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OpenAirInterface 4G: An Open LTE Network in a PC

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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. The lack of open cellular ecosystem has limited applied research in this field within the boundaries of vendor and operator R&D groups. Furthermore, 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 programmability 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 [1]. 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 also show the reconfigurability features of the platform.

1 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 [2].

In this work, we present OpenAirInterface (OAI) wireless technology platform as a first open source software-based implementation of the LTE system spanning the full protocol stack of 3GPP standard both in E-UTRAN and EPC [1]. It can be used to build and customize 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 range of build-in tools such as highly realistic emulation modes, soft monitoring and debugging tools, protocol analyser, performance profiler, and configurable logging system for all layers and channels.

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.

2 OpenAirInterface (OAI)

2.1 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;
- 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 [7];
- 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.

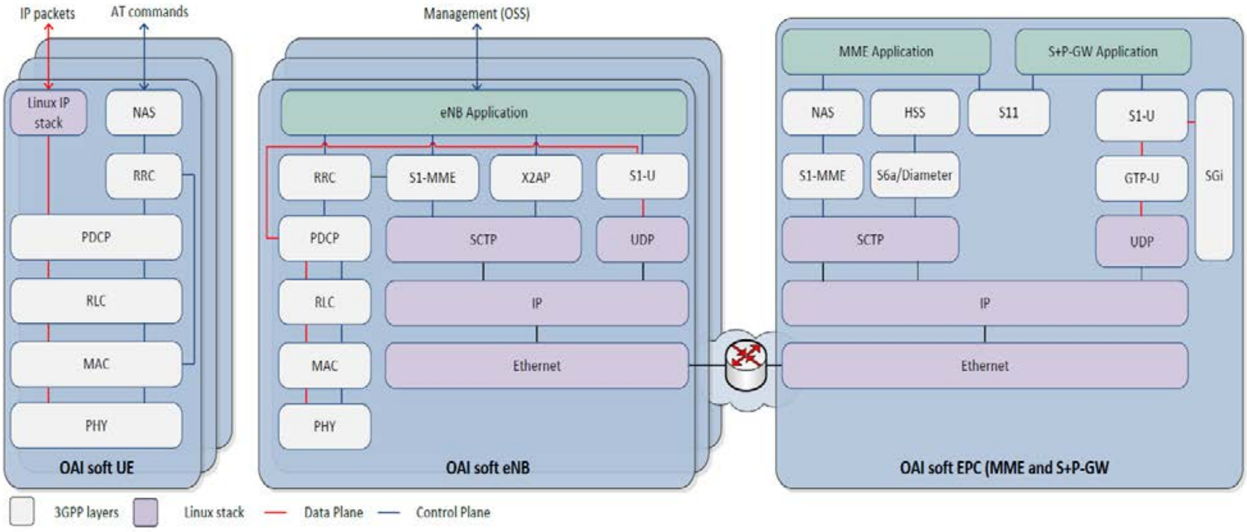

Figure 1: OpenAirInterface LTE software stack.

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
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- Commercial UE ↔ OAI eNB + OAI EPC

2.2 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.

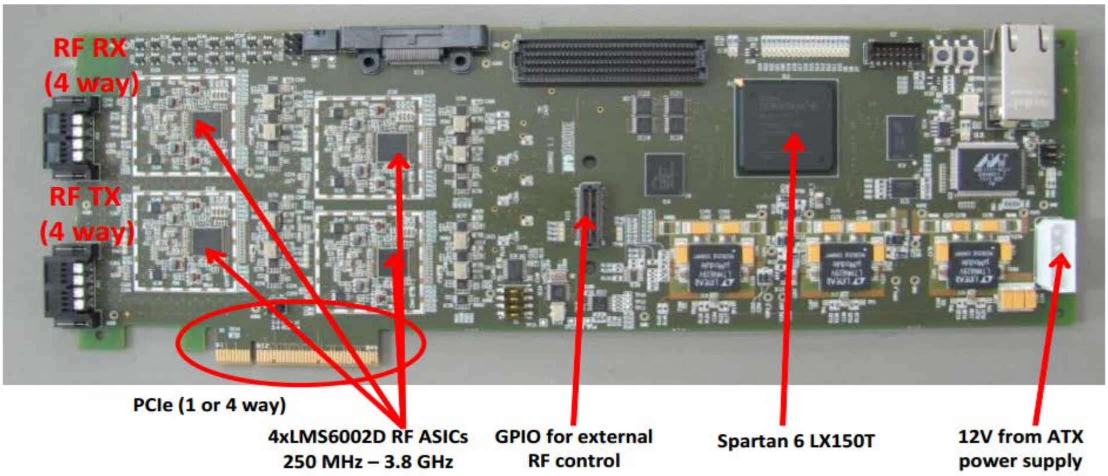

Figure 2: OAI ExpressMIMO2 hardware platform

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 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.

To enhance the current design in the FPGA, every newly added block should have an AHB bus interface. The LEON3 processor is easily configured in order to interact with every block connected to the AHB bus. The PCI express controller block has been optimized in order to support the transfer of samples between the ExpressMIMO2 card and the PC at a rate that can goes up to 30.72 Msamples/s in both directions, while using only a one-lane PCI Express interface.

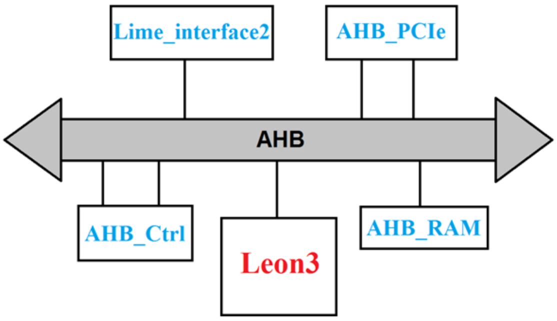

Figure 3: ExpressMIMO2 FPGA design architecture

All the DMA transfers are done through a shared allocated memory in the PC between the card and the user application. This shared memory has the size of one LTE frame (10 ms). There are also some shared allocated structures which allows to easily configure the card to the desired mode.

The interface between the user application and the card is a command based interface. The Leon3 processor reads the commands written by the driver in a dedicated register in the PCI Express controller and executes the corresponding instructions. Although the role of the integrated Leon3 processor is very limited and consists only on configuring the RF chips and executing the DMA transfers between the card and the PC, it is easily reconfigured to add new functionality because the firmware that runs on top of it is dynamically uploaded from the PC.

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 soft modem software with a USRP B210 platform[8]. This development is now delivered as part of the publicly-available software package from the OAI website and SVN server [1]. 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.

3 Demo Description

The considered demonstration scenario are depicted in Figure 4 and 5, and consists of 1 commercial LTE-enabled smartphone or Dongle (Huawei ascend P7 or E398u-1) and a laptop equipped with a USB LTE dongle (Huawei E398u-1 or Bandrich C500), 1 OAI soft eNB and 1 OAI soft EPC running on the top of Intel-based PC(s). Different setups are possible ranging from an all-in-one PC to all in a physically separated entities, which are deployment-specific. For the demo, we plan to demonstrate an all-in-one setup, where OAI soft eNB and EPC functions are performed inside the same PC.

In such a configuration, eNB is running on the host PC under realtime Linux, MME and S+P-GW running on the top of a VM, and HSS in another VM.

The demonstration will be deployed in FDD SISO mode. Two target frequencies will be used: band 13 (USA) and band 7 (Europe) in a controlled indoor radio environment. In the proposed demonstration, we will assess the following objectives

- Successful attach procedure (control-plane), and video streaming in downlink (data-plane);
- High-level of reconfigurability and programmability spanning all the layers allowing all kind of setups from protocols to radio frequency;
- demonstrate the mobile device behaviour in realtime;
- Usage of commodity hardware to run LTE network in a PC.

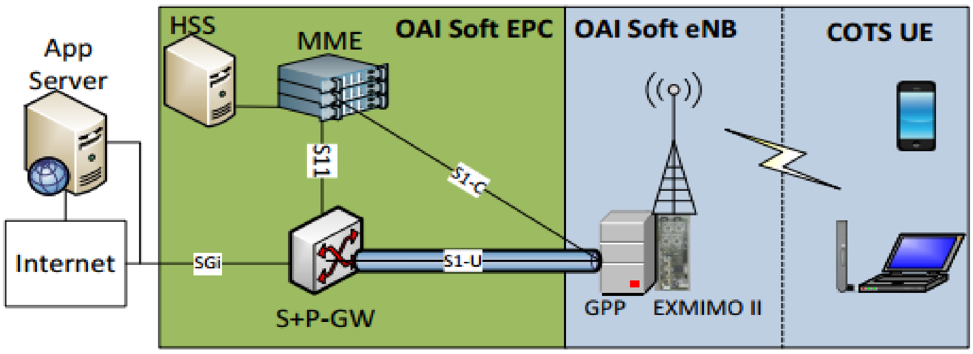

Figure 4: Demo setup and involved entities

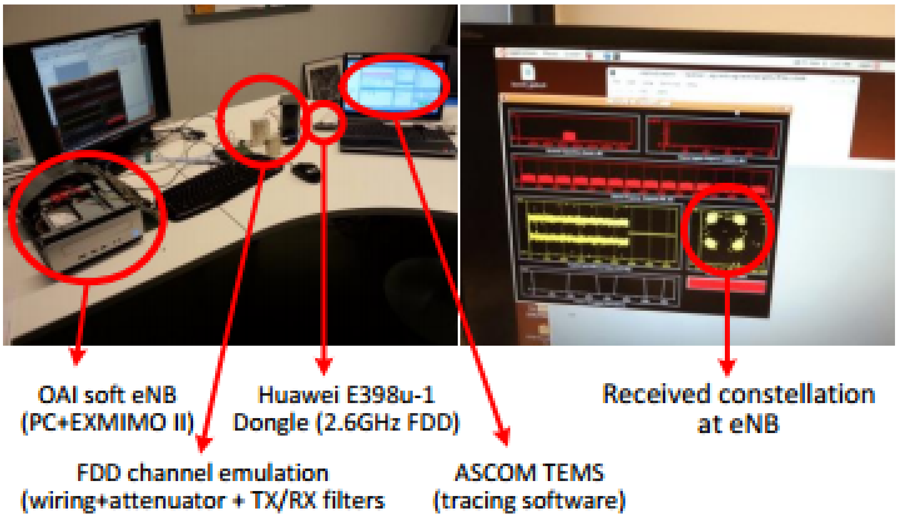

Figure 5: Hardware components of the demo.

The aforementioned experimental scenario will be demonstrated in live and the obtained results will be presented in parallel with the experiment execution. We will discuss the network programmability/reconfigurability through open APIs as well as the usage of OAI in both small-cell and cloud-RAN centralized processing.

4 *Demo Requirements*

The following equipment will be used for the demonstration:

- a PC running OAI EPC and OAI eNB with EXMIMOII card;
- one LTE UE dongle and one LTE smartphone;
- cables, filters, small antenna and attenuators.

In addition, we also require:

- a desk of 3 meters length to place the equipment;
- power supply plugs for all the devices and Internet access;
- 5 to 10 minutes to show and explain the demo.

5 *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. In the demo, we present an all-in-one LTE network deployment in a PC based on OpenAirInterface platform. We show the interoperability with commercial LTE enabled USB dongle and smartphones highlighting the complete attach procedure, establishment of default data radio bearer, and a live video transmission in downlink. We also show the reconfigurability features of the platform.

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About the Authors

Navid Nikaein is an assistant professor in mobile communication department at Eurecom since 2009, where he is exploring ideas stem from experimental system research related to radio access network (RAN) (L1.5/L2/L3) in cellular, adhoc/mesh, and cloud settings with realistic use-cases.
He is also leading the development of the radio access layer and system-level emulation of OpenAirInterface wireless technology platform.

Raymond Knopp received a B.Eng. (Honours) and a M.Eng. degrees in electrical engineering from McGill University (http://www.ece.mcgill.ca), Montreal, Canada, in 1992 and 1993, respectively.
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Christian Bonnet joined EURECOM as an associate professor in 1992. He was at the head of the Mobile Communications Department of EURECOM from 1998 to 2011. His current research topics are : Protocols for mobility management for all IP based systems, M2M Communications, Mobile Ad Hoc protocols (routing, multicast, topology management) , Cross Layer design of wireless systems and Internet of Things

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