Unleashing the potential of open-source in the 5G arena

OpenAirInterface 5G
Overview, Installation, Usage

Florian Kaltenberger
OpenAirInterface Workshop,
Beijing, 3.12.2019
Overview

- Overview and Ecosystem
- The OpenAirInterface Software Alliance (OSA)
- OpenAirInterface Radio Access Network (RAN)
  - Current and upcoming features
  - Hardware targets
  - Installation & Usage
  - Debugging tools
What is OpenAirInterface?

- **Open-source software-based implementation of 3GPP Technologies**
  - Starting at LTE (Rel 8), including features from LTE-Advanced (Rel 10/11/12), LTE-Advanced-Pro (Rel 13/14), going on to 5G Rel (15/16/…)
  - Spanning the full protocol stack of 3GPP standard
    - E-UTRAN (eNB, gNB, UE, nr-UE)
    - EPC (MME, S+P-GW, HSS)
  - Realtime RF and scalable emulation platforms
  - Works with many SDR platforms (ExpressMIMO2, USRP, LimeSDR, …)

- **Makes it is feasible to put a fully-compliant 4G eNodeB (and soon 5G gNB) and EPC in a commodity x86-based computer (or data center)**

- **Objectives**
  - Building a community of individual developers, academics and major industrials embracing open-source for 5G
  - Become a strong voice and maybe a game-changer in the 3GPP world
    - Real impact from “the little guys” on 3GPP systems
Collaborative Web Tools

- **Main page:**
  - https://www.openairinterface.org

- **Code available from**
  - RAN (eNB, UE, gNB, nr-UE)
    - https://gitlab.eurecom.fr/oai/openairinterface5g
  - EPC (MME, HSS)
    - https://github.com/OPENAIRINTERFACE/openair-cn
  - EPC (SPGW-C, SPGW-U)
    - https://github.com/OPENAIRINTERFACE/openair-cn-cups
  - 5GC
    - https://github.com/OPENAIRINTERFACE/openair5g-cn/

- **Mailing lists**
  - https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/MailingList

- **Developer meetings (Eurecom & Webex)**
  - General: Tuesday Mornings 11:00 CET (Europe/Asia)
  - NR: Thursday, 16:00 CET (Europe/Americas)

- **Forum in Chinese**
  - http://bbs.opensource5g.org/forum.php

- **Other tools:**
  - https://openairinterface.slack.com
  - https://trello.com/oaidev
The OpenAirInterface Software Alliance (OSA)

- Launched in 2014 as an endowment fund (French “Fonds de Dotation”)
- Current strategic members
  - orange
  - Fujitsu
  - Nokia
  - Bell Labs
  - TCL
  - INTERDigital
- Many associate members
- Goals:
  - Promote OpenAirInterface and its open-source licensing model
  - Support the community of developers and users
  - Accept donations to maintain engineering support team
OSA People

- **President:** Raymond Knopp (Eurecom)
- **General Secretary:** Florian Kaltenberger (Eurecom)
- **Treasury:** Pascal Gros (Eurecom)
- **Administrators:**
  - David Gesbert, Ulrich Finger, Navid Nikaein (Eurecom)
  - Pierre Bonnard (TCL), Yuko Akiyama (Fujitsu), Abhimanyu Gosain (PAWR), Christian Gallard (Orange), Laurent Despersin (Interdigital), Laurent Roullet (Nokia Bell Labs)
- **Staff**
  - Irfan Ghauri (Director)
  - Raphael Defosseux (CI Architect)
OSA Boards

- **Strategic Board**
  - OSA strategic members
  - Webex meeting every 2 weeks
  - Overview of recent activity
  - Discussion on
    - strategic objectives
    - Legal matters
    - Links with other organizations (e.g. standardization)

- **Technical Board**
  - Members: OSA, Orange, Nokia, Fujitsu, TCL, EURECOM, BCOM, Fraunhofer IIS, OpenCells
  - Webex meeting every 2 weeks
  - Roadmap implementation
  - Architecture evolution
  - Documentation & Coding guidelines
  - Review merge requests
    - Code quality
    - Adherence to architecture
The OAI Licensing model

- OAI public license 1.1 based on Apache V2.0 but allows committing software with patent rights into OSA and still keep licensing rights → inline with 3GPP FRAND

- License has also created interest from outside OAI community (e.g. ETSI)
Releases and Branches (RAN, EPC)

- **Master branch:**
  - Contains major releases and critical fixes
  - Update target: every 6 months
  - Every feature in master must be tested in CI
  - Roadmap defined by technical committee

- **Develop branch:**
  - Contains new features, new tests, bugfixes
  - Updated every week through merge request (MR) process
  - Every MR must pass regression test CI

- **Feature branches:**
  - For cutting edge development (e.g. NB-IoT, 5G-NR, etc)
  - Regular MR with develop desirable (at least should be updated regularly with develop to stay in sync)
  - Might have their own tests

- **Bugfix branches**
OAI Workflow

1. Create Ticket
2. Create Branch
3. Code Commits in branch
4. Rebase from latest develop branch
5. Push to Centralized Repo
6. Open Merge-Request to develop branch

Branch needed?

Yes

KO: dev needs extra work

No

7. Manual Inspection
8. Merge-Request Approval
9. Close Ticket/Merge Request
10. Merge from latest develop branch
11. Delete Branch

Extra-effort needed?

Yes

TC provides comments on merge-request improvements

No

CI Status?

OK

CI auto-triggered

KO

CI Status?

OK

CI auto-triggered

See also presentation from Raphael on Continuous Integration
Coming soon to OSA: Mosaic5G

- Mosaic5G is a collection of tools that sits on top of OAI RAN and CN

- https://gitlab.eurecom.fr/mosaic5g
- http://mosaic-5g.io/
- See presentation Navid this afternoon
OAI deployment options

4G Standalone

Presentation Lionel workshop

EN-DC Non-standalone

5G Standalone

Presentation Thien training

This presentation
OPENAIRINTERFACE
RAN FEATURES
Master branch history

- **v1.0.0 -> January 2019.**
  - This version implements the RAU/RRU architectural splits (FAPI, nFAPI and IF4.5)
  - Repository tree structure prepares future integrations of features such as LTE-M, NB-IoT, and 5G-NR.
  - Preliminary X2 support has been implemented.
  - S1-flex has been introduced.
  - New tools: config library, telnet server, ...
  - A lot of bugfixes and a proper automated Continuous Integration process validates contributions.

- **v1.0.1 -> February 2019:** Bug fix for the UE L1 simulator.
- **v1.0.2 -> February 2019:** Full OAI support for 3.13.1 UHD
- **v1.0.3 -> June 2019:** Bug fix for LimeSuite v19.04.0 API
Master branch history

- **v1.1.0 -> July 2019**
  - New Features
    - LTE-M,
    - X2 interface and handover,
    - CU/DU split (F1 interface),
    - CDRX,
    - eMBMS (UE),
    - multi RRU support
  - Continuous Integration
    - LTE-M,
    - F1 interface,
    - CDRX,
    - OAI UE (standard & “noS1”)
  - Other improvements
    - Build system:
      - One single build including simulators and “noS1” mode (now a runtime option --noS1)
      - TUN interface now used by default (for UE, eNB-noS1, and UE-noS1)
    - To use legacy kernel module, Can be disabled using the --nokrnmod 0
    - more code cleanup
    - cppcheck

- **V1.1.1 -> November 2019**
  - Bugfix for CQI reporting
The Physical layer implements 3GPP 36.211, 36.212, 36.213 and provides the following features:

- LTE release 8.6 compliant, and implements a subset of release 10;
- FDD and TDD configurations 1 (experimental) and 3;
- Bandwidth: 5, 10, and 20 MHz;
- Transmission modes: 1, 2 (stable), 3, 4, 5, 6, 7 (experimental);
- Max number of antennas: 2
- CQI/PMI reporting: aperiodic, feedback mode 3-0 and 3-1;
- PRACH preamble format 0
- All downlink (DL) channels are supported: PSS, SSS, PBCH, PCFICH, PHICH, PDCCH, PDSCH, PMCH;
- All uplink (UL) channels are supported: PRACH, PUSCH, PUCCH (format 1/1a/1b), SRS, DRS;
- HARQ support (UL and DL);
- Highly optimized base band processing (including turbo decoder).
- Expected throughputs DL
  - 5 MHz, 25 PRBS/ MCS 28 = 16-17 Mbit/s (measured with COTS UE Cat 3/4)
  - 10 MHz, 50 PRBS/MCS 28 = 34-35 Mbit/s (measured with COTS UE Cat 3/4)
  - 20 MHz, 100 PRBS/MCS 28 = ~70 Mbit/s (measured with COTS UE Cat 3/4)
- Expected throughputs UL
  - 5 MHz, 20 PRBs / MCS 20 = 9 Mbit/s (measured with COTS UE Cat 3/4)
  - 10 MHz, 45 PRBs / MCS 20 = 17 Mbit/s (measured with COTS UE Cat 3/4)
  - 20 MHz, 96 PRBs / MCS 20 = ~35 Mbit/s (measured with COTS UE Cat 3/4)
OpenAirInterface eNB features (MAC)

- The MAC layer implements a subset of the 3GPP 36-321 release v8.6 in support of BCH, DLSCH, RACH, and ULSCH channels.

- The eNB MAC implementation includes:
  - RRC interface for CCCH, DCCH, and DTCH
  - Proportional fair scheduler (round robin scheduler soon)
  - DCI generation
  - HARQ Support
  - RA procedures and RNTI management
  - RLC interface (AM, UM)
  - UL power control
  - Link adaptation
OpenAirInterface eNB features (PDCP)

- The current PDCP is header compliant with 3GPP 36-323 Rel 10.1.0 and implement the following functions:
  - User and control data transfer
  - Sequence number management
  - RB association with PDCP entity
  - PDCP entity association with one or two RLC entities
  - Integrity check and encryption using the AES and Snow3G algorithms
**OpenAirInterface eNB features (RLC)**

- **New implementation of RLC layer available (to be merged asap)**
- **Implements a full specification of the 3GPP 36-322 release v9.3**
  - RLC UM
    - Segment or concatenate RLC SDUs according to the TB size selected by MAC
    - Include a RLC header in the RLC PDU
    - Duplication detection
    - PDU reordering and reassembly
  - RLC AM (*default with new implementation*)
    - Segmentation, re-segmentation, concatenation, and reassembly
    - Padding
    - Data transfer to the user
    - RLC PDU retransmission in support of error control and correction
    - Generation of data/control PDUs

- **Not implemented in OAI**
  - RLC TM (mainly used for BCCH and CCCH)
    - Neither segment nor concatenate RLC SDUs
    - Do not include a RLC header in the RLC PDU
    - Delivery of received RLC PDUs to upper layers
  - OAI uses direct messages between MAC and RRC
OpenAirInterface eNB features (RRC)

- Based on 3GPP 36.331 v14.3.0.
  - System Information broadcast (SIB 1, 2, 3, and 13)
  - RRC connection establishment
  - RRC connection reconfiguration (addition and removal of radio bearers, connection release)
  - RRC connection release
  - RRC connection re-establishment
  - inter-frequency measurement collection and reporting
  - eMBMS for multicast and broadcast
  - X2 Handover
  - Paging
  - DRX (Discontinuous Reception) - CDRX (Connected Mode DRX)
Support for eMTC (Rel 13) in OAI

- **Configuration**: lots of new eMTC-related parameters to be fed to L1/L2 stack
  - **RRC**
    - Handling of Rel-13 information elements for eMTC
    - eMTC System Information handling
    - Extra bits in MIB
    - SIB1/SI: Quite Different from legacy LTE (repetitions, frequency-hopping, no DCI)
  - **PRACH handling**
    - Support for up to 4 CE levels: different number of repetitions per level => signal combining across repetitions for each level
    - New thread for eMTC PRACH (different parametrization in LTE Cell for eMTC)
  - **MPDCCH**
    - Support for EPDCCH allocation (only in MPDCCH configuration for now)
    - 3 new DCI formats
    - New procedures (search space, etc.)
    - No Repetitions yet
    - Limited to 4+2 PRB configuration
  - **PDSCH**
    - No Repetitions
  - **PUSCH**
    - No Repetitions yet
  - **PUCCH**
    - No Repetitions yet (removal of slot-frequency hopping)
  - **MAC**
    - RA procedures for eMTC
    - Basic scheduler for testing
Support for eMTC (Rel 13) in OAI

- **Very basic scheduler**
  - 1 downlink subframe every 2 frames with fixed mcs
  - 1 uplink subframe every 2 frames with fixed mcs
  - Currently limited to CEMode A (CE Levels 0,1)

- **New elements in configuration file**
  - targets/PROJECTS/Generic-LTE-ENB/CONF/enb.band13.tm1.50PRB.emtc.conf

- **Tested with commercial LTE-M Modules**
  - Nimbelink/Pycom Modules (Sequans Cat-M chipset)
  - Nimbelink Modules (QCOM chipset)
  - Nordic Semiconductor (nRF91 prototype)

- **Integration in OAI CI (Nimbelink, Pycom)**

- **Roadmap:**
  - Implementation of repetition mechanisms for coverage enhancement
  - Implementation of CDRX
OpenAirInterface eNB features (X2AP)

- The X2AP layer is based on 3GPP 36.423 v14.6.0 and implements the following functions:
  - X2 Setup Request
  - X2 Setup Response
  - X2 Setup Failure
  - Handover Request
  - Handover Request Acknowledge
  - UE Context Release
  - X2 timers (t_reloc_prep, tx2_reloc_overall)
  - Handover Cancel
eNB Functional Splits

- IF5: similar to IEEE P1914.3/eCPRI
- IF4.5: similar to O-RAN 7.2
- IF2: FAPI/nFAPI Small Cell Forum
- IF1: same as F1 in 3GPP Rel 15 (F1-U using UDP instead of GTP)
Buggy/Missing/Incomplete Features in development

- Essential
  - TM3/4/8/9/10: incomplete
    - TM3 PHY (Eurecom) and MAC (Fujitsu) available – to be integrated
  - PUCCH format 2: incomplete
  - Measurement gap handling: missing
  - Carrier Aggregation: incomplete
OPENAIRINTERFACE RAN ONGOING FEATURES AND ROADMAP
Very recent and upcoming eNB features

- Multi RRU handling and synchronization
- Rel 12 Dual Connectivity
- Rel 13 LTE-M improvements
- Rel 14 D2D/Sidelink/ProSe
- Rel 14 NB-IoT
- Rel 14 feMBMS
- Rel 15 5G-NR
Multi RRU support

- **Contributors**
  - Eurecom, Orange

- **Goal:**
  - support multiple RRUs connected to a single RAU over IF 4.5 to form a phase coherent distributed antenna array
  - Needs synchronization at 3 levels: Time, Frequency, Phase

- **Current status**
  - Time synchronization implemented & merged into develop
  - Frequency synchronization: done in hardware
  - Phase synchronization through reciprocity calibration

- **Next steps**
  - Use reciprocity calibration to obtain CSIT from SRS measurements
  - Reactivate beamforming for communication (TM7/8/…)

See dedicated presentation in workshop
Dual Connectivity

- **Contributors**
  - Eurecom, UPC

- **Goal:**
  - Rel12 dual connectivity with split radio bearer

- **Status**
  - Implemented split radio bearer over X2-U, C-plane handled independently by 2 eNBs
  - Only works with OAI UE
  - [https://github.com/ni/Orca-Dali-oai](https://github.com/ni/Orca-Dali-oai)

- **Roadmap**
  - Split bearer to be reused for EN-DC later
LTE-M roadmap

- Integration of IoT applications / MEC.
- Add the CDRX support
- Improve Scheduler
  - Design of joint LTE/LTE-M scheduling framework
    - How to share resources efficiently
    - Need UE L2 stub for testing scalability (minimal Cat-M1 functionality in OAI UE)
      - handle more than 1 UE
      - handle more than 1 HARQ process
- Coverage extension options
  - Repetitions for physical channels
OAI D2D Objectives

- Interfaces for ProSe applications running on top of OAI at UE
- Integration of Rel 14 Sidelink procedures (L1/L2)
- Extensions to support UE-Network relaying scenarios
- Testing
  - ProSe application from Perspecta Labs (not public)
  - Public D2D application available for individual testing of PC5 features: multicast traffic, discovery, 1-to-1 connection establishment and Unicast traffic, Relay traffic.
  - Small field deployment with OAI-based UEs and Infrastructure
    - Off-network and relay coverage scenarios
Recent progress and code availability

- **Recent progress**
  - Robustified operation of sidelink L1/L2 procedures in RF mode
    - Multiple bug fixes allowing much more stable performance
  - Integrated support for UE-to-network relay functionality
    - Network level (IP driver) extensions and relay supporting configuration
    - Extensions in OAI RAN and the interfaces with the RF USRP B210 devices to support UL/DL and SL operations concurrently
    - Extensions at the UE NAS layer and the Core Network to integrate relay functionality signaling

- **Code availability**
  - OAI RAN Code available at LTE-sidelink branch of public OAI-RAN repository
    - To be merged with develop branch soon
  - D2D testing application publicly available
    - [https://gitlab.eurecom.fr/tien-thinh.nguyen/d2d-l3-stub](https://gitlab.eurecom.fr/tien-thinh.nguyen/d2d-l3-stub)

- **Roadmap**
  - Extension to V2X (LTE V2X rel. 14/15), both mode 3 and mode 4
  - Multi-hop Mesh (using LTE V2X rel. 14 mode 4 as L2) (OSLR/BATMAN at L2)
**NB-IoT**

- **Contributors**
  - Eurecom, Bcom, NTUST, Nokia

- **Branch**
  - Develop-nb-iot
  - Develop-nb-iot-merge
NB-LoT

- **Status develop-nb-iot**
  - Based on very old version (>2 years) of develop-branch
  - PHY ready & demonstrated with fixed scheduler up to Msg4
  - MAC scheduler (UL/DL) and FAPI procedures ready
  - Successful reception of Msg 5 (RRCConnectionSetupComplete) at eNB
  - S1AP connection to EPC (Nokia Itexbox) ok (InitialUEMessage, Downlink NAS transport)
  - Downlink_NAS_Transport sent to UE, but UE does not accept it

- **Status develop-nb-iot-merge**
  - Goal: benefit from improvements in develop in nb-iot, have a common target
  - Merged with develop summer 2019 (v1.1.0)
  - Work ongoing, issues with configuration

- **Roadmap (unchanged)**
  - Complete end-to-end validation
  - non-IP CIoT services (requires core support)
  - Integration of multi-carrier PUSCH
  - Integration into develop
**Contributors**
- Javier Morgade (Vicomtech)

**Current status in develop**
- **UE PHY:**
  - LTE MBMS-dedicated cell (feMBMS) procedures subset for LTE release 14
  - LTE non-MBSFN subframe (feMBMS) Carrier Aquistion Subframe-CAS procedures (PSS/SSS/PBCH/PDSCH)
  - LTE MBSFN MBSFN subframe channel (feMBMS): PMCH (CS@1.25KHz) (channel estimation for 25MHz bandwidth) (experimental)
- **UE MAC:**
  - MBMS-dedicated cell (feMBMS) RRC interface for BCCH
  - MBMS-dedicated cell (feMBMS) RRC interface for MCCH, MTCH
- **UE RLC:**
  - MBMS-dedicated cell (feMBMS) SI-MBMS/SIB1-MBMS management

**Under integration (Ongoing merge request)**
- Above procedures on eNB side
- MCE (Multicast Control Entity) --> MCE_APP colocated with eNB
- M2 Interface / M2AP (eNB) --> MBMS Control Interface in between eNB and MCE
- M3 Interface / M3AP (eNB) --> MBMS Control Interface in between MCE and MME (M3AP support will be added for OAI-CN)
- M1 Interface / MBMS-GW support for OAI-CN

See dedicated presentation in workshop
5G New Radio

- Contributors
  - Eurecom, Nokia BL, Orange, Fraunhofer, IISc, TCL, NTUST

- Goals
  - Phase 1 (end 2019): “noS1” 5G-NR only (with pre-configured gNB and UE, no core network)
  - Phase 2 (Feb 2020): E-UTRA – NR dual connectivity (non-standalone architecture option 3a, with 4G core)
  - Phase 3 (2020): standalone (with 5G core)
Development phases

Non-standalone (ENDC)

Phase 1
(“noS1” with OAI UE)

Phase 2
(EN-DC with COTS UE)

Phase 3
(SA with COTS UE)

Standalone
Status of OpenAirInterface 5G-NR software

- **PHY (gNB & UE)**
  - Highly efficient 3GPP compliant LDPC encoder and decoder (BG1 and BG2 supported)
  - Highly efficient 3GPP compliant polar encoder and decoder
  - Encoder and decoder for short blocks
  - NR-PSS and NR-SSS (gNB validated with R&S FSW)
  - NR-PBCH (gNB validated with R&S FSW)
    - Supports up to 8 SSB
    - Flexible periodicity
  - NR-PDCCH (gNB validated with R&S FSW)
    - common search space configured by MIB
    - user-specific search space configured by RRC
    - DCI formats: 00, 10
  - NR-PDSCH (gNB validated with R&S FSW)
    - Single symbol DMRS, dmrs-TypeA-Position Pos2, DMRS configuration type 1
    - PDSCH mapping type A
  - NR-PUSCH (validated in real-time modem)
  - NR-PUCCH (validated in simulation only)
    - Format 0 (ACK/NACK)
  - NR-PRACH (partially validated in simulation)
    - Formats 0,1,2,3, A1-A3, B1-B3

- **PHY (UE specific)**
  - Initial sync and selection of strongest beam
  - Time tracking based on PBCH DMRS
  - Frequency offset estimation
  - First version of dual stream receiver for PDSCH
**LDPC Options**

- **Software defined (included in OAI)**
  - Developed by TCL
  - Integrated in develop-nr
  - Decoding latency 1 codeword, BG1, Z=384, B=8448, 5 iterations:
    Rate 1/3: 214.6µs, Rate 2/3: 124.6µs, Rate 8/9 83.6µs

- **Offload to GPU**
  - Developed by NCTU using CUDA
  - Available in branch 445-LDPC-implementation-on-GPU
  - Decoding latency 1 codeword, BG1, Z=384, B=8448, 5 iterations:
    Rate 1/3: 60µs (without DMA transfers)

- **Offload to FPGA**
  - IP core developed by Creonic, Interface to OAI developed by SYRTEM
  - See dedicated presentation by TCL during workshop
Status of OpenAirInterface 5G-NR software

- **gNB**
  - **RRC**
    - Import of 38.331 RRC (Rel15) messages using asn1c (new version)
    - Application to read configuration file and program gNB RRC
    - Generation of MIB (validated with R&S FSW)
    - RRC -> MAC configuration
  - **RLC**
    - Updated to Rel 15 specs
    - To be integrated
  - **MAC**
    - MAC -> PHY configuration using FAPI P5 interface
    - MAC dummy scheduler (fixed allocations) using FAPI P7 interface
    - Header generation (incl timing advance)
    - “noS1” mode (DL): interface with 4G RLC, PDCP, and TUN interface to inject user-plane traffic
  - **X2AP**
    - Update to Rel 15 specs
    - Connection to 4G eNB

- **eNB**
  - Update of RRC and X2AP to Rel15
  - Configuration of 5G-NR measurements

- **UE**
  - Initial sync and detection of MIB
  - MAC -> PHY Configuration of PHY via UE FAPI P5 interface
  - Basic MAC to control PHY via UE FAPI P7 interface
  - 5G RLC, to be integrated
  - “noS1” mode (DL): interface with 4G RLC, PDCP, and TUN interface to receive user-plane traffic
Demonstration MASS-START 9.10.2019

- In this demo:
  - Downlink only (fixed scheduling)
  - Over the air

- gNB split in BBU (in server room) and RRH (in lab), connected by fiber
- UE at the other end of corridor
- Throughput limited
Roadmap for EN-DC (Feb 2020)

- **UE**
  - PHY: Improve Throughput
    - Some improvements were made in simulation, but still issues in real-time
  - MAC: procedures for handling UL DCI
    - Today PUSCH parameters are hardcoded

- **UE & gNB**
  - Complete UL “noS1” mode
  - Stabilize real-time performance
    - Today main target is USRP N3x0
    - Poor performance when using 4 channels at full BW
    - Investigation of DPDK
  - FR 2
  - MAC
    - Integration of PRACH procedures (RACH and MSG2)
    - Integration of PUCCH procedures
    - HARQ handling
    - Integration of new RLC

- **gNB:**
  - Synchronization of gNB and eNB (specs require ½ slot)
  - X2 procedures/messages

- **eNB**
  - X2 procedures/messages
  - RRC Reconfiguration
Functional splits in OAI 5G

- **F1**
  - F1-C done for LTE, to be integrated in NR
  - F1-U partially done for LTE (not using GTP yet) – to be done for NR
  - To be done (Q1 2020)

- **5G FAPI**
  - today all L1 procedures use a preliminary version of 5G FAPI
  - update to SCF specs ongoing (Q4 2019)
  - nFAPI to be done (SCF specs ongoing, 2020)

- **Fronthaul**
  - O-RAN 7.2 or IF4.5 (upgrade from LTE)
  - To be done (Q1 2020)
Overall architecture roadmap

Control and Management

RCC

LTE/NR/NB PDCP

LTE RRC

LTE RLC/MAC

LTE L1-high

Tx Precode
Rx Combine

LTE L1-low

RAU

NR RLC/MAC

NR L1-high

Tx Precode
Rx Combine

NR L1-low

RRU

NB-IoT RLC/MAC

NB-IoT L1-high + L1-low

Data

Control

Management

Florian Kaltenberger
HARDWARE TARGETS
Hardware Requirements

- **SDR platform**
  - ExpressMIMO2 (discontinued)
  - USRP B2x0, X3x0, N3x0 (recommended)
  - Blade RF
  - LMS-SDR
  - Skylark Iris
  - Syrtem

- **Host PC**
  - 4G: A powerful x86 PC
    - Intel Core i5, i7, i9
    - Intel Xeon
    - >=4 cores, >= 3GHz, SSE 4, AVX
  - 4G RRH: Low-cost x86 PC
    - Up board (up2), Euclid board
  - 5G: x86 server or PC
    - Inter Core i9
    - Intel Xeon
    - >= 16 cores >= 3GHz, AVX2

- **Antennas, Duplexers, etc**
## Comparison

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<th>MIMO and bandwidth capabilities</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x1 MIMO 20MHz or 2x2 MIMO 10MHz</td>
<td>2x2 MIMO, 120MHz</td>
<td>4x4 MIMO 100MHz</td>
<td>2x2 MIMO 20MHz</td>
<td>2x2 MIMO 20MHz</td>
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<table>
<thead>
<tr>
<th>RF chip</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD9361</td>
<td>n/a**</td>
<td>AD9371 (x2)</td>
<td>AD9361</td>
<td>LMS7002M</td>
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<table>
<thead>
<tr>
<th>Frequency range</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>70MHz – 6GHz (depends on daughterboard)</td>
<td>DC-6GHz</td>
<td>10 MHz – 6GHz</td>
<td>47MHz to 6GHz</td>
<td>300 MHz – 3.8GHz</td>
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<table>
<thead>
<tr>
<th>Price</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>€1,130</td>
<td>~€5,000</td>
<td>~€10,000</td>
<td>$480 - $720</td>
<td>$299</td>
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<table>
<thead>
<tr>
<th>Duplexing</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDD* or TDD*</td>
<td>FDD* or TDD*</td>
<td>FDD* or TDD</td>
<td>FDD*</td>
<td>FDD* or TDD*</td>
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<table>
<thead>
<tr>
<th>Output power</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>10dBm</td>
<td>n/a**</td>
<td>12-18dBm</td>
<td>8dBm</td>
<td>10dBm</td>
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<table>
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<tr>
<th>Noise figure</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;8dB</td>
<td>n/a**</td>
<td>5.5-7.5dB</td>
<td>?</td>
<td>&lt;7dB</td>
<td></td>
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<table>
<thead>
<tr>
<th>EVM***</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>Excellent</td>
<td>Very good</td>
<td>???</td>
<td>Average</td>
<td></td>
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<table>
<thead>
<tr>
<th>Open source</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGPA/driver</td>
<td>FPGA/driver</td>
<td>FPGA/Driver</td>
<td>All</td>
<td>All</td>
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<table>
<thead>
<tr>
<th>Compatibility</th>
<th>USRP B210</th>
<th>USRP X310</th>
<th>USRP N310</th>
<th>Blade RF 2</th>
<th>LMS SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>4G/5G (40MHz with ¾ sampling)</td>
<td>4G/5G (80MHz with ¾ sampling)</td>
<td>5G up to 100MHz</td>
<td>4G</td>
<td>4G</td>
<td></td>
</tr>
</tbody>
</table>

*needs external RF elements
** depends on daughterboard
*** subjective to the author 😊
Other experimental targets

- **Epiq Sidekiq**
  - Based on AD 9361
  - Mini PCIe or M.2 form factor

- **CPRI - PClexpress**
  - IT Avero
  - Based on Xilinx eval board

- **CPRI gateway**
  - Bell Labs
  - Based on Xilinx or Intel platform

- **Skylark Iris platform**
  - Based on Lime platform
  - Scalable for massive MIMO

- **SYRTEM UED platform**
  - Based on Xilinx ZC706 eval board + AD9371 daughterboard
  - 2 full duplex channels with up to 122.88 MHz sampling
  - Not 100% open source
Software Requirements

- **Operating system**
  - Ubuntu >= 18.04
    - works for both openairinterface5g, openair-cn, openair-cn-cups
    - For real-time operation, a low-latency kernel is recommended
    - For new P/S-GW, no kernel module patches required
    - See details on Wiki
  - CentOS/Redhat Linux release >= 7
    - Better real-time performance than Ubuntu low-latency

- **Get code from our gitlab server**
  - RAN (eNB+UE): [https://gitlab.eurecom.fr/oai/openairinterface5g](https://gitlab.eurecom.fr/oai/openairinterface5g)
    - Branch develop latest features (recommended)
    - Branch develop-nr for gNB and nrUE
  - EPC (MME, HSS)
    - [https://github.com/OPENAIRINTERFACE/openair-cn](https://github.com/OPENAIRINTERFACE/openair-cn)
  - EPC (SPGW-C, SPGW-U)
    - [https://github.com/OPENAIRINTERFACE/openair-cn-cups](https://github.com/OPENAIRINTERFACE/openair-cn-cups)
OpenAirInterface5G directories

- **ci-scripts**
- **cmake_targets**
  - New directory for building all the targets
  - Contains “mother” build_oai script
- **executables (in develop-nr)**
  - nr-softmodem, nr-uesoftmodem
- **targets**
  - Hardware specific code (drivers, tools, etc)
  - lte-softmodem, lte-uesoftmodem
- **openair1**
  - Basic DSP routines for implementing subset of LTE specifications under x86 (36.211, 36.212, 36.213 3GPP specifications)
  - Channel simulation, sounding and PHY abstraction software,
- **openair2**
  - MAC/RLC/PDCP/RRC
- **openair3**
  - Contains interfaces S1-C, S1-U (GTP, SCTP, S1AP) and NAS UE
- **common/utils**
  - Utilities such as the T tracer or the ITTI
Compiling OpenAirInterface5G

- **Top-level build script** ./build_oai located in
  - cd openairinterface5g/cmake_targets

- **Recent simplifications**
  - No more separate executables for “noS1”, basic simulator, etc
  - → there is only one lte_softmodem and lte-uesoftmodem!

- **Compilation options**
  - -I installs additional required software
  - -w <hw_target> select HW target
  - --eNB compiles the lte-softmodem
  - --UE compiles the lte-uesoftmodem and UE NAS parts
  - --lte-simulators compiles the unitary simulators
  - -h help

- **This creates executables in openairinterface5g/targets/bin**
  - Liboai_device.so symbolic link to library of current hardware (oai_usrpdevif.so, rfsimulator.so, tcp_bridge_oai.so, …)
  - Liboai_eth_transpro.so Ethernet transport library (IF4.5 or IF5 split)
  - Libparams_libconfig.so Library for parameter handling
  - Libcoding.so Library for channel coding
  - Nasmesh.ko and rb_tool: kernel driver and ioctl tool for noS1
  - ue_ip.ko, usim, nvram, conf2uedata: UE NAS driver (if TUN interface is not used)
  - dlsim, ulsim, ….: unitary simulators
Simulators

- ulsim/dlsim: unitary simulator for PHY
- Basic simulator / rf simulator
- L1 simulator: uses IF4.5 interface
- L2 FAPI simulator: uses nFAPI interface
Unitary Simulators

- Simulates one physical channel (TX and RX) using (standardized) channel models
  - Good for debugging and performance analysis (Monte-Carlo simulations)

- Build using
  - ./build_oai -phy_simulators

- In develop
  - ulsim:
  - dlsim

- In develop-nr
  - Polartest, Idpctest, smallblocktest
  - Nr_pbchsim, nr_prachsim,
  - nr_dlschsim, nr_ulschsim, nr_pucchsim
  - nr_dlsim, nr_ulsim,
How to connect COTS phone to OAI eNB

- **Additional requirements**
  - Core network (e.g., OAI EPC, see later in training)
  - Sim card with corresponding parameters

- **Compile eNB**
  - `./build_oai -w USRP --eNB`

- **Configure eNB**
  - `targets/PROJECTS/Generic-LTE-EPC/CONF/`
  - Select the config file that is most appropriate for your configuration (Band and Hardware)
  - Check
    - MCC, MNC, TAC (need to match EPC)
    - downlink_frequency, bandwidth, etc
    - IP addresses of S1-MME and S1-U interfaces

- **Run eNB**
  - `sudo ./lte-softmodem -O <file.conf>`
How to connect OAI UE to OAI eNB

- **Compile UE**
  - ./build_oai –w USRP –UE
  - Initialize NAS (except when using TUN interface)
    - “init_nas_s1 UE” or “init_nas_noS1”

- **Run UE**
  - sudo ./lte-softmodem –U –C <freq> -r [25|50|100] –ue-scan-carrier –ue-txgain xx –ue-rxgain yy (-d) (--noS1 --nokrnmod 0)
How to setup RCC and RRU

- **RCC**
  - Check RCC parameters in RCC config file
    - IF name, local and remote IP addresses and ports
      - `local_rf = "no"
      - `tr_preference = "udp_if4p5"
    - `./lte-softmodem -O <file.conf`

- **RRU**
  - Check RRU parameters in RRU config file
    - IF name, local and remote IP addresses and ports
      - `local_rf = "yes"
      - `tr_preference = "udp_if4p5"
    - `./lte-softmodem -O <file.conf`
Troubleshooting

- **eNB not connection to MME / RRH**
  - Check IP addresses in config files
  - Check MCC, MNC matching

- **I get a lot of UUUs and LLLs**
  - Check the performance setting of CPU (C-states, CPU frequency)
  - Check USB3 connection (some cables are bad)

- **Phone does not connect**
  - Analyze S1AP messages in wireshark
  - Check keys in SIM card and HSS
  - ...

- **Throughput is very low**
  - Check radio conditions: duplexer, antennas, interference
DEBUGGING TOOLS
The T tracer

- The T tracer is a framework to debug and monitor the eNB softmodem.
- Combines logging, timing analysis, signal visualization, MAC PDU analysis (with wireshark)
- It is made of two main parts:
  - an events collector integrated to the real-time processing,
  - a separate set of programs to receive, record, display, replay and analyze the events sent by the collector.
- Can work locally or over network
The T tracer: usage of GUI

- **eNB is compiled by default with –T-tracer option:**
  - Otherwise disable with –disable-T-tracer

- **Compile eNB GUI:**
  - cd openairinterface5g/common/utils/T
  - make

- **Run lte-softmodem normally**
  - sudo ./lte-softmodem -O <…> --T_stdout 0

- **Run T tracer GUI**
  - ./enb -d ..//T_messages

- **Other features**
  - Recording & replay
  - VCD file generation (for gtkwave)
- HARQ ACK
- HARQ NAK
- New DCI
- Retr. DCI
Telnet server

- Telnet server can be used to show and change parameters at runtime
  - Log level and verbosity
  - Threads and their priority
  - Some PHY parameters (e.g. turbo iterations)

- Easily extendable

- Usage
  - `./build_oai -w USRP -eNB -build-telnetsrv`
  - `sudo ./lte-softmodem -O <...> --telnetsrv`
  - Telnet 127.0.0.1 9090
  - Use online help
BACKUP
Use case 1: classical 3GPP network

- OAI EPC
- Commercial/3rd party EPC
- OAI eNB
- Commercial/3rd party eNB
- OAI UE
- COTS UE
Use case II: simplified network

- Non-3GPP setup (no-S1 mode):
  - OAI eNB <-- OAI UE
Use case III: cloud-RAN

Main target of EURECOM deployment
Epiq Sidekiq

- Based on AD 9361 chipset
  - 70MHz - 6GHz with up to 50MHz bandwidth per channel

- SidekiqTM - MiniPCIe
  - MiniPCIe card form factor (30mm x 51mm x 5mm)
  - 2 independent RF channels (2xRx or Tx+Rx)
  - PCIe Gen1.1 x1 (2.5 Gbps) interface to host + USB 2.0 interface

- SidekiqTM - M.2
  - M.2 T3042-D3-B card form factor (30mm x 42mm x 4mm)
  - Up to 2x2 MIMO
  - PCIe Gen2 x1 (5 Gbps) interface to host + USB 2.0 interface

- Under beta-testing
Remote Radio Unit

- Supports SISO 20 MHz
- Total cost: ~750$
  - UPBoard (100$)
  - USRPB200-mini (500$ in quantities)
  - PA/LNA/Switch (100$)
  - PoE+ module (50$)

40MHz reference driving LO of AD9364 RFIC transceiver
Eurecom C-RAN Deployment

Band 38 (TDD, 2.6 GHz)

20Gb optical Ethernet
1Gbit Ethernet
10MHz clock reference

level -3

RRU

EURECOM Data Center
vEPC
MEC
RCC/RAU
Agg. switch
Comm. Sys
RF Lab

level -4

Shannon Meeting Room
FDU
dist switch

Fourier Meeting Room
FDU
dist switch
LTE D2D application scope and regulations

Public safety: Group Communication + proximity services

- Replacing old technologies (e.g. TETRA) for public safety authorities
- Direct communication (multicast/unicast)
- Direct discovery supporting unicast
- **Objective**: Availability when cellular networks are not available or fail (e.g., disaster after earthquake)

Proximity commercial applications

- Finding friends nearby, local-advertising, e-health etc.)
- Direct communication + Discovery

Allocated spectrum for ProSe:

- 694 – 894 MHz
- Varying per country
LTE V2X application scope and regulations

- 2015: Rel-12
  - Proximity services: LTE-D2D

- 2016: Rel-13
  - ProSE Extensions: D2D relaying

- 2017: Rel-14
  - LTE-V2X communication extensions

Mode 4: autonomous resource allocation (preconf. resource pools)

Mode 3: Resource allocation from the eNB

Allocated spectrum for V2X: 5.85 – 5.925 GHz (ITS band)
Roadmap master branch

- Difference of master (tag 1.1.1) and develop
  - Rfsimulator
  - Network controlled HO (flexran)
  - X2 HO TDD
  - LTE-M repetitions
  - Bugfixes
    - Power control
    - Nfapi
    - CDRX improvements

- \(\rightarrow \) not too many new features, but I would recommend to make this tag 1.2 before next significant merge
## Roadmap develop branch

<table>
<thead>
<tr>
<th>Feature</th>
<th>Status</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>feMBMS</td>
<td>MR ongoing, tests not ok</td>
<td></td>
</tr>
<tr>
<td>New RLC</td>
<td>MR ongoing, tests poor</td>
<td></td>
</tr>
<tr>
<td>5G NR</td>
<td>Regressions tests almost ok</td>
<td></td>
</tr>
<tr>
<td>D2D</td>
<td>Branch finished, MR to be created and tested</td>
<td></td>
</tr>
<tr>
<td>NB-IoT</td>
<td>Not yet fully functional</td>
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