

MEASURING MASSIVE MIMO

USING OVER-THE-AIR TECHNIQUES

Paving the way to 5G



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Massive MIMO Introduction

The path to 5G is bringing many changes to the telecommunications networks we are accustomed to today -

Lots of antennas

One of the key technologies needed to achieve the target data rates and coverage in 5G is the expansion of the MIMO antenna count on base stations (BS) and wireless devices from the current single-digit numbers to tens or even hundreds of antennas arranged in two dimensions. MIMO techniques that use this high number of elements are collectively known as Massive MIMO (MM).

Higher frequencies, too...

In conjunction with MM, higher frequency bands (>6GHz), where spectrum and larger bandwidths are more readily available, are a key component of 5G. The bands between 6GHz and 100GHz are known as millimeter wave (mmW) bands. 5G currently has two implementation phases with various associated signal bandwidths:

- Carrier frequency range <6GHz with signal bandwidths of 40, 80, 160, 320MHz
- Carrier frequency range >6GHz with signal bandwidths of 100, 200,... 1000, 2000MHz

New standards and deployment scenarios

Standards development organizations such as 3GPP are actively working to develop a set of standards to support the ITU requirement targets for 5G as part of the future development for International Mobile Telecommunications (IMT). A set of new radio deployment scenarios are being defined in 3GPP¹. These include:

3GPP TR36.873	3GPP TR38.901		
Frequencies under 6GHz	Frequencies over 6GHz		
3GPP TR36.873	3GPP TR38.901	3GPP TR38.913	
<i>Defines channel models for device elevation beamforming & FD-MIMO:</i>	<i>Defines channel models and the following scenarios:</i>	<i>Defines channel models and the following scenarios:</i>	
3D-Urban micro (Umi - street canyon, open area)	UMi with Outdoor-to-Outdoor (O2O) and Outdoor-to-Indoor (O2I)	Indoor hotspot	Urban coverage for massive connections
3D-Urban macro (Uma)	UMa with O2O and O2I	Dense urban	Highway
3D-Urban macro high-rise (Uma-H)	Indoor (open and closed office, shopping malls)	Rural	Urban grid for connected cars
Notes:	Backhaul (includes small cells)	Uma	Commercial air to ground
Cell radii for UMi is typically less than 100m and the access points (APs) are mounted below rooftops	Device-to-Device (D2D)/Device-to-Vehicle (D2V)	High speed: 4GHz & 30GHz deployment	Light aircraft
Cell radii for UMa is typically above 200m and the APs are mounted on or above rooftops	Other scenarios such as stadiums and gyms	Extreme long distance coverage in low density areas	Satellite extension to terrestrial



Fig. 1: Typical radio deployment scenarios

¹ 3GPP TR 36.873 v12, "Study on 3D channel model for LTE"
 3GPP TR 38.901 v14, "Study on channel model for frequencies from 0.5 to 100 GHz"
 3GPP TR 38.913 v14, "Study on Scenarios and Requirements for Next Generation Access Technologies"

An array of testing challenges

Although the new radio interfaces in 5G will be required to support a wide variety of services, one key aspect will be the introduction of MM with large element counts, termed a MM array. A MM array is made up of a uniform rectangular set of elements, where each element can either be single polarized or dual polarized. Figure 2 shows an example of a dual-polarized MM array.

In the majority of scenarios, the number of BS elements are targeted to have up to 256 transmit (Tx) and receive (Rx) antennas with a mix of frequency bands above and below 6GHz. Given these typical deployment scenarios, MM arrays with very large element counts will likely exist in the millimeter wave frequency bands.

Testing MM arrays requires a huge number of radio links for channel emulation. A typical MM antenna array of 64 elements supporting four antennas (configured as one device with four antennas, two devices with two antennas each, or four devices with one antenna each) requires 512 radio links. As 5G drives antenna counts as high as 256 elements in a single array and increased multiple antennas on devices, replacing those antennas with conducted cabled connections results in a very complex and cumbersome test setup that has difficulty scaling due to the need for a significant number of independent channels and cables. Additionally, in order to adequately test MM arrays and be able to verify all aspects of performance, the most important elements of MM, the antennas, need to be included in the testing; if cables are used, the antennas are excluded. Therefore, a different approach is needed. Drawing from the concepts of device over-the-air (OTA) testing for MIMO, this ebook presents an overview of MM testing based on OTA methodologies.

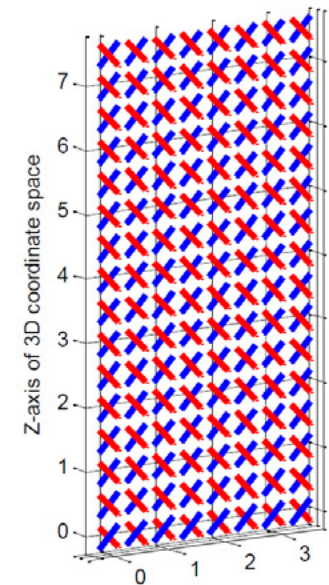


Fig. 2: Example of a dual-polarized massive MIMO array

The Approach: Massive MIMO Over-the-Air Testing

A brief explanation of MIMO

MIMO OTA creates a unique spatial signature to replicate realistic propagation scenarios in a controlled environment for comprehensive performance testing. MIMO performance is a function of the wireless channel and the antennas, so testing must combine characteristics such as:

- Antenna gain or efficiency
- Branch imbalance
- Correlation between antennas

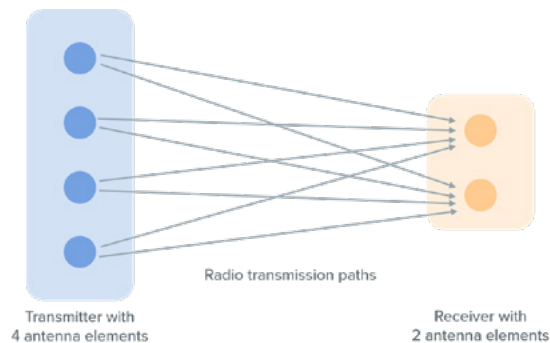


Fig. 3: Example of simple 4x2 MIMO radio transmission paths

MIMO exploits low correlation of signals to achieve better performance. Correlation depends on the gain for each antenna, the antenna phase response, and the power angle distribution of the signal, which is a function of the wireless channel. Multiple scattered copies of the signal will combine at each antenna. Each plane wave arrives at the first antenna and a moment later it arrives at the second antenna at a slightly different phase, and so on. Rayleigh fading occurs at each antenna with a different fading envelope, but it is correlated. The actual amount of correlation is determined by the phase difference between each plane wave. Figure 3 shows an example of the radio transmission paths for a 4x2 MIMO configuration.

Emulating a realistic environment

Testing beamforming and proper beam selection operation of MM arrays requires the ability to include the BS MM array properties while emulating cluster-based channel models. OTA antenna testing is the best existing approximation to real-world conditions due to its highly controlled environment. This includes the use of an anechoic chamber, which provides the capability of producing spatial channels with the correct field structure in the test chamber. Figure 4 illustrates a typical environment assumed in a MM array system, where there are multiple users, some being Line-of-Sight (LOS) users with a single path, and some being non-Line-of-Sight (NLOS) users with one or more multi-path components. Each user is emulated via a specific cluster-based channel model.

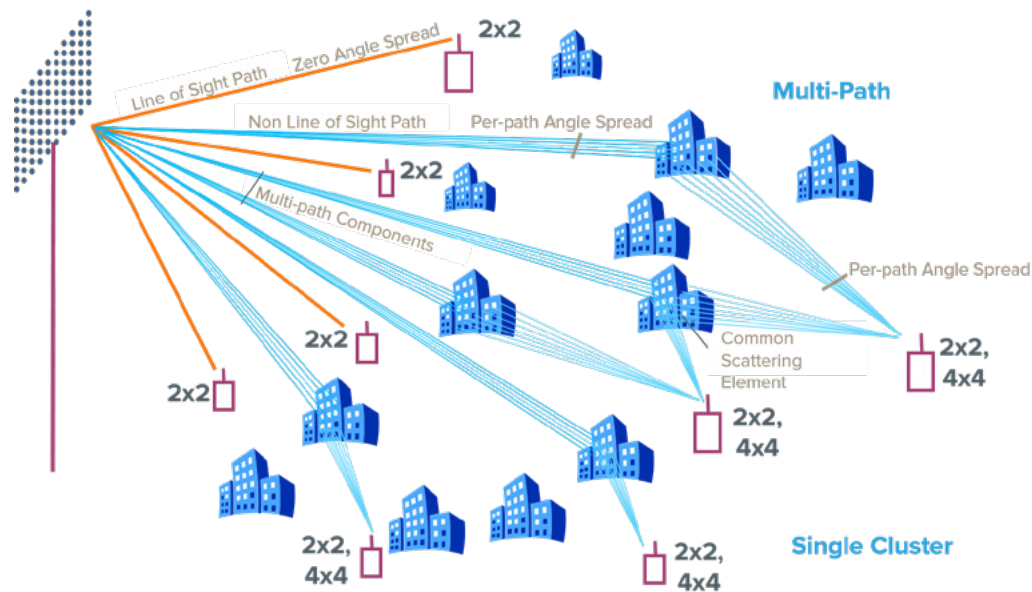


Fig. 4: Typical MM environment emulated within an OTA chamber

- Line-of-Sight (LOS) refers to signals traveling in a straight path between the BS and the device.
- Non-Line-of-Sight (NLOS) refers to signals traveling along partially obstructed paths with multiple reflections; there is no visual "line of sight" between the BS and the device.

Emulating a cluster-based channel model

Wideband cluster-based spatial channel models (SCM) were developed in standards to enable the evaluation of MIMO systems. Recently, a 5G channel model specification has been developed in 3GPP, which includes the definition of BS antenna arrays.²

For emulating MM array systems using OTA techniques, the channel model between the BS and the first bounce defines both the angles of departure and the angle spread for each component that reaches a device. These departure angle properties are specified in both horizon (azimuth) and elevation (zenith). For the purposes of modeling one or more users connected to a MM array, a set of paths are defined and specified by the departure angles and root mean square (rms) angle spreads of each. Although specified in the downlink direction, the model is assumed to be bi-directional, and reciprocal. This is necessary to support time division duplex (TDD), which is commonly used for MM array design.

Line-of-Sight channel models

For a Line-of-Sight (LOS) path, a single plane wave is modeled, which has a zero angle spread in both azimuth and zenith. This model results in 100% correlation between antenna elements at the BS, wherein the angle of the correlation coefficient indicates the phase difference between elements. A single dual-polarized probe is sufficient to model a LOS path to a user. This will enable a bi-directional connection to be set up with a static path with a Doppler shift proportional to the user speed.

Non-Line-of-Sight channel models

For Non-Line-of-Sight (NLOS) paths, representative values of azimuth spread (ASD) and zenith spread (ZSD) can be chosen to define the MM performance for one or more paths to a user. At least two probes are required in this case, with a special probe layout to simulate the NLOS angle spread signal. Figures 5 and 6 show the predicted performance and probe layout, respectively, of an example NLOS cluster.

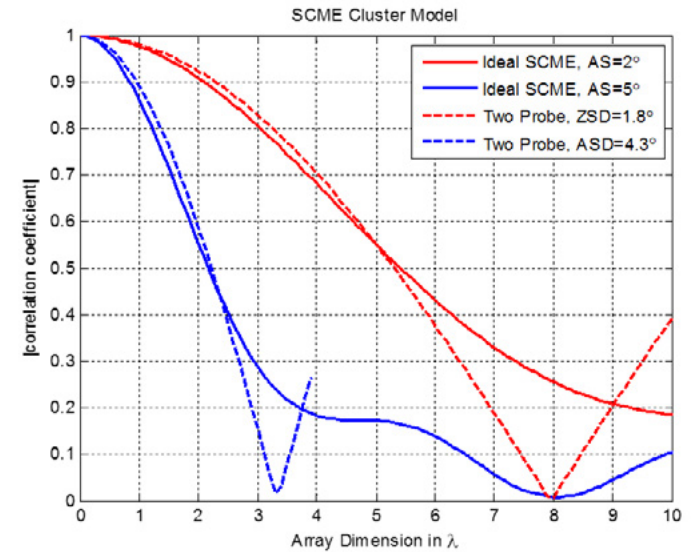


Fig. 5: Predicted performance of a NLOS cluster

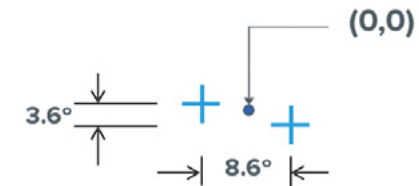


Fig. 6: Example of a probe layout for an NLOS cluster model

² 3GPP TR 38.901 v14, "Study on channel model for frequencies from 0.5 to 100 GHz"
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Configuring clusters to simulate users

By placing a number of probes in an anechoic chamber, multiple users can be emulated with a variety of channel models. Only the first-bounce NLOS path is modeled since the probes are connected to a multi-channel channel emulator, which supplies the rest of the path to each of the multiple devices [such as introduction of delay, path loss, noise, or Doppler shift (to simulate moving devices)]. Additional probes are utilized to model multi-path components. The key to MM OTA test methodology is to determine how many NLOS clusters are needed for relatively accurate modeling. Probes are distributed within the chamber, to emulate the path components mentioned. Although many probes could be used, it is better to minimize the total number to reduce cost and complexity. The probes could also be switched to change the position or location of some users, e.g., to create clumps of users close together, having spatial consistency and similarity so that the array could be required to discriminate between such users. The number and position of the probes would be determined based on various test cases and channel model assumptions. Figure 7 shows an example of a test setup with the anechoic chamber.

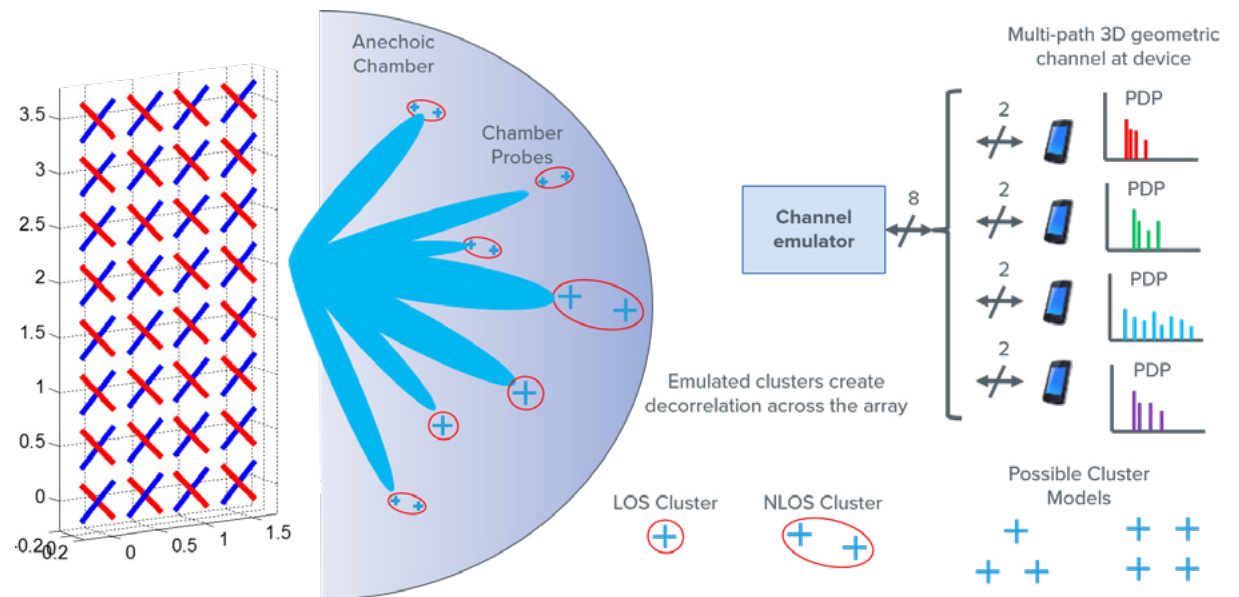


Fig. 7: Typical MM OTA chamber test setup

The reception of signals from different paths and at different arrival times is known as the Power Delay Profile (PDP). The PDP will have corresponding angles of departure and angles of arrival. Because only the initial and final angles are needed to determine the model, we only need to know the delay and power of each path, not where each reflector might have been.

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Replicating realistic scenarios in the lab

Many scenarios can be replicated easily within the MM OTA chamber environment via placement of a fixed set of probes, for example:

- Track a user in motion (pedestrian, vehicular, high speed train) via switching between probe antennas or rotating/elevating a single cluster
- Evaluate multiple users by spreading devices across the coverage area or clumping them together to check for Signal-to-Interference Ratio (SIR) due to beam overlap
- Evaluate the impact of LoS and NLoS users, including multi-path conditions
- Evaluate a range of channel conditions in real-time via simple parameter changes in the channel emulator user interface

With the ability to emulate the full range of applicable 3GPP channel models, MM OTA testing provides a comprehensive end-to-end solution, encompassing the spectrum of bandwidths and frequencies needed for upcoming 5G applications.

For a deeper dive, Spirent experts authored and published Measuring massive MIMO array systems using over the air techniques, as presented in EuCAP 2017 in Paris, France. IEEE subscribers can download the detailed technical paper here: <http://ieeexplore.ieee.org/document/7928094/>
For more information on 5G requirements testing, visit: <http://www.spirent.com/Solutions/5G>
For more information on how Spirent's Vertex Channel Emulator can support your MIMO OTA testing needs, visit: <https://www.spirent.com/Products/Vertex-Channel-Emulator>