Over-The-Air Testing of Diversity and MIMO Capable Terminals

White Paper

SATIMO

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Introduction

To meet the increased demand on high data rate applications, new wireless technologies such as LTE, LTE-Advanced, and Mobile WiMAX (Worldwide Interoperability for Microwave Access) require the use of multiple antennas in mobile terminals. Multiple-Input and Multiple-Output (MIMO) technology in a wide sense covers any multi-antenna technology, such as Spatial Multiplexing (SM), Beam Forming (BF), and spatial diversity. MIMO offers significant increases in data throughput, quality of service (QoS) and cell coverage without additional bandwidth or transmit power. Communication performance is improved by exploiting the characteristics of the propagation channel in which the device is operating. As a result, a MIMO device will adapt to the RF (Radio Frequency) environment. Hence, there is a need of an advanced testing methodology which is capable of creating such propagation conditions in a repeatable fashion.

In MIMO systems, spatial correlation, which is a function of both antenna and propagation characteristics, plays a key role. Indeed, the level of correlation cannot be determined based on propagation characteristics without knowing the characteristics of the antenna. Similarly, the level of correlation cannot be determined based on the antenna characteristics without knowing the propagation characteristics. Therefore, it is necessary to include both antenna and propagation characteristics at the same time when testing multi-antenna terminals.

In order to understand the end-to-end reception performance of a MIMO device, Over-the-Air (OTA) testing is needed. Due to the complexity of multiple antenna setups, a flexible and fast accurate testing solution becomes a major asset in the antenna design cycle and final product verification (and consequently, Time To Market).

To date three fundamentally different approaches are being studied by the wireless industry through 3GPP (3rd Generation Partnership Project), COST2100 (European Cooperation in Science and Technology), and CTIA (International Association for the Wireless Telecommunication Industry)[1].

a) Anechoic Chamber Based or Spatial Fading Emulator (SFE) methods simulate a complex multipath environment at the device location in a repeatable way by using radio channel emulators connected to a circular array of probes, i.e. Multi-probe technology (Figure 1a).

b) Reverberation Chamber methods utilize a reverberation chamber either stand alone, or in conjunction with a channel emulator. Reverberation chambers target a statistically uniform power distribution around the DUT (Device Under Test), while the antennas and channel emulator can be used to try to generate the desired delay profile. (Figure 1b). Reverberation chambers suffer from very limited capability to vary the fading environment, and so can only provide very limited evaluation of the terminal.

c) Multi-stage methods consist of measuring the active complex antenna patterns in an isotropic environment by using a traditional anechoic chamber based system with a communication tester for the first stage. The second stage convolves the antenna pattern information with the channel model via either 1) the use of a channel emulator in conducted mode (Figure 1c), or 2) a theoretical channel capacity calculation where theoretical performance is calculated using the antenna pattern information. Only limited data exists for the multi-stage method at this point, and further investigation is required and ongoing.

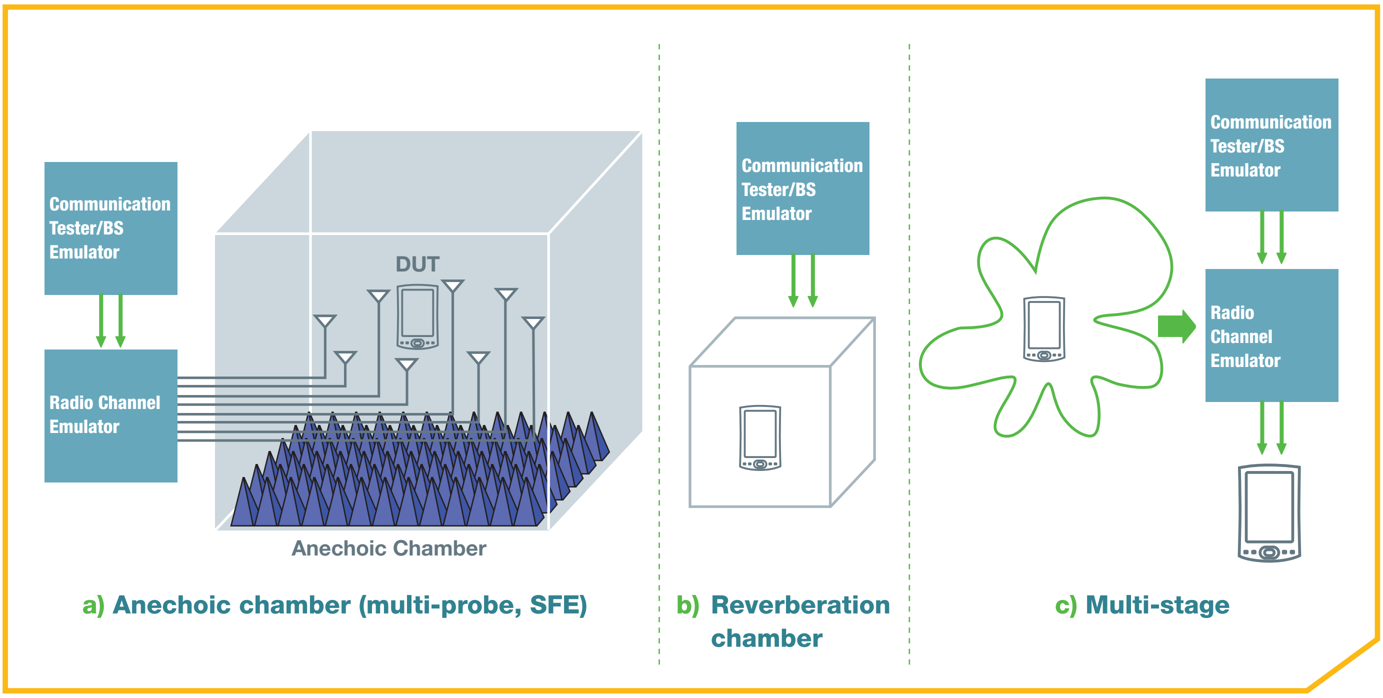


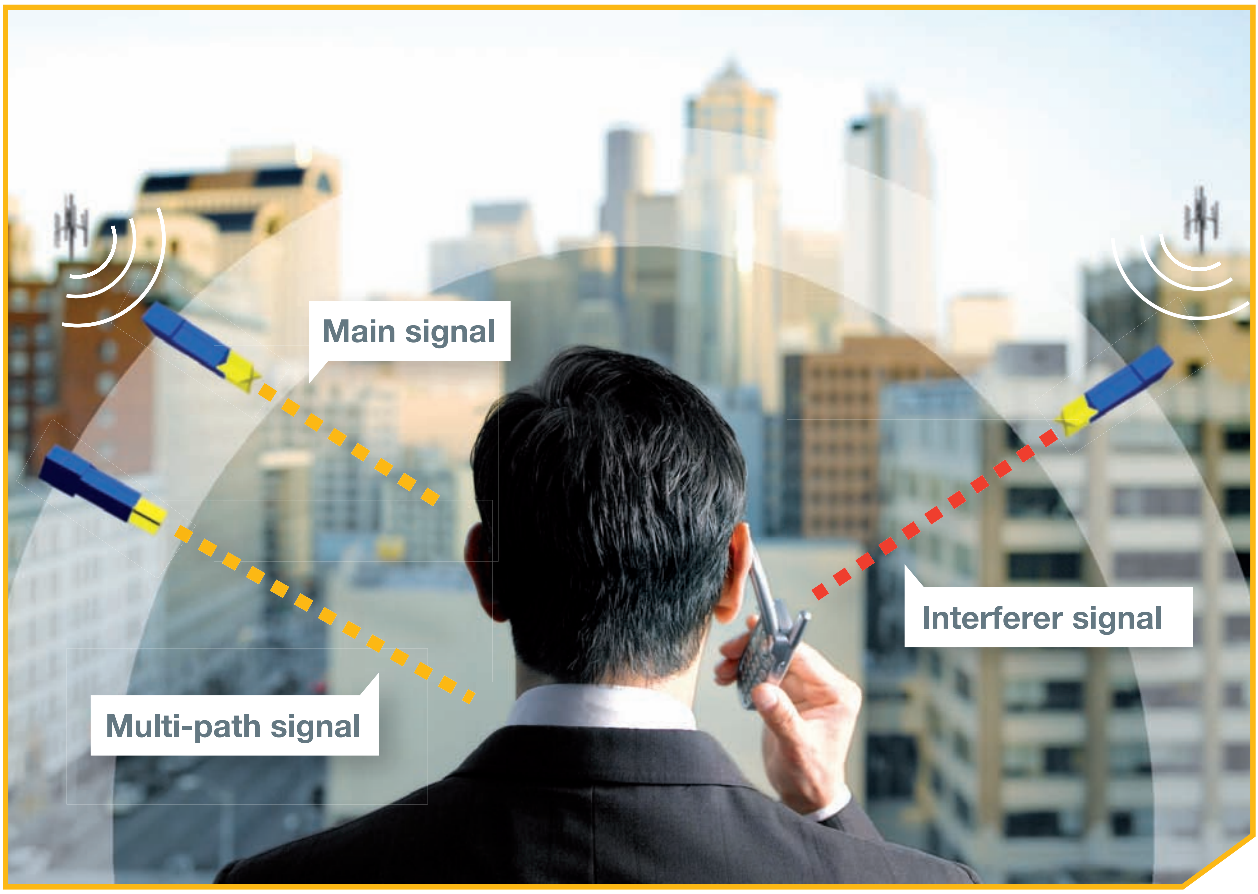
Figure 1 - Three different methodologies proposed in the various standardization bodies

SISO Test Ranges

Multi-probe technology has gained momentum and trust within the wireless industry and is widely used in existing SISO test ranges for accurate and fast OTA measurement of single antenna or diversity devices. In SISO tests, probes are operating sequentially and are in turn singularly selected. 3D pattern measurements, either radiated power or received sensitivity, are obtained in an isotropic environment (uniform channel model). The 3D pattern data are then integrated to obtain either Total Radiated Power (TRP) or Total Isotropic Sensitivity (TIS). These Figures of Merit (FoM) are used for characterizing the system level performances of the terminal.

As previously discussed, MIMO system performance is strongly dependent on both antenna properties and the channel environment, and hence SISO OTA test ranges are not suitable standalone tools for representative testing of end-to-end performance of multiple antenna terminals.

SATIMO SISO OTA testing range



MIMO multi-probe testing principle

MIMO Test Ranges

As opposed to a SISO OTA multi-probe test range, in a MIMO OTA setup signals are coming simultaneously from different directions around the device. This characteristic setup, combined with a channel emulator, enables the simulation of complex spatial-temporal propagation environments at the DUT location[2-3]. SATIMO StarMIMO systems, along with Elektrobit's EB Propsim® F8 channel emulator, is therefore a clear answer to MIMO OTA testing.

MIMO OTA testing in an anechoic chamber provides the possibility to measure realistic mobile terminal performances without using artificial cabling in the test setup. MIMO OTA testing can evaluate the end user experience of the final product, e.g., in terms of data throughput, against realistic radio channel conditions where performance varies greatly according to environment. All critical parts of the mobile terminal design (antennas, RF front end, baseband processing) are tested at once. This also allows performance comparisons of off-the-shelf mobile terminals.

1. Spatial Fading Emulation Technique

As the radio channel plays a key role in MIMO performance, the radio channel emulator is a crucial part of the MIMO OTA test system. As illustrated in figure 2, a test signal from a transmitter or base station emulator goes through the radio channel emulator, which emulates the radio channel according to a pre-defined channel model. The signal is then split inside the emulator and distributed to probes in the chamber. The signal is then radiated independently from various probes according to the channel model selected. The outcome is that the radiated multipath signals are summed in the centre of the chamber and the desired radio channel environment is generated around the DUT.

With advanced radio channel emulators such as the EB Propsim® F8, it is possible to recreate real life scenarios in the chamber. The most typically emulated parameters are path loss, multipath fading, delay spread, Doppler spread, polarization, and of course spatial parameters such as Angle of Arrival (AoA) and Angular Spreads (AS).

In order to get useful results from MIMO OTA testing, the radio channel emulator has to have excellent RF performance. Error Vector Magnitude (EVM) and internal noise level needs to be very low in order to minimize errors impacting the measurement results.

Also, the fading process has to be repeatable in order to have consistent test results across different test rounds. This is very important when benchmarking the performances of different DUTs. The EB Propsim® F8 minimizes these risks with excellent RF performance using EB's patented emulation process, where the channel condition repeatability is 100%.

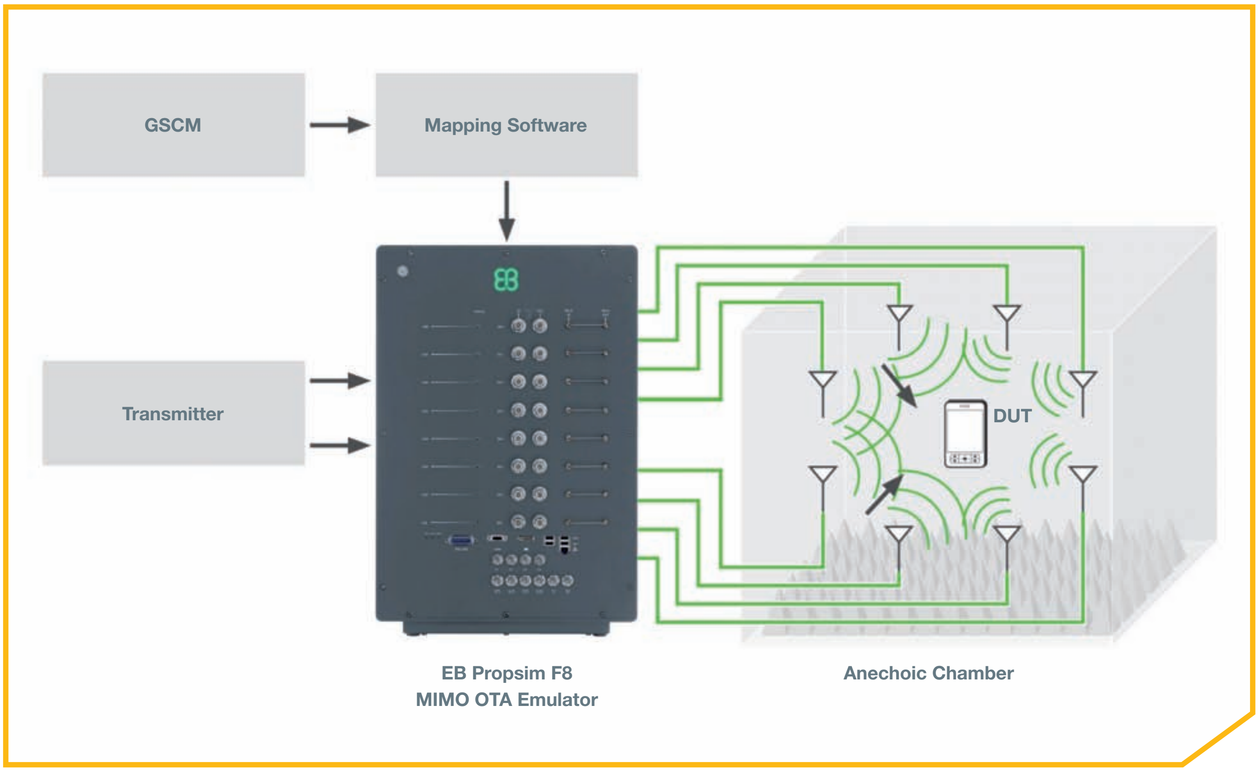


Figure 2 - Anechoic chamber method for MIMO OTA testing

Geometry-based Stochastic channel models

The channel models used for the MIMO OTA testing are Geometry-based Stochastic Channel Models (GSCM) in which the radio channels are defined by:

- Transmit antenna location and pattern,
- Propagation characteristics (delay, Doppler, AoD – Angle of Delay, AoA, Angle spread at transmitter (ASD) and at receiver (ASA), and polarization),
- Mobile velocity and direction of travel,
- Receiver antenna location and pattern,
- As well as a number of large-scale parameters.

These measurement-based channel models include all dimensions of the radio channel (time, frequency, space and polarization). Space and polarization are especially important since they are crucial parameters for the spatial correlation (on which MIMO performance is strongly dependent). Clearly, this approach accurately and realistically models the environment required for the testing of MIMO devices. Figure 3 illustrates an environment for GSCM with transmitter, receiver and scattering clusters between them. The receiver sees the transmitted signal through a multipath environment with spatial properties. Spatial properties combined with the receiver antennas are then the major factors for the receiver performance. The family of GSCM models include 3GPP Spatial Channel Model (SCM), SCM Extended (SCME), Wireless World INitiative NEw Radio (WINNER), and ITU (Union Internationale des Telecommunication) IMT-Advanced (International Mobile Telecommunications Advanced) channel models.

MIMO OTA channel model mapping

In MIMO OTA testing, the receiver antenna is not modeled, but its actual influence on the DUT performance is automatically incorporated as an integral component of the test configuration. The crucial challenge in MIMO OTA testing is to generate realistic propagation characteristics, especially AoA and ASA, within the anechoic chamber. This geometry based information, like in SCM, creates appropriate correlation at the DUT antennas. In addition, information of the transmitter antenna arrays (base station), including both array geometry and antenna field patterns, are required. Also either the terminal velocity vector or the Doppler frequency components for each cluster/clusters are needed.

These clusters are then simultaneously mapped to OTA antennas so that the sum of the transmitted signals in the centre of the chamber is as defined in the model. This mapping is done by the spatial radio channel emulator. Each cluster is split between several OTA antennas in order to enable accurate angular spreads. As a result the geometry based environment of the channel model is accurately transferred to the anechoic chamber.

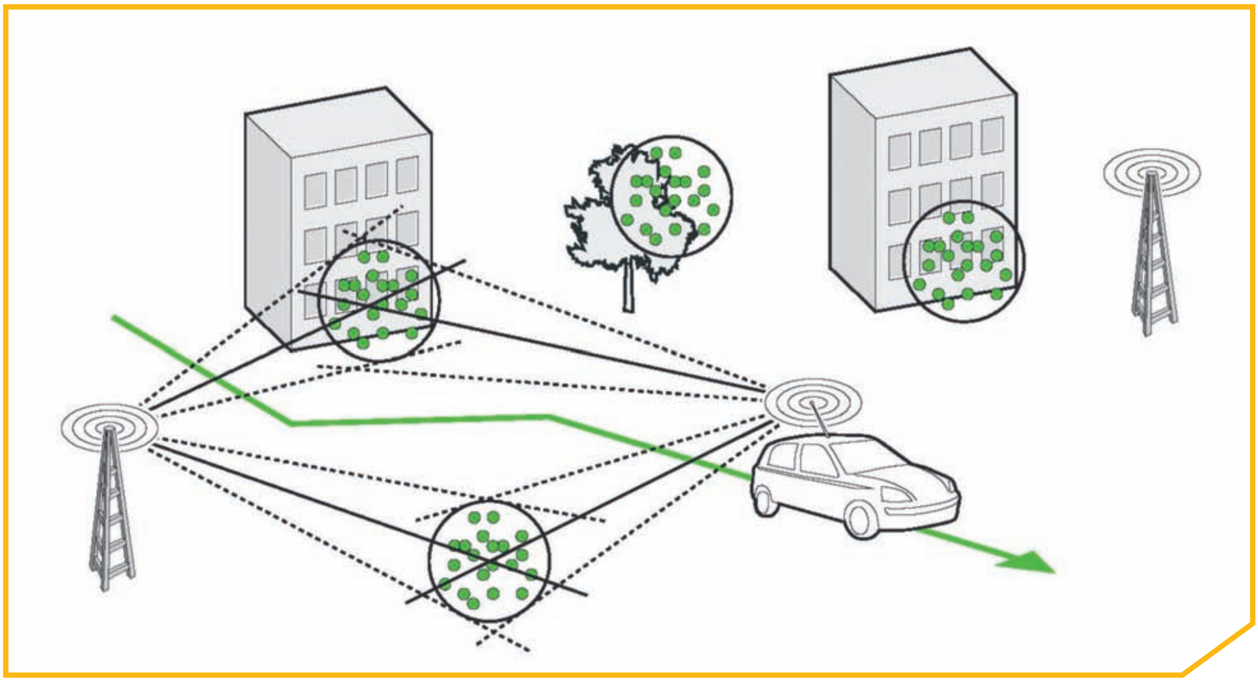


Figure 3 - Geometry-based Channel Model

The EB MIMO OTA Application is a versatile tool for creating and mapping geometry-based channel models to an anechoic chamber environment. Selection of channel models includes SCM, SCME, WINNER, IMT-Advanced, TGn, and user-defined models. The number and position of OTA antennas is fully selectable. It is also possible to import real base station antenna patterns to the models in order to make sure that the transmitter side is being emulated realistically. In addition to static models, it is possible to create scenarios where the environment is changing dynamically.

System set up

The system is scalable from a single cluster to a full 3D implementation (Figure 4). The single cluster configuration is an entry level solution for differentiating between a good terminal and a bad terminal in terms of performance (throughput). With a narrow angular spread, the correlation is high and the DUT rotation will affect the performance result significantly. With a wide angle spread, the correlation is low, and the channel is easier for Spatial Multiplexing (SM). With the full circle system, any 2D channel model (e.g., SCM, SCME, WINNER, IMT-Advanced) can be simulated. The full 3D implementation enables testing the effect of not only azimuth, but also elevation spreads. The system is upgradeable from single cluster to full ring to 3D configurations.

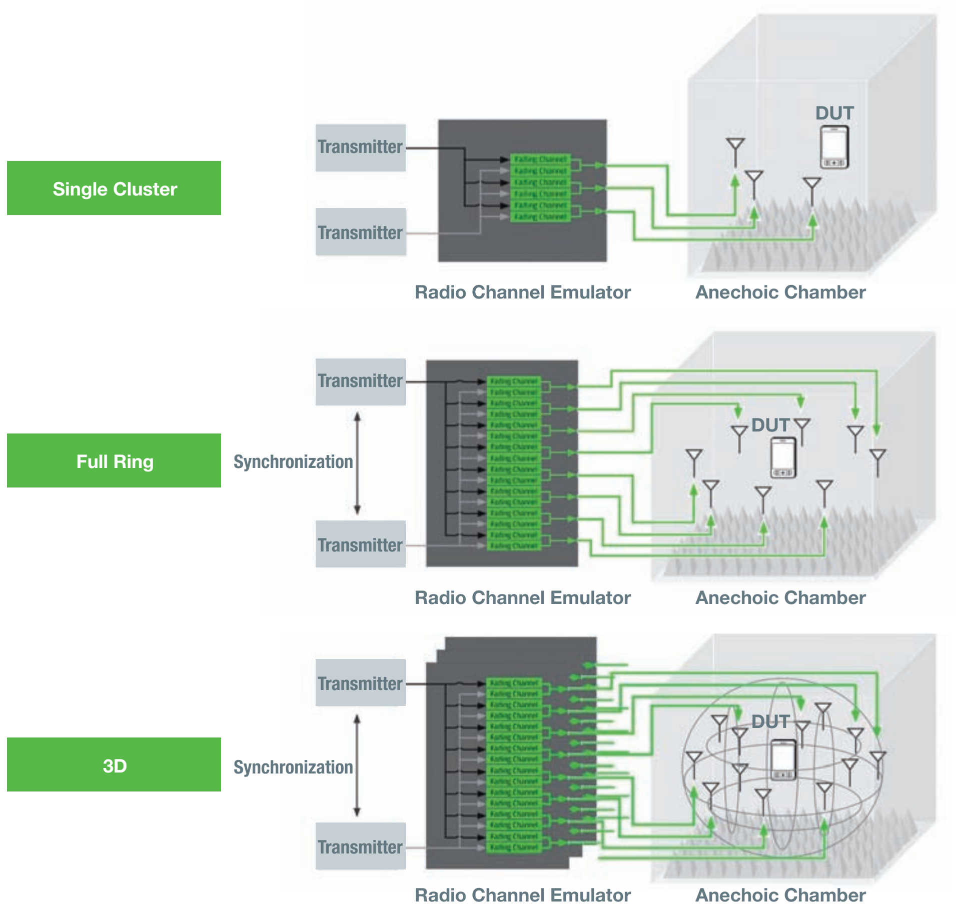


Figure 4 - Scalability of MIMO OTA test system.

2. MIMO OTA channel models

3GPP has agreed on channel models used in the evaluation of MIMO OTA methodologies[1]. The models consist of Clustered Delay Line (CDL) models and some simplified single cluster models, as can be seen from Table 1.

MIMO OTA CHANNEL MODELS

	#	Model is based on	Number of spatial clusters	Number of temporal clusters
Generic Models	1	SCME Urban micro-cell	6	6
	2	Modified SCME Urban micro-cell	6	6
	3	SCME Urban macro-cell	6	6
	4	WINNER II Outdoor-to-indoor	12	12
Single Cluster Models	5	SCME Urban micro-cell	1	6
	6	Extended Pedestrian A (EPA)	1	6
Uniform Models	7	Extended Pedestrian A (EPA)	1	6
	8	Exponential decay	1	1

The emulated base station antennas are:

❶ Vertically-polarized elements

- with a fixed 4λ separation, specified at the center frequency, or
- are uncorrelated, i.e. to allow the UE to be measured independently from BS effects.

❷ Dual-polarized-equal-power elements that are uncorrelated with a fixed 10λ separation, 45 degrees slanted.

An example of the channel models is shown in Table 2. The cluster number here refers to different delay clusters, each having different AoD and AoA characteristics. In each cluster, there are three taps with slightly different delays to ensure good frequency correlation and wide bandwidth.

The Single Cluster model is based on the SCME Urban Micro-cell model with all AoAs assumed to be zero degrees, meaning that the model has only one cluster in the spatial domain. The delay positions are the same as in the original multi-cluster model. XPR values, Direction of Travel, and Mobile Velocity are similar for both single cluster and multi-cluster models. An option in the single cluster model allows a cluster angle spread to be specified with AS AoA = 35°, or with AS AoA = 25°, to enable a range of spatial correlations for different types of devices.

SCME URBAN MICRO-CELL

Cluster #	Delay [ns]			Power [dB]			AoD [°]	AoA [°]
1	0	5	10	-3.0	-5.2	-7.0	6.6	0.7
2	285	290	295	-4.3	-6.5	-8.3	14.1	-13.2
3	205	210	215	-5.7	-7.9	-9.7	50.8	146.1
4	660	665	670	-7.3	-9.5	-11.3	38.4	-30.5
5	805	810	815	-9.0	-11.2	-13.0	6.7	-11.4
6	925	930	935	-11.4	-13.6	-15.4	40.3	-1.1

Delay spread [ns]	294
Cluster AS AoD / AS AoA [°]	5 / 35
Cluster PAS shape	Laplacian
Total AS AoD / AS AoA [°]	18.2 / 67.8
Mobile speed [km/h] / Direction of travel [°]	3, 30 / 120
XPR Note: V & H components based on assumed BS antennas	9 dB
Mid-paths Share Cluster parameter values for:	AoD, AoA, AS, XPR

3. System Calibration

This section will give an overview of the steps required to make a proper calibration of the setup depicted in section 2. The goal of the calibration process is to ensure equal responses from each probe, both amplitude and phase, by compensating for errors caused by the setup, such as probe misplacements and cable differences in gain and phase.

The calibration process consists of measuring the total path loss for each channel from the input of the channel emulator to the device location by using a static channel model, also called single tap. Compensation for the path loss differences is accomplished by adjusting the amplitude and phase weighting for each path by utilizing the channel emulator GUI. The calibration process is complete when the amplitude and phase adjustments are stored on the channel emulator for each channel. Usually, reference antennas with known gain characteristics are used for the calibration. This process is done for both polarizations of the probes (Vertical, Horizontal). SATIMO electric and magnetic dipoles can be used for accomplishing the calibration of the V and H components of the transmitted signal, respectively.

Calibration time is a key element of an OTA test range. Antenna designer and testing engineers need a tool which is easy to use and quick to set up for testing. The following are the drawbacks of the depicted calibration procedure:

- Dipoles are narrow band.
- Dipoles are singly polarized, so that for each frequency to be calibrated, electric and magnetic dipoles must be used.

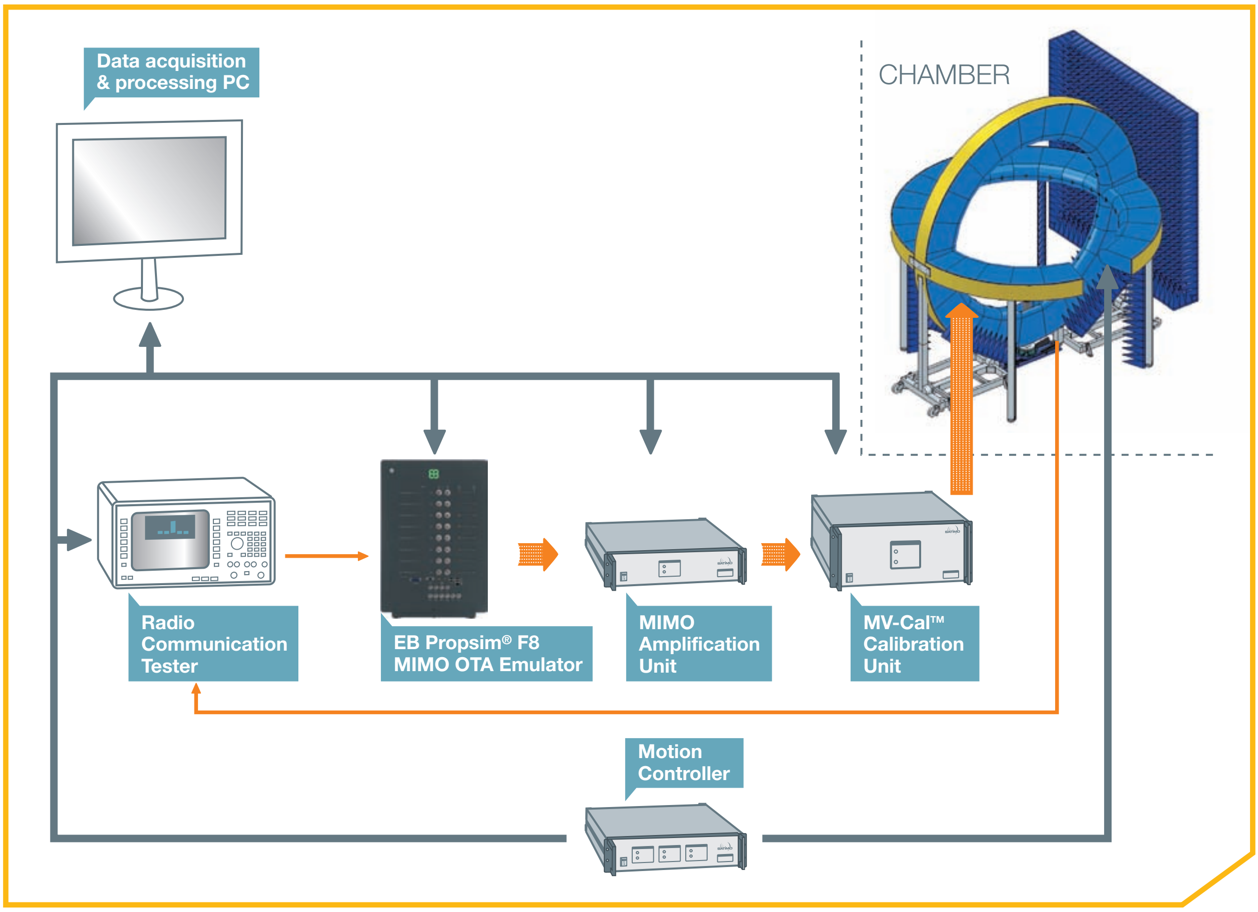


Figure 5 - MIMO OTA set-up with MV-Cal™

- Each path contains active elements such as mixers and amplifiers. They are time and temperature dependent, so that calibration must be performed up to several times per week.
- The probe array itself is not calibrated. The radioelectric axis of each probe should still be calibrated for high quality testing.

SATIMO's expertise in multi-probe systems has made it possible to come up with an automated, fast, and simple MIMO OTA Test system calibration- MV-Cal™. The calibration setup is shown in Figure 5.

Two set of coefficients are processed and stored:

1. The first set calibrates the equipments (RF and BB) outside the anechoic chamber. It is done quasi-instantaneously at any time by using the MV-Cal™ box.
2. The second set calibrates the probe array itself. The probe array calibration procedure is the same for SISO or MIMO measurements. SATIMO has years of experience with the calibration of probe arrays, and its well-validated calibration process ensures that each probe has the same amplitude, phase, and polarization response.

As the probe and cable characteristics do not vary over short time periods, the second step of the calibration process is generally done annually for high accuracy results.

Both sets of coefficients are then applied during the measurements. Calibration time is greatly reduced due to the fact that there is no need to recalibrate the system by using a set of dipoles, which normally takes significant time if more than one frequency range is calibrated.

4. Analysis of Results

Many testing activities have been performed using the above setup of the StarMIMO system plus the EB Propsim® F8 MIMO OTA channel emulator. Some of the results are shown below, and are part of the ongoing 3GPP/COST2100 Round Robin testing[4-5].

Testing has been performed by using both the single cluster (4 dual-polarized probes) and multiple cluster (8 dual-polarized probes) approaches.

The wireless industry, through 3GPP and CTIA, has agreed on having Throughput vs Channel Power as a FoM for testing the system performances, antennas, and chipsets of multiple-antenna terminals.

Throughput vs Channel power has been tested on both HSDPA (High Speed Downlink Packet Access) RX (Downlink) diversity and LTE MIMO capable devices.

HSDPA RX Diversity OTA testing

Figure 6 and 7 show a comparison between a NOKIA CS-15 USB (Universal Serial Bus) Dongle, and a DELL E4300 laptop with embedded 3G chipset when tested under Urban Micro and Urban Macro channel models with multiple clusters. Both devices support HSDPA Category 9 and are equipped with two RX embedded antennas.

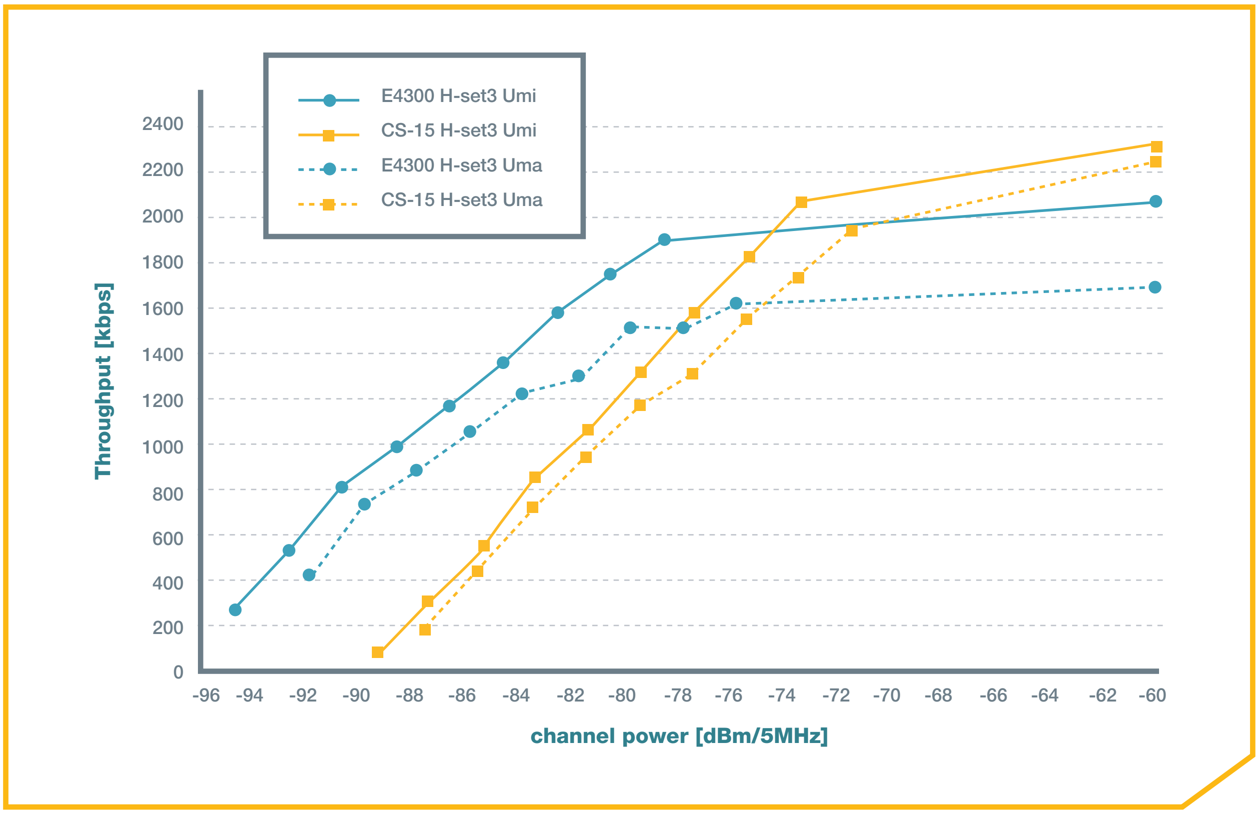


Figure 6 - Hset-3 Throughput versus channel power

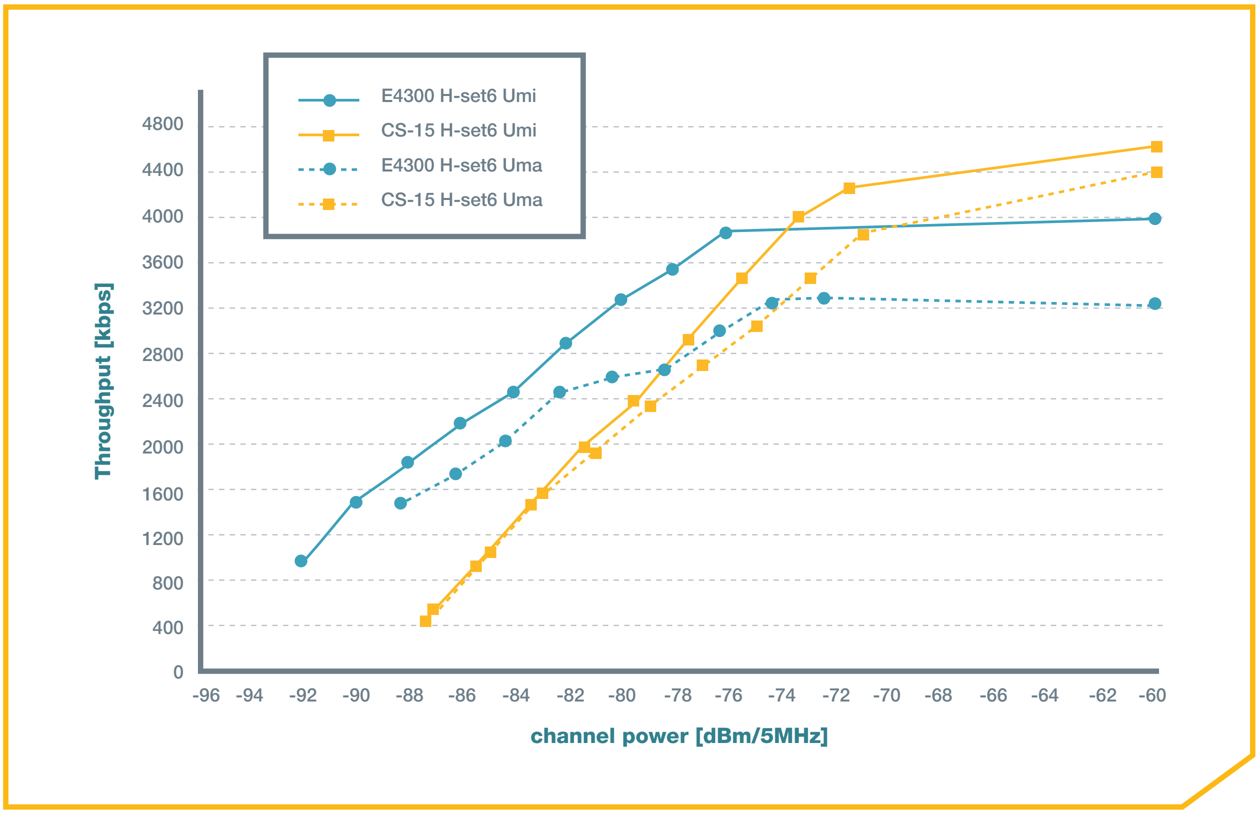


Figure 7 - Hset-6 Throughput versus channel power

H-set3, and H-set6 are related to different relative power settings of HSDPA downlink physical channels [reference 3GPP TS 34.121-1 section 9]

The following observations can be taken:

- Throughput is decreasing when decreasing the channel power.
- There is a difference in terms of device performance between Urban Micro-cell and Urban Macro-cell.
- The Urban Macro-cell channel model looks more challenging than the Urban Micro-cell for both the devices.

LTE MIMO OTA testing

Figures 8 and 9 show the throughput vs. channel power curves for two LTE MIMO capable devices when using single cluster and multiple cluster approaches, respectively.

The Huawei E398 and the Samsung GT-B371 are both USB dongles and have been tested by using the same host laptop and plugged in the same USB port to avoid any differences in the UE setup.

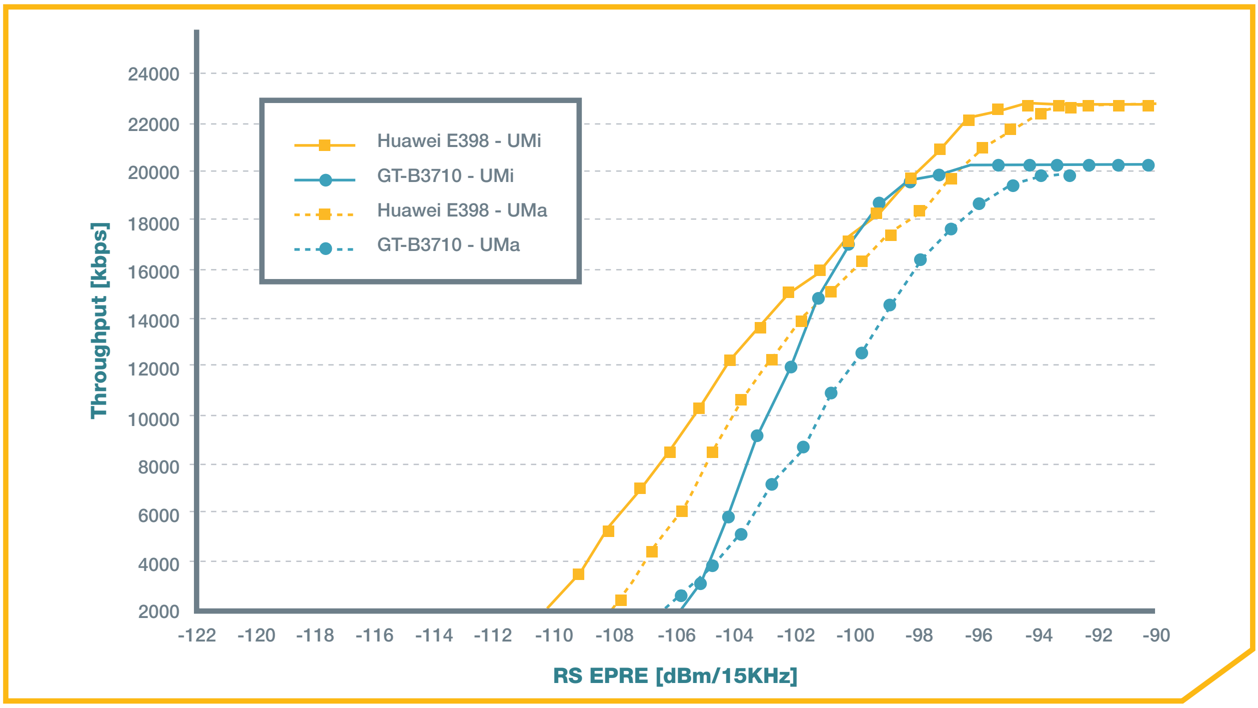


Figure 8 - Single cluster Urban Micro-cell versus Urban Macro-cell

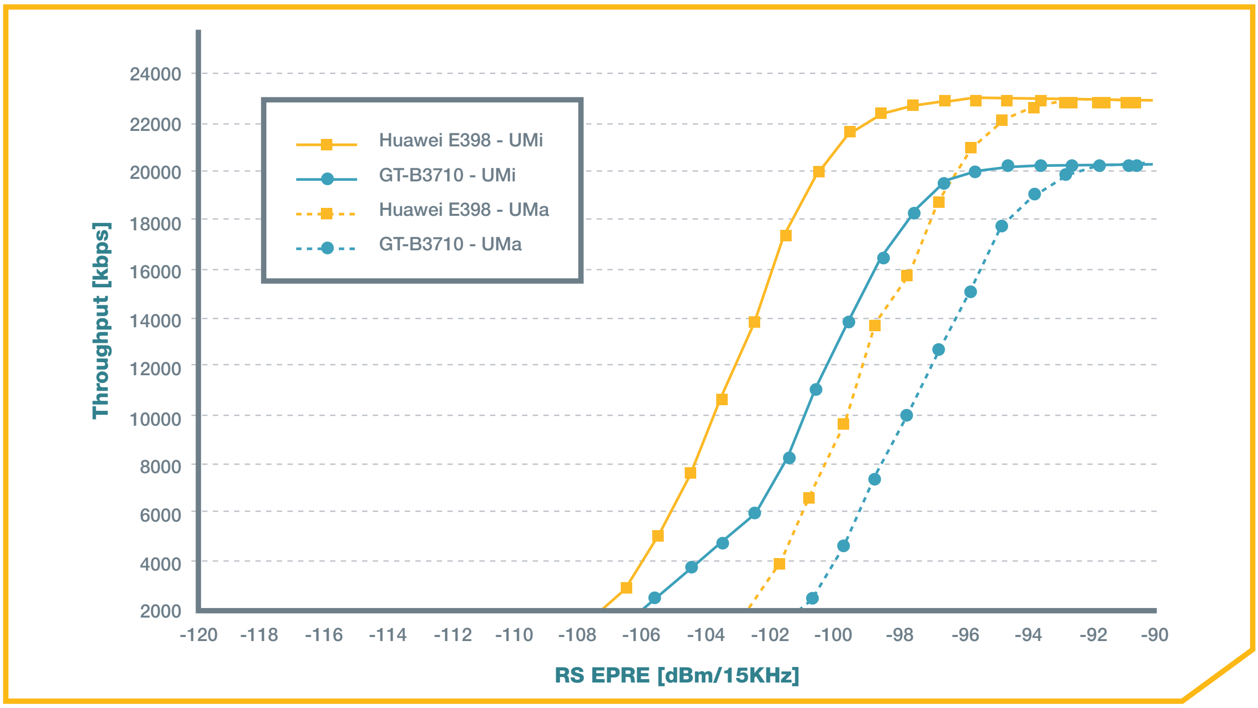


Figure 9 - Multiple clusters Urban Micro-cell versus Urban Macro-cell

As per the RX diversity testing, the following observations can be taken:

- Methodology can discriminate between device performances.
- Throughput is decreasing with the channel power.
- Urban Macro-cell channel model looks more challenging than Urban Micro-cell for LTE devices as well.
- The channel model has a great impact on device performance. This can be observed by looking at the Throughput vs channel power curves of Urban Micro-cell vs. Macro-cell channel models. The MIMO OTA test system is able to accurately emulate different propagation scenarios, which makes it possible to investigate the impact of different parameters on the system performance.

Measurement Time

Measurement time is a key parameter in OTA testing. Antenna designers, and test houses need to perform measurements with good accuracy and in relatively short amounts of time. Test time is important also in the sense that typically the performance is evaluated under several different propagation conditions. Considering Throughput as the FoM of MIMO OTA testing, measurement time can be decreased by calculating the Throughput using a smaller number of blocks. Based on the statistical nature of the channel models, a trade off between the number of blocks and channel model statistics must be found.

Figure 10 shows Throughput vs Channel Power comparison curves using 20000 and 10000 as the number of blocks.

It can be seen that the decreasing in number of blocks from 20000 to 10000 doesn't have a significant impact in the throughput vs channel power curves, although it does significantly reduce the measurement time. Decreasing the blocks from 20000 to 10000 cuts the measurement time from 1h10 min to almost 40 min.

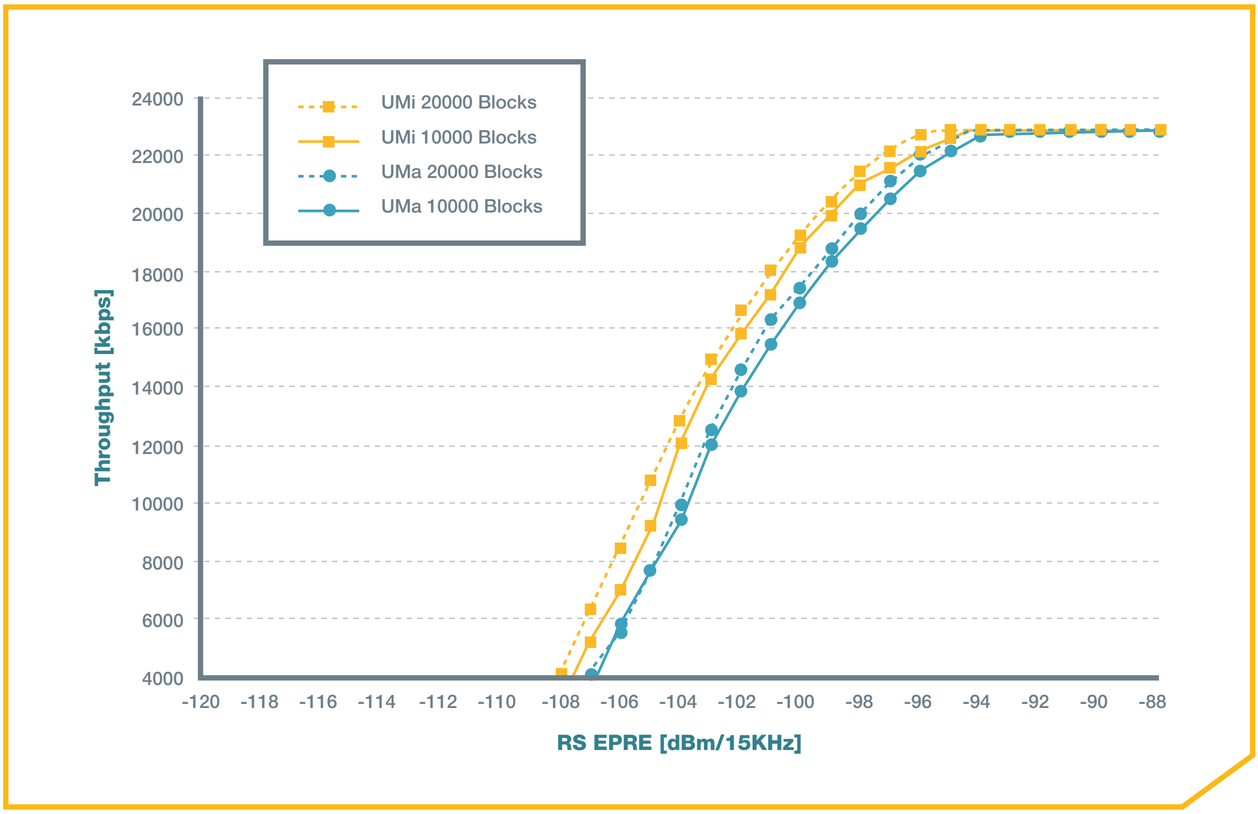


Figure 10 - Throughput versus number of blocks

Conclusions

MIMO is all about correlation! Correlation has a major impact on the throughput of the wireless link. Since correlation is purely a function of the antenna characteristics and the propagation channel, MIMO OTA measurements enable direct measurement of true terminal performances.

The design of good antenna solutions is a highly complex task, especially considering the form factor requirements imposed on the terminal.

In this article we presented a completely new test system which is specially designed for measuring the end-to-end performance of multi-antenna terminals. In a single measurement, it is possible to characterize the complete terminal performance, including baseband, RF front-end, and antennas. SATIMO's long experience in multi-probe technology is utilized to implement accurate system calibration.

The combination of SATIMO's multi-probe technology with the EB Propsim® F8 MIMO OTA channel emulator provides an elegant and accurate solution which can create any spatial-temporal characteristics for the DUT. The spatial-temporal channel model is implemented by placing the probe antennas at different physical locations, and emulating the MIMO channel with the EB Propsim® F8 MIMO OTA emulator. The conversion or mapping from conductive model to the MIMO OTA model is performed automatically using software developed by EB. MIMO OTA measurement technology enables both pass/fail type testing, and also real-world performance evaluation by providing the answer to the question "How good is my terminal?"

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Abbreviations

3GPP	3rd Generation Partnership Project
AoA	Angle of Arrival
AoD	Angle of Delay
AS	Angular Spread
ASA	Angle spread at receiver
ASD	Angle spread at transmitter
BB	Based Band
BF	Beam Forming
BS	Base Station
CDL	Clustered Delay Line
COST2100	European Cooperation in Science and Technology
CTIA	International association for the wireless telecommunication industry
DUT	Device Under Test
EB	Elektrobit
EPA	Extended Pedestrian A
EVM	Error Vector Magnitude
FoM	Figure of Merit
GSCM	Geometry-based Stochastic Channel Models
GUI	General User Interface
HSDPA	High Speed Downlink Packet Access
IMT	International Mobile Telecommunications Advanced
ITU	Union Internationale des Télécommunications
LTE	Long Term Evolution
MIMO	Multiple-Input and Multiple-Output
OTA	Over-the-Air
PAS	Power Angular Spectrum
QoS	Quality of Service
RF	Radio Frequency
RX	Downlink
SCM	Spatial Channel Model
SCME	SCM Extended
SFE	Spatial Fading Emulator
SISO	Single-Input Single-Output
SM	Spatial Multiplexing
TGn	IEEE Channel model used for WiMAX
TIS	Total Isotropic Sensitivity
TRP	Total Radiated Power
UE	User Equipment
USB	Universal Serial Bus
WiMAX	Worldwide Interoperability for Microwave Access
WINNER	Wireless World INitiative NEw Radio
XPR	Cross Power Ratio