A Software-Defined-Radio Platform for Multiple-Input-Multiple-Output Over-The-Air Measurement

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***Abstract*—This paper presents a 2 × 2 multiple-input-multiple-output over-the-air (MIMO OTA) measurement system with user-programmable, reconfigurable and real-time signal processing field-programmable gate arrays (FPGAs)-based software-defined radio (SDR) capability. Signal generation and analysis as well as channel emulation are all implemented using vector signal transceivers (VSTs). As a demonstration, we performed the Third Generation Partnership Project (3GPP) two-stage MIMO OTA conducted test using a downlink time division long-term evolution (TD-LTE) duplex scheme. The channel emulation was operated in a stochastic mode. Some preliminary results of the system verification are shown.**

***Index Terms*—FPGA, SDR, MIMO, OTA measurement.**

I. Introduction

Over the past two decades the market for modern wireless communication systems has grown rapidly in response to consumer demand. This has encouraged, in recent years, extensive research activities in the application of multiple-input-multiple-output (MIMO) technologies for these wireless systems, due to their ability to provide improved spectral efficiencies and increased network capacity. It is appropriate to include both antenna and propagation characteristics at the same time when testing MIMO systems. In order to understand the end-to-end reception performance of a MIMO device, over-the-air (OTA) testing is needed.

Many different MIMO OTA test methods [1]–[4] have been proposed. Wireless industry groups such as 3GPP (Third Generation Partnership Project) [1] and CTIA (International Association for the Wireless Telecommunication Industry) [4] have researched into MIMO OTA for standardization purposes. The current capability of test-equipment available for MIMO under the current 4G Long-Term Evolution (LTE) communications technology, and activity within COST Actions [5]–[6] illustrates that the traceable measurement issues have not been fully resolved.

Furthermore, user-programmable and reconfigurable test instruments have become popular due to the requirement of addressing the need for fast evaluating and implementing adaptive communications algorithms and protocols. Hence user-programmable field-programmable gate arrays (FPGAs)-based software-defined radio (SDR) that offer real-time signal processing are envisaged to become the dominant technology in emerging wireless communications.

This paper presents a flexible 2 × 2 MIMO OTA user-programmable FPGAs-based SDR measurement platform, which consists of signal generator and signal analyzer as well as channel emulator, all implemented using vector signal transceiver (VST) modules [7]. Each VST contents a vector signal analyzer and a vector signal generator with user-programmable FPGA for real-time signal processing and control. The channel emulator (CE) can either operate in stochastic or deterministic mode. It is envisaged that this system would enable flexible evaluation over channel model, modulation scheme, communications algorithms and protocols as well as enabling traceability study.

In this paper, this SDR measurement platform was configured to perform 3GPP MIMO OTA two-stage conducted test using a downlink time division long-term evolution (TD-LTE) duplex scheme and a stochastic mode [8] was chosen to implement in the CE. Some preliminary evaluations of this SDR platform are presented where only isotropic antenna was considered. This paper is organized as follows: Section II describes how the system is made up, Section III presents some verification results of the system, finally, some discussions and suggested future works are given in Section IV.

II. System Description

Fig. 1 depicts the schematic of the VST-based 2 × 2 MIMO OTA test system setup with conducted links using cables. It consists of four NI PXIe-5644R VST [7] modules housed in a PXIe-1085 chassis with a PXIe-8135 embedded controller.

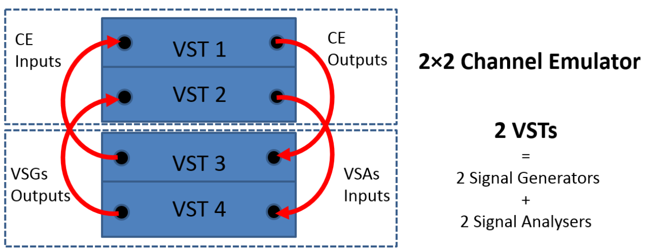


Fig. 1. Illustration of the 2 × 2 MIMO OTA measurement system using four NI VST modules.

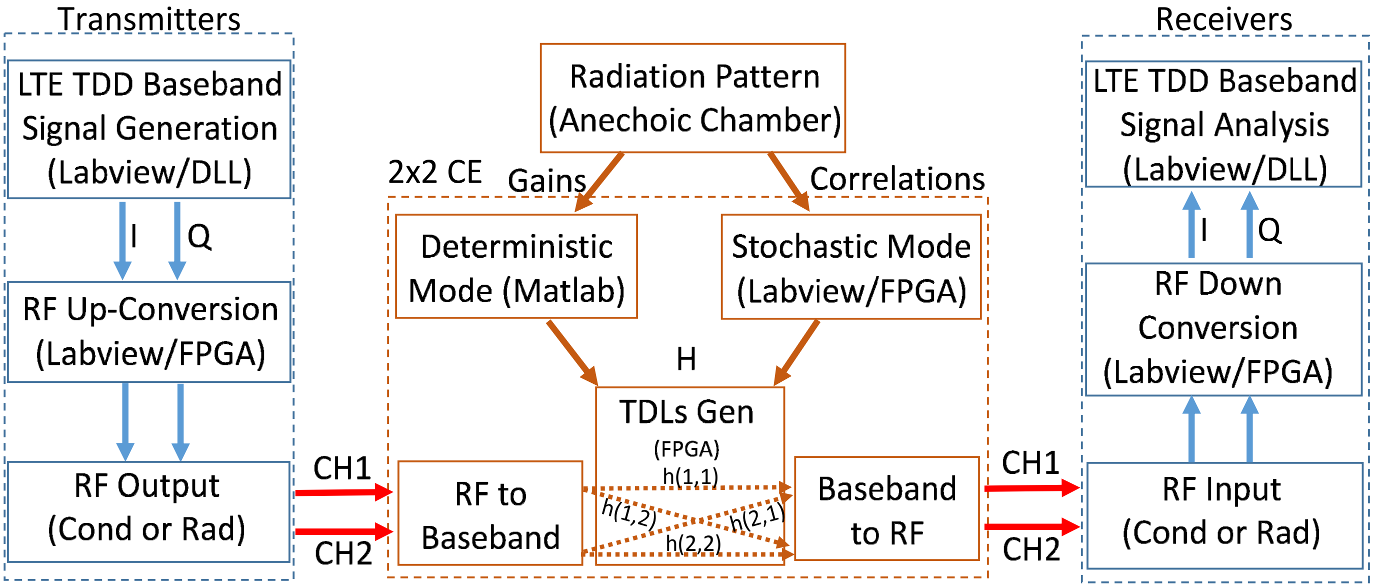


Fig. 2. Data flow diagram of the 2 × 2 MIMO OTA SDR measurement platform.

Two VSTs are programmed as a 2 × 2 MIMO system with TD-LTE signal generation and signal analysis and the other two are programmed as CE. The VST modules employed within the TD-LTE MIMO system (VST 3 and VST 4) and CE (VST 1 and VST 2) are synchronized, respectively, as each VST module has its own RF input/output and input/output local oscillators (LOs).

Fig. 2 illustrates the data flow diagram of the MIMO OTA SDR measurement system. At the transmission side (shown at left hand side in Fig. 2), baseband data are processed in C++ (DLL in runtime) including payload generation, coding, modulation, OFDM symbol generation, etc. The generated baseband I/Q data are fed to VSTs' FPGAs for digital-to-analogue converter (DAC) processing and then up-converted to RF band and amplified to the RF output ports of the transmitters.

The output RF signals from transmitters (VST 3 and VST 4) are connected to the inputs of channel emulators via coaxial cables. The channel emulator (middle part in Fig. 2) first down-converted the input RF signals to baseband signals and fed to the FPGA onboard for fading processing. After that the baseband signals are up-converted into RF signals at the CE outputs and they are either directly connected to the receivers for performing MIMO OTA conducted test or to transmitting antennas within an anechoic chamber for performing MIMO OTA radiated test.

The CE has two operating modes: the stochastic mode and the deterministic mode. The stochastic mode intakes fading parameters such as time delays and antenna correlations and uses Jake's model [8] to generate faded channel coefficients which will be mixed with the down-converted input signal. Antenna correlations can be obtained from radiation pattern of the MIMO device, measured in an anechoic chamber.

Under deterministic mode, the faded channel coefficients can be generated directly from a chosen channel model such as 3GPP Spatial Channel Model Extended (SCME) channel model [9] where channel fading parameters, antenna radiation pattern, angle-of-arrivals (AoAs), etc. are required.

At the receiver side (shown at right hand side in Fig. 2), the signals acquired from two RF-in ports of receivers (VST 3 and VST 4) could either be directly connected to the CE outputs for performing MIMO OTA conducted test or to receiving antennas within the anechoic chamber for performing MIMO OTA radiated test. The received signals will be down-converted to baseband I/Q data streams to be processed by DLL developed in C++. The processed metrics such as EVM in physical layer, and throughput in media access control (MAC) layer would be fed back to LabView for display and data record purposes.

III. System Functionality Evaluation

The system evaluation consists of three parts: 1) CE evaluation using VNA; 2) 2 × 2 TD-LTE MIMO system evaluation with and without CE; 3) preliminary results on throughput of 2 × 2 TD-LTE MIMO OTA system.

A. Evaluation of Channel Emulator using VNA

The CE was evaluated under stochastic mode where the power delay profile (PDP) was calculated using the measured S-parameters obtained from a vector network analyzer (VNA) for SCME urban micro-cell channel model with the isotropic AoAs. 3GPP [1] has made a general agreement on the parameters for different channel models that can be used for MIMO OTA channel emulation.

Table 8.2-1 in [1] gives a single spatial cluster model with multi-path based on SCME urban micro-cell channel model. A four-port Rohde & Schwarz ZVB8 VNA was used to perform PDP evaluation of CE and the VNA was configured following values specified in Table 8.3.2.1-1 [1] except a span of 80 MHz was employed due to instantaneous bandwidth capability limit by the VST system. In the SCME urban micro-cell model, an isotropic radiation antenna gain pattern was employed, which emulates the isotropic AoAs scenario. The center frequency and the power level were set to be 2.535 GHz and -15 dBm, respectively.

Fig. 3 show the measured PDP for all channels (i.e. h (1,1), h (1,2), h (2,1) and h (2,2)) against the theoretical reference PDP values [1]. The results show reasonable agreement with the theoretical reference where the small discrepancy is believed to be caused by the VST delay time rounding error.

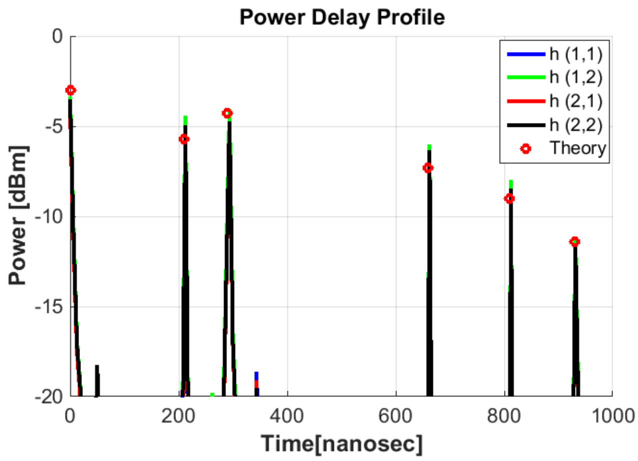


Fig. 3. The PDP verification measurement for the channel emulator using VNA.

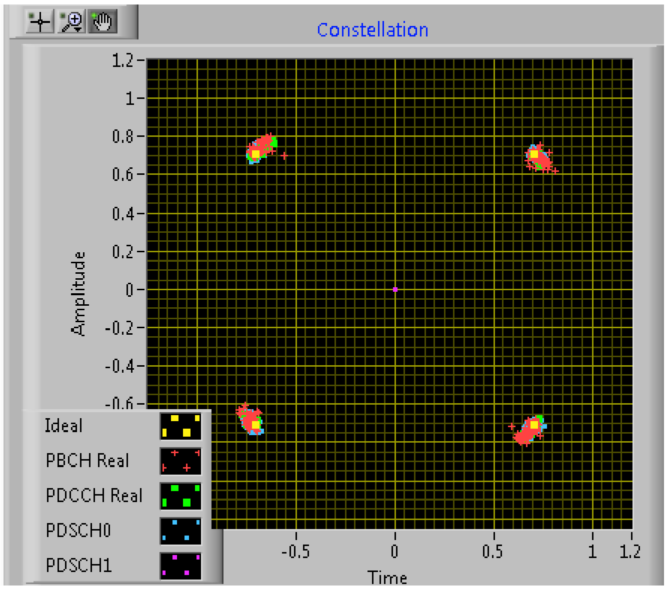
B. Evaluation of 2 × 2 MIMO system with and without CE

The MIMO system provides full function of TD-LTE based on 3GPP Release 8 [10]. For demonstration purpose, we show one of the fundamental physical parameters of the signals, which is the constellation diagram, so to evaluate the 2 × 2 TD-LTE MIMO system performance where Quadrature Phase Shift Keying (QPSK) digital modulation was employed. Other parameters are shown in Table I. Fig. 4 shows the measured system constellation plots of one complete LTE data frame with and without CE.

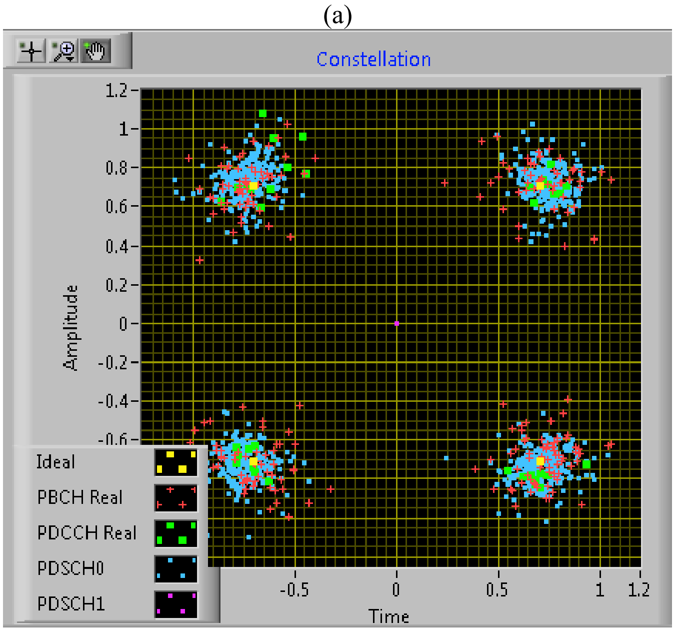
TABLE I. SOME OF THE PARAMETERS USED WHEN EVALUATING THE SYSTEM.

Item	Value
Centre Frequency (GHz)	2.535
Bandwidth (MHz)	20
Number of Frequency Carriers	1
Frame Configuration	0
Special Frame Configuration	1
User Equipment Transmission mode	2
PDSCH MCS (Modulation and Coding Scheme)	1
Transmission Scheme	Transmit Diversity

The results indicate that, without CE, the conducted system setup gives anticipated QPSK constellation plot whereas with CE between the 2 × 2 MIMO systems, the channel emulation has introduced the expected deviation from the perfect QPSK.



(a)



(b)

Fig. 4. The constellation diagram of the 2 × 2 MIMO transciever system: (a) without channel emulation; (b) with channel emulation.

C. Preliminary evaluation results of througput test

We carried out some preliminary test on the system throughput. Test parameters used were the same as previously used in the system evaluation and the initial results for throughput of Physical Downlink Shared Channel (PDSCH) are shown in Fig. 5 against the total power of the LTE transmitters sweep from -67 dBm to -57 dBm with 1 dBm step resolution.

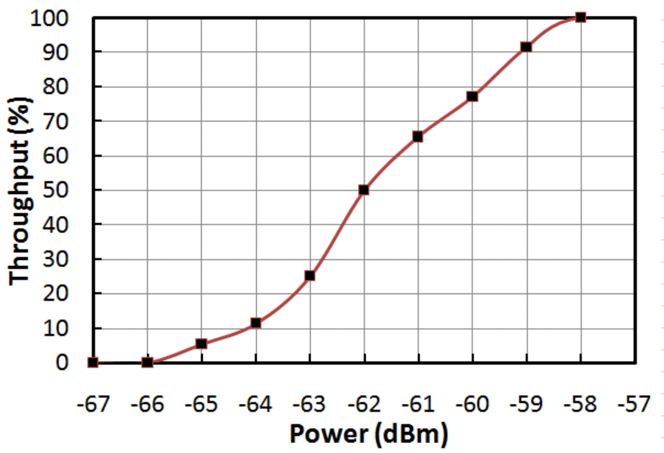


Fig. 5. Throughput of PDSCH obtained using the MIMO OTA system.

IV. Discussion and Future Works

In this paper, we have presented a 2 × 2 MIMO OTA test measurement system based on user-programmable and reconfigurable FPGA-based VSTs that offer SDR capability. It is envisaged that such system does not only enable traceability study with fast prototyping, but also is capable of accommodating multiple communications protocols without the need to deploy new hardware.

A 3GPP MIMO OTA two-stage conducted test was performed using a downlink TD-LTE duplex scheme in which the CE was operated in stochastic mode with ideal isotropic antenna pattern being considered. To perform a MIMO OTA radiated test of a specific device under test (DUT), in which its chipset is envisaged to provide the amplitude and relative phase measurements of the antennas, one could establish protocol handshake between the transmitter and DUT using the proposed MIMO OTA SDA platform.

Some system functionality evaluations such as PDP, constellation diagram and throughput of PDSCH have been carried out for TD-LTE downlink following the 3GPP two-stage method. The proposed system is user programmable, which offer flexibility that enables the unlimited potential functionality exploitation, especially, the configurability to adapt the emergence of new standards and protocols.

Using such a system, we envisage that we could carry out measurement uncertainty evaluation on 3GPP approved OTA methods such as the two-stage method (with an approved anechoic chamber), or reverberation chamber with and without channel emulator methods. Furthermore, this system could potentially enable the development of signal test, communication algorithm, and measurement metrology for 5G communications.

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