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Channel Spatial Profile Validation for FR2 New Radio Over-the-air Testing

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***Abstract*—Over-the-air (OTA) radiated testing of 5G new radio (NR) at frequency range 2 (FR2) is seen mandatory due to integrated radio frequency circuits and antenna design. Multiprobe-anechoic chamber (MPAC) solution is the reference method for performance testing of FR2 NR in the standardization. One of the key topics for the MPAC solution is channel validation. The test zone size in wavelength is much larger for FR2 MPAC setups. Furthermore, the far-field assumption will be violated due to the compact MPAC system. Those new aspects have introduced new challenges for the channel spatial profile validation in the test zone. In this work, a generic channel spatial profile validation method is numerically analyzed, with a focus on the the impact of test zone radius, measurement distance error and spatial location selection in the test zone on the channel spatial profile validation results.**

***Index Terms*—MIMO over-the-air testing, radio channel modeling, channel model validation, wideband power-angle-delay profile, millimeter-wave communication**

I. Introduction

It is of importance to evaluate performance of multiple-input multiple-output (MIMO) capable terminals under realistic fading channel conditions [1], [2]. Conventional cable conducted testing, where testing signals are directly guided to respective antenna ports on the deive under test (DUT), has become been the dominant solution in the industry. However, it has become obsolete for 5G new radio (NR) devices. This is mainly introduced by advanced antenna and radio frequency (RF) technologies introduced for 5G NR, e.g. utilization of large-scale antenna configurations and millimeter-wave (mmWave) frequencies, integrated system design, etc. Specifically, for NR at frequency region two (FR2) (i.e. frequency range 24.25 GHz – 52.6 GHz), it is seen that NR testing will move exclusively to radiated over-the-air (OTA) testing mode [2]–[4]. OTA testing will be more challenging, due to the fact that the testing signals are unguided, susceptible to interference, multipath in the testing environment, and etc.

OTA testing for multiple-input multiple output (MIMO) capable terminals have been discussed and standardized for the past decade. It is of great importance to verify the multi-antenna performance of 5G NR under realistic testing conditions [5]. To achieve this goal, strong efforts have been taken in the standardization, both for the FR1 and FR2 [5]. The multi-probe anechoic chamber (MPAC) method is the reference methodology for LTE MIMO OTA testing and has also been selected as reference methodology for MIMO OTA testing of UEs supporting NR FR1 and FR2. The key idea of the MPAC solution is to physically reproduce the standard spatial channel models within the test zone in the anechoic chamber, with the help of the channel emulator and multiple probes placed around the test zone. The DUT placed in the test zone can operate as it would in the target deployment scenario, since it will be unable to distinguish between the emulated and target spatial channels.

One of the important aspects for MIMO OTA testing is the validation of the emulated spatial channels in the test zone. The objective is to ensure that the target channels inside the test zone are correctly and accurately emulated according to the defined testing propagation environment. MIMO OTA channel validation is essential, since it can ensure that different DUTs can be tested under the same emulated channel conditions. Due to its importance, channel validation for 4G LTE terminals are widely investigated and reported in the literature [6]–[10]. The focus on channel validation has been on a few key channel parameters, i.e., the spatial, temporal, polarimetric and delay characteristics of the channels. The spatial profile of emulated channels is of particular importance for MIMO OTA testing. On one hand, the DUT multi-antenna performance depends directly on the spatial characteristics of the channel. On the other hand, the accuracy of the emulated channel spatial profile rules the system cost, e.g. channel emulator and probe antenna configuration.

In this paper, we first discuss how spatial profiles of the emulated channels are validated in the test zone for the MPAC solution in the literature for sub-6GHz applications, including 4G LTE and 5G FR1. After that, we elaborate why joint power-angle-delay-profile (PADP) of the emulated channel is a better choice for channel validation for 5G FR2 MPAC setups. Then we discuss possible solutions to detect the PADP of the emulated channels. Two new challenges for FR2 channel validation are identified, including how to select spatial samples in the test zone (i.e. the balance between performance and accuracy) and how to accurately obtain the joint-angle-delay profile of the emulated channel in near-field MPAC setups (i.e. when far-field assumption is violated). A new algorithm proposed in [11] is also applied to analyze the impact of spatial sample selection in the test zone and MPAC setup parameters on the performance.

II. Problem Statement

In the MPAC solution for LTE terminals, spatial correlation, which is a statistical measure of the similarity between received signals at different spatial locations, has been used to represent the channel spatial characteristics at the DUT side. The spatial correlation is a Fourier pair of the power angular spectrum (PAS). It is also selected as the figure of merit (FoM) in the MPAC setup FR1 NR. This is due to the importance of correlation in MIMO performance (e.g. for spatial multiplexing and transmit diversity) testing. Furthermore, the deviation in spatial correlation between target and emulated channels is used to evaluate how accurate the channel spatial profile is reproduced. For 4G LTE terminals, a uniform linear array (ULA) composed of 11 spatial samples with $0.1\ \lambda$ is employed in the test zone [6], [10]. For 5G NR FR1, spatial samples on a uniform circular array (UCA) is adopted to calculate the spatial correlation.

Joint PADP is a more informative metric for channel validation [3], [9], [12]. For FR2 DUTs, the power angular spectrum (PAS) of the emulated channels relates directly to its beamforming performance. Furthermore, the system bandwidths of FR2 systems will be much larger, leading to higher delay resolution in power delay profile measurement. The joint PADP offers several attractive advantages over conventional marginal profiles (i.e. spatial correlation and power delay profile).

- mmWave channels are more specular and due to the beamforming operation at the other end of the communication link, the mmWave channels seen by the DUT will be dominated by few specular paths. The spatial correlation might be rather high in this case. For example, the magnitude of the spatial correlation will be always 1 under a line-of-sight channel, regardless of the impinging angle. Therefore, the spatial correlation might be less informative.
- Spatial correlation of the emulated channels can be easily calculated from the joint PADP and spatial sample configuration in the test zone.
- For beam-steerable devices, PAS is more relevant, which demonstrates directly where the signal originates.
- The joint power-angle-delay profile measurement does not require extra hardware in the measurement system (compared to spatial correlation validation measurement). The measurement can also be fully automated.
- The joint power-angle-delay profile might also help identify unwanted reflections in the anechoic chamber.

In [9], an algorithm is proposed to detect the joint PADP for the validation of emulated environment in the MPAC setups. A virtual UCA is employed to estimate a 2D emulated spatial channels in the MPAC setup. However, it is not trivial to directly adopt the same algorithm for the joint PADP estimation for the FR2 testing system due to several reasons:

- 3D spatial channel models are specified for FR2 testing, which necessitates 3D MPAC setup. Consequently, to detect the PADP of the 3D emulated channels, spatial samples in the test zone should be carefully determined.
- The measurement range (i.e. the distance between the probe antenna and the test zone center) is to short for FR2, which will violate the far-field assumption.

III. PADP ESTIMATION METHOD

An illustration of the 3D MPAC system layout for NR FR2 MIMO OTA testing is shown in Fig. 1. The PADP seen in the test zone can be easily obtained if we can accurately detect the wideband radiated signals from each probe antenna. To detect the wideband radiated signals from each probe antenna, several approaches can be applied:

- We can employ directional scanning scheme to record the wideband channels in the test zone. The basic idea is that we can point a directional antenna in the test zone to each probe antenna to record the radiated signals from the probe. This is a popular approach for channel sounding at mmWave bands in the literature. However, there are some drawbacks. There will be interfering signals from other probes when we point to a target probe direction, due to the limited beam-width of the directive antenna. Furthermore, accurate probe antenna-horn antenna alignment is required.
- In principle it works if we point the directive antenna towards one single OTA probe at one time (with the corresponding OTA antenna on and the rest of the OTA antennas off) and repeat the measurements for all probe antennas. However, the aperture size of the horn antenna is typically very large, making it difficult to point to the target OTA antenna, especially when the OTA probe antennas are closely spaced. In addition, the impinging angles of the emulated channels cannot be accurately estimated with the horn antenna. Furthermore, radiated signals from all probe antennas should be measured simultaneously in the validation measurement, since this is the case for the actual throughput measurement. It is the super-positioned signals from all OTA antennas of interest for the validation.
- Virtual array concept, where an omnidirectional antenna can be placed in many predefined spatial locations inside the test zone is another alternative. The virtual array concept has been widely adopted in the literature to estimate the channel spatial profile for indoor static scenario. It does not work for time-variant channels due to the nature of virtual array. However, for the MPAC solution, although time-variant spatial channel models are emulated, the channel snapshots can be stepped and paused, and repeated for each spatial location in the channel validation measurements, which means the virtual array concept can be applied. The virtual array concept has been widely adopted for MIMO OTA channel validation for 4G mobile handset. For example, in CTIA standardization for MIMO terminal, a virtual ULA is a selected to record spatial correlation for the 2D MPAC setup. In this work, we aim to validate the 3D channel models emulated with the MPAC setup. Therefore, a virtual array with its elements distributed on both horizontal and vertical planes is needed. In practice, a virtual array is realized with the help of an automated linear positioner or turntable in practice, which limits the configuration of the virtual array to a linear or circular structure. Based on the linear or circular sub-array, a planar array or

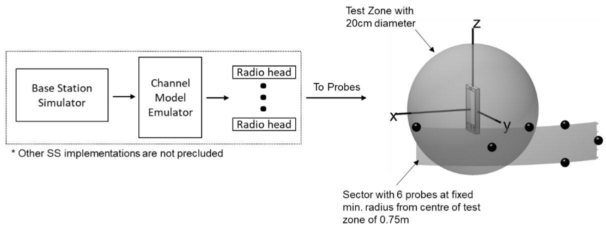

Figure 1. 3D MPAC system layout for NR FR2 MIMO OTA testing [source 3GPP 38.827 [5]].

spherical array can be realized. However, to form a planar array or a spherical array is very time consuming due to the large number of locations is required. Therefore, a simplified virtual array composed of one horizontal semi-circle array and 2 vertical semi-circle arrays is adopted in the standardization to save the measurement time, which is a key requirement in the validation. As discussed in [9], the advantage of the virtual array solution is that we can form a beam towards the target probe direction while forming nulls towards all the other probe directions. By doing so, we can effectively record the radiated signal from the target probe direction while suppressing the interference from all other probe directions. Then we can repeat the process to capture the radiated signals from all probe directions.

IV. Simulation Results

In [11], a generic channel estimation algorithm, which works for 3D channel models in near-field conditions is proposed to estimate the emulated wideband channels within the test zone at mmWave frequencies. In this work, we will numerically investigate the impact of virtual array configuration, test zone radius and impact of measurement distance error on the channel estimation accuracy using the algorithm proposed in [11].

The 3GPP cluster delay line (CDL) spatial channel model for indoor office (InO) scenario, i.e. InO-CDL-A in Table 7.2.2-6 in [13] is selected as the target reference channel. The CIRs in the CE are generated and mapped to the OTA probe antennas using Keysight GCM simulation tool.

A. Test zone size

The virtual array is configured to have 51 virtual array elements, with 31 elements on the horizontal circle and 10 elements on each vertical circle as done in [5]. The element spacing on all semi-circles is set to half wavelength. The simulation frequency is set to 28 GHz.

In the standardization 3GPP TR 38.827 [5], 5 cm test zone size and MPAC radius 0.75m are selected. A test zone with a radius of 5cm is small if the DUT is viewed as a black box. Generally speaking, the exact antenna size of the DUT is unknown since the device will be in its own casing during the test and this also depends on other factors such as ground coupling effects that depend on the design. The largest device size (e.g. diagonal) could be used; However, this would lead to unnecessarily demanding requirement on chamber size. It might be sufficient from practical point of view since the physical size of mmWave antenna systems will be rather small (e.g. 5cm corresponding to 4.7λ at 28 GHz), and the radiating area of the DUT is limited as well.

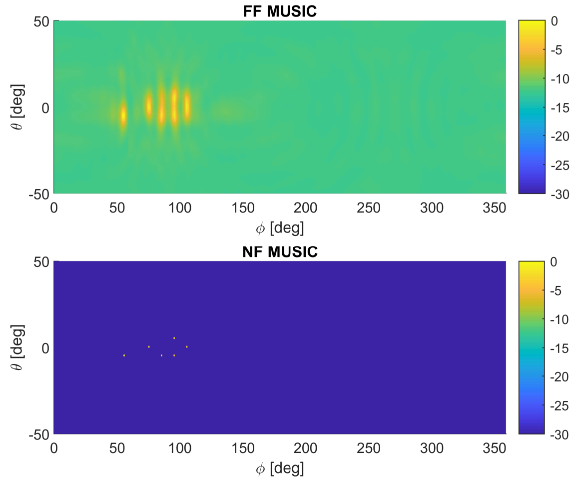

Figure 2. Power-angle profile estimated with far field MUSIC and near field MUSIC for a test zone with a radius of 5 cm.

A larger test zone size might be needed if the size of the DUT increases, where the virtual antenna array can be easily extended to cover a larger test zone via allocating more virtual array elements along the enlarged circles to ensure a half wavelength element spacing along each circle. If the probe locations in a MPAC setup are kept unchanged, a larger test zone size makes the near field problem more pronounced, which requires the proposed generic algorithm to validate the channel emulated by the probes.

The top figure in Fig. 2 shows that the far field MUSIC algorithm [9] performs poorly to estimate the angles of arrival for the test zone with a radius of 5cm. When the radius of test zone is enlarged to 10cm, the far field MUSIC algorithm fails to estimate any angles as illustrated in the top figure of Fig. 3 due to more significant plane-wave and spherical-wave model mismatch. In the contrast, the algorithm based on the more generic spherical wave model in [11] works consistently well when the size of the test zone increases, as demonstrated in the bottom figures in Fig. 2 (for a test zone with a radius of 5 cm) and Fig. 3 (for a test zone with a radius of 10 cm). Hence a MPAC setup with a larger test zone size further motivates the need for a near-field estimation algorithm.

B. Measurement distance error

In practical MPAC setup, the measurement range might not be accurate, and therefore we need to understand how robust the algorithm is towards the measurement distance error. The distance error varying from -5 cm to 5cm with a step-size of 1 cm, i.e. the measurement range is 75 cm and the actual R varies from 70 cm to 80 cm, is considered. The impact of the distance error on the power level of the ripples is illustrated in Fig. 4. The figure shows that the ripple level in the PAS

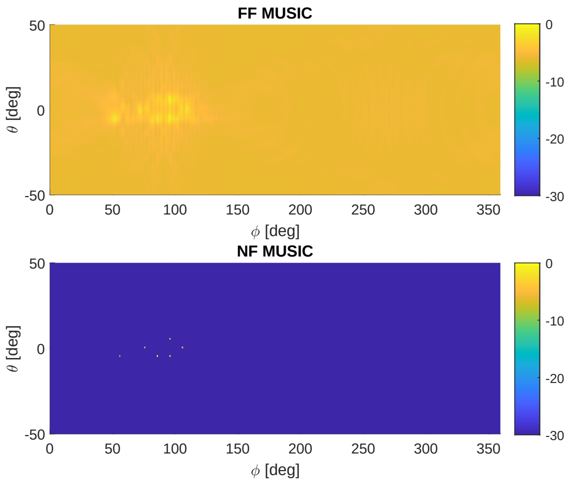

Figure 3. Power-angle profile estimated with far field MUSIC and near field MUSIC for a test zone with a radius of 10 cm.

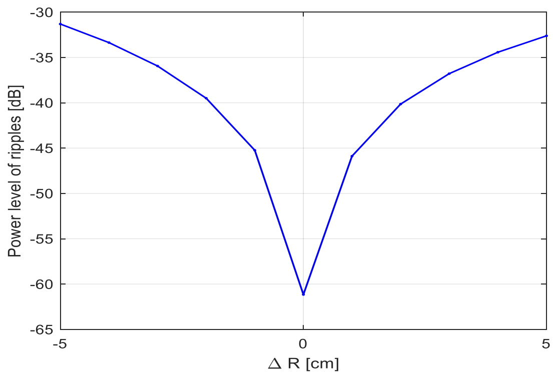

Figure 4. The power level of the ripples in PAS versus the distance errors.

rises as the absolute distance error increases, implying that some fake peaks might appear when the distance error keeps increasing. The distance error within [-5,5] cm has a negligible effect on estimation accuracy of angle, delay and power value per OTA probe antenna, demonstrating that the proposed DUT array and algorithm is not sensitive to the distance errors.

C. Virtual array configuration

A virtual array composed of one semi-circle array (with a half wave-length element spacing) on the horizontal plane and two parallel arc arrays (with a half wave-length element spacing) on the vertical plane, is employed to validate the power-angle delay profiles in the test zone. Although this array is not optimal for a given MPAC setup, e.g. the setup for emulating InO-CDL-A channel model in 3GPP, it generally works well for 3D MPAC setups to emulate various spatial channel models with different channel parameter settings, e.g. angles of arrival and power dynamic ranges of channels. For a given 3D MPAC setup (to emulate a specified spatial channel

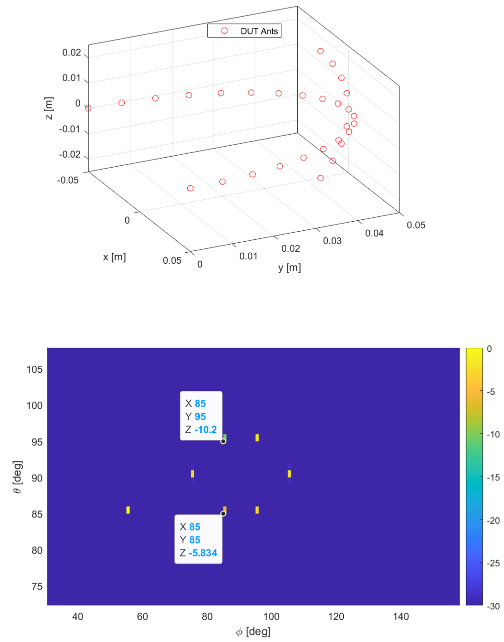

Figure 5. The virtual array configuration (top) and the estimated PADP using the near-field MUSIC algorithm (below).

model with specified angles of arrival and a given power range of channels), a virtual antenna array can be optimized to have non-uniform element spacings and a minimum number of antenna elements. However, this 'customized' array might fail to work for other channel models.

To demonstrate the impact of virtual array configuration on the channel estimation algorithm, we employ a virtual array with one semi-circle array on the horizontal plane and only one arc array on the vertical plane, as shown in Fig. 5 (top). The estimated PADP using this virtual array configuration is shown in Fig. 5 (bottom). As we can see, though all six peaks can be identified, there exists a fake peak in the estimated PADP result. Therefore, two arc arrays on the vertical plane can avoid the fake paths on the elevation plane.

V. Conclusion

In this work, we discuss how to validate the spatial profile of the emulated channels inside the test zone in the MPAC setup. The joint PADP of the emulated channel is selected as the metric since it is more informative and it relates directly to the performance of FR2 NR. A generic channel estimation algorithm is discussed, with a focus on the test zone size, measurement distance error and virtual array configuration inside the test zone. We have shown that the algorithm is robust towards measurement distance error and works well for arbitrary test zone size. Furthermore, we have shown that selection of virtual array configuration is important for the estimation of the PADP, e.g. to avoid fake paths in the power spectrum. The discussed algorithm is very promising for channel spatial profile validation for FR2 NR OTA testing.

REFERENCES

[1] Y. Qi, G. Yang, L. Liu, J. Fan, A. Orlandi, H. Kong, W. Yu, and Z. Yang, "5g over-the-air measurement challenges: Overview," *IEEE Transactions on Electromagnetic Compatibility*, vol. 59, no. 6, pp. 1661–1670, Dec 2017.

[2] M. Rumney, "Testing 5g: Time to throw away the cables," *Microw. J.*, vol. 59, no. 11, 2016.

[3] W. Fan, P. Kyosti, M. Rumney, X. Chen, and G. F. Pedersen, "Over-the-air radiated testing of millimeter-wave beam-steerable devices in a cost-effective measurement setup," *IEEE Communications Magazine*, vol. 56, no. 7, pp. 64–71, July 2018.

[4] W. Hong, "Solving the 5g mobile antenna puzzle: Assessing future directions for the 5g mobile antenna paradigm shift," *IEEE Microwave Magazine*, vol. 18, no. 7, pp. 86–102, Nov 2017.

[5] 3GPP, "Study on radiated metrics and test methodology for the verification of multi-antenna reception performance of nr user equipment (ue);," June 2020.

[6] C. T. Plan, "2x2 downlink mimo and transmit diversity over-the-air performance version 1.2," 2018.

[7] G. TR37.976, "Measurement of radiated performance for multiple input multiple output (mimo) and multi-antenna reception for high speed packet access (hspa) and lte terminals release 13," 2016.

[8] Lin Guo, Can Sun, Xudong An, Xiao Zhang, and Meng Yang, "Over the air mimo channel model validation," in *2013 7th European Conference on Antennas and Propagation (EuCAP)*, 2013, pp. 1848–1852.

[9] W. Fan, F. Zhang, and Z. Wang, "Over-the-air testing of 5g communication systems: Validation of the test environment in simple-sectored multiprobe anechoic chamber setups," *IEEE Antennas and Propagation Magazine*, pp. 0–0, 2019.

[10] A. Scannavini, L. J. Foged, N. Gross, L. Hentila, J. Virtala, and K. Raju, "Test zone characterization for the multiprobe anechoic chamber setup (mpac)," in *2016 10th European Conference on Antennas and Propagation (EuCAP)*, 2016, pp. 1–5.

[11] F. Zhang, L. Hentila, and P. Kyosti, "Millimeter-wave new radio test zone validation for mimo over-the-air testing," *IEEE Transactions on Antennas and Propagation*, 2021.

[12] P. Kyösti, L. Hentilä, W. Fan, J. Lehtomäki, and M. Latva-Aho, "On radiated performance evaluation of massive mimo devices in multiprobe anechoic chamber ota setups," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 10, pp. 5485–5497, 2018.

[13] G. 38.901, "Study on channel model for frequencies from 0.5 to 100 ghz," January 2020.