# LuMaMi - A flexible testbed for massive MIMO

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Abstract-Massive multiple-input multiple-output (MIMO) is one of the strong candidates for future generation mobile systems. Theoretical studies promise orders-of-magnitude improvements in both spectral and energy efficiency, as the number of antenna elements on base-stations grow large. While these studies are performed under simplifying assumptions, such as independent and identically distributed elements in channel matrices, it is well known that the performance of massive MIMO ultimately depend on the propagation conditions. Channel measurements have, however, shown that it is often possible to harvest a large fraction of the promised gains also in real propagation environments - even with linear precoding and detection schemes. Lund University has teamed up with National Instruments to take the next step in the direction of evaluating the possibilities and practical limits of massive MIMO. Together we have developed a flexible 100antenna testbed for real-time massive MIMO evaluations. The Lund University massive MIMO testbed (LuMaMi) consists of 50 synchronized universal software-radio pheripherals/softwaredefined radios (USRPs/SDRs) with two transceiver chains each. On the terminal side we have 5 USRPs acting as 10 singleantenna terminals. Here we report on the overall testbed design and first results from communication tests will be given during the presentation.

### I. INTRODUCTION

ASSIVE MIMO is a promising technology and a strong L candidate for future-generation wireless systems. Compared to conventional MIMO, the extra degrees-of-freedom due to an excess number of base-station (BS) antennas implies several benefits [2] [3]. Both system capacity and radiated energy efficiency can be improved by several orders of magnitude, while requirements on hardware impairments can be relaxed. Further, by performing most of the heavyduty processing on the base-station side, user equipment (UE) complexity can be kept low. Next steps in the development and verification of massive MIMO include testbed development, where massive MIMO can operate under real-life conditions. With increased knowledge about how massive MIMO perform in real propagation environments we can support algorithm development and circuit design for massive MIMO systems with better requirements specifications.

Together with National instruments we have developed an extensible platform, the LuMaMi testbed, currently realizing up to 20 MHz bandwidth 100-antenna massive MIMO. The main objectives for the testbed are:

- implementing BS architectures to meet high-throughput/low-latency processing requirements;
- evaluating practical performance of different baseband processing algorithms;

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• implementing time and frequency synchronization solutions between BS RF chains;

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- identifying scenarios where favorable propagation conditions for Masssive MIMO exist (or do not exist);
- demonstrating a Massive MIMO proof-of-concept by concurrent high-speed data streaming to and from multiple users, via high-density spatial multiplexing within the same time-frequency resource.

## II. TESTBED DESIGN

#### A. Base-station build

The testbed BS consists of four 18-slot PCIe/PXIe chassis, of which one act as master chassis in a star configuration. The master chassis contains a central controller running LabView and this is where data aggregation and centralized processing is performed. The central controller also perform mesurement tasks, such as collecting bit-error, packet-error, and other statistics. The master chassis connects to the other three chassis, acting as switches, through cabled Gen 2 x8 PCI Express (MXIe). The 50 USRPs/SDRs are then connected to the switches using Gen 1 x4 MXIe cables. This allows data to be transferred efficiently between USRPs/SDRs and between USRPs/SDRs and the central controller.

The USRPs/SDRs (NI 2943R/USRP-RIO) each contain a reconfigurable (Xilinx Kintex-7) FPGA and two full-duplex 40 MHz RF bandwidth transceivers that can be configured for center frequencies 1.2-6 GHz, and can transmit with up to 15 dBm. Baseband processing is partitioned and distributed across the fifty FGPAs, as detailed in Sec. II-B, and the RF transceivers connect to the antenna array.

Time synchronization and phase coherency between the RF chains is achieved using a reference clock and timing/trigger distribution network. This synchronization network consists of eight OctoClock modules in a tree structure with a master OctoClock feeding seven secondary OctoClocks. Low-skew buffering circuits and matched-length transmission cables ensure that there is low skew between the reference clock input at each SDR. Initial results show that reference clock skew is within 100 ps and trigger skew is within 1.5 ns, which is well below the sampling period of 33 ns.

Two rack mounts assemble all BS components with combined measures of  $0.8 \times 1.2 \times 1$  m shown in Fig. 1 and Fig. 2. They were attached on top of a four-wheel trolley not to compromise its mobility when testing different scenarios. Approximate combined weight and average power consumption are 300 kg and 2.5 kW, respectively.



Fig. 1. Side view of the mechanical assembly the BS. The two racks sit sideby-side (not as shown) with the SDRs facing the same direction (towards the antenna array). Two columns of URSPs are mounted in each rack, totaling 50.



Fig. 2. Picture of the assembled BS, with mounted antenna array.

#### B. Base-band processing

The testbed is based on orthogonal frequency-division multiplex (OFDM) in combination with massive MIMO. The baseband processing is partitioned across available FPGAs, where the occupied bandwidth is divided into eight OFDM sub-bands which are processed independently to relax the IO requirements of a single FPGA. One subsystem of eight FPGAs, shown in the Fig. 3, operate per sub-band. Additional folding of MIMO detectors and precoders (since we do not have eight subsystems) is performed and end nodes are inserted to achieve a full 100-antenna platform.

## C. Antenna Array

The planar "T"-shaped antenna array was designed and built in-house with 160 dual polarized  $\lambda/2$  shorted patch elements.



Fig. 3. BS subsystem for partitioned baseband processing.

The "T" upper horizontal rectangle has  $4 \times 25$  elements and the central square  $10 \times 10$  elements, (see Fig. 2). This yields 320 possible antenna ports that can be used to explore different antenna array arrangements.

#### D. User Equipment

Five USRPs/SDRs (NI 2953Rs/USRP-RIOs) are used at the terminal ends to emulate the UEs. They yield similar properties as the ones at the BS with the additional feature of their internal clocks can be locked to a GPS reference signal. This provides a reliable timing reference for sampling purposes, and a frequency offset of less than 1 ppb.

## III. GENERAL PARAMETERS

Current testbed parameters chosen similar those in LTE systems, as shown in Table I.

TABLE I High-level system parameters

Parameter	Variable	Value	
Bandwidth	W	20 MHz	
Carrier frequency	$f_c$	3.7 GHz	
Sampling Rate	$F_s$	30.72 MS/s	
FFT Size	$N_{FFT}$	2048	
# Used subcarriers	$N_{used}$	1200	
Slot time	$T_S$	0.5 ms	
Sub-Frame time	$T_{sf}$	1 ms	
Frame time	$T_{f}$	10 ms	
# UEs	$\check{K}$	10	
# BS antennas	M	100	

#### REFERENCES

- J. Vieira, S. Malkowsky, K. Nieman, Z. Miers, N. Kundargi, L. Liu, I. Wong, V. Öwall, O. Edfors, and F. Tufvesson, "A flexible 100-antenna testbed for massive MIMO," in *Global Communications Conference* (*GLOBECOM*), 2014 IEEE, Dec 2014.
- [2] H. Q. Ngo, E. Larsson, and T. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *Communications, IEEE Transactions on*, vol. 61, no. 4, pp. 1436–1449, April 2013.
- [3] E. Larsson, O. Edfors, F. Tufvesson, and T. Marzetta, "Massive MIMO for next generation wireless systems," *Communications Magazine*, *IEEE*, vol. 52, no. 2, pp. 186–195, February 2014.