NATO STANDARD

AEP-4839

MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) ELECTRONIC COUNTERMEASURE TESTING PROCEDURES

Edition A, Version 1

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NATO LETTER OF PROMULGATION

14 July 2021

1. The enclosed Allied Engineering Publication AEP-4839, Edition A, Version 1, MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) ELECTRONIC COUNTERMEASURE TESTING PROCEDURES, which has been approved by the nations in the NATO AIR FORCE ARMAMENTS GROUP (NAFAG), is promulgated herewith. The recommendation of nations to use this publication is recorded in STANREC 4839.

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RECORD OF SPECIFIC RESERVATIONS

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CHAPTER 1 INTRODUCTION

1. INTRODUCTION

This document is issued to fulfil the processes governing the AEP-4839 STANREC. It defines a series of technical testing recommendations in relation to Long Term Evolution (LTE) networks with the inclusion of integrated wireless channel effects and Multiple Input Multiple Output (MIMO) transmit and receive characteristics.

1.1 AIM

This document provides parameter guidelines and recommendations for the testing of LTE network configurations which include MIMO transmit and receive characteristics. The guidelines include integrated wireless channel configurations which are critical for ensuring accurate and realistic network, User Equipment (UE) and Electronic Countermeasure (ECM) performance results. In addition to LTE, recommendations made for the channel characterisation will also suit more general MIMO radio communications.

1.2. SCOPE

This document fulfils Over the Air (OTA) testing requirements which are directly applicable to ECM applications. Broader commercial vendors and international standardisation committees may find some use in the recommendations laid out in this work, but the focus and nature of practical testing will be distinctly different for requirements fulfilling commercial/civilian use and those for assuring military domain applications.

To elaborate further, the commercial & civilian domain will be interested in validating a range of handset and network performance parameters including but not limited to:

i. Antenna radiation patterns and gain
ii. Total Radiated Power (TRP) for the network / UE
iii. Total Isotropic Sensitivity (TIS) for the handset
iv. Network Throughput (TP) and channel capacity
v. Block Error Rate (BLER) and Bit Error Rate (BER)

From a military requirements viewpoint, it is accepted that the commercial channel and network characterisation will have been performed and that network infrastructure is operational. The primary interest and goal from a military viewpoint concerns the testing and performance of their own system/equipment/capability in relation to that of the network which forms the focus of this document.

This document describes testing requirements for Downlink (DL) signaling of LTE and Frequency Division Duplex (FDD). Any consideration for uplink (UL) requirements is at the discretion of individual nations and if required, testing approaches will be addressed in a separate edition.

In addition, any requirements for Time division Duplex (TDD), should they need to deviate from recommendations in this work, will be treated in a separate edition.

1.3. PURPOSE

For any international collaboration and sharing initiative, it is important to understand the methodology and process description of how technical results have been obtained. This provides traceability that helps nations to understand the accuracy and suitability of what is being shared, which enable reliance and acceptance judgements to be made.

This document provides a series of testing parameter and procedure recommendations in relation to the characterisation of LTE and MIMO for ECM applications which fulfils the stated aims.

Having internationally agreed testing recommendations supports burden sharing and cross working initiatives between partner nations.

1.4. MILITARY RELEVANCE

This document provides technical testing recommendations for military systems in relation to LTE network configurations with a view to international acceptance and agreement. Having such agreements should enable broader understanding, reliance and possible burden sharing between partner nations for operational waveforms, techniques and equipment.

1.5. USING THIS DOCUMENT

It is accepted that subtly different measurement set ups will exist across different nations, so generic recommendations are made to appeal to a broad a cross section. Each nation will be expected to apply as many of the recommended parameters as reasonably practicable to their own test setups to adequately understand system performance. Two example set ups are described in Chapter 2 to illustrate testing scenarios.

A dedicated facility known as a Reverberation Chamber is referred to which can offer some advantages for the testing of MIMO OTA performance.

1.6. ORGANISATION

This document is organised as follows.

Chapter two discusses OTA MIMO measurement scenarios. Two scenarios are discussed based on an OTA field trial set up and a laboratory based approach. Some measurement pitfalls/challenges are also highlighted.

Chapter three describes procedures and parameters to successfully analyse different MIMO configurations and varying Transmission Modes (TM). These are important to understand as the LTE network configuration is adaptable depending on numerous factors which impacts on the level of performance offered by the network and its precise behaviour. Chapter four describes procedures and parameters to account for variations in the wireless 'channel[1]'. As described in footnote one, the wireless channel is subjected to varying environmental and atmospheric effects which directly influences its exact behaviour. This in turn can directly impact on both the network and wireless link performance so assessing such variations is critical for accurate system performance measurements.

Annex A provides some further details on channel models, TM configurations and channel emulation information in reverberation chambers. Annex B provides procedures on how to set up and configure channel emulators used for testing.

1.7. DISCLAIMER

The parameters and descriptions in this work are issued to provide guidance recommendations only. It remains the responsibility of each individual nation to perform their own appropriate levels of Verification and Validation (V&V) to fulfil their national assurance requirements prior to any deployment. No responsibility will be accepted as a result of guidance issued in this work.

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[1] The channel can be thought of as the wireless 'link' between a transmitter and a receiver which is subjected to a wide variety of different environmental and atmospheric effects. These effects directly influence the exact behaviour and performance of the link and hence the wider network.

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CHAPTER 2 MIMO OTA RECOMMENDED TEST METHODS

2.1. GENERIC OTA SET UP (FIELD APPROACH)

Figure 1 illustrates a generic OTA test setup for MIMO Evaluation based on a field approach.

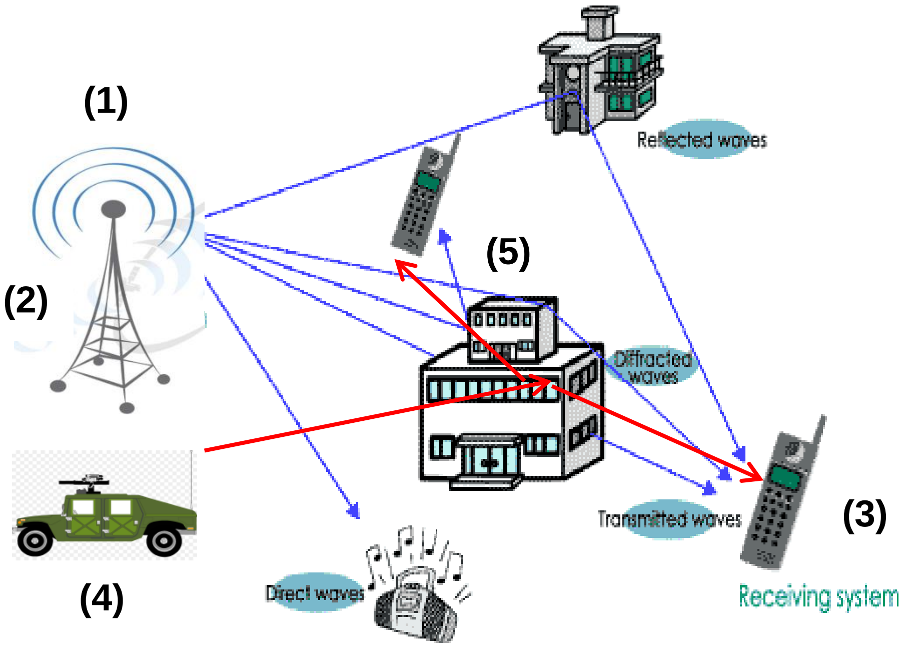

Figure 1: Generic OTA Trials Measurement Requirements

The requirements for any test setup consist of:

1. **eNodeB (source)**. This must be capable of transmitting at least one LTE TM although for completeness the ability to vary the specific TM is desirable to fully understand network and any wider system performance.

2. **Base station antenna(s)**. Must be capable of radiating more than one data stream at the same time (i.e. must be a multi-port antenna) and be able to operate in the required LTE frequency bands. The antenna characteristics should match the Industrial standard designs as close as reasonably practicable (i.e. the ideal is a multi-element dual polarised array with +/- 45 degree polarisation characteristics).

As a minimum, any dual (linear) polarised multi-port antenna should be selected or in line with [1], vertical polarised radiating elements may be selected with a 4λ separation distance[2] between each element when multi-elements are employed.

3. **User Equipment or UE (receiver)**. Commercial Off The Shelf (COTS) design that supports LTE and MIMO features which also operates in frequency bands of interest.

4. **'Noise' or 'External' Source (with antenna).** Additional antenna and equipment source as desired for 'domain' use. A requirement is to situate this source at sufficient distances from the base station antenna and the handset to fulfil individual testing requirements but this radiating source must also be uncorrelated from the network transmit streams.

   The performance of this source in conjunction with the network must be evaluated under dynamic as well as static means (i.e. with a person or vehicle physically moving as well as in fixed location)

5. **The 'Channel' and a Means of Influencing Channel Behaviour.** In an operational context, the behaviour and response of the channel can take many different forms in response to a wide variety of influencing factors such as geographical location, frequency, cell tower and handset proximity, building infrastructure for example.

   It is vitally important to understand and emulate the effect that channel variations can have in order to provide sufficient levels of assurance for deployed systems.

   Complex building infrastructure may not always exist in every field trial location. To modify the behavior and form of the wireless channel, channel emulators are often connected and employed for this purpose – please see Annex A and B for further details.

2.2. REVERBERATION CHAMBER OVER THE AIR TEST SET UP (LAB APPROACH)

Figure 2 (a) and (b) illustrates a bespoke laboratory based OTA test set up for MIMO evaluation, based on a facility called a Reverberation Chamber (RC).

The test setup for the RC consist of the same 1-5 requirements as those listed for the generic OTA test set up.

In addition, the RC is seen to have rotational paddles that are installed on the inside of the chamber. The purpose of these paddles is to introduce variations on the wave and electromagnetic field behaviour inside the chamber as a function of time.

It has been shown that the time varying behaviour in the RC can map to a variety of conditions witnessed in real physical (outdoor) environments which include velocity related Doppler variations [2 - 4].

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[2] Where: λ = speed of light (m/s) divided by operational frequency in hertz. This is specified at the centre frequency of operation.

Figure 2 (a): Reverberation Chamber - External View[3]

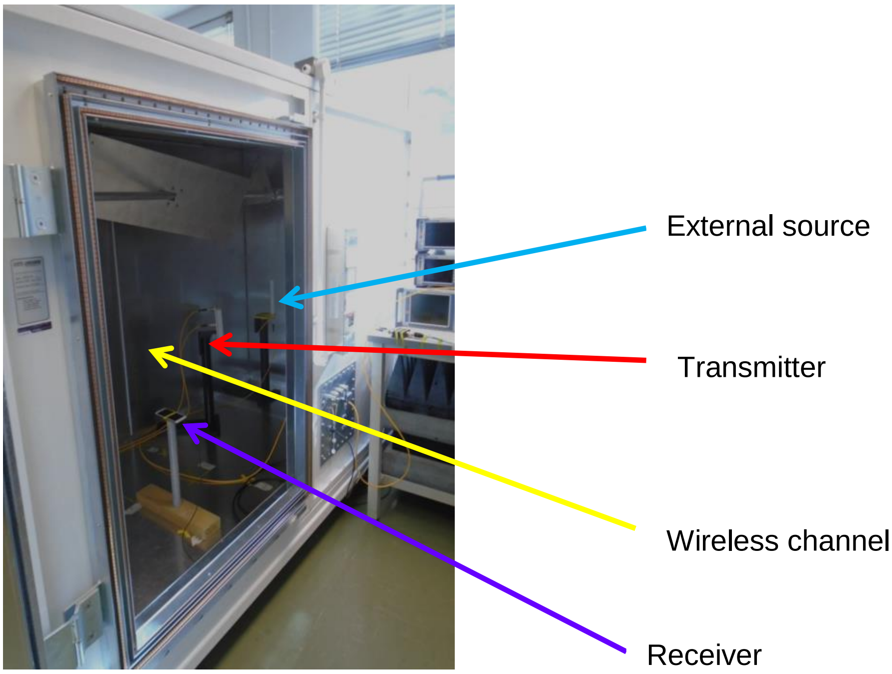

Figure 2 (b): Reverberation Chamber - Internal View

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Defence Science and Technology Laboratory

The following test and measurement challenges are to be noted and avoided.

- When measuring under Line of Sight (LOS) assumptions with single transmitting antennas, note that cell phones typically have complex radiation pattern characteristics and a multitude of receive antennas embedded on the phone chassis.

- In practice, it can be difficult to achieve sufficiently repeatable results under LOS conditions as relatively small movements in the handset can translate into many dB's difference in received power owing to the complex nature of the (cell) antenna patterns.

- LOS conditions with absolutely no reflections would seldom be witnessed in a real world environment[4]. For accurate testing, a means of including time and frequency varying channel effects into the testing method is required.

- Typically, LTE operational UEs will employ receive diversity techniques to overcome multipath propagation effects and add robustness to the received signal level.

  The overall receive diversity performance of a typical handset is a function of the available number of antennas, the correlation between each of the antenna ports and the receive diversity combination scheme selected, but additional signal performance increases of over 10 dB are not uncommon and may be much higher[5] in practice. For accurate assurance, it is important that this is adequately exercised to understand the full range of network and handset performance.

- Bench test set ups that couple energy directly into a phone chassis either in a near field condition or tapped into the port slots on the cell phone chassis which bypass the antennas and also neglects the behavior of the channel are not to be considered recommended practice.

  To fully understand network and ECM system performance, the accurate behaviour UE, the transmission streams from the eNodeB, the time and frequency varying effects of the wireless channel as well as all associated antennas must be included in OTA testing results.

- OTA test methodologies form a recommended part of international test standards for commercial networks and handset performance [1, 6]. This has directly influenced recommendations in this work.

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[4] High Ricean K factor conditions will exist when very close to base station antennas.

[5] The theoretical two port maximum assuming Selection Combining (SC) techniques is 10.2 dB. This increases to 15 dB for use of Maximal Ratio Combining (MRC).

CHAPTER 3 ANALYSIS OF MIMO CONFIGURATIONS & VARYING TRANSMISSION MODES

Various LTE Transmission Modes (TM) exist which adaptively select to communicate with handsets depending on the signal quality, link speed and other related factors [4]. The boundaries between what TM are applied in practice is difficult to distinguish in advance and may vary between geographical locations as the adaption is often left to vendor implementation [5].

Some recommended base station settings are listed in Table I with reference to the 3GPP standards in [6]. Settings for the operating frequency bands, DL bandwidths have been omitted – these should be selected accordingly based on national operational requirements.

Table I: LTE eNodeB Recommended Base Station Test Settings [6].

eNodeB (Base Station) Settings	Value
Connection mode	Phone connected
DL MIMO mode	2 x 2 open loop spatial multiplexing (TM 3)
Duplex mode	FDD
DL bands	To be selected according to national requirements
Modulation DL	64 QAM
Number of resource blocks / DL	50
Number of HARQ transmissions	1
DL power level	To be set at the eNodeB according to national requirements
Channel configurations	See requirements in section 4

LTE network configurations are adaptable and can exploit various technical parameters in different ways to improve and maximise the performance of data over the radio channel. To provide adequate assurance, it is important to understand the performance ‘sensitivity’ of the network and the performance of each nations system in conjunction to varying network configurations. Ultimately, this provides confidence in a deployed system capability.

In addition to the parameters listed in Table I, additional network configurations must also feature in testing as detailed in Table II. The purpose of additional configurations is to understand the ‘sensitivity’ of system capabilities to varying network configurations and any performance variations.

The additional parameters have been selected as a trade-off between testing complexity and time taken for understanding the sensitivity and variation of installed network performance. Overall, it remains the responsibility of individual nations to fulfil their own national assurance requirements and to test accordingly.

Table II: Additional Recommended LTE Parameters for System Sensitivity Analysis.

eNodeB (Base Station) Settings	Value
Connection mode	Phone connected
Additional DL MIMO modes	TM2 (Transmit Diversity), TM4 (Closed Loop spatial multiplexing), TM5 (Multi-user MIMO)[6]
Duplex mode	FDD
Number of transmit channels	Maximum number that test system can effectively handle (commercial base station emulators will allow for at least 4 transmit channels[7])
Additional modulation DL	QPSK
LTE handsets (UE)	Nations to select based on individual requirements

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[6] No higher order TM for direct beamforming has yet been included until mature and agreed measurement procedures in International standards become fully available (3GPP rel 13 does feature some discussions). This will change in progression towards 5G and future versions of this document and testing recommendations will expect to test this feature.

[7] Correct at the initial time of writing (first drafted Nov 2019).

CHAPTER 4 THE INCLUSION OF CHANNEL EFFECTS & ACCOUNTING FOR VARIATIONS IN THE CHANNEL

This chapter addresses requirements for LTE UEs but recommendations made for the channel characterisation will also suit MIMO radio communications in general.

LTE mobile / cell phones do not necessarily operate under the premise of a direct LOS scenario[8]. The antennas inside these phones might seldom 'see' a base station and are expected to work perfectly in a Non LOS environment [7]. This type of environment readily gives rise to signals that are exposed to reflections caused by large smooth objects, diffraction effects caused by the edges of sharp objects and scattering effects caused by small or irregular objects [7].

When these effects occur, they cause the creation of additional wave paths which eventually combine on the receive side according to the superposition principle (i.e. they will add). These wave contributions have independent complex amplitudes (i.e. magnitude and phase information), such that at recombination, they may add constructively, destructively or anything between these two extremes [7].

The wave paths and their complex amplitudes are also subject to rapid changes with time, with the environment (communication channel) constantly changing. This brings about variations in the signal at the receiver which is referred to as ***fading***. The largest variations occur when there is a complete block on the LOS which is more accurately referred to as large-scale fading as opposed to small scale fading which considers variations in the distance only or from part shadowing [7].

The provision of diversity is exploited by the network and UE to add robustness to the wireless links and overcome destructive multipath propagation / interference effects. On the receive side, this works by having a multitude of receive channels (antennas) available which are sufficiently uncorrelated from one another. Many streams of data are received which can be post-processed to mitigate any destructive channel effects – common techniques include Maximal Ratio Combining (MRC), Selection Combing (SC) and Equal Gain Combining (EGC). Please see [7] for further in-depth details.

The exact behaviour of the 'channel' is a function of the deployed network characteristics, its geographical location, frequency, and the time varying environmental conditions that exist. Overall, this behaviour will differ from network to network, location to location.

To adequately understand network and UE performance, it is vitally important that different channel conditions are emulated to understand wider system performance in the presence of varying network and channel conditions.

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[8] Statement is valid when not considering any specific beamforming techniques or algorithms. This may be subject to change as communication protocols advance towards 5G and 6G in the future where direct beamforming techniques are expected to feature more prominently.

The 3GPP and Cellular Telecommunications Industry Association (CTIA) standards [1, 8] have agreed on a series of channel models for use in the evaluation of LTE and MIMO behaviour which can be found in Table III. The models consist of Clustered Delay Lines (CDL) and some simplified cluster models. These form the subsequent testing recommendations for LTE to examine the performance of the network under varying ‘channel’ conditions.

A number of spatial clusters have also been defined which may be selected and configured according to individual test set ups.

Table III: 3GPP and CTIA Recommended Channel Models for MIMO and LTE Evaluation [1, 8].

Model Test Number	Description	Model Name	Typical Number of Spatial Clusters
1	Generic model	SCME urban micro cell	6
2	Generic model	Modified SCME urban micro cell	6
3	Generic model	SCME urban macro cell	6
4	Generic model	WINNER II outdoor to indoor	12
5	Single cluster	SCME urban micro cell	1
6	Single cluster	Extended Pedestrian A (EPA)	1
7	Uniform model	Extended Pedestrian A (EPA)	1
8	Uniform model	Exponential decay	1

In addition, in line with discussions and measurement campaign results presented in [9 - 11], ensuring that LTE network performance is adequately validated under the presence of varying fading profiles and K factor conditions in Table IV are also recommended.

Table IV: Fading Profiles to Consider

Profile Number	Fading Profile	Typical K Factors
1	Rayleigh	<1 but <<1 (ideally)
2	Ricean	1-10

Guidelines and procedures from the CTIA and 3GPP standards recommend that channel models and varying K factor[9] (fading) conditions can be configured by use of dedicated channel emulators which apply mathematical models to the signalling as opposed to the modification of electromagnetic ‘field’ behaviour. Set up procedures are detailed in Annex B.

With the appropriate tests configured and each nation’s systems tested in the presence of varying network characteristics, this will impact positively on the level of assurance and understanding of each fielded system. This will be achieved as the ‘sensitivity’ of technique and equipment performance will be more widely understood in the presence of characteristics likely faced in real life operational settings.

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[9] Defined as the ratio of direct power to scattered power.

ANNEX A CHANNEL MODELS & TRANSMISSION MODES

This appendix section provides further detail on the referenced channel models and the meaning of transmission modes.

A.1. CHANNEL MODELS

Commercial networks and UEs are evaluated over a given number of channel realisations. Computational costs and measurement complexities do vary with the testing method selected which has led to the development of Geometry based Stochastic Channel Models (G-SCM). These models look to emulate multipath effects in a cluster form (i.e. where groups of rays propagate along a similar path), where the underlying idea is to physical place multiple directional ‘clusters’ around a handset to theoretically replicate the physical scattering effects that occur from objects in real channel environments [11].

The Spatial Channel Model (SCM) was originally designed for evaluating multi antenna systems and algorithms [11]. The extension to SCM – Spatial Channel Model Extension (SCME) was proposed and developed to principally extend channel bandwidth and add additional intra wave paths [11].

Two levels of models for SCM can be defined: *Link level model* and *System level model*. Link level models are associated with a snapshot of the channel characteristics are not usually considered sufficient for understanding system behaviour. The system model is essentially a multi-link model which provides for the performance evaluation in which the link provides for a sector within a given cell [11].

Figure 3 illustrates the system model concept for one cluster.

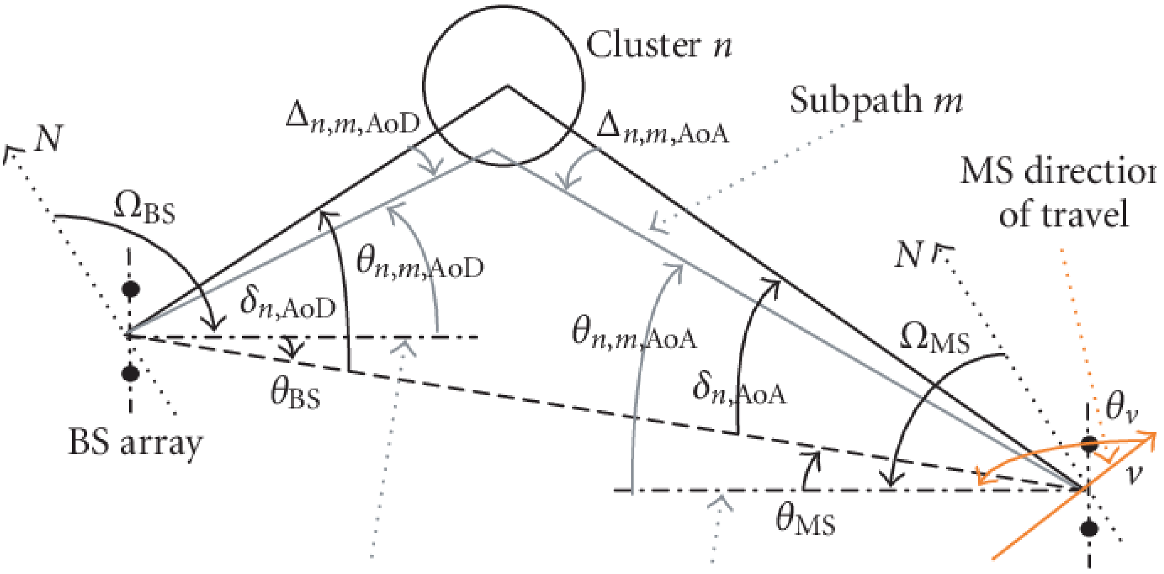


Figure 3: One Cluster SCM Channel Model [12].

The SCM concept provides for three classes of environments:

a) **Urban macro-cell:** Emulates a scenario where the user or handset is in a very reflective (urban type) environment and a certain distance is present between the UE and the BS.

b) **Suburban macro-cell:** The model provides for a reduced delay spread and is typically employed for modelling low density environments.

c) **Urban micro-cell:** Emulates a case whereby a user or UE is in a reflective environment and being serviced by a BS which is in relatively close proximity (stated typically within walking distance of… [11]).

The extension to SCME provides additional frequency applicability to the 5 GHz band [11]. The path loss data inherent in the model has been modified from the original SCM formulation, and has a stated distance applicability range from 0.02 – 5 km [11].

The WINNER II model has been developed from measurement results and describes the channel propagation as a sum of difference paths regrouped into clusters [11]. The cluster is stated to have the same properties in terms of power but had different delays [11]. These delays result from the wave paths having interacted with obstacles that are within the channel.

Figure 4 illustrates the concept.

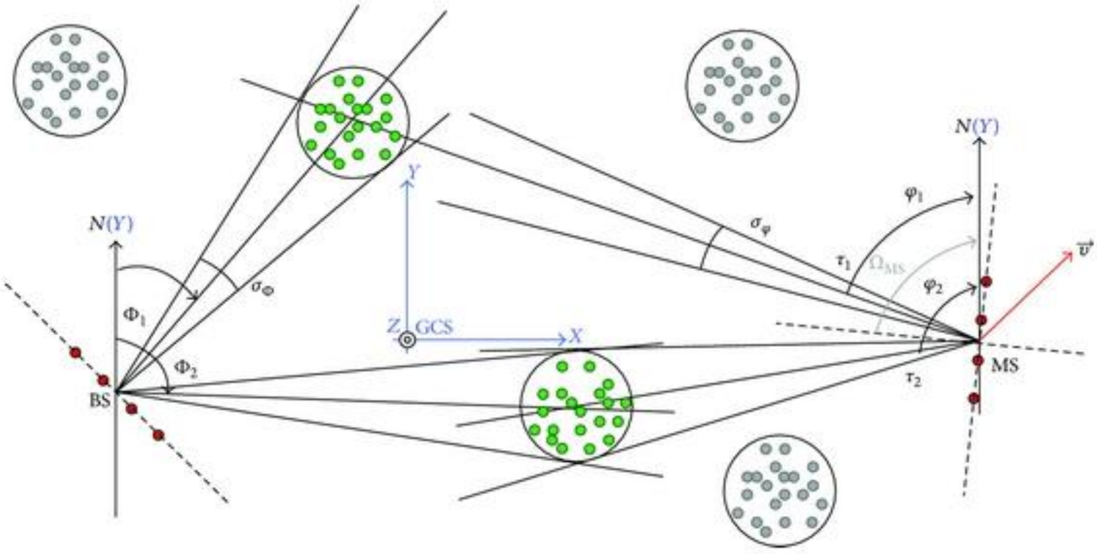


Figure 4: Single Link in WINNER II Channel Model [13].

The WINNER II model is an extension to the original WINNER model to extend the applicability to the range 2-6 GHz and up to 100 MHz bandwidth [11].

Extended Pedestrian A:

The Extended Pedestrian A (EPA) channel model can be considered as a category of a multipath fading model having pre-defined delay profiles. The delay profile is stated to represent a low delay spread environment [14].

Table V issues the tap delays Vs the relative power profile for the model, whilst Figure 5 illustrates the model form.

Table V: EPA Delay Profile [14]

Excess Tap Delay (ns)	Relative Power (dB)
0	0
30	-1
70	-2
90	-3
110	-8
190	-17.2
410	-20.8

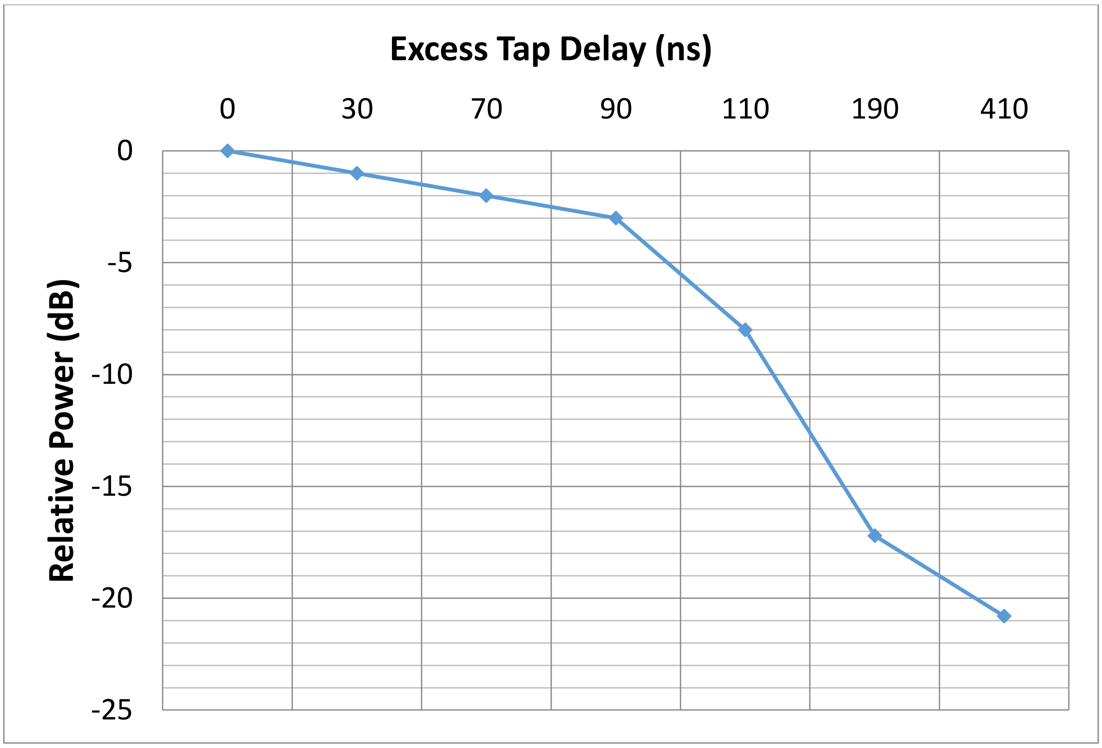


Figure 5: EPA model form [14].

Exponential Decay:

An exponential decaying channel model is one simply where the power delay profile has the form of an exponential function (i.e. it decreases at a rate proportional to its current value). Figure 6 illustrates this form which has been measured in a reverberation chamber for different channel conditions (corresponding to different emulated delay spreads).

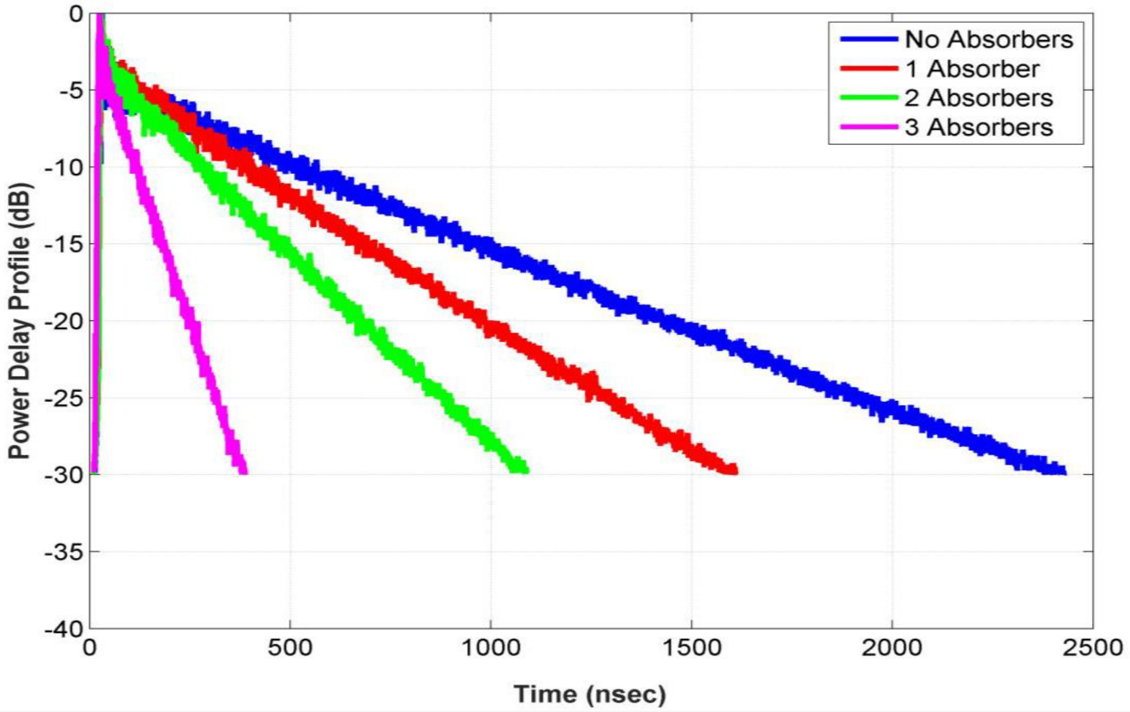


Figure 6: Exponential Decaying Channel Model – extracted from [15].

A.2. TRANSMISSION MODES

The following summarises details and the meaning of different transmission modes in LTE according to [16].

TM 1 – Single Transmit Antenna: This mode uses only one transmit antenna and one transmit channel.

TM 2 – Transmit Diversity: Transmit diversity is the default MIMO mode. It sends the same information by various channels whereby each channel uses different coding and different frequency resources. This is stated to improve the Signal to Noise Ratio (SNR) and makes transmissions more robust.
In LTE, transmit diversity is used as a fallback option when other transmission modes cannot be used (such as spatial multiplexing). Control channel such as Physical Broadcast Channel (PBCH) and Physical Downlink Control Channel (PDCCH) are also transmitted using transmit diversity [16].

TM 3 – Open Loop Spatial Multiplexing: This TM supports spatial multiplexing of two or four layers which are multiplexed onto two or four antennas to achieve increases in data rates. The TM is used when Channel State Information (CSI) is missing or when the channel is subject to rapid changes [16].

TM 4 – Closed Loop Spatial Multiplexing: This TM supports the same layers as TM 3 but allows for channel estimation functionality. To allow for channel estimation at the receiver, cell specific reference signals are transmitted by the base station which are distributed over various resource elements and over various timeslots. The UE or handset sends a response to indicate channel condition which includes information about which precoding is preferred from a defined codebook [16].
This preference is accomplished by use of an index in the form of a Precoding Matrix Indicator (PMI) which is defined in the codebook and which is known to both sides (Tx and Rx) [16].

TM 5 – Multi-User MIMO
TM 5 is similar to TM 4 in that codebook based closed loop spatial multiplexing is configured. However, one layer is dedicated for one UE [16].

A generalised scenario of configured TM for LTE advanced based on UE speed and UE Signal to Interference Noise Ratio (SINR) was discussed in [5] and showed an example of the levels of network reconfigurability; this is replicated in Figure 7. Real deployed networks cannot be guaranteed to always behave in the manner shown and should not be relied upon as such.

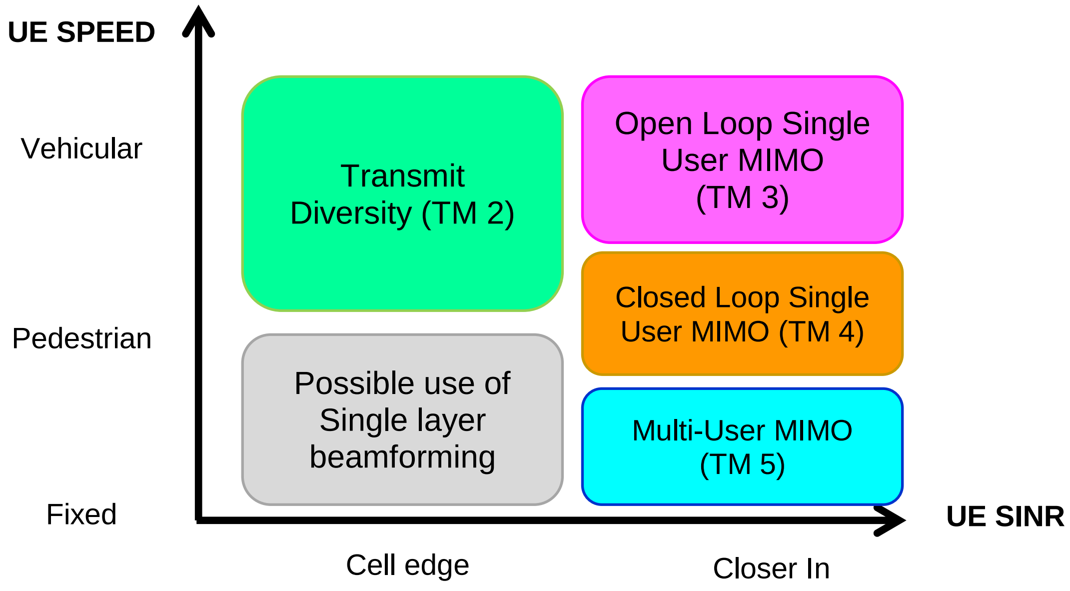


Figure 7: MIMO Modes in LTE Advanced Selected on the Basis of UE SINR and Speed [5]

As network evolution progresses more towards 5G and mm-Wave frequencies, one possible change expected will be the greater application of beamforming techniques closer into the base station.

A.3. REVERBERATION CHAMBER & CHANNEL EMULATION

For in-depth theory and measurement procedure discussions for the reverberation chamber please see [7, 15]. This appendix section will simply describe a key aspect associated with channel sounding and the reverberation chamber which is important to note.

It is commonly accepted that when conducting wireless measurements in the reverberation chamber, there is a statistical contribution from the chamber on any measured forms [15]. In section four, a series of channel models have been described for testing – when emulated in the RC, the resultant final channel model achieved for different methods will be a combined effect of the chamber and the channel emulator [1].

By use of the chamber itself, a single decaying exponential power delay profile can be emulated (thereby fulfilling test model number 8 from Table III). In addition, by sole operation, the Doppler variation that can be emulated is finite based on the maximum rotational speed of the installed stirrers [1].

The above constraints can be eliminated by use of a channel emulator which is cascaded with the RC [1]. The channel emulator is programmed to modify the fading taps at the desired excess delays, with the result being a convolution of the channel emulator and the reverberation chamber (sole) response [1].

The following conditions and acceptance has been reported by the 3GPP standards:

“The benefit (of using channel emulators) is testing with a much higher maximum Doppler, on the order of 100 Hz or higher, than is possible with the reverberation chamber alone. Under these conditions, the reverberation chamber-induced fading will effectively be constant while the channel emulator-induced fading will dominate. Therefore, while a receiver’s performance under such circumstances will definitely be different than under normal Rayleigh fading conditions, it should not undermine the receiver’s ability to demodulate. Tests have shown that this is indeed the case [1]”.

Therefore, from a testing standards viewpoint, the cascaded use of reverberation chambers and channel emulators for MIMO and LTE OTA measurements has foundation.

ANNEX B CHANNEL EMULATOR SET UP PROCEDURES

Figure 8 details a generic block diagram of how to set up a channel emulator for a given measurement.

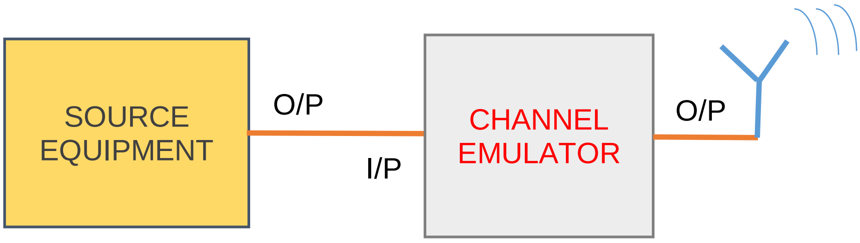


Figure 8: Channel Emulator Set Up

The following details have been produced assuming a Keysite Propsim channel emulator [17]. Note that the output of the channel emulator can be used to drive more than one antenna feed if required. For configuration of a channel emulator, the unit is usually connected to a laptop (not shown). Source equipment block can represent a commercial base station or a military system.

The following detail show how a general profile can be configured and called. The channel emulator should feature the channel models described in Annex A.

The emulation can be generated in two ways using the scenario wizard or Geometric channel Modelling (GCM) tool.

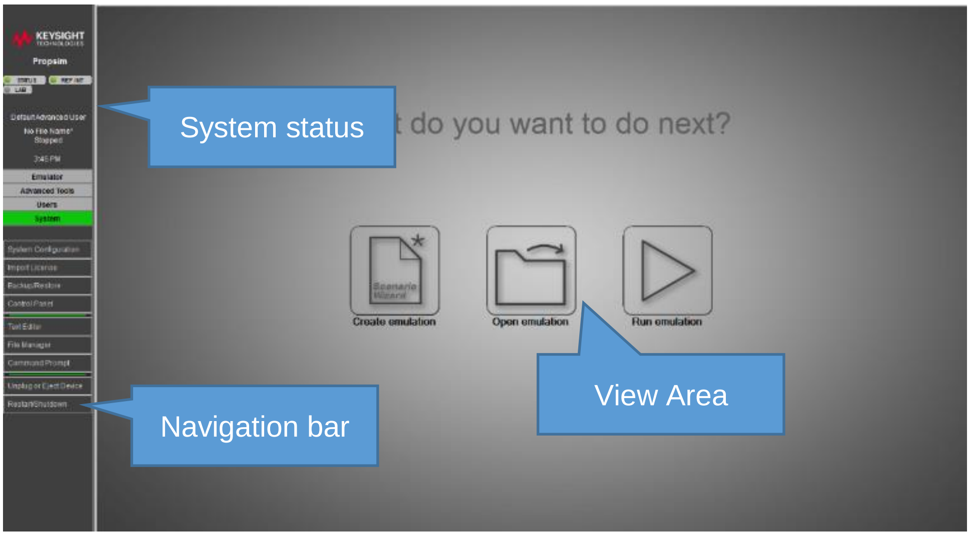
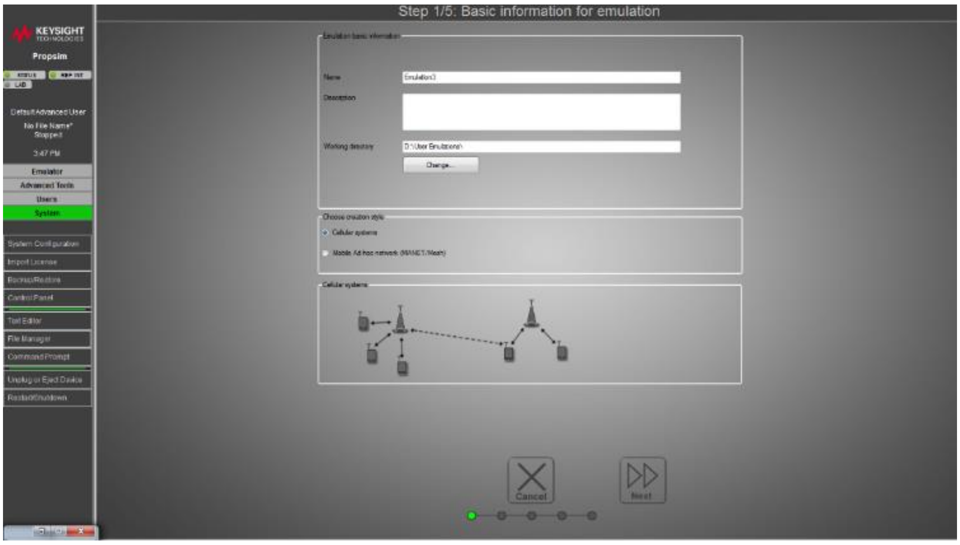


Figure 9 Emulator Home View

- The GUI is divided into navigation bar, view area and system status.
- To create a new emulation with emulation wizard use the create emulation tab.
- To open a pre-sorted emulation use the open emulation tab.

- The run emulations tab is used to load and run emulations, recently used, pre-stored and new emulations can run using this tab.



Step 1/5: Basic information for emulation

Emulation basic information

Name: Emulation3

Description:

Working directory: D:\User Emulations\

Choose creation style

● Cellular systems

○ Mobile Ad hoc network (MANET/Mesh)

Figure 10 Scenario Wizard, first step of creating emulation

- In Figure 10, the user can modify the name and description of test scenario and also change the working folder.
- The user may select any technology they intend to use for the creation style, there are two typical options: cellular systems or Mobile adhoc
- Depending on the on the Propsim Model being used, the user can also select the required bandwidth

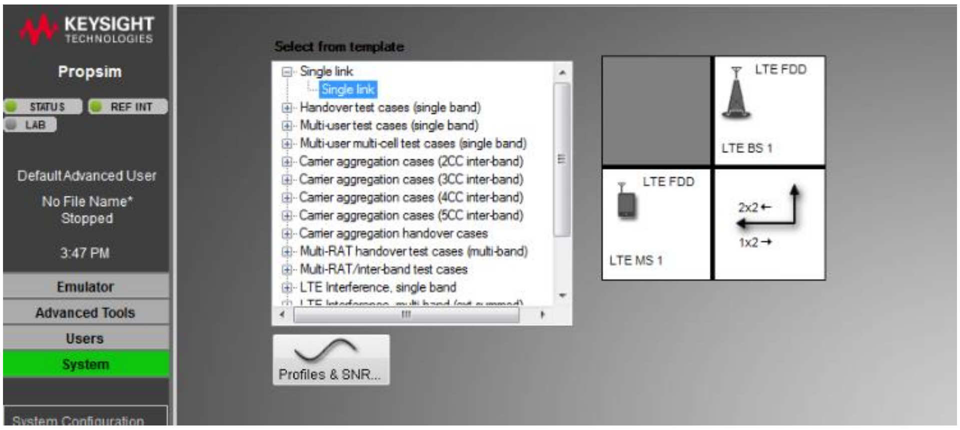
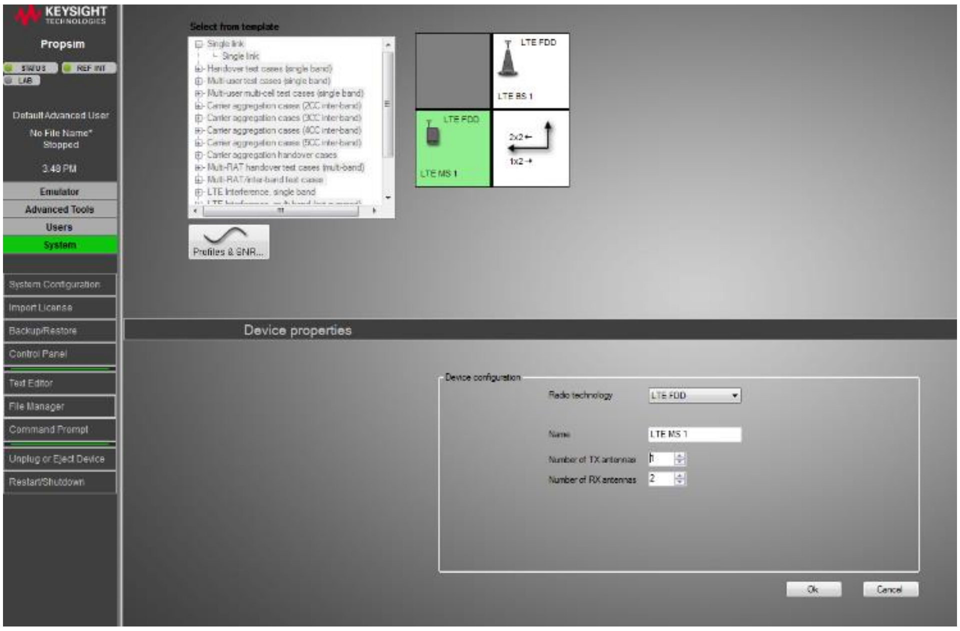


Figure 11 Link selection

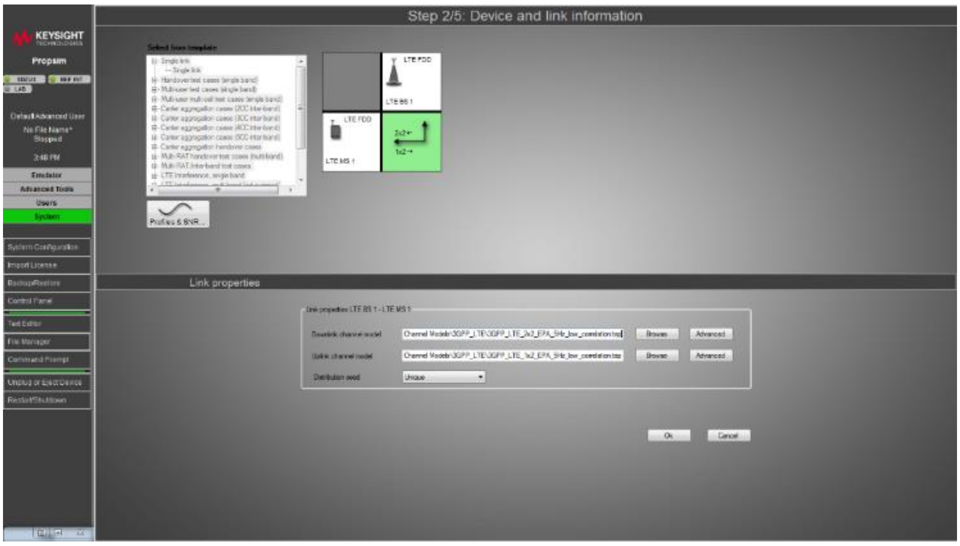
- The next step is to define appropriate test setup for the emulation, the default template is for a “single link”; i.e. one Base station (BS) and one mobile station (MS) or UE using earlier adopted terminology - please see Figure 11.



Radio technology: LTE FDD
Name: LTE MS 1
Number of TX antennas: 1
Number of RX antennas: 2

Figure 12 (MS or UE) properties

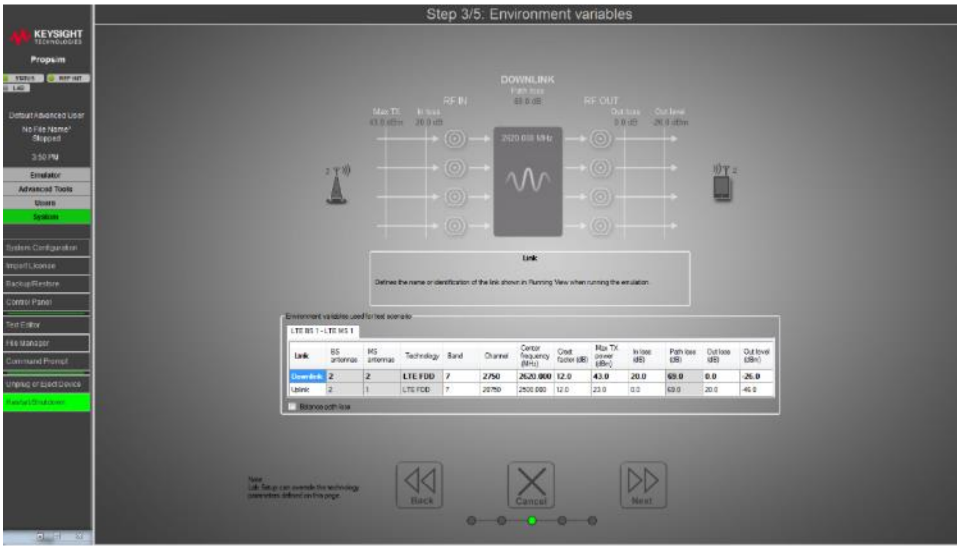
- The desired radio technology can be selected from the dropdown list, this predefines common environment variables in the test scenario (e.g. crest factor, maximum transmit power)
- The number of transmit and receive antennas define the MIMO dimensions of the uplink and downlink, configure and press ok to close device properties.



Downlink channel model: Channel Models\3GPP_LTE\3GPP_LTE_2x2_EPA_5Hz_low_correlation.bsp
Uplink channel model: Channel Models\3GPP_LTE\3GPP_LTE_1x2_EPA_5Hz_low_correlation.bsp
Distribution seed: Unique

Figure 13 link properties

- Default channel models are selected automatically from the installed standard channel models packages depending on the radio technology and antenna configuration.
- To change channel model for any uplink and down link the click browse to select the desired channel model.



Link

Defines the name or identification of the link shown in Running View when running the emulation.

Environment variables used for test scenario

LTE BS 1 - LTE MS 1

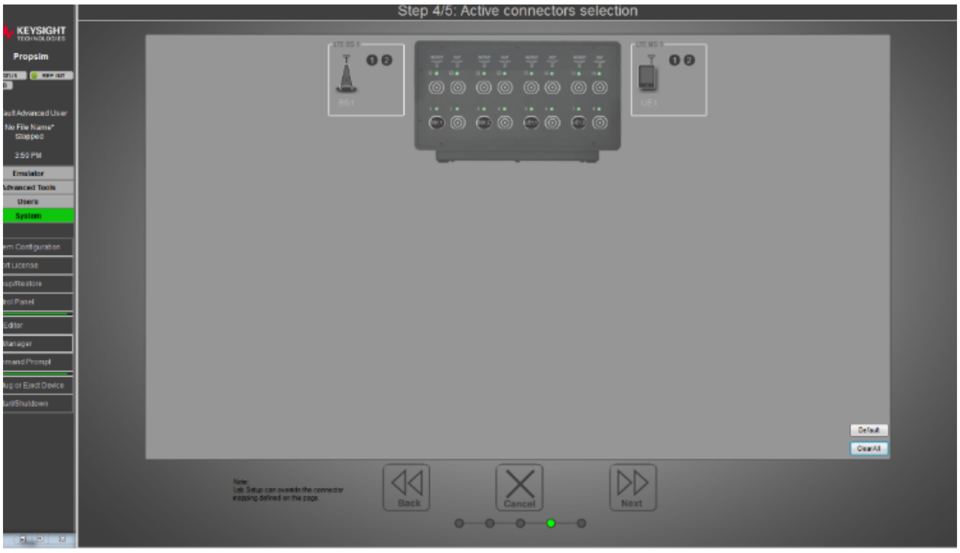
Link	BS antennas	MS antennas	Technology	Band	Channel	Center frequency (MHz)	Crest factor (dB)	Max TX power (dBm)	In loss (dB)	Path loss (dB)	Out loss (dB)	Out level (dBm)
Downlink	2	2	LTE FDD	7	2750	2620.000	12.0	43.0	20.0	69.0	0.0	-26.0
Uplink	2	1	LTE FDD	7	20750	2500.000	12.0	23.0	0.0	69.0	20.0	-46.0

☐ Balance path loss

Note:
Link Setup can override the technology parameters defined on this page.

Figure 14 Predefined emulation environment variables

- Figure 14 shows a representation of a predefined environment variable for a bi-directional 2x2 MIMO channel emulation.
- To set the environment, the user should configure the following steps:
- Change downlink and up link centre frequencies.
- Change downlink and uplink max transmit powers.
- When the emulation is set to use bi-directional links the RF IN/OUT connectors should be used as the in-loss value for the down link is changed when the uplink is changed and vice versa.



Note:
Link Setup can override the connector mapping defined on this page.

Figure 15 Active Connectors selection

- Figure 15 shows the active connector of the emulation. This depends on the number of antennas that have been selected for the BS and MS (or UE)

Step 5/5: Summary

Basic info

Emulation name: Emulation3
Emulation description:
Emulation working directory: D:\User Emulations
Radio technology: LTE FDD

Downlink

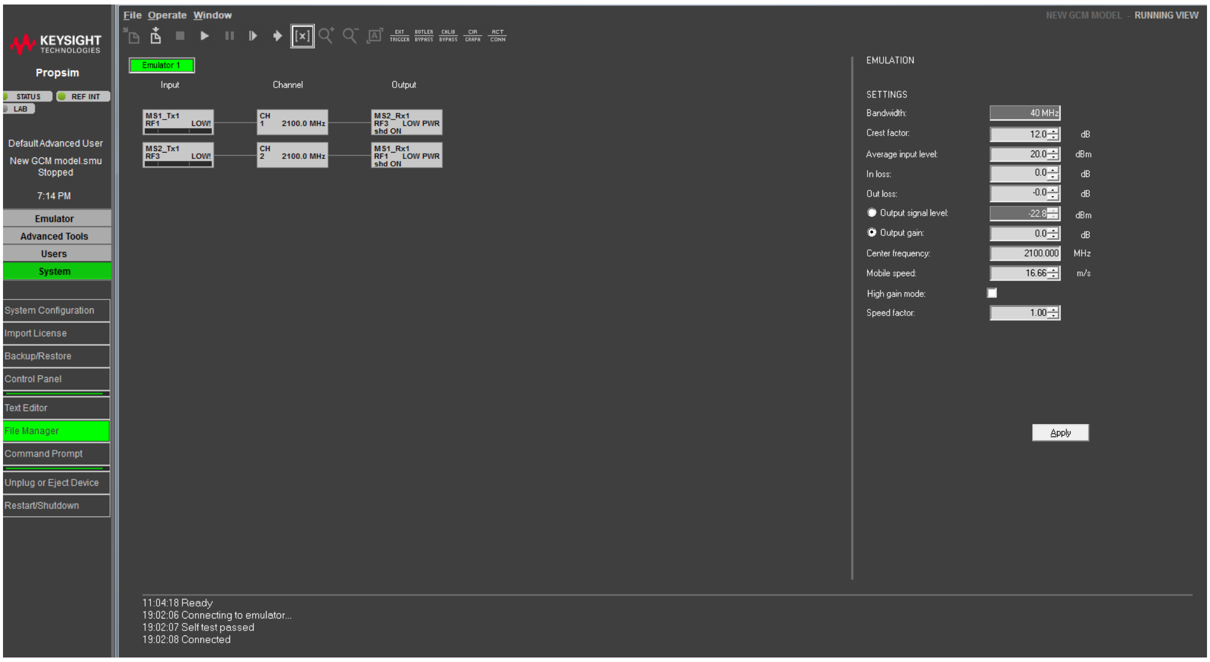
Number of Tx antennas: 2
Number of Rx antennas: 2
Center frequency: 2620.000 MHz
Channel model: 3GPP_LTE_2x2_EPA_5Hz_low_correlation.tap

Uplink

Number of Tx antennas: 1
Number of Rx antennas: 2
Center frequency: 2500.000 MHz
Channel model: 3GPP_LTE_1x2_EPA_5Hz_low_correlation.tap

Figure 16 Example of Emulation Summary

- In Figure 16, the user has the option to go back to modify previous sections or cancel.
- When the 'finish emulation' button has been clicked user will have options to:
- Finish and build emulation, save emulation and build it.
- Finish and run emulation, build it and open to the running view.
- Finish: save emulation.



EMULATION

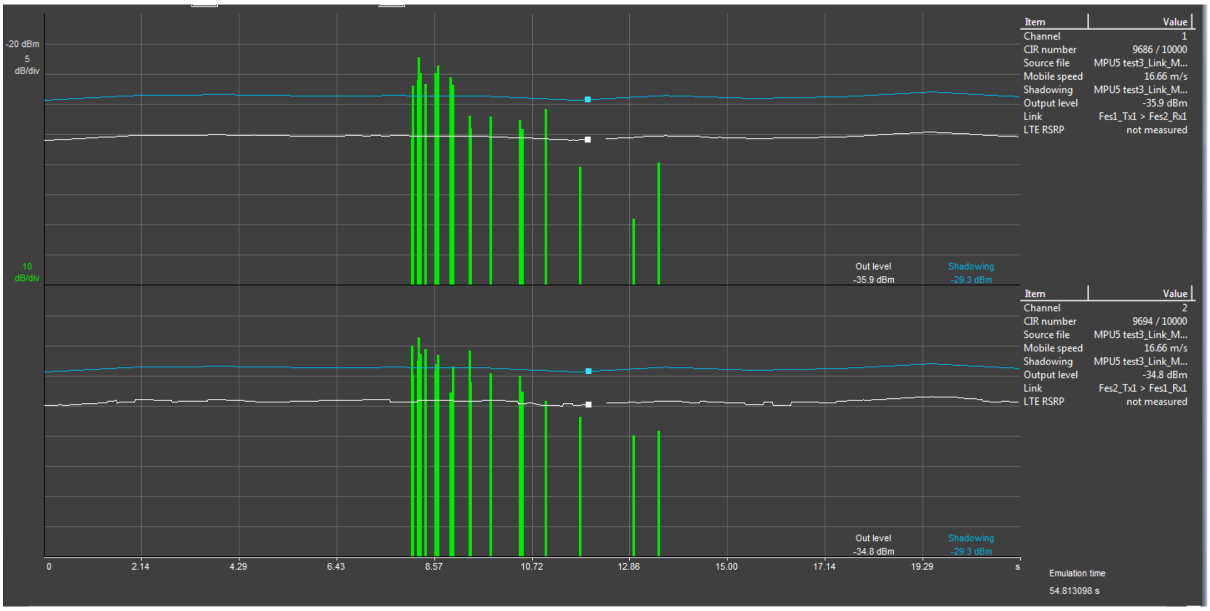
SETTINGS

Bandwidth: 40 MHz
Crest factor: 12.0 dB
Average input level: 20.0 dBm
In loss: 0.0 dB
Out loss: -0.0 dB
○ Output signal level: -22.8 dBm
● Output gain: 0.0 dB
Center frequency: 2100.000 MHz
Mobile speed: 16.66 m/s
High gain mode: ☐
Speed factor: 1.00

```
11:04:18 Ready
19:02:06 Connecting to emulator...
19:02:07 Self test passed
19:02:08 Connected
```

Figure 17: Example of Propsim Running View

- Selecting the play button on the tool bar will start the emulator running. This will apply to all models regardless of what tool was used to create the model
- Emulation status can be seen displayed on the top left navigation bar
- In the running view, users can control hardware emulation operations
- The user can also select to see the channel impulse response of the model



Item	Value
Channel	1
CIR number	9686 / 10000
Source file	MPU5 test3_Link_M...
Mobile speed	16.66 m/s
Shadowing	MPU5 test3_Link_M...
Output level	-35.9 dBm
Link	Fes1_Tx1 > Fes2_Rx1
LTE RSRP	not measured

Out level
-35.9 dBm

Shadowing
-29.3 dBm

Item	Value
Channel	2
CIR number	9694 / 10000
Source file	MPU5 test3_Link_M...
Mobile speed	16.66 m/s
Shadowing	MPU5 test3_Link_M...
Output level	-34.8 dBm
Link	Fes2_Tx1 > Fes1_Rx1
LTE RSRP	not measured

Out level
-34.8 dBm

Shadowing
-29.3 dBm

Emulation time
54.813098 s

Figure 18 Propsim Running view channel impulse response graph

REFERENCES

[1] 3GPP TR37.976 v11.0.0 (2012-03). 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Measurement of Radiated performance for Multiple Input Multiple Output (MIMO) and multi antenna reception for High Speed Packet Access (HSPA) & LTE terminals.

[2] J. Carlsson; U. Carlberg; A. Hussein; P. S. Kildal, “About Measurements in Reverberation Chamber and Isotropic Reference Environment”, *In Proc. IEEE 2010 Conference Proceedings ICECom, 20th International Conference on Applied Electromagnetics and Communications, Dubrovnik, Croatia, 20-23 Sept 2010.*

[3] P.S. Kildal and K. Rosengren, “Correlation and capacity of MIMO systems and Mutual Coupling, Radiation Efficiency, and Diversity Gain of their Antennas: Simulations and Measurements in a Reverberation Chamber,” *IEEE Communications Magazine*, vol. 42, no. 12, pp. 104–112, 2004.

[4] X. Chen; P.S. Kildal; J. Carlsson, "Determination of Maximum Doppler Shift in Reverberation Chamber using Level Crossing Rate". *In Proc. 5th European Conference on Antennas and Propagation*, EUCAP 2011. Rome, 11-15 April 2011.

[5] K. Linehan; J. Robson, “What base station antenna configuration is best for LTE-Advanced?”, *CommScope White Paper,* www.commscope.com/Docs/What_BSA_Configuration_for_LTE_Advanced_WP-106096.pdf, accessed 24/8/19.

[6] 3GPP TR37.977 v12.1.0 (2014-03). 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Universal Terrestrial Radio Access (UTRA) and Enhanced Universal Terrestrial Radio Access (E-UTRA); Verification of radiated multi-antenna reception performance of User Equipment (UE).

[7] S. J. Boyes. Y. Huang, “Reverberation Chambers: Theory & Applications to EMC and Antenna Measurements”, *John Wiley & Sons Ltd*, Chp.1, 2016.

[8] Extracted from www.ctia.org, accessed 2/9/19.

[9] W. Kotterman; G. F. Pedersen, “Cooperative Radio Communications for Green Smart Environments”, Chp. 11 (MIMO OTA Testing), pp. 423-468, *River Publishers Ltd*, 2016.

[10] “*Over The Air Testing of Receive Diversity and MIMO Capable Terminals*”, White Paper, Microwave Vision Group (MVG), available from: http://www.mvg-workd.com/en/system/files/whitepaper_mimo_2015_bd.pdf, accessed 03/09/19.

[11] M. Belhabib, “I*nvestigation on Radio Channel Over the Air Emulation by Multi-Probe Set Up*”, Electronics, Universite Rennes 1, 2017, English. NNT: 2017REN1S070.

[12] 3GPP, TR 25.996, “Spatial channel model for multiple input multiple output (MIMO) simulations (Rel. 6),” 2003.

[13] J. Yang; B. Ai; Z. Zhong, “Construction and Capacity Analysis of High-Rank LoS MIMO Channels in High Speed Railway Scenarios”. *International Journal of Antennas and Propagation*. 2012. 10.1109/WiCOM.2012.6478462.

[14] Extracted from http://www.mathworks.com/help/lte/ug/propagation-channel-models, accessed 4/9/19.

[15] S. J. Boyes; F. Mangurie, “*Reverberation Chamber ECM Measurement Procedures*”, DstlTR106524, UK MOD, 30 March 2018.

[16] “*LTE Transmission Modes and Beamforming*”, White Paper, Rohde and Schwarz, version 2e, 10 July 2015, accessed 5/9/19.

[17] See: https://www.keysight.com/en/pd-3036461/propsim-f32-f8-and-fs8-rf-channel-emulators?nid=-31796.1284018&cc=GB&lc=eng, accessed 8th July 2020.

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