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Fan, Wei; Pedersen, Gert F.; Kyösti, Pekka; Hekkala, Aki; Jämsä, Tommi; Gustafsson, Mattias

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Recent Advances on OTA Testing for 5G Antenna Systems in Multi-probe Anechoic Chamber Setups

Wei Fan, Gert F. Pedersen
Aalborg University
Selma Lagerløfs Vej, 312
Aalborg 9220, Denmark

Pekka Kyösti, Aki Hekkala
Keysight Technologies Oy
Tutkijantie 6, 90590 Oulu, Finland

Tommi Jämsä, Mattias Gustafsson
Huawei Technologies AB
Vädursgatan 5,
41250 Gothenburg, Sweden

***Abstract*-Over-the-air (OTA) testing is seen as an essential method for evaluating 5G antenna systems, since conventional cable testing are no longer applicable. In the paper, we discussed the similarities and discrepancies of OTA testing in the multiprobe anechoic chamber (MPAC) setups for 4G user equipment (UE) antenna systems and massive multiple-input multiple-output (MIMO) base station (BS) antenna systems. Further, recent progress on OTA testing for 5G antenna systems in the MPAC setups are summarized.**

I. Introduction

The next-generation wireless telecommunication system (i.e. 5G) is under intensive development [1]. Two technologies have been identified for 5G systems, i.e. exploration of mm-Wave frequencies and utilization of massive MIMO antenna arrays [2]. One of the challenges in the research and development of 5G antenna systems is the performance evaluation methods [1]. For 4G antenna systems (including mobile handset and base station), an antenna connector for each antenna is implemented, therefore, antennas can be detached from antenna connectors and replaced by radio frequency (RF) cables. RF testing signals can be therefore carried to the antenna systems directly with the RF cable. However, it is predicted that conducted testing is no longer applicable for 5G antenna systems, due to several reasons. 5G antennas will be small and highly integrated units, and the number will be massive. Therefore, it is expected that antenna connectors will not be available due to cost, size and design challenges. Even if antenna connectors would be available, for future 5G antenna systems equipped with possibly hundreds of antennas, hundreds of RF cable connections to the antenna ports and respective hardware would be required, leading to error prone, complicated and cost-prohibitive setups. Moreover, the features of 5G antennas systems rely highly on antenna array signal processing, e.g. beamforming, null steering, etc. These essential features cannot be evaluated in the conducted setup [1].

Over-the-air (OTA) testing has been used to evaluate radio performance of antenna systems [3,4]. The testing is done in a wireless manner (i.e. over-the-air), where antennas are used directly as an air interface to receive/transmit testing signals. OTA testing for 4G MIMO capable terminals have been developed and researched for many years, where several OTA methods were proposed [3], e.g. the reverberation chamber (RC), the radiated two-stage (RTS), and the multi-probe anechoic chamber (MPAC) method. The applicability of three OTA methods for massive MIMO BSs is discussed in [4]. The RC method emulates special multipath environments with statistically isotropic angular distribution and Rayleigh (or Rician) fading channels. However, it offers no control over channel spatial and polarimetric profiles, and thus might not be suitable for 5G antenna systems. RTS in principle is a wireless cable testing method. Therefore, it is not suitable for testing adaptive antenna systems and the system cost increase significantly if antenna count on the 5G systems is massive. The MPAC method is technically sound for 5G antenna system performance testing, where propagation environments can be physically emulated in the test area [5-13]. It is expected that the MPAC setup has the great potential for OTA testing of 5G antenna systems. However, a major concern for the MPAC system is that the system cost might be overwhelming for 5G antenna systems. Therefore, the main research direction is to investigate whether the MPAC method can suffice the need for testing 5G antenna systems, with an acceptable system cost.

II. MPAC method for 4G and 5G antennas

In this section, the MPAC method for 4G UE and 5G antennas OTA testing is discussed, with a focus on similarities and discrepancies. It is noted that the discussion is limited to 4G handset and 5G BS antenna systems.

1) DUT

4G MIMO handsets are typically equipped with few built-in antennas. Commercial LTE handsets nowadays generally support 2×2 MIMO in the downlink, and few 4×4 MIMO handsets are reported. For the UE, antenna designs and locations are typically unknown, and the element radiation pattern is often quasi-omnidirectional with unknown polarization. Moreover, DUT equipped with adaptive antenna systems are not discussed for 4G UE OTA testing. 5G massive MIMO BSs potentially comprised of hundreds of antennas. The antenna designs and locations might be known. The antenna elements are often directive with known polarization characteristics. Further, adaptive antenna array is an enabling technology for 5G.

The test zone size in the MPAC setup is defined as a geometry area where enclosed antenna systems can not distinguish the target propagation channel and emulated propagation channels in the MPAC setup [4-6]. The test zone size should be larger than the maximum antenna separation on the DUT. For 4G UEs, since the antenna locations are unknown, it is often required that the test zone size is larger than the maximum physical dimension of the handsets, which typically is up to 1.5 λ. For 5G antenna systems, the test zone size requirement can be up to tens of wavelength, mainly due to small wavelength at high frequency band and implementation of massive antenna arrays. For 4G UEs, the test zone is typically selected as a circular area located on the OTA ring (as shown in Fig. 1), though different placement of the UEs are possible. For the 5G BS, it should be evaluated as it is typically placed in the real-world, i.e. a test area in the elevation plane (as shown in Fig. 2).

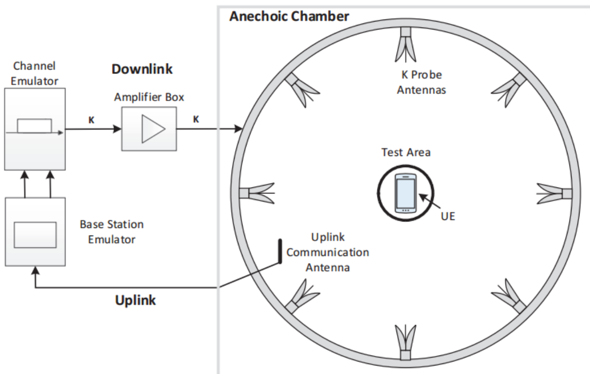

Figure 1. An illustration of the MPAC setup for 4G MIMO UE performance evaluation. K OTA antennas are connected to K radio frequency (RF) interface channels.

2) Radio channels

For the 4G UE OTA testing in the MPAC setups, a 2D uniform probe configuration is adopted in the literature, due to several reasons [4,8]. The scatterers in the environment are often nearby and randomly located around the UE, resulting in a less specular multipath profile. Therefore, a uniform probe configuration is adopted to have the flexibility of emulating arbitrary channel spatial profiles. Moreover, it is often assumed that 2D channel models are sufficient for performance evaluation, which indicates a 2D probe configuration, as shown in Fig. 1. SCME urban macro (UMa) and urban micro (UMi) channel models are selected in the standardization for 4G UE OTA testing.

For 5G massive MIMO BSs, the BS is placed higher and further away from scatterers [4,8]. Therefore, it is expected that the angle profiles of the impinging power spectra at the BS side are more specular and confined in an angle region. The propagation channels seen by the BS array would be confined in space due to practical installation or/and the fact that a BS antenna normally is restricted to receive and transmit power in a desired angular zone. Therefore, a sectorized MPAC setup is typically considered for 5G BS OTA testing, as shown in Fig. 2. 3D beamforming is essential for 5G antenna systems, which would need spatial channel modelled both in azimuth and elevation domain. 3GPP 38.900 channel models [2], which are proposed for channel models above 6 GHz, support channel modeling in the elevation domain and are utilized for OTA testing of 5G base stations in [12,13].

3) Radio channel emulation algorithms in MPAC setups

The main idea of channel emulation is to ensure that the signals emitted from the probe antennas are properly controlled such that the emulated channels experienced by the DUT approximate the target channel models. For 4G UE OTA testing, three different channel emulation algorithms are discussed in the literature, namely spatial channel emulator method, prefaded signal synthesis (PFS) method and plane wave synthesis (PWS) method [4]. The PFS technique has been adopted in the several commercial radio channel emulator solutions, though hardware requirements are similar for the PWS and PFS technique. Different channel emulation algorithms have been discussed for 5G antenna OTA testing. In [9], it was concluded that the PWS technique would require a very high number of probes and emulator resources for electrically large DUT, and hence might not be suitable. As for the PFS technique, several strategies were discussed in the literature to reduce system cost, e.g. sectorized probe configuration [7,8,11-13], probe selection mechanism with a switch box [12,13], utilization of specular channel models [6,12,13], etc. Moreover, via sacrificing the flexibility and generality in target channel models, large test zone size might be achievable, see some examples in [6,11].

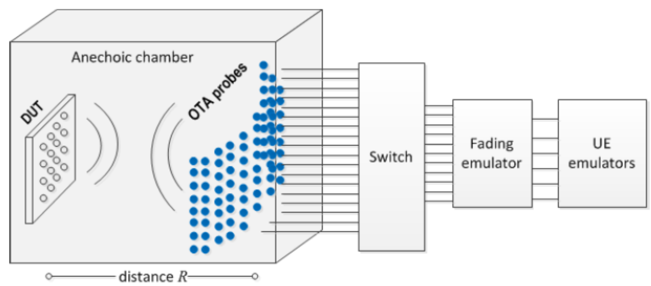

Figure 2. An illustration of the MPAC setup for 5G BS performance evaluation.

4) MPAC configuration

Two key design parameters for MPAC setup are the number of required OTA antennas and the measurement range (i.e. the distance between probe antennas and DUT), since they are the main cost-determining factors. For UE OTA testing, the 2D uniform probe configuration is typically equipped with eight dual-polarized probe antennas, which are driven by 16 channel emulator RF interfaces. The supported test area is around 1λ. For the measurement range, far field assumption can be easily fulfilled for 4G UE testing, since the ring radius is several tens of wavelength and small electrical size for the UE. Wideband horn or Vivalid antennas are often utilized as probe antennas.

For OTA testing of 5G antenna systems, the 3D sectorized probe configuration is more applicable. Far field assumption might be violated due to large array aperture of the DUT. The requirement on the physical dimension is extensively investigated in [4,6-8], where the objective is to determine whether the conventional far field criteria must be followed when determining the range of the setup or if they can be relieved. Different FoMs, e.g. far field criteria, field distribution (phase, amplitude and angle) within the test area, system link budget analysis, direction of arrival estimation algorithm, fixed beam power loss as well as multi-user MIMO sum-rate capacity are investigated to determine the range of the test setup. It was concluded that the link budget does not support for the measurement distances claimed by the far field criteria [7]. Most antenna array and MIMO related metrices indicate that smaller setup dimension can still yield reasonable measurement accuracy [4,6-8]. The number of required probe antennas depend highly on the considered channel models and probe configurations. In [6], it was demonstrated that with few probes (two or three), it is possible to reconstruct a single spatial cluster with narrow cluster spread (e.g. 2^o or 5^o) for a test area of size 10λ. However, this result is only valid for a cluster impinging from probe direction and with a narrow cluster spread. In [11], it was shown that a 2D sectorized MPAC setup with 16 probe antennas distributed uniformly within $[-60^o, 60^o]$ is sufficient to support a test area size of $5\lambda\times5\lambda$ for SCME channel models. 3D MPAC setup and 3D channel models might be more suitable. Radio channel models are generally directional in real world scenarios. However, a uniform and fixed probe configuration is typically adopted. A probe selection mechanism, which select a subset of probes and therefore adapt to target channel spatial profile, has potential to save cost, via reducing the required number of fading channel RF interfaces (i.e. active probe antennas). It was mentioned in [12,13] that probes for 28 GHz can be fabricated on printed circuit board. The manufacture cost can be very cheap, and therefore massive installation of such probes can be possible if allowed by the space. It was suggested that we can stack probe panels (which houses a number of probes) to cover the sector of interest. A probe selection mechanism together with a switch box, which offers optimal selection of active probes, can reduce the system cost, and should be implemented in 5G OTA testing systems, as shown in Fig. 2.

5) FoM to determine test zone size

For 4G UE OTA testing, mainly two FoMs are utilized to determine the test zone size, and thereby determining the number of probe antennas and range, i.e. the field synthesis error and the spatial correlation error [4]. The field synthesis error is selected for field synthesis algorithm in the MPAC setups, while the spatial correlation error is selected for the PFS technique. For 5G antenna system testing, these two metrics are often evaluated as well. Moreover, several new metrics are proposed in [12,13], e.g. similarity of the power angular spectrum seen by the DUT under target and emulated channel profiles, similarity of beam selections under target and emulated channels. There two new metrics are attractive and useful, since they are directly linked to key 5G antenna performance, i.e. beam acquisition and beam tracking.

6) Other discrepancies

There are some other discrepancies between OTA testing for 4G UE handsets and 5G BSs. For example, for 4G UE OTA testing, the focus is typically on the downlink, while the uplink is realized via connecting a communication antenna in the chamber to the BS emulator directly. Moreover, end-to-end performance (throughput) is the final FoM selected in the standardization. As for 5G BS systems, bi-directional channel modeling (i.e. both uplink and downlink) are essential. Further, multiple UEs or UE emulators should be considered to evaluate the multi-user performance, which is an essential feature of massive MIMO. Moreover, final performance evaluation metric for 5G BSs are not clear yet.

Conclusion

In the paper, we discussed the similarities and discrepancies of OTA testing in MPAC setups for 4G UE antenna systems and massive MIMO BS antenna systems. Though the MPAC method is technical sound for 5G antenna systems, there are many challenges. In the paper, different aspects of the MPAC method are discussed and the recent work in the literature are summarized. The main research direction is to investigate whether the MPAC method can suffice the need for testing 5G antenna systems, with an acceptable system cost. Further, most works are theoretical analysis only, and there is a strong need for experimental results in 5G OTA testing.

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