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An Experimental study on LTE and LTE-Advanced technologies of wireless communication

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ABSTRACT- The Long Term Evolution (LTE) and LTE-Advanced (LTE-A) wireless communication standards was postulated by 3GPP to realize the objectives of the International Mobile Telecommunications-Advanced (IMT-A) organization for 4G cellular systems. To achieve these goals, modern and sophisticated communication techniques such as OFDM and MIMO are utilized at the physical layer. To verify and make measurements on such standards, instrumentation equipment with high specifications together with specialized software is required. In this paper, an experimental framework for studying and measuring LTE and LTE-A is presented, consisting of high-end laboratory equipment and software tools. Using this experimental framework, demonstration experiments for the physical layer are performed for SISO, MISO, and MIMO transmission according to the LTE and LTE-A standards, verifying the 3GPP Reference Measurement Channels (RMCs) specifications and depicting the framework's functionality.

Categories and Subject Descriptors

B.4.1 [**Data Communications Devices**]: • Wireless access networks • Hardware Communication hardware, interfaces and storage • Hardware Digital signal processing.

General Terms

Measurement, Design, Experimentation, Verification.

Keywords

LTE, LTE-A, OFDM, MIMO, 3GPP, RMCs.

1. INTRODUCTION

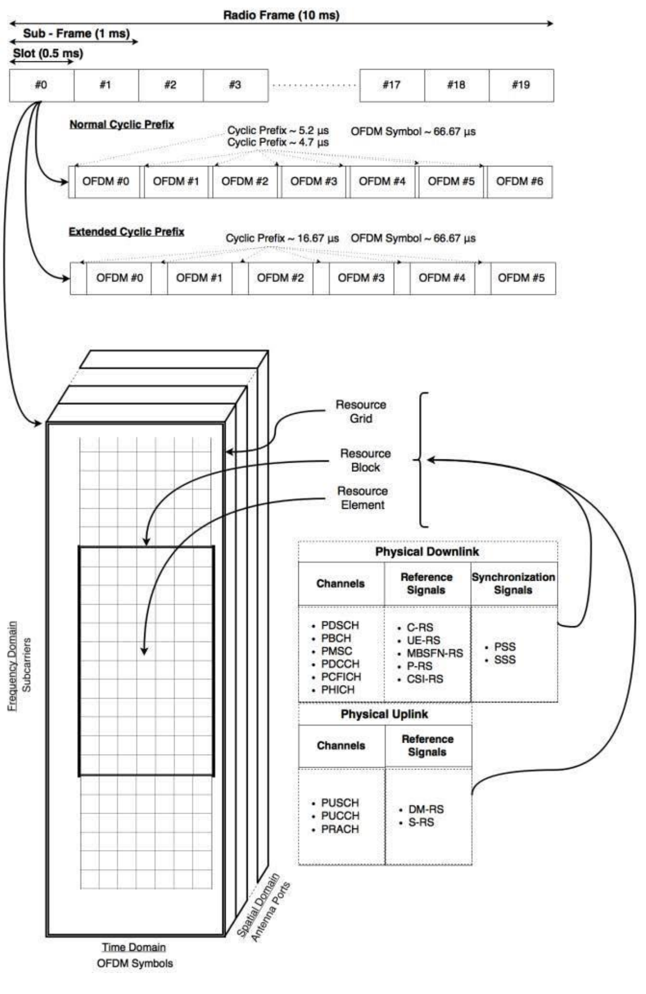
The physical layer specification standards in modern wireless communications are continuously evolving in order to increase the transmission data rates and to enhance the spectral efficiency.

In fourth generation (4G) cellular systems, the Long Term Evolution (LTE) and LTE-Advanced (LTE-A) achieve these goals by utilizing sophisticated transmission techniques, such as Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input – Multiple Output (MIMO) configurations [1], [2]. LTE and LTE-A were created by the 3rd Generation Partnership Project (3GPP) in Release-8 [3] and Release-10 [4], accordingly. LTE and LTE-A support downlink data rates of 300 Mbps to 3 Gbps and a spectral efficiency of up to 30 bps/Hz over a maximum bandwidth of 100 MHz as well as MIMO techniques (i.e., Spatial Multiplexing (SM), Transmit Diversity (TD) and Beam Forming) with up to eight antennas.

To study, generate and measure signals according to these standards, not only laboratory equipment with high specifications is needed, but also specialized software for parameterization and adjustment. The equipment should provide high and configurable sampling frequencies and many channels to support MIMO. It should also connect to a computer, or be a part of a computer system, in order to efficiently process high volumes of data. In this paper, an experimental framework for studying and measuring LTE and LTE-A is presented, consisting of high-end laboratory equipment and software tools. In particular, an arbitrary signal generator is exploited i.e., the Le Croy 1102D together with the ArbStudio software, providing two channels necessary for MIMO. The LTE and LTE-A signals are created by using the Matlab LTE Toolbox as well as by own developed functions. Two Agilent N9010A vector signal analyzers with their VSA 89600B software analysis tools are used for the signals reception and analysis. The vector signal generator Aeroflex SGD-6 is also used as a reference local oscillator. A set of experimental measurements is presented aiming to demonstrate the experimental framework and verify the LTE/LTE-A standards. In particular, three experiments are demonstrated according to the Reference Measurement Channels (RMCs) defined by 3GPP [5], [6]. These include Single Input – Single Output (SISO) transmission according to the RMC R.3, as well as Multiple Input – Single Output (MISO) transmission and MIMO transmission according to the RMC R.11 for demonstrating the TD technique using 2x1 and the SM using 2x2 antenna configurations respectively [7].

2. THE LTE AND LTE-A STANDARDS

The LTE and LTE-A standards were introduced by the 3GPP organization in order to increase the throughput and to enhance the users services in cellular systems. Firstly, LTE was presented in Release-8, while LTE-A was presented in Release-10 to improve LTE and meet the requirements of the International Telecommunication Union (ITU) for the 4G radio communication standard known as International Mobile Telecommunications-Advanced (IMT-A). In downlink, LTE provides 300 Mbps transmission data rate and 15 bps/Hz spectral efficiency using OFDM as a modulation scheme with 20 MHz channel bandwidth and 4x4 SM MIMO [7], [8]. LTE-A provides a 3 Gbps peak transmission data rate and a 30 bps/Hz spectral efficiency using the Carrier Aggregation (CA) technique and 100 MHz total channel bandwidth and 8x8 SM MIMO. For the uplink, LTE provides 75 Mbps transmission data rate and 3.75 bps/Hz spectral efficiency using the Discrete Fourier Transform – Spread – OFDM (DFT-S-OFDM) or Single Carrier FDMA (SC-FDMA) with 20 MHz channel bandwidth, whereas LTE-A provides 1.5 Gbps peak transmission data rate and 15 bps/Hz spectral efficiency enhanced with the CA technique and a 100 MHz total channel bandwidth and a 4x4 SM MIMO [1].



Transmission in both downlink and uplink is organized into Radio-Frames with 10 ms duration (Figure 1). Each Radio-Frame consists of 20 Slots of length 0.5 ms, numbered from 0 to 19. A Subframe is defined as two consecutive slots and lasts 1 ms. Therefore, each Radio-Frame consists of 10 Subframes, numbered from 0 to 9. Each Slot consists of one Physical Resource Grid (PRG) per transmitting antenna. The PRG is an array with two dimensions. The first dimension corresponds to the time domain and its length is 7 OFDM symbols (or 6 OFDM symbols when the extended cyclic prefix is used). The other dimension corresponds to the frequency domain and its length is equal to the number of subcarriers that are used. The PRG is divided in Physical Resource Elements (PRE). A PRE is defined as the smallest time-frequency unit in the standard and it consists of a subcarrier in an OFDM symbol. Each PRE corresponds to a complex value which is generated from a Physical Channel or a Physical Signal. A Physical Resource Block (PRB) is used for mapping the complex values to the PREs and its size is 7 or 6 OFDM symbols i.e., corresponding to a Slot in the time domain and 12 subcarriers in the frequency domain.

The physical channels and the physical signals (Table 1) are groups of complex values (modulation symbols) which are mapped to the PREs. The physical downlink channels, transfer information from the higher layers to the physical layer. They are separated in Transport Channels, which carry data, and in Control Channels, which carry information and control parameters for the physical layer. The physical uplink channels transfer information from the physical layer to higher layers. The physical signals do not transfer any information. They are separated in References Signals, which are used for Channel Estimation, and Synchronization Signals, which are used for synchronization.

Table 1: Physical channels and physical signals.

Physical Downlink Transport Channels	
PBCH	Physical Broadcast Channel
PDSCH	Physical Downlink Shared Channel
PMCH	Physical Multicast Channel
Physical Downlink Control Channels	
PDCCH	Physical Downlink Control Channel
PCFICH	Physical Control Format Indicator Channel
PHICH	Physical Hybrid ARQ Indicator Channel
Physical Downlink Reference Signals	
CRS	Cell – Specific Reference Signals
UE-RS	UE – Specific Reference Signals
MBSFN-RS	MBSFN Reference Signals
PRS	Positioning Reference Signals
CSI-RS	CSI Reference Signals
Physical Downlink Synchronization Signals	
PSS	Primary Synchronization Signals
SSS	Secondary Synchronization Signals
Physical Uplink Channels	
PUSCH	Physical Uplink Shared Channel
PUCCH	Physical Uplink Control Channel
PRACH	Physical Random Access Channel
Physical Uplink Reference Signals	
DM-RS	Demodulation Reference Signals
SRS	Sounding Reference Signals

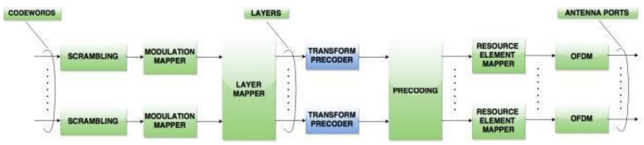


Figure 2: LTE baseband transmitter diagram. Blue blocks are used only in the Uplink

The physical channels are modulated using the following procedure (Figure 2). At baseband processing, data bits are separated in one or two Codewords. The length of the data bits corresponds to one Subframe. The data bits are scrambled and then are mapped to complex values with BPSK, QPSK, 16-QAM or 64-QAM modulation techniques. The BPSK is used only to ensure robustness for the Control Channels. The complex values are separated in Layers. The number of Layers depends on the MIMO technique and the number of the transmitting antennas. In uplink transmission, the Transform Precoder separates the complex values in clusters, for each Layer, and transforms the data using Discrete Fourier Transform (DFT). In the Precoding block, the Layers are processed and the MIMO techniques are implemented. The number of the Precoding block's outputs is equal to the transmitting antennas. The Codebook is only used in conjunction with the Cell Specific - Reference Signals (CRS). Then, the data from each Precoding block's output are mapped in their corresponding PREs on the PRG, via the PRBs. Finally, OFDM in downlink or DFT-S-OFDM in uplink is applied to the data for each transmitting antenna. This general structure mainly concerns the Physical Downlink Shared Channel (PDSCH) and the Physical Uplink Shared Channel (PUSCH), but it is also applicable to the other channels in a similar way. The modulation parameters are summarized in Table 2.

Table 2: Modulation parameters.

BW (MHz)	1.2	3	5	10	15	20
Oc.BW(MHz)	1.08	2.7	4.5	9	13.5	18
PRBs	6	15	25	50	75	100
Subcarriers	72	180	300	600	900	1200

IFFT Length	128	256	512	1024	1536	2048
Sampl.Freq. (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Freq. Spacing	15 KHz					
Modulation	B-PSK, Q-PSK, 16-QAM, 64-QAM					
MIMO	Beamforming, CDD, SM, TD					
Cyclic Prefix	Normal, Extended					
Normal (#0 / #1-#6)	10/ 9	20/ 18	40/ 36	80/ 72	120/ 108	160/ 144
Extended	32	64	128	256	384	512

In LTE-A, the CA technique can be performed in both downlink and uplink transmissions. Up to 5 channels of 20 MHz maximum bandwidth can be aggregated forming a total 100 MHz bandwidth. The component carriers can be contiguous in the same band (Intra-band Contiguous), non contiguous in the same band (Intra-band non Contiguous), or non contiguous in different bands (Inter-band non Contiguous).

3. THE EXPERIMENTAL FRAMEWORK ARCHITECTURE

The presented framework which is also used for the experiments (Figure 3) in this work, consists of the instrumentation equipment, a PC with the software tools and the RF components. The instrumentation equipment consists of the Le Croy 1102D two-channel arbitrary waveform generator, the Aeroflex SGD-6 vector signal generator, and two Agilent N9010A vector signal analyzers. The PC provides the Arbstudio application, which is used for the control of the Le Croy 1102D generator, the Agilent VSA 89600 application, which is used as an extra tool for the Agilent N9010A analyzers, and the Matlab application with the LTE System Toolbox. The RF components are a splitter, two mixers and four antennas. The Le Croy 1102D generator is connected to the PC via Universal Serial Bus (USB) and is controlled from the Arbstudio application. The Agilent N9010A analyzers are remotely controlled from the VSA application via Local Area Network (LAN).

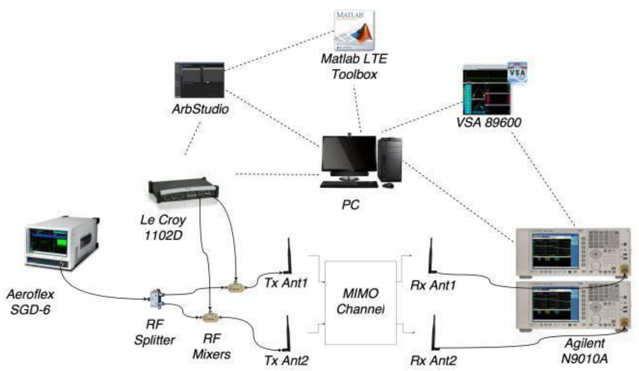


Figure 3: Setup of the LTE/LTE-A experimental framework.

For the baseband signal generation the Matlab LTE System Toolbox is used together with own developed functions for LTE signal processing and adaptation. A set of parameters, based on the downlink RMCs, can be configured for the desired LTE signal generation. The baseband signal is up-converted on an intermediate frequency (IF) carrier with an IQ modulator developed in Matlab. The IF passband signal samples are exported from Matlab to a Comma Separated Values (CSV) file witch is then imported to the Arbstudio application and the Le Croy 1102D generator.

The Aeroflex SGD-6 generator is used as a local oscillator (LO). The carrier frequency of the LO in conjunction with the IF carrier produce the desired RF carrier frequency (Table 3), as a result of the mixer operation. A filter for the rejection of the mixer's image and RF amplifiers could be additionally used.

The experimental framework setup currently supports SISO, MISO and MIMO transmission of up to a 2x2 configuration. For the MIMO signal reception, the two Agilent N9010A analyzers are set in a Master – Slave connection. In the VSA application, the two Agilent N9010A one-channel analyzers are declared as a two-channel analyzer and the connection between them is established. The VSA application down-converts and demodulates the received signal.

4. EXPERIMENTS AND RESULTS

4.1 Signals Parameters

The framework which presented in Section 3 is used for the following performance evaluation. The demonstrated experiments are representative according to the RMCs that defined from 3GPP, aiming to the verification of the standards. For the first experiment, a SISO 1x1 transmission is performed according to the RMC R.3. The transmissions in the two other experiments are according to the RMC R.11. More specifically, the second experiment is about a 2x1 MISO transmission demonstrating the TD technique and the third is about a 2x2 MIMO transmission demonstrating the SM technique. The configuration parameters are summarized in Table 3.

Table 3: Configuration parameters

	Experiment1	Experiment2	Experiment3
Transmission Scheme	SISO (1x1)	MISO (2x1)	MIMO (2x2)
RMC	R.3	R.11	R.11
Ref. Signals	CRS	CRS	CRS
MIMO	-	TD (SFBC)	SM - CDD
Codewords	1	1	2
Layers	1	2	2
Coding Rate	1/2	1/2	1/2
Modulation	16-QAM	16-QAM	16-QAM
PRBs	50	50	50
Chan. BW	10 MHz	10 MHz	10 MHz
Bits/Frame/CW	125856	116640	116640
IF	63 MHz	63 MHz	63 MHz
LO	1187 MHz	1187 MHz	1187 MHz
RF	1250 MHz	1250 MHz	1250 MHz
Tx Channel Power/Antenna	-19.4 dBm	-22.4 dBm	-22.4 dBm

4.2 SISO Measurements

In the first experiment a SISO wireless transmission is performed. The passband signal, which is generated from the Le Croy 1102D and is carried on the IF carrier of 63 MHz, is plotted in Figure 4. The final passband signal which is carried on the RF frequency carrier of 1.25 GHz has a -19.4 dBm channel power.

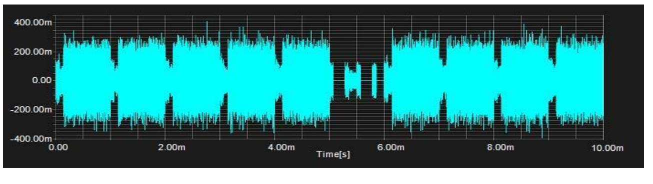


Figure 4: SISO – The transmitted signal for one Radio-Frame on the IF of 63 MHz.

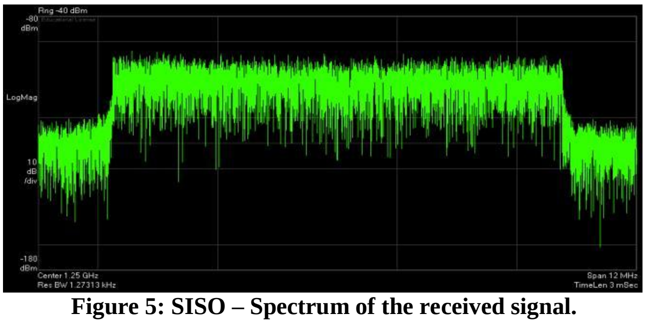


Figure 5: SISO – Spectrum of the received signal.

The 10 MHz received spectrum with the VSA application is shown in figure 5, while the constellations of the PDSCH with the 16-QAM and the CRS with the QPSK modulation schemes are shown in figure 6. In figures 7 and 8 the constellations of the other physical channels, such as PBCH, PCFICH, PHICH and PDCCH, and synchronization signals, PSS and SSS, are shown.

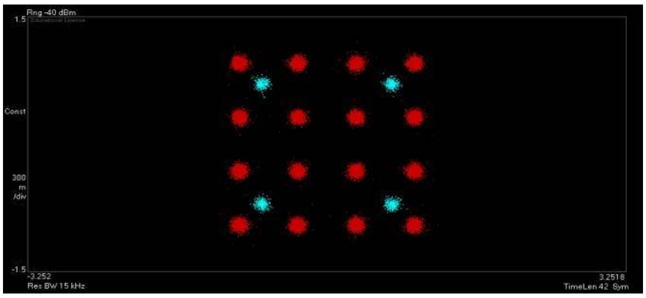


Figure 6: SISO – Constellations for PDSCH (red) and CRS (light blue

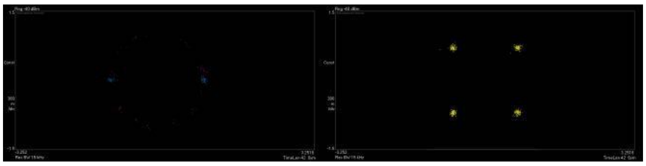


Figure 7: SISO – Constellations for PSS (purple) and SSS (blue) on the left and for PDCCH (yellow) on the right

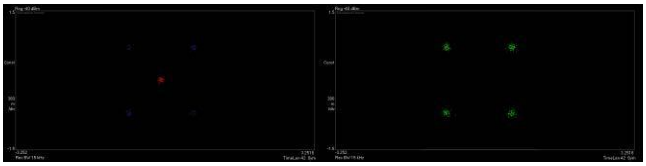
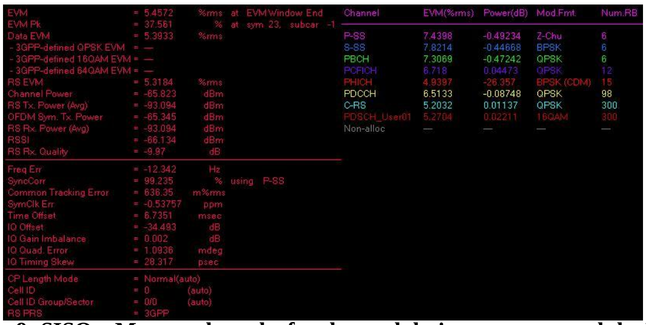


Figure 8: SISO – Constellations for PCFICH (blue) and PHICH (red) on the left and for PBCH (green) on the right



EVM	= 5.4572	%rms	at EVM Window End
EVM Pk	= 37.561	%	at sym 23, subcar -1
Data EVM	= 5.3933	%rms	
- 3GPP-defined QPSK EVM	= —		
- 3GPP-defined 16QAM EVM	= —		
- 3GPP-defined 64QAM EVM	= —		
RS EVM	= 5.3184	%rms	
Channel Power	= -65.823	dBm	
RS Tx. Power (Avg)	= -93.094	dBm	
OFDM Sym. Tx. Power	= -65.345	dBm	
RS Rx. Power (Avg)	= -93.094	dBm	
RSSI	= -66.134	dBm	
RS Rx. Quality	= -9.97	dB	
Freq Err	= -12.342	Hz	
SyncCorr	= 99.235	%	using P-SS
Common Tracking Error	= 636.35	m%rms	
SymClk Err	= -0.53757	ppm	
Time Offset	= 6.7351	msec	
IQ Offset	= -34.493	dB	
IQ Gain Imbalance	= 0.002	dB	
IQ Quad. Error	= 1.0936	mdeg	
IQ Timing Skew	= 28.317	psec	
CP Length Mode	= Normal(auto)		
Cell ID	= 0	(auto)	
Cell ID Group/Sector	= 0/0	(auto)	
RS PRS	= 3GPP		

Channel	EVM(%rms)	Power(dB)	Mod.Fmt.	Num.RB
P-SS	7.4398	-0.49234	Z-Chu	6
S-SS	7.8214	-0.44668	BPSK	6
PBCH	7.3069	-0.47242	QPSK	6
PCFICH	6.718	0.04473	QPSK	12
PHICH	4.9397	-26.357	BPSK (CDM)	15
PDCCH	6.5133	-0.08748	QPSK	98
C-RS	5.2032	0.01137	QPSK	300
PDSCH_User01	5.2704	0.02211	16QAM	300
Non-alloc	—	—	—	—

Figure 9: SISO – Measured results for the modulation accuracy and the Radio-Frame errors

The PHICH does not carry any data in this transmission, so its constellation is zero points. Measured results for the modulation accuracy and the Radio-Frame, such as Error Vector Magnitude (EVM) and received power, are summarized in figure 9.

4.3 MISO Measurements

In this experiment a MISO wireless transmission is performed, demonstrating the TD technique. Two antennas are used at the transmitter and one at the receiver. The passband signals, which are generated from the Le Croy 1102D (one per transmitting antenna) on the IF carrier, are plotted in Figure 10. The final passband signals which are carried on the RF frequency carrier of 1.25 GHz have a -22.4 dBm channel power per antenna.

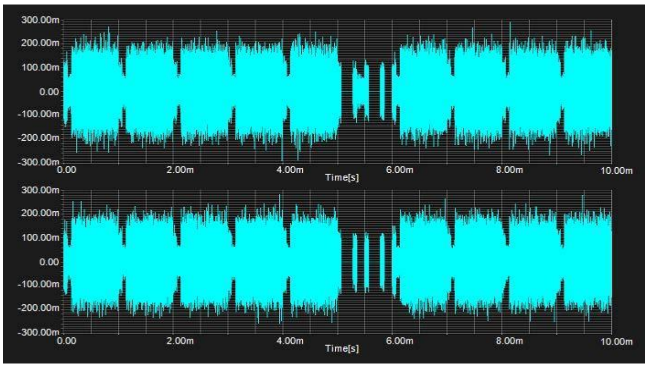


Figure 10: MISO – The transmitted signals for one Radio-Frame on the IF of 63 MHz. Channel1 is on the top and Channel2 is on the bottom

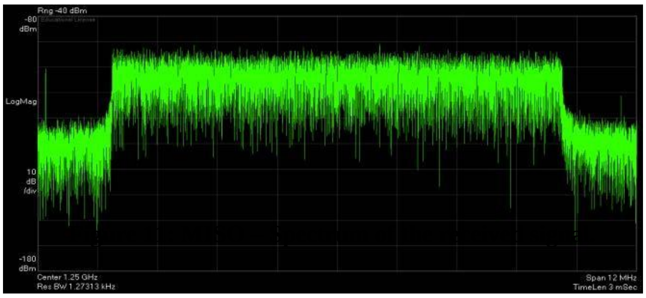


Figure 11: MISO – Spectrum of the received signal.

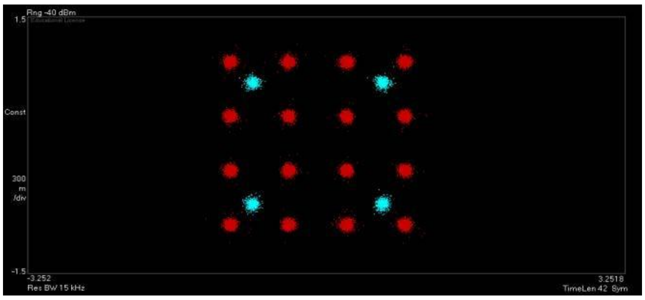
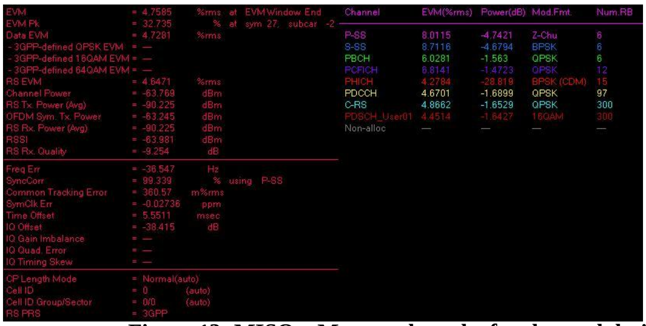


Figure 12: MISO – Constellations for PDSCH (red) and CRS (light blue).



EVM	= 4.7585	%rms	at EVM Window End
EVM Pk	= 32.735	%	at sym 27, subcar -2
Data EVM	= 4.7281	%rms	
- 3GPP-defined QPSK EVM	= —		
- 3GPP-defined 16QAM EVM	= —		
- 3GPP-defined 64QAM EVM	= —		
RS EVM	= 4.6471	%rms	
Channel Power	= -63.769	dBm	
RS Tx. Power (Avg)	= -90.225	dBm	
OFDM Sym. Tx. Power	= -63.245	dBm	
RS Rx. Power (Avg)	= -90.225	dBm	
RSSI	= -63.981	dBm	
RS Rx. Quality	= -9.254	dB	
Freq Err	= -36.547	Hz	
SyncCorr	= 99.339	%	using P-SS
Common Tracking Error	= 360.57	m%rms	
SymClk Err	= -0.02736	ppm	
Time Offset	= 5.5511	msec	
IQ Offset	= -38.415	dB	
IQ Gain Imbalance	= —		
IQ Quad. Error	= —		
IQ Timing Skew	= —		
CP Length Mode	= Normal(auto)		
Cell ID	= 0	(auto)	
Cell ID Group/Sector	= 0/0	(auto)	
RS PRS	= 3GPP		

Channel	EVM(%rms)	Power(dB)	Mod.Fmt.	Num.RB
P-SS	8.0115	-4.7421	Z-Chu	6
S-SS	8.7116	-4.6794	BPSK	6
PBCH	6.0281	-1.563	QPSK	6
PCFICH	6.8141	-1.4723	QPSK	12
PHICH	4.2784	-28.819	BPSK (CDM)	15
PDCCH	4.6701	-1.6899	QPSK	97
C-RS	4.8662	-1.6529	QPSK	300
PDSCH_User01	4.4514	-1.6427	16QAM	300
Non-alloc	—	—	—	—

Figure 13: MISO – Measured results for the modulation accuracy and the Radio-Frame errors.

This channel power is 3 dB less than the SISO transmission power. The received 10 MHz spectrum is shown in figure 11. Figure 12 shows the constellations of the PDSCH with the 16-QAM and the CRS with the QPSK modulation schemes In figure 13, measured results for the modulation accuracy and the Radio-Frame are summarized, verifying sufficient demodulation performance also in contrast to the SISO case. In figure 14, the channel frequency responses of the two independent wireless paths are also shown.

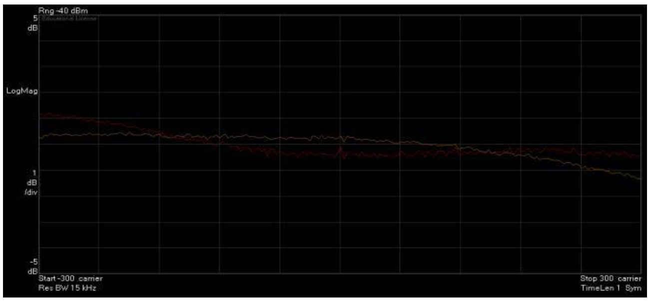


Figure 14: MISO – Channel frequency responses

4.4 MIMO Measurements

In the last experiment a MIMO wireless transmission is performed, demonstrating the SM technique with Large Delay Cyclic Delay Diversity (Large Delay CDD). Two antennas are used at the transmitter and two at the receiver. The passband signals which are generated from the Le Croy 1102D, one per antenna, on the IF carrier of 63 MHz are plotted in Figure 15. The final passband signals which are carried on the RF frequency carrier of 1.25 GHz have a -22.4 dBm channel power per antenna, similar to the MISO transmission case.

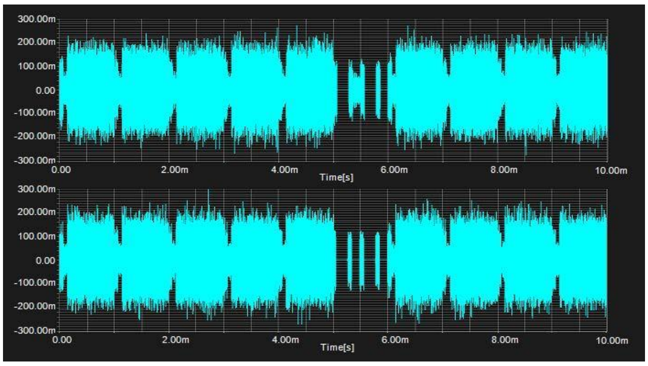


Figure 15: MIMO – The transmitted signals for one Radio-Frame on the IF of 63 MHz. Channel1 is on the top and Channel2 is on the bottom.

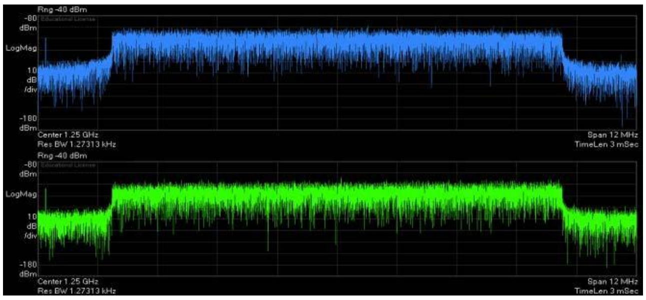


Figure 16: MIMO – Spectrums of the received signals. Channel1 is on the top and Channel2 is on the bottom

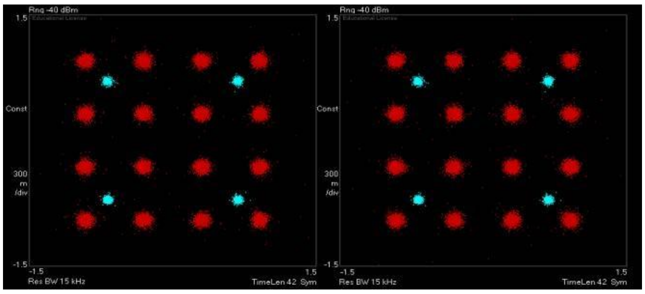
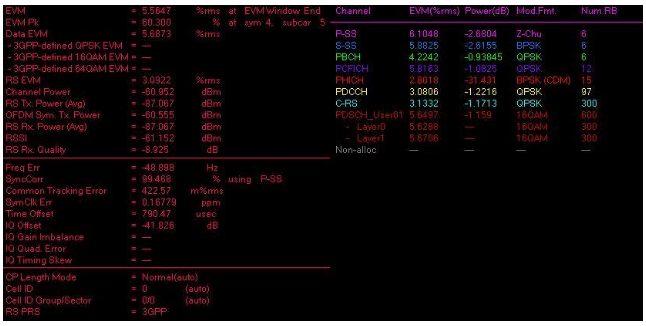


Figure 17: MIMO – Constellations for PDSCH (red) and CRS (light blue) - Channel1 (left) and Channel2 (right).



EVM	= 5.5647	%rms	at EVM Window End
EVM Pk	= 60.300	%	at sym 4, subcar 5
Data EVM	= 5.6873	%rms	
- 3GPP-defined QPSK EVM	= —		
- 3GPP-defined 16QAM EVM	= —		
- 3GPP-defined 64QAM EVM	= —		
RS EVM	= 3.0922	%rms	
Channel Power	= -60.952	dBm	
RS Tx. Power (Avg)	= -87.067	dBm	
OFDM Sym. Tx. Power	= -60.555	dBm	
RS Rx. Power (Avg)	= -87.067	dBm	
RSSI	= -61.152	dBm	
RS Rx. Quality	= -8.925	dB	
Freq Err	= -48.898	Hz	
SyncCorr	= 99.468	%	using P-SS
Common Tracking Error	= 422.57	m%rms	
SymClk Err	= 0.16779	ppm	
Time Offset	= 790.47	usec	
IQ Offset	= -41.826	dB	
IQ Gain Imbalance	= —		
IQ Quad. Error	= —		
IQ Timing Skew	= —		
CP Length Mode	= Normal(auto)		
Cell ID	= 0	(auto)	
Cell ID Group/Sector	= 0/0	(auto)	
RS PRS	= 3GPP		

Channel	EVM(%rms)	Power(dB)	Mod.Fmt.	Num.RB
P-SS	6.1048	-2.6804	Z-Chu	6
S-SS	5.8825	-2.6155	BPSK	6
PBCH	4.2242	-0.93845	QPSK	6
PCFICH	5.8163	-1.0825	QPSK	12
PHICH	2.8018	-31.431	BPSK (CDM)	15
PDCCH	3.0806	-1.2216	QPSK	97
C-RS	3.1332	-1.1713	QPSK	300
PDSCH_User01	5.6497	-1.159	16QAM	600
- Layer0	5.6288	—	16QAM	300
- Layer1	5.6706	—	16QAM	300
Non-alloc	—	—	—	—

Figure 18: MIMO – Measured results for the modulation accuracy and the Radio-Frame errors

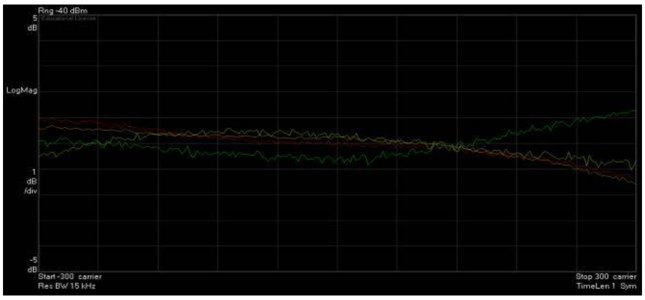
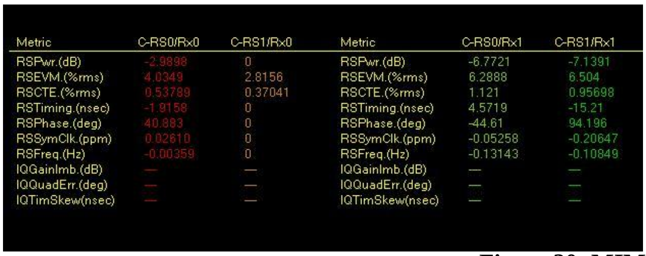


Figure 19: MIMO – Channel frequency responses of the four wireless paths



Metric	C-RS0/Rx0	C-RS1/Rx0	Metric	C-RS0/Rx1	C-RS1/Rx1
RSPwr.(dB)	-2.9898	0	RSPwr.(dB)	-6.7721	-7.1391
RSEVM.(%rms)	4.0349	2.8156	RSEVM.(%rms)	6.2888	6.504
RSCTE.(%rms)	0.53789	0.37041	RSCTE.(%rms)	1.121	0.95698
RSTiming.(nsec)	-1.9158	0	RSTiming.(nsec)	4.5719	-15.21
RSPhase.(deg)	40.883	0	RSPhase.(deg)	-44.61	94.196
RSSymClk.(ppm)	0.02610	0	RSSymClk.(ppm)	-0.05258	-0.20647
RSFreq.(Hz)	-0.00359	0	RSFreq.(Hz)	-0.13143	-0.10849
IQGainImb.(dB)	—	—	IQGainImb.(dB)	—	—
IQQuadErr.(deg)	—	—	IQQuadErr.(deg)	—	—
IQTimSkew(nsec)	—	—	IQTimSkew(nsec)	—	—

Figure 20: MIMO – Summary results

The 10 MHz received spectrums of both channels are shown in figure 16. The constellations of the PDSCH with the 16-QAM and the CRS with the QPSK modulation schemes are shown in figure 17 for each channel. Figure 18 summarizes measured results for the modulation accuracy and the Radio-Frame errors, depicting demodulation efficacy also in contrast to the SISO and MISO cases. In figure 19, the MIMO channel frequency responses of the four wireless paths are shown and in figure 20 summarization results about MIMO information are illustrated. It should be noticed here that, although MIMO seems to achieve a comparable or even worse EVM performance against the SISO and MISO cases, this is attributed to the fact that current experiments are performed over a short fixed distance with no mobility, hence the channels are assumed to be correlated.

5. CONCLUSIONS

In this paper, the setup of an experimental framework for studying, measuring and verifying the LTE and LTE-A standards was presented. These standards use sophisticated techniques, such as OFDM and MIMO, in order to meet the IMT-A 4G requirements in terms of achieved data rates (throughput) and spectral efficiency. The experimental framework involved high-end instrumentation equipment and specialized software for supporting many of the techniques of the standards as well as custom components for the RF link. A set of representative experimental measurements was presented aiming to verify the standards based on suggested 3GPP configurations. A SISO transmission was demonstrated according to the RMC R.3 and a MISO TD 2x1 as well as a MIMO SM 2x2 with Large Delay CDD were demonstrated according to the RMC R.11 confirming proper functionality and demodulation efficacy. The framework can be further exploited to attest various LTE and LTE-A configurations and transmission issues.

6. REFERENCES

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