MIMO Antenna Performance Assessment Based on Open Source Software Defined Radio

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***Abstract*—This paper presents a low-cost measurement method for MIMO antenna performance assessment based on the open-source OpenAirInterface initiative. A first measurement is presented with a prototype with 8 antennas at 2.6 GHz integrated into a 140x140x40mm femto cell and using Laser Direct Structuring (LDS) technique. The setup is validated trough a beamforming gain measurement in a MISO 4x1 configuration in LTE TDD mode. We achieved the expected 6 dB beamforming gain between a SISO and 4x1 MISO configuration.**

***Index Terms*—OTA measurement, MIMO, LDS technology, Beamforming, OpenAirInterface.**

I. Introduction

Exponential increase in mobile data traffic [1] encourages the telecommunications industry to develop new technologies. Over the last decade MIMO techniques have been established in the wireless communications to enhance spectrum efficiency. Latest LTE releases target up to 8x8 MIMO schemes. Assessment of MIMO antenna radiated performance needs to take into account the global telecommunication system and channel characteristics instead of considering the radiating element alone. The so-called Over The Air (OTA) measurements are performed at the system level and include modulation code schemes (MCS) and 3GPPP standards [2].

New multi-antennas techniques such as beamforming, spatial multiplexing and diversity, aim to take advantage of channel characteristics to increase data rates or reliability [3] through SNR improvement. Characterizing this type of radiating system is a major challenge for antenna designers because it is mandatory to use or emulate a multi-path channel. Indeed, MIMO techniques have to be developed and evaluated in multi-path environment, so classical measurement in anechoic chamber is not sufficient. The industrial solution to assess MIMO performance aim to emulate a channel in a controlled environment such as an anechoic chamber [3], [4], [5]. This method implies the use of the Device Under Test (DUT) surrounded by multiple probes in order to emulate the multi-path environment. The emulated channel is based on standard channel models describing the variations of the electromagnetic waves between a radio transmitter and a receiver, as a function of time, frequency and space.

Radio channel emulators are expensive equipment proposed only by a few suppliers (e.g., Agilent, Rhodes&Schwarz, Satimo, Anite) and are still under development for Massive MIMO techniques. In this paper, we describe the design of a custom testbed using existing Software Defined Radio (SDR) boards. The general purpose of this work is to develop an Over The Air (OTA) measurement system to characterize a MIMO access point. The main idea is to leverage the OpenAirInterface (OAI) platform developed by EURECOM [6], interfaced with ExpressMIMO2 PCI Express (PCIe) boards, which are the default software radio frontends for OAI. This "soft-emulator" runs on a simple Linux machine allowing for a strong cost reduction.

Fig. 1. Pictures of the LDS antenna prototype

II. New opportunities in antenna design

5G requirements are challenging for antenna designers because of the miniaturization of the access point. Some emerging technologies such as 3D printing [7] and plastronic are offering new degrees of freedom and more flexibility in antenna design. The Laser Direct Structuring (LDS) [8] and Laser Induced Metallization (LIM) [9] allow the antennas to be directly printed on plastic. These are promising new methods for optimizing the volume in small devices such as femtocells.

Fig. 1 shows the prototype of a plastronic gateway fabricated with LDS technology, with 8 dual-band antennas at 2.5 & 5 GHz. The 2.5 GHz band include a Wi-Fi and a LTE band. Antennas are connected with coaxial cables. The different length

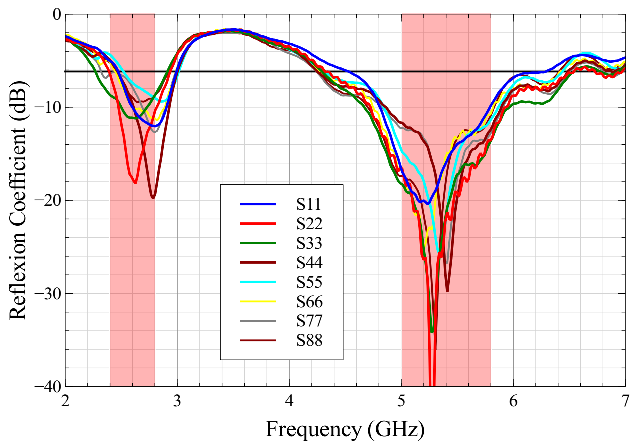

Fig. 2. Measured Reflection Coefficient per antenna

of the cables will be compensate by a calibration phase. The topology of those antennas and their characteristics have been presented in [10]. This prototype uses the same configuration as in [10] but antennas are printed on a plastic box made of polycarbonate using LDS technology. This material has a permittivity of ε_r = 2.7 and a loss tangent of tanδ = 0.01. The metallized zones of the plastic (antennas, ground plane, feed lines) are electronically activated by a laser.

Fig. 2 presents the reflection coefficient for each antenna in the prototype. We observe that matching is better -6dB at each band. A few set of antennas are out of the 2.4 GHz Wi-Fi band because of the handmade flawed welding and a very fragile prototype. In this study we focus on the 2.68 GHz carrier frequency. The average gain for this frequency is 3.2 dB with an average efficiency of 0.6 dB. The mutual coupling between each antenna is lower than 10 dB. This design will be used as the evolve Node B (eNB) to assess the performance of the proposed testbed.

III. Proposed Testbed

Future wireless systems consisting of a large number of antennas must be characterized in a multipath channel environment. Indeed S-parameters and free space radiation measurements are not sufficient when it comes to assessing MIMO or beamforming performance. The OAI platform allows us to test in almost real conditions various innovative antennas configurations.

A. OpenAirInterface

OpenAirInterface Software Alliance (OSA) [6] is a non-profit consortium to develop an ecosystem for open source software/hardware development for the core network (EPC) and access-network (EUTRAN) of 3GPP cellular networks.

OAI can be used to build and customize an LTE base station and core network on a standard PC and connect a commercial UE to test different configurations and network setups and monitor the network and mobile device in real-time. With OAI, the transceiver functionality is realized via a software radio frontend connected to a host computer for processing.

Our goal is to evaluate the performance of the antenna arrays. This makes the experimental approach necessary in order to validate and compare different antenna design solutions. The execution environment has to be that of a real system in order to obtain realistic results. However, real testbeds are expensive and not scalable and the measurements produced on them are hard to predict and reproduce. This is why we effectively utilize the OAI platform which is built to represent a realistic system in a controlled and real-time environment.

B. MIMO-TDD technology

It is widely recognized that multi-antenna technologies achieve higher spectral efficiencies. One main feature provided by the multiple antenna techniques is the array gain, which allows the concentration of energy in one or more directions via precoding or beamforming. Thus, multiple users located in different directions can be served simultaneously (multi-user MIMO). In order to perform beamforming and achieve these gains, the base station (BS) must have good knowledge of the downlink (DL) channel (so-called channel state information at the transmitter (CSIT)). Usually, in a frequency division duplexing (FDD) system, CSIT is obtained using feedback, but this wont be feasible when a large number of antennas is used as the channel would be outdated by the time it is measured by the receiver and fed back to the BS.

The solution is to operate in Time Division Duplexing (TDD) mode within the channel coherence time and rely on reciprocity between the uplink (UL) and DL channels. Channel reciprocity means that the BS can acquire knowledge of the channel just through UL channel estimates. However, the hardware chains in the transceivers may not be reciprocal between the UL and DL, due to the random phase and amplitude differences in the RF front-end components. Thus, the reciprocity holds only at the antennas, and normally it gets lost in the baseband after the IQ mixer. For that reason, various calibration methods have been proposed. As part of our work we are using the relative calibration procedure proposed in [11], which is totally based on signal processing techniques. The entire channel seen from the digital signal processing point of view is composed of the hardware blocks on the transceivers and the physical channel in the air. The key concept behind this relative calibration method used to compensate the RF impairments is the fact that the hardware's system characteristics change much slower than the physical channel in the air. So, we can model them in a so-called calibration matrix, whose diagonal elements represent the gains on each transmit chain whereas the off-diagonal elements correspond to the RF-chain crosstalk and the antenna mutual coupling.

C. Measurement Setup

The architecture of the 4x1 MISO system is shown in Fig. 3. It consists of two ExpressMIMO2 boards acting as

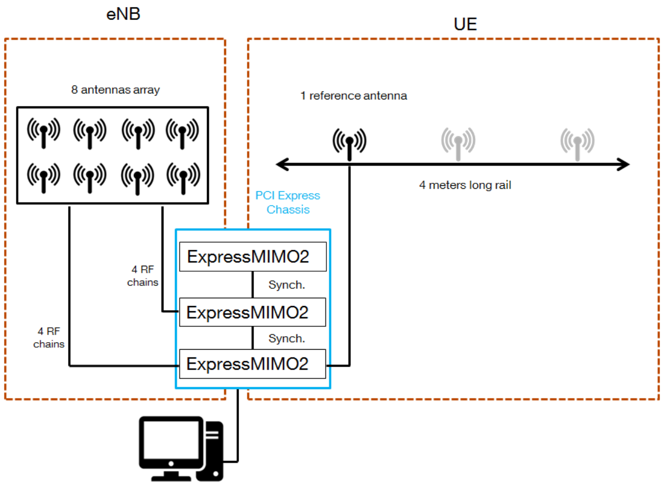

Fig. 3. Schema of the proposed setup

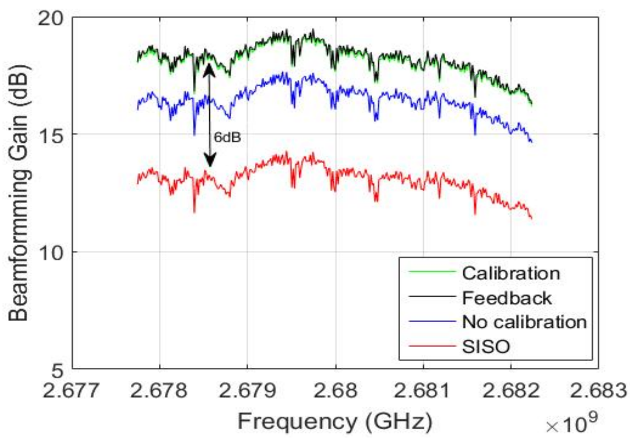

Fig. 4. Beamforming Gain between SISO and MISO 4x1

eNB and UE, running on common x86 Linux machines. Each motherboard features 4 parallel RF chains with bandwidths up to 20 MHz (4x5 MHz, 2x10 MHz, 1x20 MHz) per chain covering a range of $350 - 3800$ MHz of the available RF spectrum. It interconnects with a baseband computing engine using Gen1 1-way PCIexpress. The latest version of the ExpressMIMO2 board also has built-in amplifiers, LNAs, and switches for TDD operation. The eNB is connected to four antennas integrated in a plastic box obtained by LDS technology. The UE uses a monopole reference antenna. Moreover, the UE is embedded on an automated 4 meters long rail to perform statistic measurements in different propagation channels.

The proposed setup is configured for 4x1 MISO communication aiming to characterize beamforming gain through SNR measurements. Our main goal is to assess the measurement setup by verifying the 3 dB increase on the beamforming gain when doubling the number of antennas. The testbed also validates the signal processing algorithms implemented in the simulation platform Octave before integrating them into the OAI real-time environment. eNB transmits 10 LTE OFDM frames at 2.68 GHz with a bandwidth of 5 MHz and a transmitted power of 10 dBm. The power is chosen to insure a good level of reception in the whole room while avoiding saturation of receiving RF chains. We repeat the above transmissions for 20 different positions and afterwards we average, in the space domain, the measured SNR.

IV. Measurement results

Our goal is to increase channel capacity through SNR. According to the channel capacity formula Eq.1 we should have a 3 dB increase of the SNR when doubling the number of antennas at the transmitter.

$$C = \sum_{i=1}^{min(M,N)} B_i \log(1 + SNR_i) \qquad (1)$$

where B is the bandwidth, M and N the number of antennas at the receiver and the transmitter, respectively, and SNR represents the signal to noise ratio. Fig. 4 illustrates a 6 dB increase on the SNR for the 4x1 MISO case compared to the SISO one. We also observe that the calibration method achieves the same beamforming gain compared to the feedback method. Both calibration and feedback methods show a 2 dB improvement of the SNR compared to a no calibration measurement.

V. Conclusion

In this paper we presented a new low-cost measurement method to characterize MIMO performance. The first results confirm the 6dB array gain between a SISO case and a 4x1 MISO system. In the conference presentation we will show statistical results taken by the embedded UE on the rail in a 8x1 MISO system. This measurement method will be used to compare different antenna configurations. In order to characterize the benefits of the LDS technology we will also perform measurements using a classic PCB. The open-source aspect of OAI allows the development of various algorithms to test more scenarios such as MU-MIMO or carrier aggregation. OAI will be capable of accommodating various communication protocols without additional hardware. Since OpenAirInterface is a 3GPP LTE compliant platform, we intend to use a commercial smartphone as UE.

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