MIMO OTA Channel Verification and Performance Testing

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***Abstract*—MIMO OTA testing is a promising solution to evaluate terminal performance. Standards like 3GPP and CTIA are investigating different MIMO OTA testing methods, thus test results from different labs are needed. However, there is no standard for MIMO OTA testing with 3D channel model until now. In this paper, we have verified 2D channel model parameters in MPAC and investigated the spatial correlation of 3D channel model by simulating it on channel emulator. The performance comparison between 2D MPAC setup and 3D MPAC setup is shown.**

***Index Terms*—MIMO OTA Testing, 3D MPAC, Channel Emulation, Throughput**

I. Introduction

With the increasing demand for high speed data transmission. New Standards like 3GPP High Speed Downlink Packet Access (HSDPA), LTE, LTE-Advanced and IEEE 802.16m have developed multi-antenna technology at mobile terminals. IEEE 802.11n and IEEE 802.11ac specify multiple antennas in wireless local area network (WLAN) devices. MIMO technology can improve throughput, quality of service (QoS) and cell coverage without increasing bandwidth and transmit power. Spatial correlation is an important parameter in MIMO system. It depends both on antennas and propagation characteristics. Due to the complex multiple antenna setups in terminals, accurate test method is needed to ensure the real performance of the terminal.

MIMO over-the-air (OTA) test method can provide a realistic environment in the lab to evaluate MIMO terminals. Several MIMO OTA methodologies have been proposed in many research and standardizations, which vary widely in how they emulate the propagation channel. Three main MIMO OTA test methodologies are illustrated in [1][8]. Multi-probe anechoic chamber (MPAC) methodology is used in this paper. CTIA MIMO OTA Sub Group (MOSG) has defined detailed test prerequisites [2] including ENodeB configuration, MIMO channel model used for evaluating MIMO devices, Device under test(DUT) and maximum theoretical throughput. One important prerequisite is that channel model should be accurately reproduced in MPAC, so channel verification is also very important. 2D standard channel models are used in the MIMO OTA testing so far [2], However 2D channel model assumption is not valid, the elevation spread cannot be ignored in many propagation scenes. It would be desirable that 3D channel model is used in MIMO OTA testing. However, there is no standard for 3D channel model applied to MIMO OTA test so far.

In this paper, we first describe the multi-probe anechoic chamber and MPAC based MIMO OTA test methodology. We verified the reproducibility of 2D channel models in MPAC and investigated the 3D channel model used in MIMO OTA testing. Finally, we present the comparison of terminal performance between 2D MPAC setup and 3D MPAC setup.

II. Measurement System

As shown in Fig. 1, the system used for 3D MIMO OTA testing is illustrated below. The main components are a Base Station emulator, a channel emulator, a multiple probe anechoic chamber, a vector analyzer, power amplifiers and switch boxes. The Base Station emulator is used to generate analog signal to the channel emulator. The channel model is generated by the channel emulator and the CIRs output by the channel emulator are mapped onto the probe antennas by algorithms implemented in the channel emulator from Elektrobit (EB) (as shown in Fig. 2(a)). The power amplifiers are used to compensate channel loss from the probe antennas to the center of the test area.

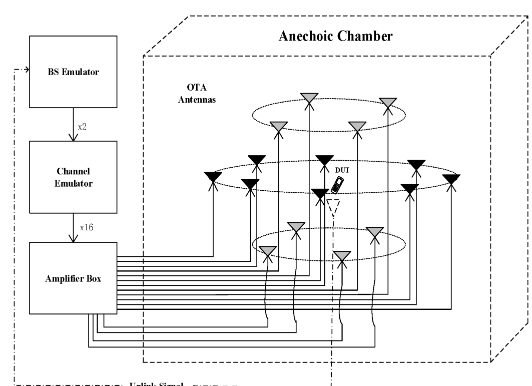


Fig. 1: 3D MPAC based MIMO OTA setup in BUPT

The radius of sphere is 1.6 meters. Various absorbing materials are placed in the chamber to reduce unnecessary electromagnetic reflection, as shown in Fig. 2(b). 16 dual polarized horn antennas are spaced on a sphere and equally

(a) channel emulator (b) Multi-probe anechoic chamber

Fig. 2: channel emulator and MPAC used in testing

spaced on 3 different rings. The DUT is placed in the center of the anechoic chamber.

A. *Calibration of the system*

In order to get the correct environment for MIMO OTA testing, subsystems and the entire system need to be calibrated. Subsystem Calibration consists of probe calibration, MV-CAL calibration and gain calibration. The purpose of the probe calibration is to calibrate RF paths inside the chamber, while the MV-CAL calibration is to calibrate RF paths outside the chamber. The gain calibration is taken to obtain the total gain of the system. The calibration of the entire system consists of conducted uniformity and radiated uniformity. Conducted uniformity calibration is taken bypass the channel emulator while radiated uniformity calibration calibrate all the RF paths from inputs of the channel emulator to the center of the test area.

The calibration results with Band3 are shown in Fig. 3 and Fig. 4. The deviation of all the paths are below the acceptance criteria given by SATIMO. Therefore, we can be sure that any difference in gain or phase between paths at the center of the test area due to the channel model.

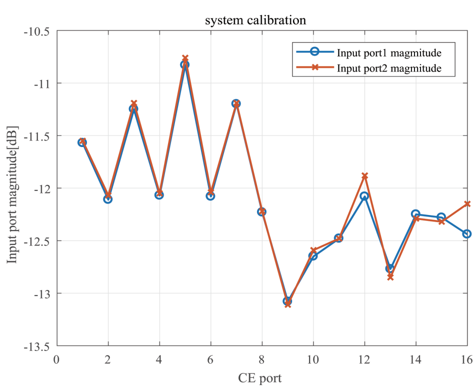


Fig. 3: Radiated uniformity result of system calibration

III. Channel model used in MIMO OTA test

A. *2D channel model*

The channel model used in CTIA test plan [2] is standard SCME channel model [9] in Urban Macro (Uma) propagation.

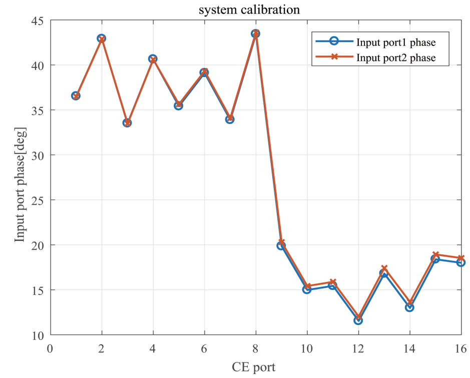


Fig. 4: Radiated uniformity result of system calibration

The model consists of 6 clusters, Laplace distribution is used for PAS distribution. As stated above, channel verification measurements are necessary in the test campaign. Three key parameters are verified as detailed below. We set 8 dual polarized probes equally placed on a ring. All testing process are performed in accordance with CTIA standards.

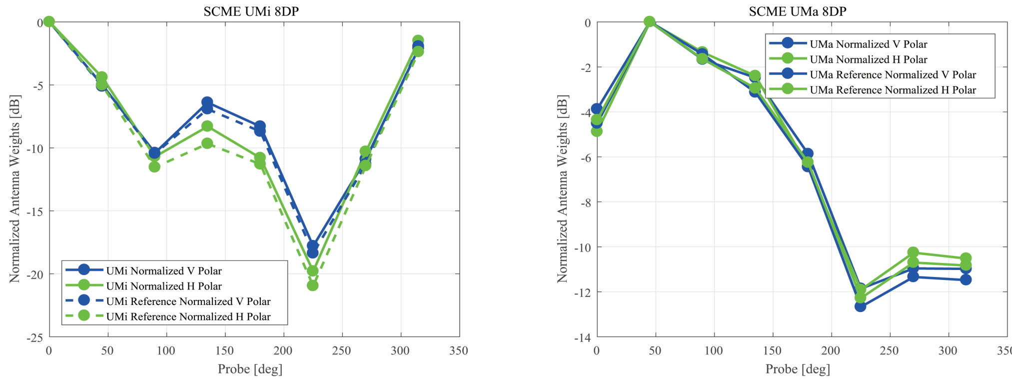
a) Power Angular Spread (PAS): One cluster has a specific power angular spread shape. The PAS is of great importance for multiple antenna techniques with spatial treatment of the incoming signals. PAS is often used to describe the angular dispersion of multiple antenna channels. The angular power spectrum reflects the average power distribution of the signals in different directions at terminals. The channel emulator collects the power of each probe antenna after it turns on. Fig. 5 shows the comparison between target PAS and measured PAS. The maximum deviation for SCME UMi Scene is 0.57dB and the deviation for SCME UMa scene is 1.16dB, which shows good fitting degree.

b) Power Delay Profile (PDP): Power delay spectrum is used to describe time dispersion in fading channels. The power delay spectrum directly reflects the multi-path fading effect of wireless channel, and describes the time dispersion characteristics of wireless channel.

This measurement checks that the resulting power delay profile (PDP) is in-line with the PDP defined for the channel model. This comparison is to make sure that the anechoic chamber loss did not affect the simulated power delay profile. The test system has been calibrated in advance with a vector network analyzer.

- Set the simulated frequency, mobile speed and channel model in the channel emulator. Note the mobile speed must be set large enough to avoid interference between channels.
- A vector network analyzer (VNA) is used to measure the frequency response. The VNA center frequency must be set to channel model center frequency. The number of sweep points is 1000.
- Step the emulation and store traces from VNA.

Measured VNA traces are saved to the hard drive.The analysis is performed by taking the Fourier transform of each



(a) PAS for SCME UMi

(b) PAS for SCME UMa

Fig. 5: Target and measurement PAS for SCME UMi(a) and SCME UMa(b)

TABLE I: Acceptance Criteria

Parameter	information	value
Power	All taps	<+/-0.85dB
Delay	All taps	<+/-11ns

frequency response. The resulting impulse response $h(\tau)$ are averaged in power over times as shown in:

$$p(\tau) = \frac{1}{T}\sum_{t=1}^{T} |h(t,\tau)|^2 \qquad (1)$$

Table I gives the acceptance criteria of power delay distribution test. Fig. 6 shows the comparison between target PDP and maximum measured PDP. The maximum measured PDP follows well with the target PDP.

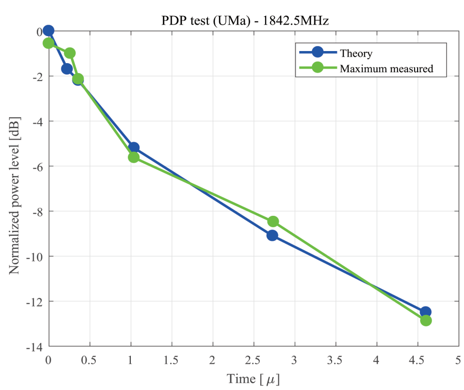


Fig. 6: Target and measurement PDP for SCME UMa

c) Spatial Correlation: The spatial correlation is a statistical measure of the similarity of the received signals and it is selected as a figure of merit (FoM) to model 3D channel spatial characteristics. Since the patterns of the device under test (DUT) antennas are unknown, assuming that two antenna elements exhibit the same omnidirectional radiation pattern and the phase difference is determined by the wavelength and relative positions of two antenna elements. As Shown in Fig. 7, radio waves arrive at the antennas by plane waves.The spacing between antenna is d. The AoA of the plane wave is ϕ_p, the direction of the array boresight is ϕ_a. $p(\phi)$ is PAS. The PAS is modelled by mean AoA (ϕ_p)and angular spread (σ_p). The PAS has many distributions, namely wrapped Gaussian, uniform, truncated Laplacian and Von Mises distribution [4]. In order to be used as an angular power density, the $p(\phi)$ must satisfy $\int_{-\pi}^{\pi} p(\phi) = 1$.As illustrated in [3], the spatial correlation can be written as:

$$\rho(d,\phi_p) = \int_{-\pi}^{\pi} exp(-j2\pi\frac{d}{\lambda}sin(\phi_p - \phi_a))p(\phi_p)d\phi_p \qquad (2)$$

As we can see from the formula, spatial correlation depends on the mean AOA and distance d. As shown in [4][5], if proper power weighings are found, the channel spatial correlations can be recreated in multi-probe anechoic chamber. Several articles are investigating methods to accurately reconstruct channel spatial characteristic. Method named prefaded signal synthesis technology are detailed in [4]. The reconstruct technology has already implemented in EB F32. The target spatial correlation resulting from continues PAS and the simulated spatial correlation resulting from the discrete PAS by algorithm embedded in F32. The measurement is taken according to [2].

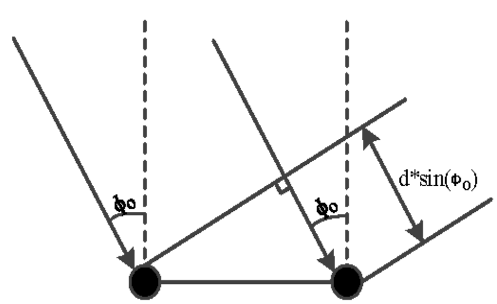


Fig. 7: Antenna array receiving plane waves

The measurement procedure is as follows:

- Based on the typical configuration of the network analyzer, a diploe antenna is vertically placed on the turntable. The probes in MPAC must be fully open.
- In the center of the MPAC, select the line segment of 1 wavelength, the center of the line segment is perpendicular to the 0 degree arrival angle in the system, and select 11 test points at intervals of 0.1 wavelengths on the line segment.
- Set the VNA center frequency equal to the center frequency of the channel emulator, set the bandwidth to 200MHz.
- Step the emulation and store traces from the VNA. Continue until frequency response of 1000 CIRs in 11 positions are stored.

As can be seen in Fig. 8, it can be considered that the verification result of the spatial correlation basically matches the theoretical channel model.

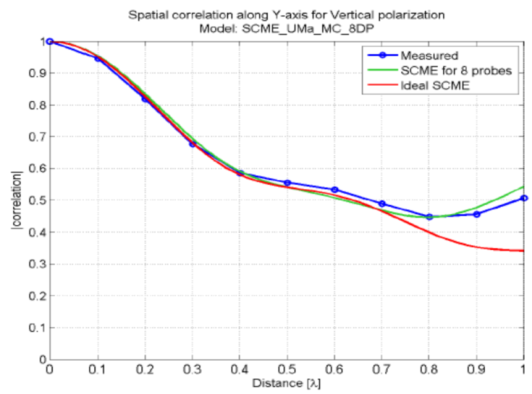


Fig. 8: Target, simulated and measured spatial correlation

B. 3D channel model

As illustrated in Table II, The 3D channel model parameters used in MIMO OTA testing are based on SCME and WINNERII. The elevation extension is from WINNERII[6]. The 3D channel model consists of 19 clusters. Laplace are used for PAS and PES distribution. Due to the limited power amplifiers, Cross Polarization Ratio(XPR) are ignored in the test.

As mentioned before, spatial correlation is selected to be a main figure of merit to characterize the channel spatial information. The waves impinging on two antenna elements depends on the PAS and on the radiation pattern. In [7], the 3D reconstruction technology is described. The 3D reconstruction technology has already been implemented in EB F32 in which Laplace distribution is used for power angular spread (PAS) and power azimuth spread (PES). Note the theoretical spatial correlation resulting from continuous PAS and the simulated spatial correlation resulting from the discrete PAS.

Fig. 9 shows the target and simulated spatial correlation. The deviation between the simulated and target spatial correlation is due to the limited number of probes (16 in our measurements) used for channel emulation. The more probes we use, the smaller deviation we should expect [10].

TABLE II: Configuration of model parameters

Channel Scenario	Urban Miacro
Number of clusters	19
Cluster ASA	15°
Cluster ASD	2°
Cluster ESA	7°
Cluster ESD	0.2°
XPR	7

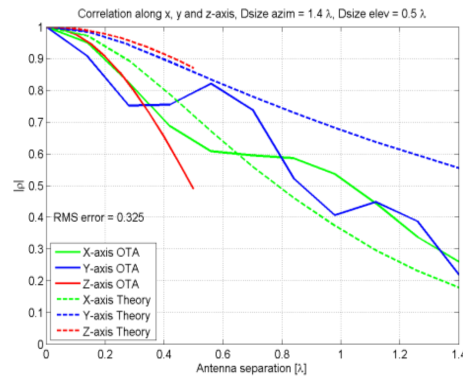


Fig. 9: Target and simulated 3D spatial correlation

IV. Test result in MIMO OTA MPAC setup

A. Test configuration

Throughput is selected to be a main figure of merit (FoM) to evaluate the performance of DUT in MIMO OTA testing. The DUT is placed in the center of the test area. Measurement is taken every 45 degrees in 360 degrees. Table III shows the configuration of the test case. The 3D setup is shown in Fig. 10.

B. Test comparison

The comparison of throughput between 2D setup and 3D setup is shown in Fig. 11. As illustrated in the previous section, the measurement is taken every 45 degrees from 0 degree to

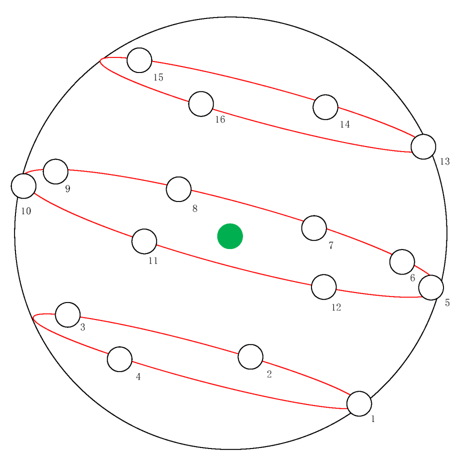
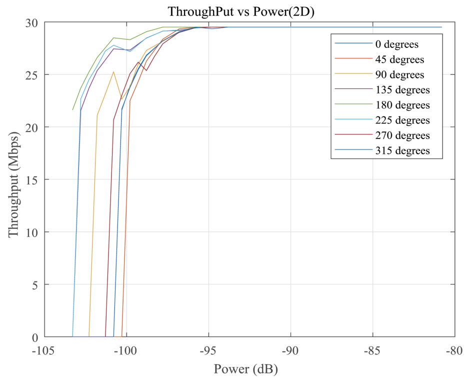
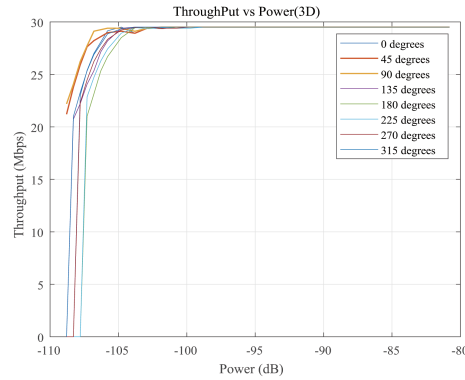


Fig. 10: 3D probe setup



(a) Performance for 2D setup



(b) Performance for 3D setup

Fig. 11: Test result comparison between 2D setup and 3D setup

TABLE III: Configuration of the test case

Parameter	Value
Duplex Mode	TDD Band40
Frequency	2.35GHz
Downlink Bandwidth	20MHz
Downlink Modulation	64QAM
Downlink Transmission Mode	TM3
Downlink Reference Channel	SCME, WINNER
OTA Probes	3D setup (only vertical polarization) Fig. 10
phone	Huawei

360 degrees, The colored lines mean throughput results from different measurement directions. Throughput in both settings can reach maximum theoretical throughput specified by CTIA standard. However, at 70% of the maximum throughput, the average transmit power of 2D setup is greater than the average transmit power of 3D setup.

V. Conclusion

This paper describes the 3D multi-probe anechoic chamber used in MIMO OTA test and proved the reliability of the MPAC in BUPT. It represents the verification results measured in MPAC with standard SCME channel model. Besides, this paper studied the possibility to reconstruct 3D channel model. Terminal performances are tested with both 2D channel model and 3D channel model and throughputs are compared in the end. It can be seen that the terminal performance with 3D channel model is better than the performance with 2D channel model.

Acknowledgment

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