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Tuomo Vidberg

OVER-THE-AIR TEST CONFIGURATIONS FOR MIMO IN LONG TERM EVOLUTION

TURUN AMMATTIKORKEAKOULU
TURKU UNIVERSITY OF APPLIED SCIENCES

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One of the main challenges for the mobile industry is the growing demand for the high speed mobile data. The 3GPP (3rd Generation Partner Project) is the organization that specifies most mobile data communication standards used globally. For the demand for high data rates, 3GPP has specified LTE (Long Term Evolution). One solution included in LTE among many is the MIMO (Multiple Input Multiple Output) technology.

This thesis discusses the basic features included in LTE Release 9 focusing on MIMO-technology. This thesis also discusses the MIMO-OTA (Over-the-Air) testing configurations introduced in 3GPP Technical Report 37.976. These configurations are divided into two main types: anechoic chamber-based environments and reverberation chamber-based environments. 3GPP divides these two methods into five different anechoic chamber methods and two reverberation chamber methods.

Testing MIMO-technology in LTE introduces new requirements for OTA-testing. While test requirements for GSM and WCDMA networks have included TRS (Total Radiated Sensitivity) and TRP (Total Radiated Power), the LTE MIMO testing adds the requirements for throughput testing. When using MIMO-configurations, the throughput depends on power transmitted to UE (User Equipment) that depends on the position of the UE. Addition to that, the throughput also depends on used TM (Transmission Mode). So test specifications need to include throughput tests for all TMs.

Performance of TMs and the overall performance of MIMO cannot be tested in traditional OTA-measurement chambers because the transmission channels in traditional OTA-chambers are configured to be as simple as possible, so that the power and sensitivity measurements could be repeatable. Suggestions for LTE testing chambers have included configuring the transmission channel to be more versatile. This has been achieved by methods such as using multiple antennas or including a channel emulator to the system. Using these methods, the UE's MIMO performance can be tested in different channel environments in laboratory, therefore improving possibilities for research and development.

KEYWORDS:

LTE, Long Term Evolution, MIMO, Multiple Input Multiple Output, OTA, OTA.testing, test environments, Mobile Networks

Tuomo Vidberg

MIMO:N TESTAAMINEN ILMATEITSE LONG TERM EVOLUTIONISSA

Opinnäytetyössä tutkittiin LTE-teknologian perusperiaatteita keskittyen siihen sisälletyn MIMO-tekniikan toimintaan. Opinnäytetyö tutki myös 3GPP:n TR 37.976 -raportissa esiteltyjä testausympäristövaihtoehtoja. Nämä jakautuvat 2 pääkategoriaan: kaiuttoman kammion järjestelmiin ja heijastavan kammion järjestelmiin. 3GPP jakaa nämä vielä 5:een eri kaiuttoman kammion järjestelmään ja 2:een heijastamattoman kammion järjestelmään.

MIMO-tekniikan testaaminen LTE-teknologiassa asettaa suuria vaatimuksia OTA-testaamiselle. GSM- ja WCDMA-verkkojen testaamiseen ovat riittäneet vain herkkyysmittaukset (Total Radiated Sensitivity, TRS) ja tehomittaukset (Total Radiated Power, TRP). LTE:n MIMO-tekniikka lisää testausvaatimuksiin tiedonsiirtonopeuden, joka on MIMO-tekniikkaa käytettäessä riippuvainen herkkyydestä ja lähetetystä sekä vastaanotetusta tehosta, jotka riippuvat puhelimen asennosta. Näiden lisäksi tiedonsiirtonopeus riippuu myös MIMO:n käyttämien siirtotapojen (Transmission Mode, TM) toiminnasta.

Siirtotapojen ja MIMO:n toimintaa ei pystytä testaamaan perinteisissä OTA-mittauskammioissa, sillä näissä siirtokanava on yritetty tehdä yksinkertaiseksi, jotta tehojen ja herkkyyden mittaukset olisivat mahdollisimman toistettavia. LTE:n MIMO-testauksen vaatimissa mittauskammioissa on pyritty tekemään siirtokanavasta mahdollisimman monimuotoinen. Tähän on pyritty eri ympäristövaihtoehdoissa erilaisin menetelmin, kuten käyttäen useaa antennia tai kanavaemulaattoria. Tällöin pystytään testaamaan laitteen MIMO:n toimintaa erilaisissa reaalimaailman ympäristöissä laboratorio-olosuhteissa.

ASIASANAT:

LTE, Long Term Evolution, MIMO, OTA, MIMO-OTA, Mobiiliverkot, Testaus

CONTENT

FIGURES

TABLES

LIST OF ABBREVIATIONS

Abbreviation	Explanation of abbreviation (Source)
3GPP	3rd Generation Partnership is a collaboration between groups of telecommunication associations
ACK/NACK	Acknowledgement/Negative Acknowledgement is transmitted in uplink indicating the success rate of downlink data
CQI	Channel Quality indicator is a uplink control signal indicating the quality of downlink channel
CL-SM	Closed Loop-Spatial Multiplexing is one of Transmission Modes for MIMO
DL	Downlink
EDGE	Enhanced Data rates for GSM Evolution is an improved data access for GSM network
eNB	Evolved NodeB is the base station for LTE
EPS	Evolved Package System is the core network for LTE system
E-UTRAN	Evolved-Universal Terrestrial Access Network is the air interface for LTE
FDD	Frequency Divided Duplex is name for method where uplink and downlink operate in different frequency
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Service
HARQ	Hybrid Automatic Repeat Request is an error reporting method used in LTE
HSDPA	High Speed Downlink Packet Access is an enhanced 3G mobile communications protocol for downlink
HSPA	High Speed Packet Access is combination of HSDPA and HSUPA, when packet access is used for both uplink and downlink in 3G mobile network
IP	Internet Protocol
LTE	Long Term Evolution is the access technology for EPS and the marketing name for 4G-network
MAC	Media Access Control
MCS	Modulation and Coding Scheme is a term used to denote the matching of the modulation, coding and other signal and protocol to the conditions of radio link

MIMO	Multiple Input Multiple Output is the name for multiple antenna technique used in LTE, where there are multiple transmitting antennas and multiple receiving antennas.
MISO	Multiple Input Single Output is a multiple antenna technique used in LTE, where there are multiple transmitting antennas, but just one receiving antenna
MU-MIMO	Multi User-MIMO is a multiple antenna technique where multiple transmitting antennas transmit the signal to multiple user equipment
OFDMA	Orthogonal Frequency Divided Multiple Access is the multi-carrier technology used in LTE downlink signaling
OL-SM	Open Loop-Spatial Multiplexing is one of Transmission Modes for MIMO
OTA	Over the Air
PAPR	Peak-to-Average-Power Ratio
PCFICH	Physical Control Format Indicator Channel is name for downlink physical control channel
PDCCH	Physical DL Control Channel is a downlink physical control channel
PHICH	Physical Hybrid Automatic Repeat Request Indicator Channel is a downlink physical control channel
PMI	Pre-coding Matrix Indicator is a feedback provided from UE to eNB while using TM 4
RB	Resource Block consists of 12 sub-carriers for the duration of one slot
RE	Resource Element is the smallest defined unit which consists of one OFDM sub-carrier during one OFDM symbol interval
SC-FDMA	Single Carrier – Frequency Divided Multiple Access is a technology used in LTE uplink
SCME	Spatial Channel Model Extended is an extended model for 3GPP's Spatial Channel Model. SCME includes some more features
SIMO	Single Input Multiple Output is multiple antenna method, where is one transmitting antenna and multiple receiving antenna
SINR	Signal-to-Interference-plus-Noise Ratio
SISO	Single Input Single Output is the traditional single antenna method

SU-MIMO	Single User-MIMO is the basic MIMO configuration, where there are multiple streams transmitted to one user
TB	Transport Block is synonym to slot and consists of 2 slots
TDD	Time Divided Duplex is the technique where uplink and downlink operate in same frequency, but not simultaneously
TDMA	Time Division Multiple Access is a channel access method that allows several users to use same frequency for transmission
TD-SCDMA	Time Division Synchronous Code Division Multiple Access is time divided access method for 3G networks
TM	Transmission Mode is name for MIMO-modes used in LTE
TRI	Transmit Rank Indicator is indicator transmitted from UE to eNB to determine the used modulation and transmission mode
TRP	Total Radiated Power
TRS	Total Radiated Sensitivity
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Terrestrial System is a 3rd generation mobile cellular system for networks
WCDMA	Wideband Code Division Multiple Access is the access method of 3rd mobile generation

1 INTRODUCTION

The requirement for high data rates for wireless transmission at the moment is exponentially growing and the mobile industry is trying to keep up with the market's needs. 3GPP (3rd Generation Partnership Project) is the specification organization that is constantly working on new ways to improve mobile data rates. In 2008 3GPP released a technology called LTE (Long Term Evolution) to improve the data rates.

The 3GPP's Release 9 introduced the Multiple Input Multiple Output (MIMO) technology, which is one main technology used to improve overall data rates in the mobile network. MIMO has been a cornerstone of the LTE standard, but initially, in Releases 8 and 9 multiple transmit antennas on the UE (User Equipment) was not supported because in interest of the power reduction, only a single RF power amplifier was assumed to be available. In Release 10 3GPP introduced support for multiple antennas on the UE and also a number of new schemes to LTE including CL-SM (Closed Loop Spatial Multiplexing) for SU-MIMO (Single User-MIMO). [1]

Basically the only way of testing performance of MIMO technology is performing the tests OTA. The testing for OTA has been specified for GSM and WCDMA (Wideband Code Divided Multiple Access) by 3GPP, but specifications for LTE OTA are still ongoing. Conducted testing method has some limitations, such as testing the antenna performance, which can be gone around testing user equipment Over the Air. 3GPP also implies that MIMO performance testing could also imitate field testing conditions better, when performing testing OTA.

There are seven testing environment configurations that 3GPP has suggested for implementation of MIMO-OTA testing in TR 37.976 [2]. There are two primary topologies, anechoic chamber based methods and reverberation chamber based methods. Anechoic chamber method is divided into five different configurations and reverberation chamber method is divided to two different configurations.

Globally there are few theses made on MIMO-OTA testing for LTE, but none of these have compared the methods 3GPP have suggested for testing. This is probably because the investments for company to study different environments in practice, would be radical.

This thesis briefly covers the basics of LTE technology and concentrates on MIMO technology and transmission modes used in LTE and discusses about the MIMO-OTA testing candidates that 3GPP has offered. Finally thesis compares the upsides and downsides of the test candidates.

2 LTE – LONG TERM EVOLUTION

This chapter gives an overview of the LTE technology. The chapter also goes through the evolution from GSM systems to LTE, so it would be easier to understand why and how LTE is that much different compared to other mobile baseband systems. This chapter gives sight of the LTE architecture and basic technologies used, such as radio access methods. MIMO technology is in key role in this chapter, since it has great impact on OTA testing and performance.

2.1 Evolution to LTE

LTE or the E-UTRAN (Evolved Universal Terrestrial Access Network), introduced in 3GPP Release 8, is the access technology of the EPS (Evolved Packet System). In specification the main requirements for LTE network were high peak data rates, short round trip time, high spectral efficiency as well as flexibility in frequency and bandwidth. [3]
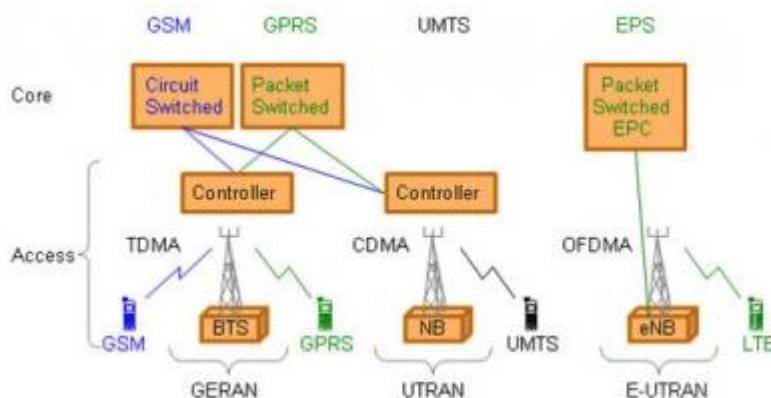

Figure 1. Network solution from GSM to LTE. [3]

Figure 1 shows the main differences in evolution of network solutions from GSM to LTE. GSM was originally developed to carry real time services in a circuit switched manner, with data services only possible over a circuit switched modem connection, which resulted in very low data rates. In evolution from GSM to GPRS

the first step towards an IP based packet switched solution was taken, while continuing the usage of the same air interface and access method, TDMA (Time Division Multiple Access). [3]

In pursuit to reach higher data rates for the next generation a new access technology WCDMA (Wideband Code Division Multiple Access) was developed for UMTS (Universal Mobile Terrestrial System). For real time services the access network in UMTS emulates a circuit switched connection and for data services a packet switched connection. In UMTS the IP (Internet Protocol) address is allocated to the UE when a data service is established and released when the services is released. [3]

The EPS and therefore the LTE is purely IP based. Real time services and data services are carried by the packet switched connection. The IP address is allocated to UE when terminal is switched on and released when UE switched off. For LTE the theoretical data rates are 300 Mbps for downlink and 75 Mbps for uplink. There are multiple methods used to achieve these data rates: the new access methods for downlink and uplink, modulations used for transmit channels, bandwidths up to 20 MHz and multiple MIMO configurations. [3]

Downlink in LTE network uses OFDMA (Orthogonal Frequency Division Multiple Access) and uplink uses SC-FDMA (Single Carrier-Frequency Division Multiple Access). The used modulations are QPSK, 16QAM and 64QAM and used bandwidths are 1.4MHz, 3 MHz, 5 MHz, 10 MHz and 20 MHz. [3]

2.2 LTE Network

The LTE access network is a network of base stations, evolved NodeBs (eNB). This generates a flat architecture which is demonstrated in Figure 2. There is no centralized intelligent controller, and the eNBs are inter-connected via the X2-interface and towards the core network by the S1 interface. The distribution of intelligence between eNBs improves the connection set-up speed and reduces the handover time between base stations. [3]
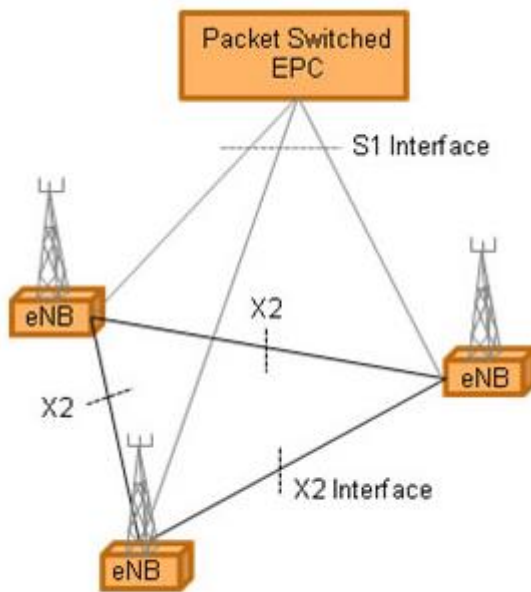
Figure 2. LTE network structure, S1 and X2 interfaces presented. [3]

Another advantage with the distributed intelligence solution gives, is that the MAC (Media Access Control) protocol layer, which is responsible for scheduling, can be only performed in the UE. [3]

2.3 Radio Access in LTE

To achieving the enable scheduling in both time and frequency domain and to achieve high spectral efficiency, a multicarrier approach was chosen for LTE. The downlink is handled with OFDMA (Orthogonal Frequency Division Multiple Access) and the uplink is handled with SC-FDMA (Single Carrier-Frequency Multiple Access). [3]
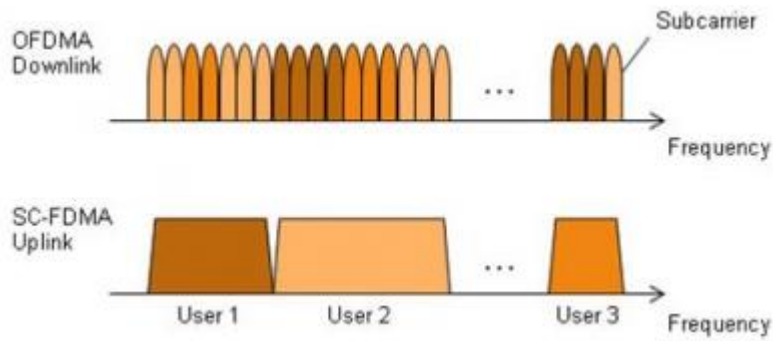
Figure 3. Frequency spectrums of OFDMA and SC-FDMA. [3]

OFDMA is a multicarrier technology where available bandwith is divided into multiple mutual orthogonal narrowband subcarriers. In OFDMA these subcarriers allocated between multiple users. The OFDMA leads to high PAPR (Peak-to-Average Power Ratio) which requires expensive power amplifiers with high requirements on linearity, this increases power consumption for the transmitter. For eNB this does not show as a problem, but for UEs this would lead to expensive solutions. [3]

As seen in Figure 3, the SC-FDMA spectrum consists of signal with single carrier characteristics, and therefore low PAPR. Flexible frequency allocation and good multipath resistance were also reason for selecting SC-FDMA for uplink signaling. [3]

2.4 Physical Channel in LTE

LTE defines a number of channels for the both DL (Downlink) and UL (Uplink). Table 1 defines DL and UL physical channels. The structure for DL (Downlink) subframe is common for both FDD (Frequency Divided Duplex) and TDD (Time Divided Duplex). [4]

Table 1. Explanations for LTE physical channels. [4]

	Channel	Purpose
DL	PDSCH	Carry user data (DL)
	Physical broadcast channel (PBCH)	Carry broadcast information
	Physical multicast channel (PMCH)	Carry multicast services
	PCFICH	Indicate the size of the control region in number of OFDM symbols
	PHICH	Carry ACK/NACK associated with UL transmission
	PDCCH	Carry DL scheduling assignments and UL scheduling grants
UL	PUSCH	Carry user data (UL)
	PUCCH	Carry ACK/NACK associated with DL transmission, scheduling request, and feedback of DL channel quality and precoding vector
	Physical random access channel (PRACH)	Carry random access transmission

This structure is shown in Figure 4 for four transmitting antennas. Each subframe consists of two slots of length 0.5 ms. Slots consists of seven OFDM symbols. The reference symbols are located in each slot. For DL the control channels are located in the first three OFDM symbols, followed by the data transmission.. Each element in the time and frequency resource grid is called a RE (Resource Element). Each DL subframe contains control information, data transmission and reference signals. PCFICH (Physical Control Format Indicator Channel), PHICH (Physical Hybrid Automatic Repeat Request (HARQ) Indicator Channel) and PDCCH (Physical DL Control Channel) provide the control signaling for DL. [5]

The scheduling assignment for DL and UL are transmitted on the PDCCH, which is addressed to a specific user. PDCCH also contains control information needed for data reception and demodulation. The data allocation is assigned for users in quantity of RBs (Resource Block). [4]
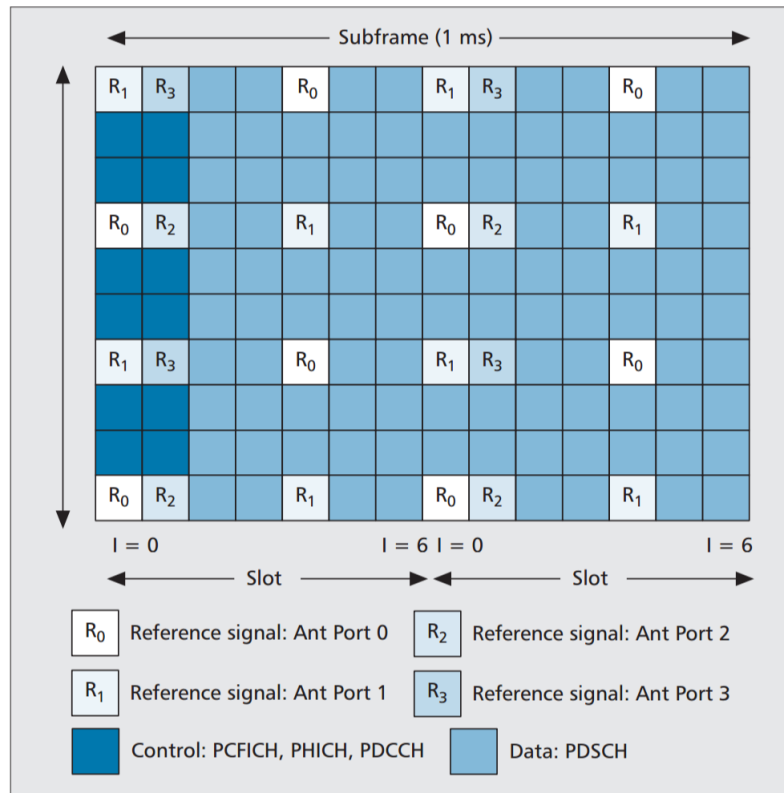
Figure 4. LTE downlink subframe structure, and the places of control channels in time and frequency dimensions. [4]

The UL subframe structure is also common for both FDD and TDD. Similar to DL subframe, UL subframe also consists two slots that are 0.5 ms long, with one reference symbol located in each slot. UL control signaling such as CQI (Channel Quality Indicator) and ACK/NACK (Acknowledgment/Negative Acknowledgment) are located in the edge of UL band. Since the UL only supports one antenna in Release 8 and Release 9, there are no reference signals for multiple antennas. The uplink subframe structure is shown in Figure 5. [4]
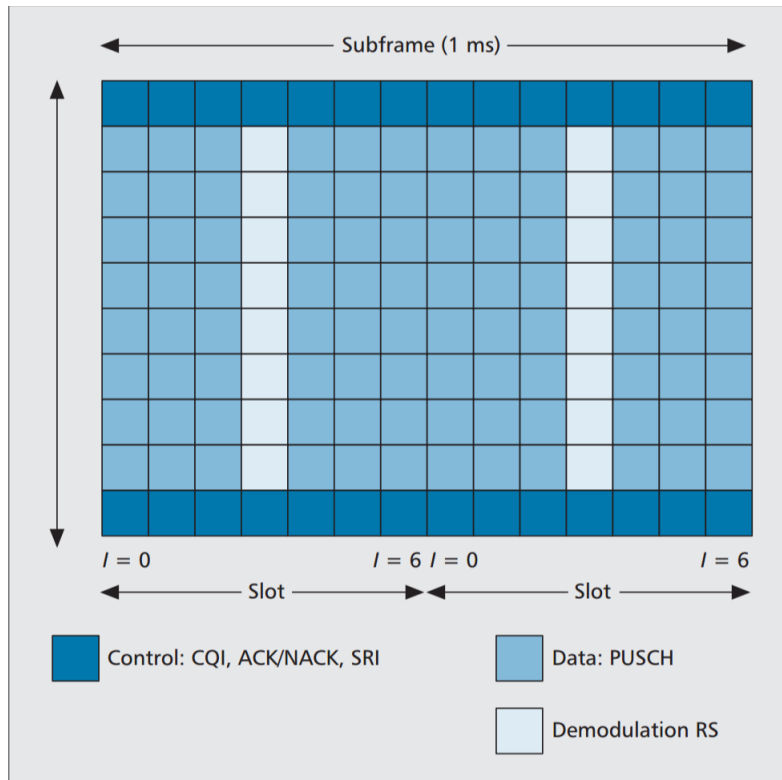
Figure 5. LTE uplink subframe structure in time and frequency dimension. [4]

2.5 MIMO Technology

3GPP introduces in Rel. 9 a multiple antenna technique called MIMO (Multiple input Multiple output) to LTE. MIMO technology was introduced to increase robustness coverage or capacity and data rate of physical layer by adding more antennas to radio system. There are four different basic MIMO configurations that can be used, shown in Figure 4. These are SISO (Single Input Single Output), MISO (Multiple Input Single Output), SIMO (Single Input Multiple Output) and MIMO (Multiple Input Multiple Output).

Figure 6. Basic MIMO antenna configurations. [6]

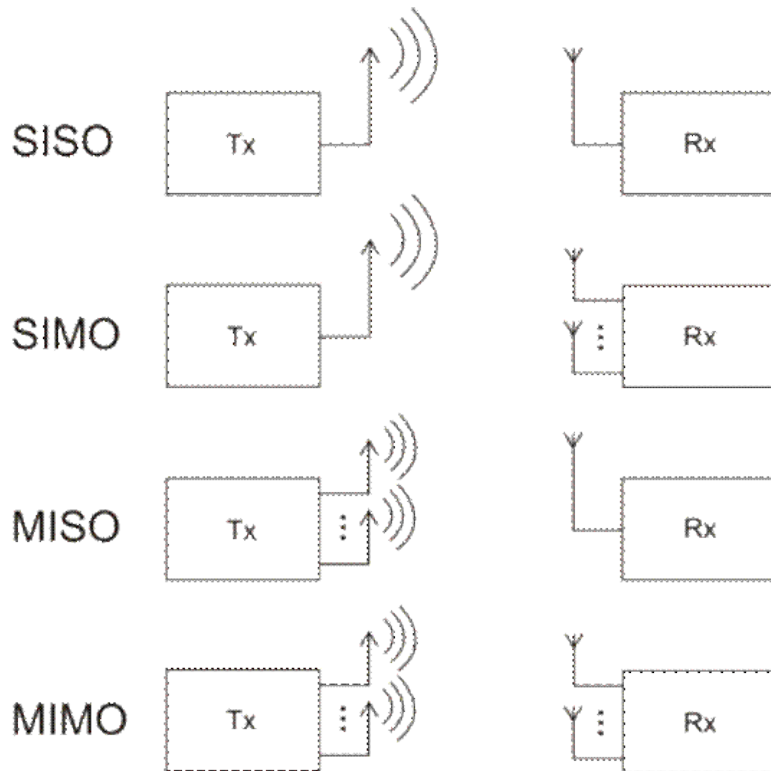MIMO can be used for two main purposes: Increasing the coverage and robustness of data transmission or increasing the data rate and capacity.

Increasing the robustness of data transmission can be done using a diversity antenna or multiple diversity antennas. These antennas transmit the same data stream as primary TX antenna increasing the SNR (Signal-to-Noise Ratio).

Increase in the data rate can be achieved using spatial multiplexing techniques. Data is divided into multiple separate streams, which are transmitted simultaneously over the same air interface. The transmission is included with special sections, also known as reference signals that are known in the receiver. The receiver can perform a channel estimation for each transmitted signal streams. While using spatial multiplexing, the space dimension is therefore used more than once, making data transfer more spectral efficient. [7]

The number of spatial layters of the radio channel is a key factor to MIMO's spatial multiplexing technique performance. The number of spatial layers determines the

spectral efficiency. Spatial layers are born from scattering environment and multipath of the channel between the transmitter and the receiver. Another key component to performance is the number of transmitting and receiving antennas. The rank is a measure of the number of independent spatial layers. Hence, a 4×2 MIMO system provides double the data rate, provided that there are two spatial layers in the wireless channel. If it is a line-of-sight condition, the channel matrix is 1, so even with four antennas the spectral efficiency of the channel cannot be increased in line-of-sight case. Also the correlation between the data streams will be too high. So there is only one spatial stream in line-of-sight situation. [7]

2.5.1 MIMO Operation

MIMO operation can be understood by using a static equivalent circuit to represent the channel. The channel for MIMO $m \times n$ system is represented as ports which demonstrate the channels amplitude and phase responses. In the Figure 7 these are marked as h_{00}, h_{01}, h_{10} and h_{11} to h_{nm}.
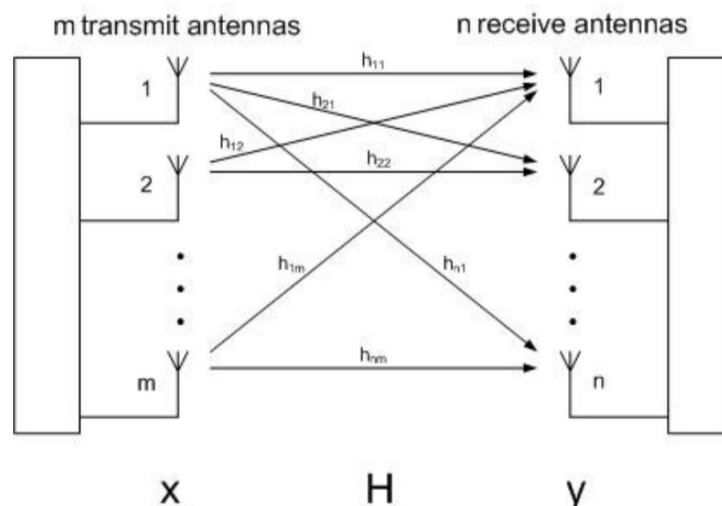

Figure 7. The presentation of coupling between antennas. [7]

As it can be seen from figure there will never be ideal case, since in ideal case signal from TX0 would go only to RX0 and signal from TX1 only to RX1. In practice, this is impossible to achieve and there will always be coupling between signals as soon as they are transmitted. Therefore the challenge is to reverse the coupling after the signals have been received. For this purpose LTE uses a "non-blind" technique. That means that pre-defined orthogonal training signals are transmitted from all transmitting antennas. The receiver knows which training signals were used for each antenna and therefore the channel amplitude and phase responses can be calculated.

2.5.2 MIMO Modes in LTE

In release 9 LTE can use seven modes of MIMO for downlink paths [7]. These are called TMs (Transmission Mode):

TM 1 – Single-antenna port; port 0: This is analogous to most current cellular systems such as GSM, GPRS and EDGE, where a single data stream is transmitted on one antenna and received by either one (SISO) or more antennas (SIMO).

TM 2 – Transmit diversity: This is the default mode in LTE. Transmit diversity mode involves the transmission of the same data stream on multiple antennas (in Release 11, LTE supports usage of up to eight antennas). [7]

This mode is used in LTE by default for the Common Channels as well as for control and broadcast channels. Since it is a single-layer it is used to make signal quality more robust and by using transmit diversity also lower SINR (Signal to Interference plus Noise Ratio) is required to decode signal rather than improving the peak data rate. [7]

In LTE, transmit diversity is used as a fallback option for some transmission modes, such as when spatial multiplexing cannot be used. Control channels are also transmitted using transmit diversity. [7]

TM 3 – Open loop-spatial multiplexing (OL-SM): In case of OL-SM, two data streams are transmitted over two or more antennas (up to 4 in LTE and up to 8 in LTE-A (LTE-Advanced)). There is no explicit feedback from the UE, although a TRI (Transmit Rank Indication) transmitted by the UE is used by the base station to select the number of spatial layers. [7]

As multiple data streams are transmitted, OL-SM provides better peak throughput than transmit diversity that transmits only one stream at a time. It is also relatively simple to implement and is one of the main modes of MIMO implemented in LTE systems. [7]

TM 4 – Closed loop spatial multiplexing (CL-SM): This mode is similar to the OL-SM, two data streams are transmitted from up to 4 antennas. The difference is PMI (Pre-coding Matrix Indicator) which is fed back from the UE to the base station. This feedback mechanism allows the transmitter to pre-code the data to optimize transmission over the wireless channel so the signals at the receiver can be easily separated into the original streams. This mode is expected to be highest performing mode of MIMO in LTE. [7]

TM 5 – Multi-User MIMO (MU-MIMO): In MU-MIMO, separate data streams are sent to spatially separated UEs over the same sub-channel, with each UE serving as one of the multiple receiving antennas. This way the overall capacity of system can be increased, though it does not increase the throughput of individual UE over single antenna technique. Same way as single user techniques, the MU-MIMO is dependent on rich scattering environment for low correlation on each UE to decode the data streams meant for that UE. In case of spatial layers are not completely orthogonal, individual users will experience interference from other users. [7]

In LTE Release 9 MU-MIMO is expected to have lower performance than SU-MIMO. [7]. As a result, MU-MIMO is not expected to be widely deployed until LTE networks are starting to become heavily loaded.

TM 6 – Closed loop Rank 1 with pre-coding: This mode represents the scenario when a single data stream is transmitted over a single spatial layer. Many consider this case to be a fall back scenario of CL-SM and it has been associated with beam-forming. [7]

TM 7 – Single-antenna port; Port 5: This is a beam-forming mode where a single data stream is transmitted over a single spatial layer. A dedicated reference signal forms an additional antenna port and allows transmission from more than 4 antennas. The terminal estimates the channel quality from the common reference signal on antennas 1-4. Linear antenna arrays are expected to be used for this mode. [7]

MIMO performance depends on a number of factors such as the signal quality which is measured by SINR (Signal-to-Interference-Plus-Noise Ratio), the state of the channel (for example low vs. high scattering environment), the speed of the mobile terminal and the correlation of the received signals at the receiver antennas. For that reason in varying environments certain MIMO modes are more efficient that other. [8]

The benefits of open and closed loop spatial multiplexing schemes are achieved when the SINR is at its highest. At the cell edge, a weak signal strength and high SNR (Signal-to-Noise Ratio) reduce the benefits of spatial multiplexing modes. In those scenarios Closed-loop Rank 1 or Transmit Diversity become more efficient. Transmit Diversity is also more attractive than CL-SM and OL-SM in environment where signal scattering is low, which could be for example rural areas. Switching between these modes as the mobile terminal moves away from cell center or the scattering environment changes is crucial for optimizing the system performance. [8]

As mentioned, the speed of mobile terminal impacts the performance of MIMO systems. In general in high speeds the CL-SM mode provides better spectral efficiency than OL-SM mode as the channel parameters are fed back to the transmitter from the receiver and used to code the data stream. However, as the speed of the mobile terminal increases and channel conditions change more rapidly,

CL-SM loses much of its advantage over OL-SM since delays and inaccuracies are affecting the channel feedback to the transmitter, therefore the transmitter cannot adjust the channel optimally. The OL-SM is also simpler to implement compared to the CL-SM, which makes it more attractive solution for developers of LTE terminals. Transmit diversity is robust to speed while its performance in low scattering environment and high SINR does not degrade as that of OL-SM. Therefore, for a vehicle moving with high speed along a highway with a clear line of sight to the base station, transmit diversity would provide the better spectral efficiency while OL-SM would be preferred when the terminal is moving at high speed in a rich multipath environment and high SINR. [8]

Spatial multiplexing schemes perform best when the signals have low correlation coefficient. As the signal correlation increases the performance of SM schemes decrease. Signal correlation is related to the scattering environment of the channel between base station and UE. So the higher signal scattering the more effective spatial multiplexing becomes. In urban areas, which are high-scattering environment, the received signal has a relatively large angular spreads, the spatial multiplexing schemes are expected to perform at their best. [8]

Signal correlation is also dependent on the placement of the antennas. The larger distance between the multiple antennas at each of the transmitter and receiver, the lower correlation and better performance of SM schemes can be achieved. This is a challenge for antenna design composing up to four downlink antennas as far away from each other into small mobile terminal.

Table 2. Simplified choice of MIMO mode in varying environments.

MIMO mode	Signal quality (SINR)	Scattering environment	Speed of terminal
Transmit diversity	Low	Low	High
Open-loop spatial multiplexing	High	High	High
Closed-loop spatial multiplexing	High	High	Low

3 MIMO-OTA TESTING

The primary Figure of Merit (FOM) in MIMO-OTA testing for LTE, is throughput. MIMO-OTA throughput is defined as the time-average of correctly received transport blocks. The MIMO-OTA throughput is measured, in the same point as in conductive measurement setup, at top of the physical layer of LTE. The eNB simulator sends fixed sized payload bits to the UE, the UE sends back either ACK or NACK to the eNB simulator. The formula to count the MIMO throughput:

$$MIMO\ (OTA)\ Throughput = \frac{Transmitted\ TBS \times Num\ of\ ACKs}{Measurement\ Time}$$

MIMO-OTA tests are performed in chamber-based environments, in which wireless channel emulators apply real-world spatial channel modes to the signals sent to antenna probes mounted in the chamber. This allows for vendor or customer to precisely characterize how well UE with MIMO can receive signals with these real-world spatial properties. [10]

3.1 3GPP Candidate Methods for LTE MIMO-OTA Testing

As a result of the 3GPP study, seven different test methods have been proposed to 3GPP in TR 37.967 [2] for creating the necessary environment to test MIMO performance. Test methods can be separated into two main groups: anechoic chambers methods and reverberation chamber methods. There are five method candidates which use anechoic chamber and two that use reverberation chamber. [2]

The anechoic and reverberation methods take fundamentally different approaches towards achieving the same goal – the creation of a spatially diverse radio channel. In anechoic chamber, multiple probes are used to launch signals at the UE in order to create known angles of arrival, which map onto the required channel spatial model. This approach is powerful, although in order to achieve arbitrary channel model flexibility, large number of antenna probes are required,

which increases the price and makes calibrating more challenging due to issues like back scattering. In case of reverberation chamber method, the spatial richness is provided by relying on the natural reflections within the chamber. These reflections can be further randomized by use of mode stirrers that oscillate to provide spatial field, which over long periods of time approach an isotropic field. The following previews of methods are collected from TR 37.967 [2].

3.1.1 Multiple Probe Method for Anechoic Chamber

The configuration for this method is shown in Figure 8. This method is conceptually the most simple since there is a direct relationship between the required angular spread of the channel and the physical location of the probes. The goal is to create the desired channel model by positioning an arbitrary number of probe antennas in arbitrary positions in the anechoic chamber equidistant from UE. All probe antennas are faded by a channel emulator to provide the desired temporal component. So the tuning the environment for specific requirement is done by moving the antenna probes around the chamber. [2]
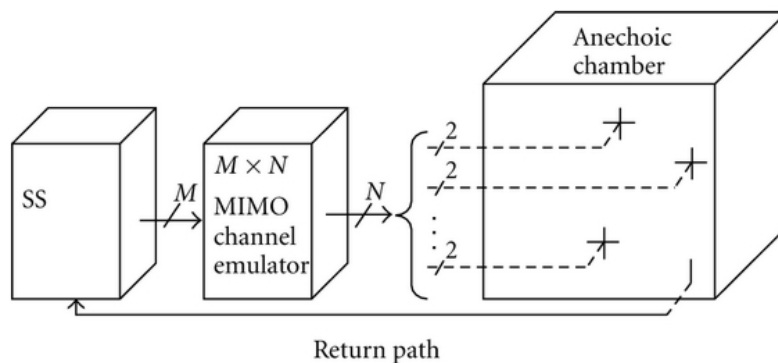

Figure 8. Basic configuration for the multiple probe method for anechoic chamber. [2]

3.1.2 Ring of Probe Method for Anechoic Chamber

The ring of probes method is based on symmetric ring of probe antennas equidistant around the UE, which is placed at the center of the anechoic chamber as

shown in Figure 9. Similar to the multiple probe method, each probe is controlled by a channel emulator to generate characteristics of the desired channel model. In the ring of probes method there is no longer fixed relationship between the probe antennas and the angle of departure. Instead, the spatial components of the channel model are mapped into the probe antennas in such way that the angular spreads can be generated. This solution provides any 2D spatial channel model without having to reposition the probe antennas. [2]
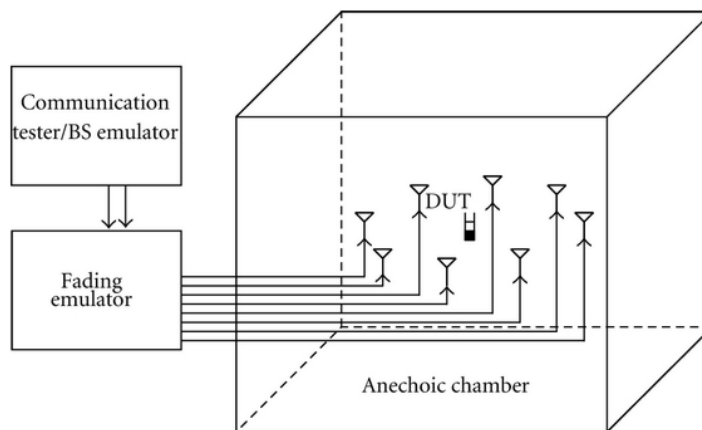

Figure 9. The basic configuration for the ring of probe method for anechoic chamber. [2]

In ring of probes method the number of the probes effect the accuracy with which the spatial dimension of the channel mode can be simulated. [2]

3.1.3 Two-Stage Method for Anechoic Chamber

The two-stage method takes a different approach to creating the necessary conditions to test MIMO performance. The configuration is shown in Figure 10. The first stage involves the measurement of the 3D antenna pattern of the UE using an anechoic chamber. The second stage takes measured antenna pattern and convolves it with the desired channel model using a channel emulator. The output of the channel emulator represents the faded downlink signal modified by the spatial properties of the UEs antenna. The signal then is conducted to the UE

with RF cables. Therefore the second stage does not require chamber environment. [2]
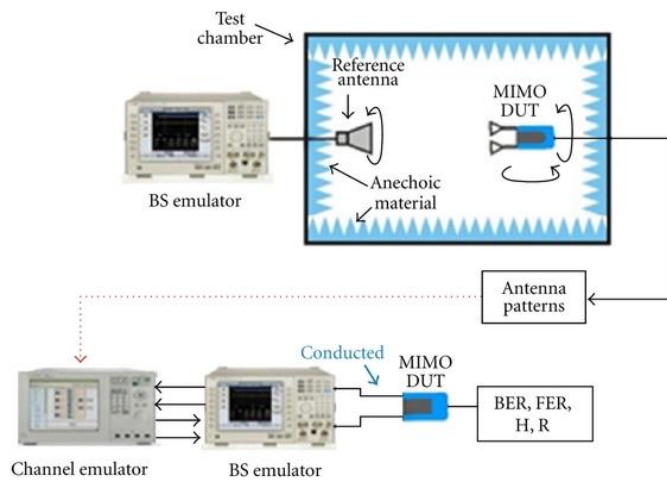

Figure 10. Configuration for 2-stage method. [2]

3.1.4 Two-Channel Method for Anechoic Chamber

The Two-Channel method is a special case of the multiple probe method with just two probes and no channel emulator. The principle of this method is to evaluate the impact of the direction and angular separation of the two signals on the UE's performance. Two-channel method is shown in Figure 9. [2]
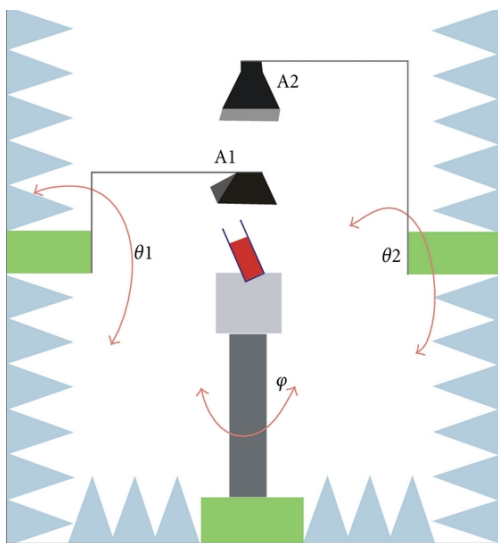

Figure 11. Configuration for 2-channel method for anechoic chamber. [2]

3.1.5 Spatial Channel Emulator for Anechoic Chamber

The Spatial Channel Emulator is a variation of the Ring of Probes method, where the channel emulatior is replaced with much simpler programmable attenuator and phase shifter per antenna. The setup is shown in Figure 12. [2]
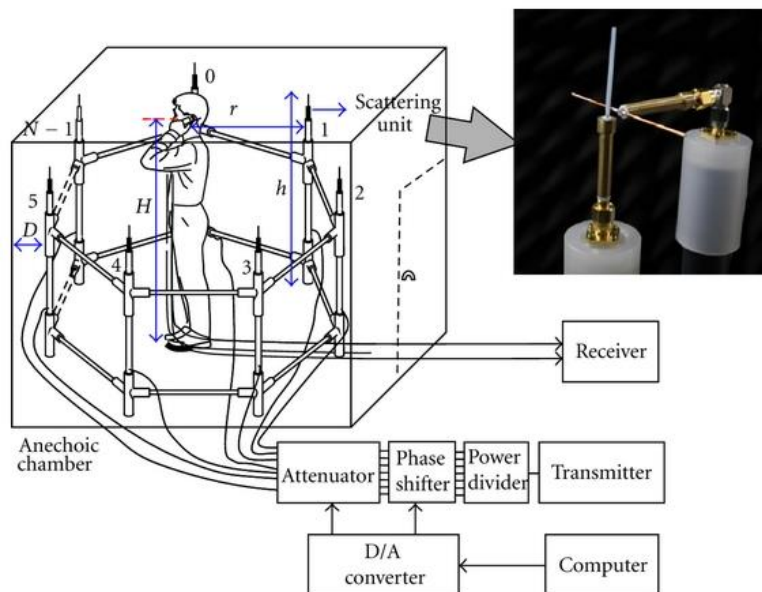

Figure 12. Configuration for spatial channel emulator for anechoic chamber. [2]

By controlling the amplitude and phase in real time, a Rayleigh distribution or other relevant multipath distribution can be obtained. [2]

3.1.6 Reverberation Chamber Method

The reverberation chamber method uses the reflective properties of the reverberation chamber with mode-stirrers to transform the downlink test signal into a 3D multipath signal. The spatial characteristics of the signal are random and can be shown to be isotropic over time. But they can also be observed to be highly directional, when observed over time period of demodulated data symbol. This un-uniformity provides the UE diverse signals on each antenna enabling multiplexing gain. Example of implementation is shown in Figure 13. [2]
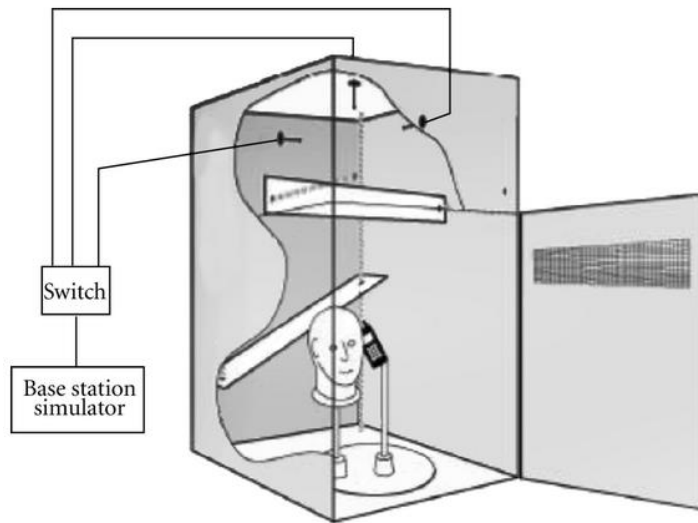
Figure 13. Configuration for reverberation chamber method. [2]

This reverberation chamber method including only reverberation chamber with mode-stirrers is limited relatively slow Doppler spectrum that is determined by the speed of mode-stirrer and only single fixed power delay profile. One option for further control of the power delay profile and spatial aspects can be obtained by cascading two or more reverberation chambers together as shown in Figure 14. [2]
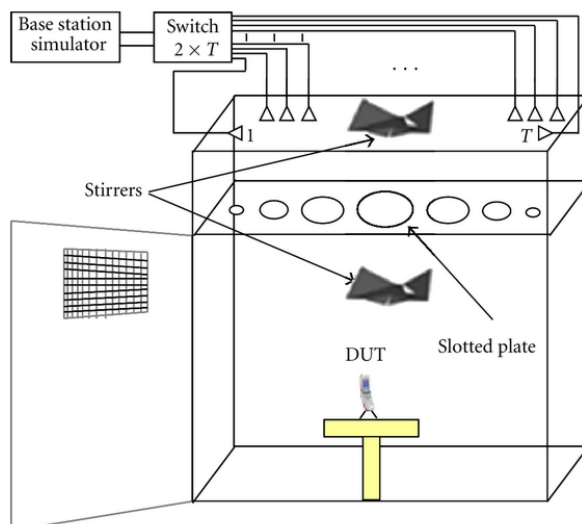

Figure 14. Configuration of reverberation chamber method with two cavities. [2]

3.1.7 Reverberation Chamber with Channel Emulator Method

The second reverberation method is reverberation method with channel emulator. The channel emulator can be used to pass limitations of the reverberation method on Doppler spectrum and power delay profile by adding fading scenarios to the downlink signal before signal is launched into the chamber. This makes the channel mode fully controllable, although the natural and very short decay time of the chamber will spread the power delay profile. The basic principle can be seen in Figure 15. [2]
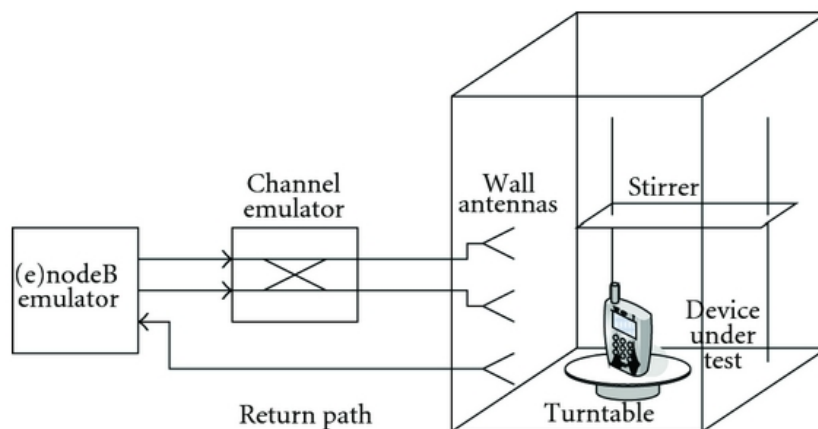
Figure 15. Configuration for reverberation chamber with channel emulator method. [2]

Power delay profiles of 3GPP SCME (Spatial Channel Model Extended) channel modes can be emulated with reverberation chamber with channel emulator method, when the used channel emulator is capable of negative time delays and in the chamber there are multiple cavity stirrers. [2]

3.2 Comparison of Methods

As discussed in previous chapter, there are multiple options suggested by 3GPP to implement a LTE MIMO-OTA test environment. Summary of these methods collected from TR 37.967 [2] are listed in Table 3.

Table 3. Summary of environment options for LTE MIMO testing.

Attribute	Reverberation chamber		Anechoic chamber				
	Reverberation chamber	Reverberation chamber+Channel emulator	Single Cluster	Ring of probes	2-channel	2-stage	Spatial channel emulator
Number of probe antennas	2-9	2-9	3-16	8-32	2-3	1	1
Angular Spread	Random	Random	Controllable	Controllable	Controllable	Controllable	Controllable
Power delay profile	Exponential decay	Controllable+Exponential	Controllable	Controllable	Controllable	Controllable	Controllable
Delay spread	Slightly controllable decay	Controllable	Controllable	Controllable	Controllable	Controllable	Controllable
Doppler shift	Limited	Controllable	Controllable	Controllable	Controllable	Controllable	Controllable
Supported channel modes	Unifrom	Uniform spatial, controllable multipath	Single-cluster, multipath (varies)	SCME, single-cluster, Uniform arbitrary	SCME, single-cluster, Uniform arbitrary	SCME, single-cluster, Uniform arbitrary	SCME, single-cluster, Uniform arbitrary

For LTE MIMO testing OTA, there are some requirements for including multiple spatial streams, making it necessary to either have multiple input antenna probes in testing system, include channel emulator or use both of these options. While comparing these methods, the first choice to be made is between anechoic and reverberation chambers.

Anechoic chamber offers five choices to choose from, while reverberation chamber offers two methods. First notion to be made from Table 3 is that the requirement for channel emulator is quite obvious and the only method that does not include channel emulator is the reverberation channel method. The investment for channel emulator is relatively cheap and the benefits for including one to the test environment are obvious.

The reverberation chamber with channel emulator offers a simple way to achieve isotropic field around the UE for relatively low cost, but lacs possibility to control Angular spread. Other possibilities are almost identical for anechoic chamber methods and reverberation chamber with channel emulator, only difference being in few supported channel modes.

Therefore the decision between the anechoic chamber and reverberation chamber is complicated. Since the methods including anechoic chamber require more antenna probes than environments using reverberation chamber, they are likely to be more expensive and assumedly more complicated to implement. But the environments using anechoic chamber offer possibility to control the angular spread, which is not controllable in reverberation chamber, even with channel emulator included in test environment. Therefore the decision is always individual for every manufacturer's needs, if the controllability for angular spread is critical, the investment for anechoic chamber, channel emulator and required antenna probes is completely reasonable.

If manufacturer uses reverberation chamber to implement LTE MIMO-OTA test environment, the obvious choice is to use channel emulator. With this option the investment is not that great, but the benefits are massive. If manufacturer decides to implement test environment using one of the anechoic chamber methods, the

choice is not that simple. Since all methods with anechoic chamber offer basically the same functionalities, this decision is dependent on individual manufacturer's needs and requirements.

4 CONCLUSIONS

In 2015 there are still no full specifications for LTE MIMO-OTA. The 3GPP TS34.114 [11] states that for specified systems: GSM, WCDMA and TD-SCDMA, the only required measurements for OTA-testing are TRP (Total Radiated Power) and TRS (Total Radiated Sensitivity). The LTE specifications will most likely also include these tests, but combined with testing requirements for MIMO antenna configurations and performance requirements for transmission modes with throughput being the primary focus of testing.

3GPP suggests seven different testing methods for LTE MIMO-OTA testing. These include five anechoic chamber methods and two reverberation chamber methods. Between the two reverberation chamber methods, the difference is the added channel emulator in another one. With anechoic chamber methods there are few different approaches to solve the problem. There is a straight forward method of applying multiple antenna probes to system, creating a field around the UE. The other way is the two-staged method, where antenna array is measured in first stage, and then applied to the throughput measurements are done with conducted testing method.

For LTE MIMO testing OTA, there are requirements for including multiple spatial streams, making it necessary to either multiply input antennas in testing system, include channel emulator or use both options. The decision between the anechoic chamber and reverberation chamber is more complicated. And therefore the decision is individual for all manufacturers' depending on the specific needs and requirements.

If manufacturer uses reverberation chamber to implement LTE MIMO-OTA test environment, the obvious choice is to use channel emulator. But in case of manufacturer decides to implement one of the methods using anechoic chamber, the choice is equally difficult. Since all methods offer basically the same applications, therefore this decision is dependent on individual manufacturer's needs and requirements.

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