed $\min M, N$ where M denotes the number of independent streams and N the number of antennas in the UE. We take for granted that in a meaningful measurement procedure $N \geq M$. Employing more than N probes then necessarily amounts to pre-correlation of DL signals over that which is due to the UE antenna system itself. One may end up with testing SM performance, which is bound to MIMO favourable channel conditions, in a rank deficient channel. In an N-probe test setup with N independent streams the channel matrix is effectively given by the compound complex, polarimetric pattern $\mathbf{T}(\Omega)$ of the UE antenna system (see e.g. [18]). The statistics of observed throughput over a set of N-probe constellations are then implicitly given by the statistics of the singular value spectrum of $\mathbf{T}$ and are in this sense a meaningful and relevant characterization of the DUT alone. This is no longer assured if more than N probes are used and pre-correlated paths are received. At best the effect on throughput statistics is marginal. Otherwise DUT performance will be disguised by channel properties.

Elevation and Polarization. Downlink transmission in LTE makes use of orthogonal polarizations at the eNB. Further, the Power Angular Spectrum (PAS) in relevant high data rate usage scenarios (indoor, outdoor-to-indoor) is clearly not confined to the horizon line. It should therefore be out of question that orthogonal polarizations and constellations over the sphere (opposed to circle) enclosing the DUT must be taken into account to characterize UE. But as a consequence of the high cost and complexity of test setups with multiple probes and multiple faded channels, restriction to test scenarios which realize a two-dimensional PAS (ring of probes) and restriction to vertically polarized probes only are discussed. Fig. 2 is included here to illustrate the consequences. The figure displays the sensitivity pattern of a commercially available HSPA dongle with respect to either a vertically, a horizontally or a dual-polarized path. In the latter case two decorrelated copies of the DL signal were routed to a dual-polarized probe with half power each [12]. Comparison of the three test cases reveals that grossly misleading results would be obtained considering only Fig. 2a in the azimuthal plane. The patterns are typical for USB dongles coupling to the chassis of a laptop.

Channel models, Mockups and Phantoms. A lot of attention has been given to accurate emulation of geometrical detail of the SCME such as Angular Spread (AS) in ACs [19]. In reality however, such “free-space detail” is seldom visible to the UE at all. It is rather masked and strongly modified by the near-field environment of the UE, in case of hand-held devices e.g. by the user’s hand and / or head. Measurements with appropriate phantoms are well established in existing OTA test plans (e.g. [20]). Since the performance of MIMO UE is potentially more susceptible to the near-field environment than that of single antenna devices, the quest for realistic test conditions should be redirected accordingly. The situation is even more difficult for combined equipment such as USB dongles or datacards in a laptop. Electromagnetic coupling between the modem and the host device may have a large impact on the compound antenna pattern and depends on the users’s choice of USB port for plugging. Suitable mockups will have to be defined as part of a MIMO OTA test plan. The idea to evade these difficulties by inserting a USB cable between laptop and dongle is misguided [21].

Interference, Virtual vs. real OTA test. One of the most relevant issues for UE performance is self-interference and, in case of combined equipment, cross-interference [22]. This fact restricts the role of virtual OTA testing, i.e. the separate characterization of the UE antenna system followed by conducted characterization of the receiver. It can be used to economize on physical OTA measurements by interpolation but can not substitute for the latter. In addition, it appears necessary to define extended cross-interference test cases for combined equipment in order to establish confidence that a given dongle or datacard will perform satisfactorily with a variety of host devices.

3 Conclusion

Some essential aspects of MIMO OTA test design have been reviewed. It is observed that approaches which emphasize the use of "realistic channels" have not arrived at a balanced tradeoff between aspects of realistic channels which are accounted for and which are dismissed, respectively. In the beginning of the discussion on MIMO OTA test methods there was an understandable interest in comparing not only devices but also LTE performance in general against that of existing networks. This may have contributed to the "realistic channel" paradigm. Such comparison, however, is beyond what MIMO OTA tests can deliver and may also be considered obsolete by now. Established engineering and measurement practices which always aim to isolate the performance of the device under test and to minimize the influence of the measurement approach should be preferred.

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