OpenAirInterface: Open-source software radio solutions for 5G

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***Abstract*—LTE 4G cellular networks are gradually being adopted by all major operators in the world and are expected to rule the cellular landscape at least for the current decade. They will also form the starting point for further progress beyond the current generation of mobile cellular networks to chalk a path towards fifth generation mobile networks. Several new approaches and technologies are being considered as potential elements making up such a future mobile network, including cloudification of radio network, radio network programability and APIs following SDN principles, native support of machine-type communication, and massive MIMO. Research on these technologies requires realistic and flexible experimentation platforms that offer a wide range of experimentation modes from real-world experimentation to controlled and scalable evaluations while at the same time retaining backward compatibility with current generation systems.**

In this work, we present OpenAirInterface (OAI) as a suitably flexible platform towards open LTE ecosystem and playground. We will demonstrate an example of the use of OAI to deploy a low-cost open LTE network using commodity hardware with standard LTE-compatible devices. We will further show the feasibility of using OpenAirInterface to implement some features of 5G, such as cloud-RAN centralized processing, massive MIMO, and alternative waveforms for low-latency communications.

I. Introduction

Cellular systems are among one of the last industries expected to converge from a slow-moving proprietary and expensive HW/SW platforms towards an open SW platforms leveraging commodity hardware. This is required to build an open cellular ecosystem and foster innovations in the wireless world as already produced in OpenStack for cloud services and Android for mobile OS. Currently, the only open cellular ecosystem is that of OpenBTS, which provides an open development kit for 2G systems [1].

In this work, we present OpenAirInterface (OAI) wireless technology platform as a first opensource software-based implementation of the LTE system spanning the full protocol stack of 3GPP standard both in E-UTRAN and EPC [2]. It can be used to build and customized an LTE base station and core network on a PC and connect a commercial UEs to test different configurations and network setups and monitor the network and mobile device in realtime. OAI is based on a PC hosted software radio frontend architecture. With OAI, the transceiver functionality is realized via a software radio front end connected to a host computer for processing. This approach is similar to other software-defined radio (SDR) prototyping platforms in the wireless networking research community such as SORA [3]. Other similar approaches combining PCs and FPGA-based processing make use of NI LabVIEW software [4] or using the WARP [5] architecture. To our best knowledge, OpenAirInterface is the only fully x86-based SDR solution in open-source, providing both UE, eNB, and core-network functionality. A similar closed-source development commercialized by Amarisoft (LTE 100) which targets several USRP platforms provides eNB and core-network functionality on standard Linux-based PCs [6]. OAI is written in standard C for several realtime Linux variants optimized for x86 and released as free software under the terms of version 3 of the GNU General Public License (GPLv3). OAI provides a rich development environment with a rang of build-in tools such as highly realistic emulation modes, soft monitoring and debugging tools, protocol analyzer, performance profiler, and configurable logging system for all layers and channels [7], [8].

Towards building an open cellular ecosystem for flexible and low-cost 4G deployment and experimentations, OAI aims at the following objectives:

- Open and integrated development environment under the control of the experimenters;
- Fully software-based network functions offering flexibility to architect, instantiate, and reconfigure the network components (at the edge, core, or cloud using the same or different addressing space);
- Playground for commercial handsets as well as application, service, and content providers;
- Rapid prototyping of 3GPP compliant and non-compliant use-cases as well as new concepts towards 5G systems ranging from M2M/IoT and software-defined networking to cloud-RAN and massive MIMO.

II. OpenAirInterface (OAI)

A. Software

Currently, the OAI platform includes a full software implementation of 4th generation mobile cellular systems compliant with 3GPP LTE standards in C under realtime Linux optimized for x86. At the Physical layer, it provides the following features:

- LTE release 8.6 compliant, with a subset of release 10;
- FDD and TDD configurations in 5, 10, and 20 MHz bandwidth;
- Transmission mode: 1 (SISO), and 2, 4, 5, and 6 (MIMO 2x2);
- CQI/PMI reporting;

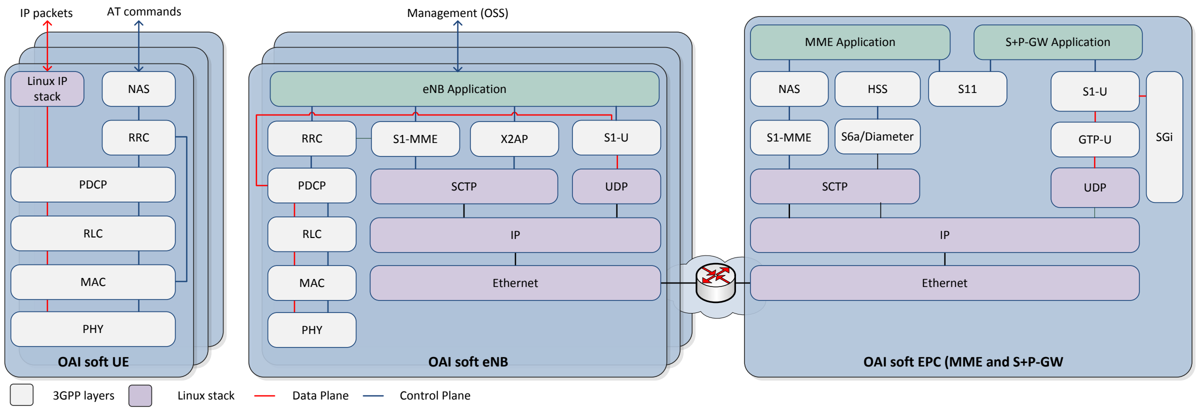


Fig. 1: OpenAirInterface LTE software stack.

- All DL channels are supported: PSS, SSS, PBCH, PCFICH, PHICH, PDCCH, PDSCH, PMCH;
- All UL channels are supported: PRACH, PUSCH, PUCCH, SRS, DRS;
- HARQ support (UL and DL);
- Highly optimized base band processing (including turbo decoder). With AVX2 optimization, a full software solution would fit with an average of 1x86 core per eNB instance (64QAM in downlink, 16QAM in uplink, 20MHz, SISO).

For the E-UTRAN protocol stack, it provides:

- LTE release 8.6 compliant and a subset of release 10 features;
- Implements the MAC, RLC, PDCP and RRC layers;
- protocol service for Rel10 eMBMS (MCH, MCCH, MTCH)
- Priority-based MAC scheduler with dynamic MCS selection;
- Fully reconfigurable protocol stack;
- Integrity check and encryption using the AES algorithm;
- Support of RRC measurement with measurement gap;
- Standard S1AP and GTP-U interfaces to the Core Network;
- IPv4 and IPv6 support.

Evolved packet core network features:

- MME, SGW, PGW and HSS implementations. OAI reuses standards compliant stacks of GTPv1u and GTPv2c application protocols from the open-source software implementation of EPC called nwEPC [9];
- NAS integrity and encryption using the AES algorithm;
- UE procedures handling: attach, authentication, service access, radio bearer establishment;
- Transparent access to the IP network (no external Serving Gateway nor PDN Gateway are necessary). Configurable access point name, IP range, DNS and E-RAB QoS;
- IPv4 and IPv6 support.

Figure 1 shows a schematic of the implemented LTE protocol stack in OAI. OAI can be used in the context of a rich software development environment including Aeroflex-Geisler LEON / GRLIB, RTOS either RTAI or RT-PREEMPT, Linux, GNU, Wireshark, control and monitoring tools, message and time analyser, low level loggin system, traffic generator, profiling tools and soft scope. It also provide tools for protocol validation, performance evaluation and pre-deployment system test. Several interoperability tests have been successfully performed with the commercial LTE-enabled mobile devices, namely Huawei E392, E398u-1, Bandrich 500 as well as with commercial 3rd party EPC prototypes. OAI platform can be used in several different configurations involving commercial components to varying degrees:

- OAI UE ↔ OAI eNB + OAI EPC
- OAI UE ↔ OAI eNB + Commercial EPC
- OAI UE ↔ Commercial eNB + OAI EPC
- OAI UE ↔ Commercial eNB + Commercial EPC
- Commercial UE ↔ Commercial eNB + OAI EPC
- Commercial UE ↔ OAI eNB + Commercial EPC
- Commercial UE ↔ OAI eNB + OAI EPC

B. *Hardware*

For real-world experimentation and validation, the default software radio frontend for OAI is ExpressMIMO2 PCI Express (PCIe) board. This board features a LEON3 embedded system based on Spartan 6 LX150T FPGA as well as 4 high-quality RF chipsets from Lime Micro Systems (LMS6002), which are LTE-grade MIMO RF front-ends for small cell eNBs. It supports stand-alone operation at low-power levels (maximum 0 dBm transmit power per channel) simply by connecting an antenna to the board. External RF for high-power and TDD/FDD duplexing can be connected to ExpressMIMO2 depending on the deployment scenario. RF equipment can be configured for both TDD or FDD operation with channel bandwidths up to 20 MHz covering a very large part of the available RF spectrum (250 MHz-3.8 GHz) and a subset of LTE MIMO transmission modes. ExpressMIMO2 boards are reasonably-priced and completely open (GNU GPL), both at the hardware and software level. Figure 2 shows the ExpressMIMO2 hardware platform.

The embedded software for the FPGA is booted via the PC or can reside entirely in the boot ROM which is part of the FPGA design. In the current design, the embedded software is booted by PCIexpress dynamically under control of the PC

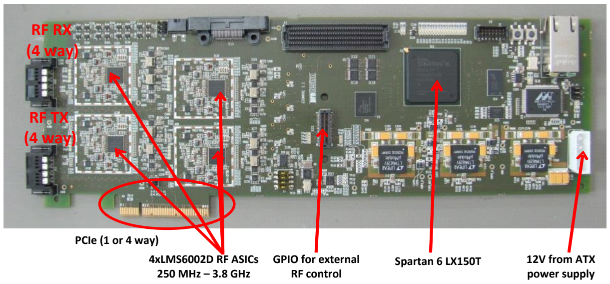


Fig. 2: OAI ExpressMIMO2 hardware platform.

device driver. The basic design does not include any on-FPGA signal processing and consumes approximately 10-15% of the FPGA resources. There is significant room left for additional processing on the FPGA, for instance Xilinx FFT processors to offload some processing from the host PC if required.

Besides ExpressMIMO2, OAI now supports the UHD interface on recent USRP PC-hosted software radio platforms which are widely used in the research community. Specifically, Agilent China has recently succeeded in interconnecting the OpenAirInterface softmodem software with a USRP B210 platform [10]. This development is now delivered as part of the publicly-available software package from the OAI website and SVN server [2]. EURECOM will continue to maintain this development and extend to X300 (USRP-Rio) family products. This achievement illustrates the validity of the standard PC plus generic SDR frontend approach taken in OAI since the code has been independently ported successfully on a totally different hardware target.

III. OpenAirInterface for 5G

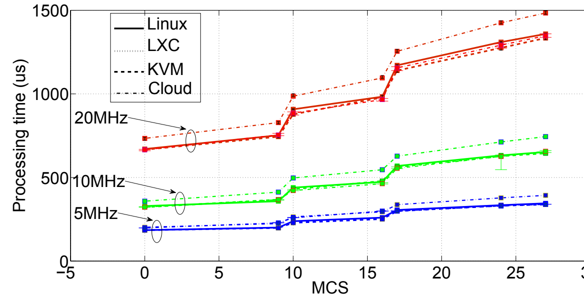
In this section we present three different application scenarios of OpenAirInterface for 5th generation networks.

A. Cloud RAN

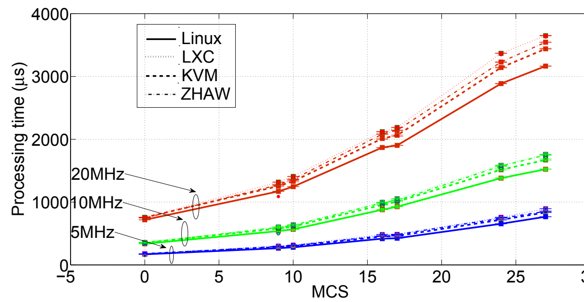
Cloudification of the Centralized-Radio Access Network (C-RAN) in which signal processing runs on general purpose processors inside virtual machines has lately received significant attention. Due to short deadlines in the LTE frequency division duplex access method, processing time fluctuations introduced by the virtualization process have a deep impact on C-RAN performance. In [11] we evaluate bottlenecks of the OpenAirInterface cloud performance, provide feasibility studies on C-RAN execution, and introduce recommendations for cloud architecture that significantly reduces the encountered execution problems. In typical cloud environments, the OAI processing time deadlines cannot be guaranteed. Our proposed cloud architecture shows good characteristics for OAI cloud execution. As an example, in our setup more than 99.5processed LTE subframes reach reasonable processing deadlines close to performance of a dedicated machine of a single core CPU.

B. Massive MIMO

For time division duplexing (TDD) systems, the physical channel in the air is reciprocal for uplink (UL) and downlink (DL) within the channel coherence time. However when the transceivers radio frequency (RF) hardware is taken into consideration, TDD channel reciprocity no longer holds because of the non-symmetric characteristics of RF transmit and receive chains. Relative calibration has been proposed to compensate this hardware impairment with a multiplicative matrix. In [12] we perform hardware measurements on this



(a) (a)



(b) (b)

Fig. 3: Processing time of a subframe at the eNB for downlink (a) and uplink (b) for different virtual machine environments [11].

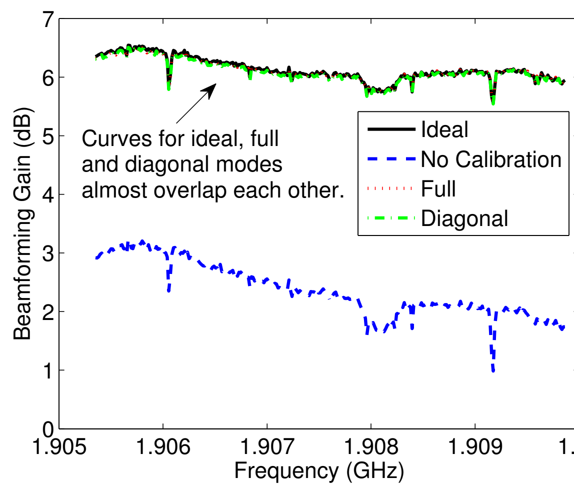


Fig. 4: Beamforming gain of a 4×1 MISO system with regard to a SISO system under the assumption of ideal calibration, no calibration, calibration assuming a diagonal matrix and calibration assuming a full matrix (SNR averaged over 28 random locations) [12].

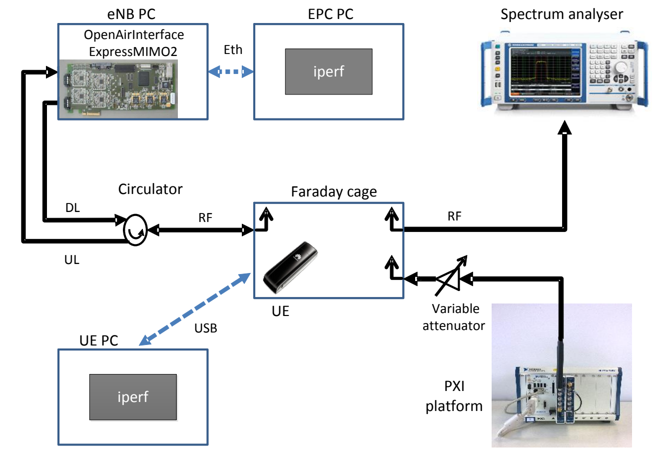


Fig. 5: Experimental setup for 4G/5G co-existence testing [13].

calibration matrix which gives a direct insight on the physical phenomenon of TDD transceivers. Especially, we experimentally verify the assumption that this calibration matrix is diagonal, which is widely adopted in literature but has never been verified by experiments.

This work can be regarded as an basis for reciprocity calibration in massive MIMO systems. In the future we plan to integrate this method in the software modem in order to support LTE transmission mode 7. This transmission mode allows arbitrary beamforming with arbitrary sized antenna arrays transparent to the user. We further plan to extend the OAI hardware platform to support up to 64 antenna elements.

C. Alternative waveforms

5G mobile networks will very likely include features that allow for a dynamic spectrum access (DSA) in order to exploit spectrum holes of a primary system. The efficient utilization of spectrum holes with minimum impairment of the primary system requires a waveform with a very low adjacent channel leakage ratio as well as robustness to time and frequency offsets. One of the approaches for new waveforms is Generalized Frequency Division Multiplexing (GFDM), a digital multicarrier transceiver concept that employs pulse shaping filters to provide control over the transmitted signals spectral properties. In [13] we present experimental results that evaluate the impact of the new GFDM waveform on an existing 4G system. The 4G system was based on Eurecoms OpenAirInterface for the eNB and a commercial UE. The 5G system was emulated using the LabVIEW/PXI platform with corresponding RF adapter modules from National Instruments and TUDs GFDM implementation. The experimental results show that GFDM can be used with about 5 dB higher transmit power than a corresponding orthogonal frequency division multiplexing (OFDM) system, before any impact on the primary system is noticeable. The results from our real-time measurements were validated by simulations.

IV. Conclusion

We present the OpenAirInterface as a suitably flexible platform for an open cellular ecosystem both for 4G experimentation as well as for 5G research. It offers an open-source reference software implementation of 3GPP-compliant LTE system and a subset of LTE-A features for real-time indoor/outdoor experimentation and demonstration.

We show the flexibility and reconfigurability of the platform with the help of three different research areas where OpenAirInterface can be used: massive MIMO, cloud RAN, and alternative waveforms.

Acknowledgement

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