EURECOM
Sophia Antipolis

OPEN AIR 5G INTERFACE
5G SOFTWARE ALLIANCE

OpenAirInterface 5G

Overview, Installation, Usage

Florian Kaltenberger

OAI workshop, BUPT, 20.6.2018

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

Overview

- Overview and Ecosystem
- Use cases
- 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, 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 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

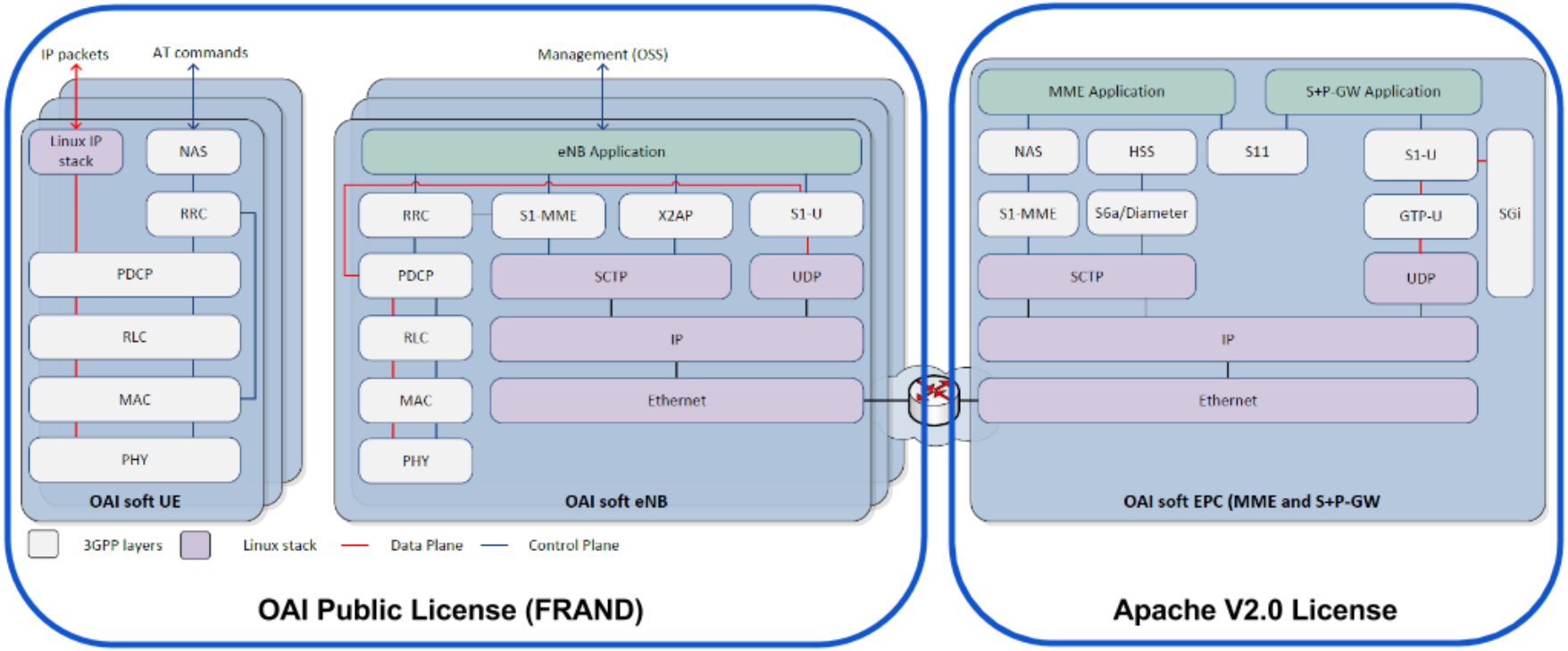
Collaborative Web Tools

- Main page:
  - https://www.openairinterface.org
- Code available from
  - RAN (eNB + UE)
    https://gitlab.eurecom.fr/oai/openairinterface5g
  - EPC
    https://github.com/OPENAIRINTERFACE/openair-cn
- Mailing lists
  - https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/MailingList
- Forum in Chinese
  - http://bbs.opensource5g.org/forum.php
- Other tools:
  - https://openairinterface.slack.com
  - https://trello.com/oaidev

The OpenAirInterface Software Alliance

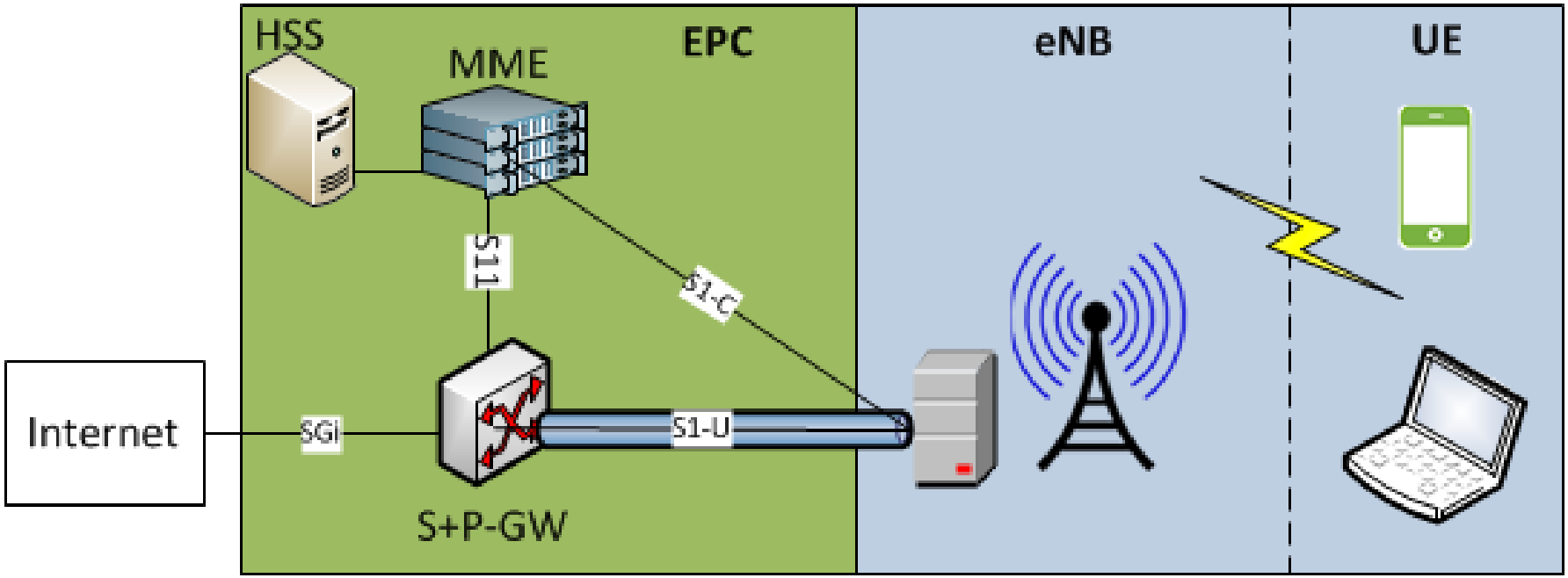
- Launched in 2014 as an endowment fund (French "Fonds de Dotation")
- Current strategic members (Orange, TCL, Nokia Bell Labs, Fujitsu)
- Many associate members (Samsung, Interdigital, ng4t, Cisco, B-COM, INRIA, IMT, TNO, III, Rutgers WINLAB, U. Washington, IITH, BUPT, etc.)
- Goals:
  - Promote OpenAirInterface and its open-source licensing model
  - Support the community of developers and users

The OAI Licensing model



- FRAND License is based on Apache V2.0 but allows committing software with patent rights into OSA and still keep licensing rights -> Inline with 3GPP fair use licensing policy
- We work closely with ETSI on implications of open-source for licensing/certification

Use case I: classical 3GPP network



- OAI EPC
- Commercial/3rd party EPC

+

- OAI eNB
- Commercial/3rd party eNB

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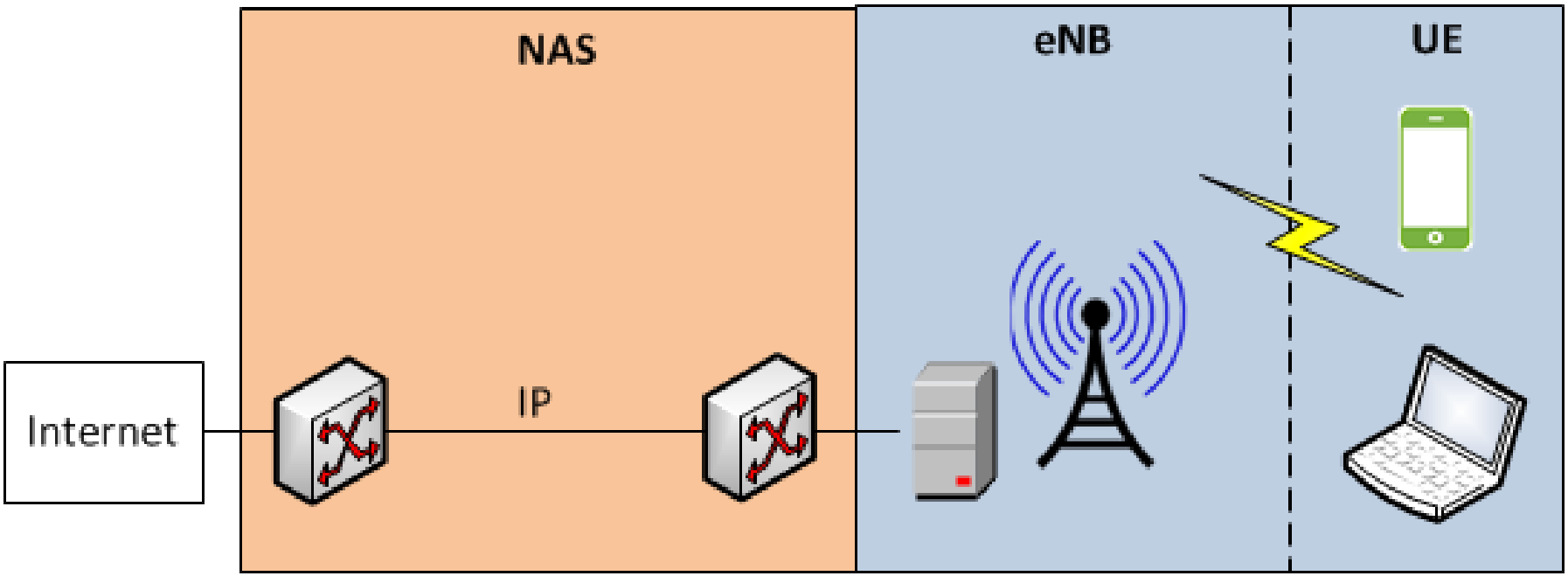
- OAI UE
- COTS UE

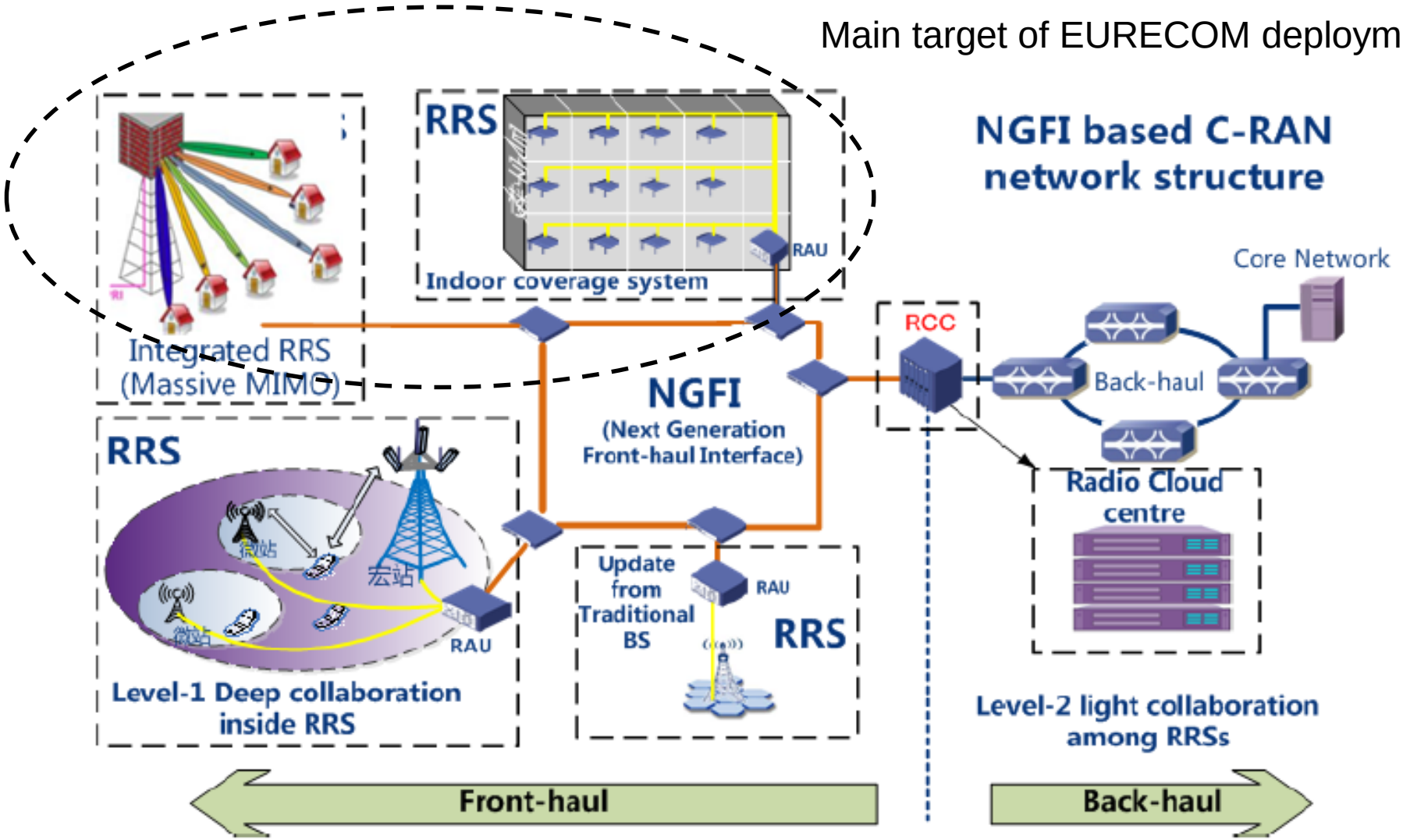
Use case II: simplified network

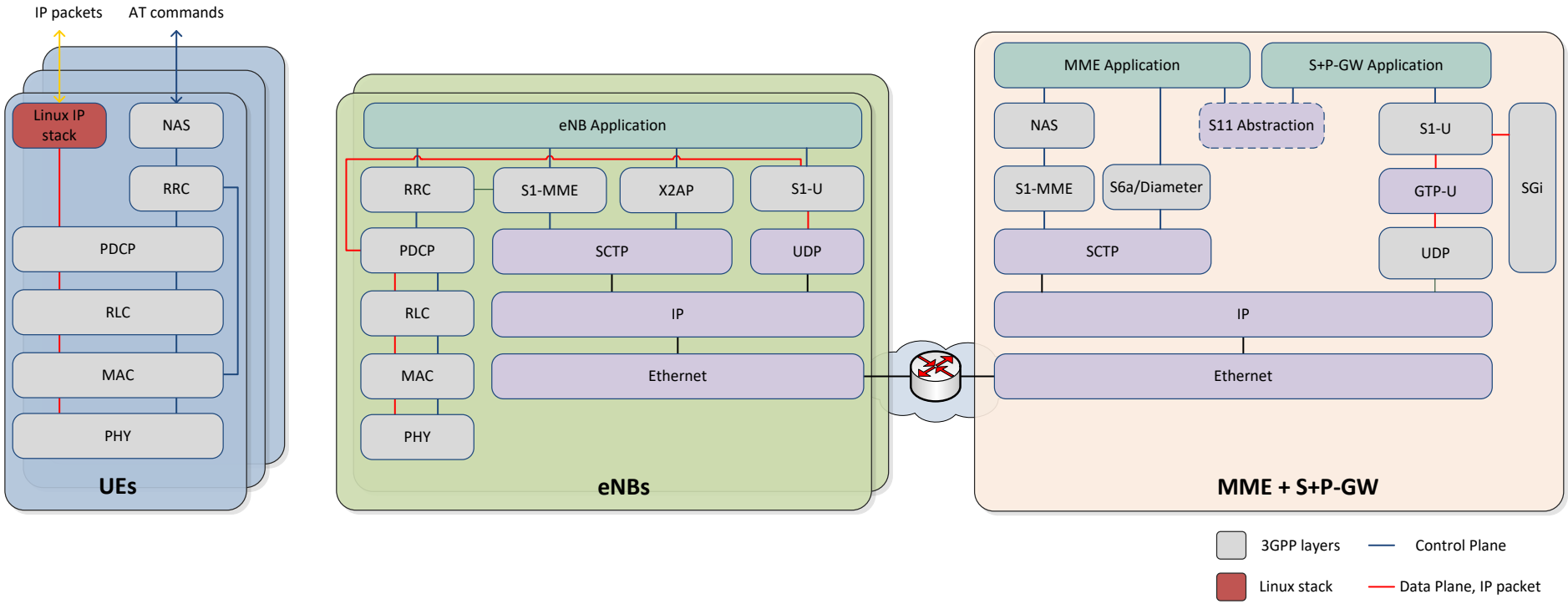


- Non-3GPP setup (no-S1 mode):
  - OAI eNB <--> OAI UE

Use case III: cloud-RAN

Main target of EURECOM deployment





OPENAIRINTERFACE FEATURES

OpenAirInterface eNB features (PHY)

- 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)

- The RLC layer implements a full specification of the 3GPP 36-322 release v9.3
- 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
- RLC UM (mainly used for DTCH)
  - 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, compatible with 9.3
  - 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

OpenAirInterface eNB features (RRC)

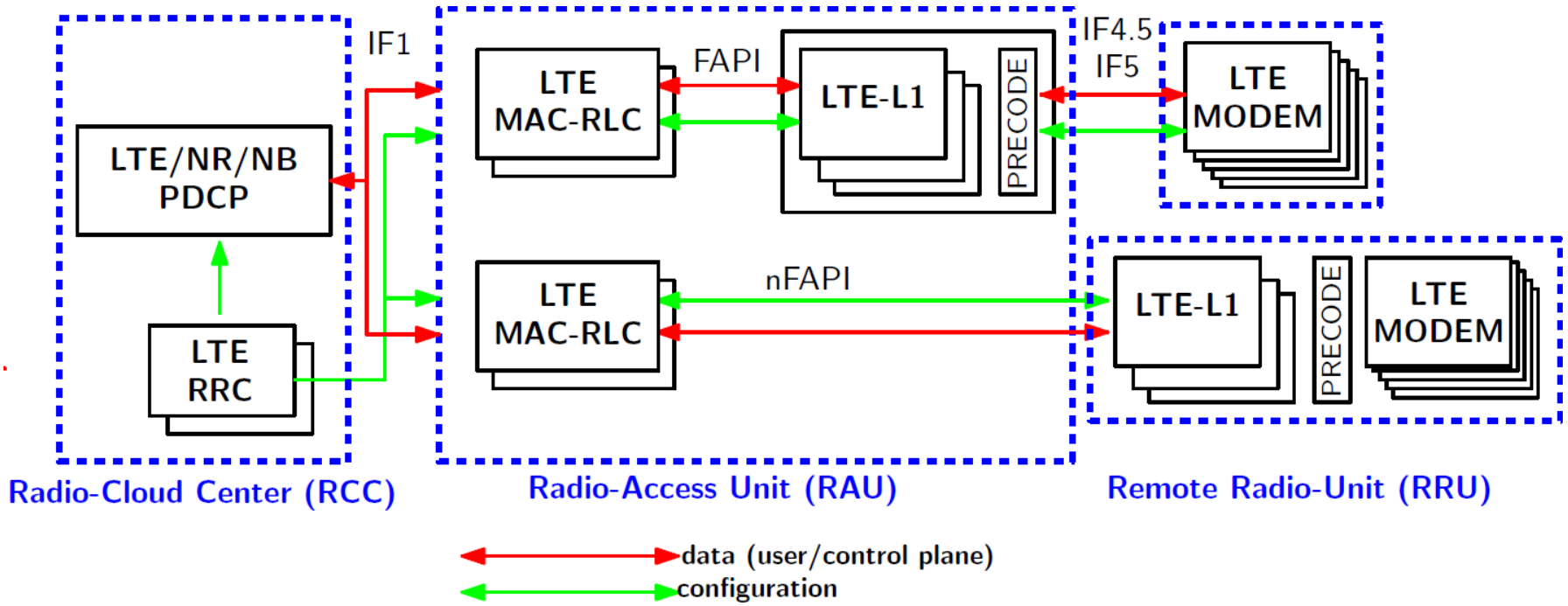
- Based on 3GPP 36.331 v14.3.0.
  - System Information broadcast (SIB 1, 2, 3, and 13)
  - RRC connection establishment
  - RRC connection reconfiguration (addition and removal of radio bearers, connection release)
  - RRC connection release
  - RRC connection re-establishment
  - inter-frequency measurement collection and reporting (experimental)
  - eMBMS for multicast and broadcast (experimental)
  - Handover (experimental)
  - Paging (soon)

Experimental/upcoming eNB features

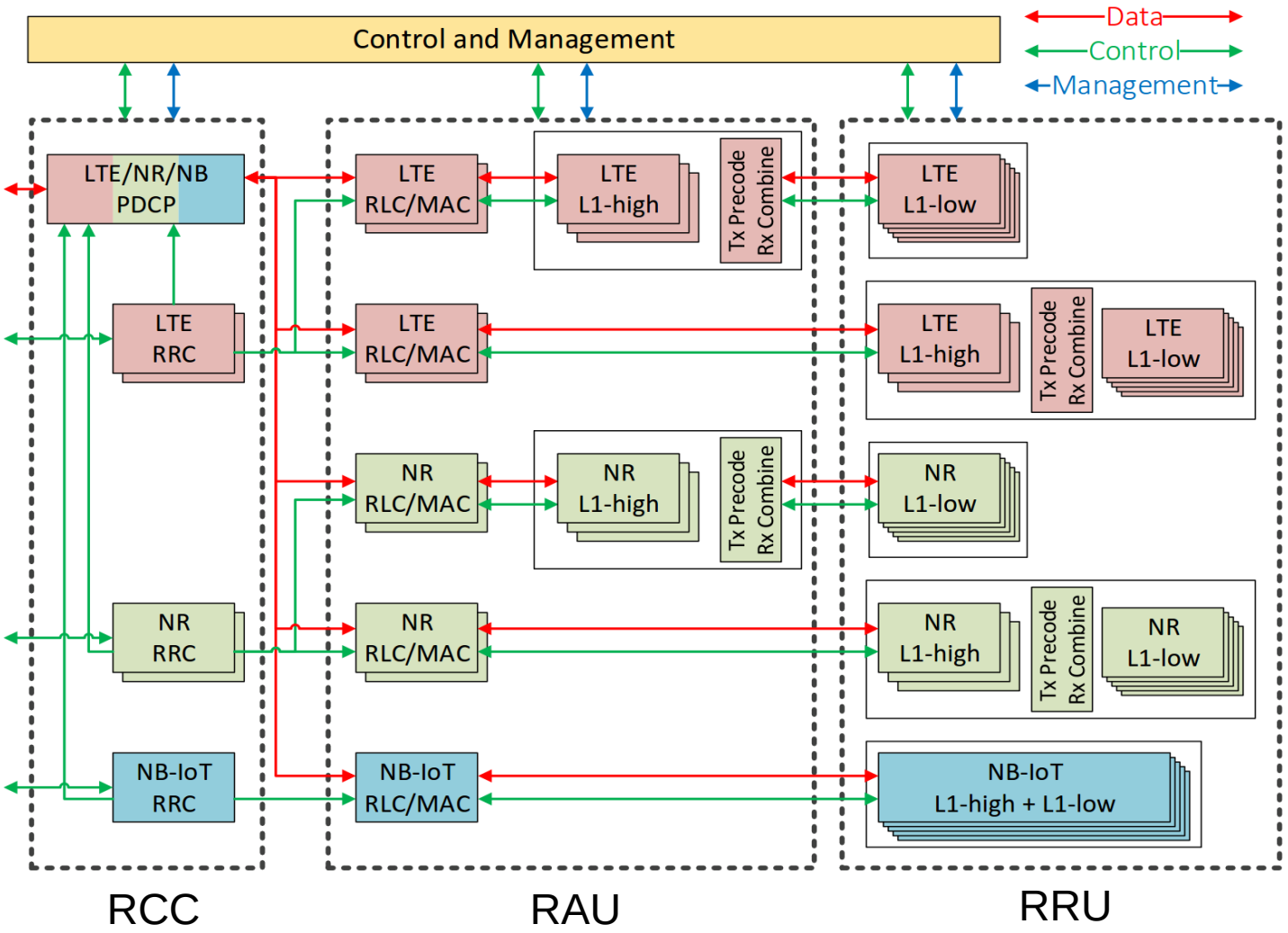
- X2 handover
- Rel 10 carrier aggregation
  - 2DL carriers, 1 UL carrier
  - In old branch, to be reactivated
- Rel 10 Transmission modes 3/4/7/8/9
- Rel 13 LTE-M
- Rel 14 NB-IoT
- Rel 14 D2D
- Rel 15 5G-NR

eNB Functional Splits

- IF4.5/IF5: similar to IEEE P1914.1
- FAPI (IF2): specified by small cell forum, implementation (open-nFAPI) by CISCO
- IF1 (F1 in 3GPP Rel 15): under development



eNB Functional Split Architecture



HARDWARE TARGETS

Hardware Requirements

- SDR platform
  - ExpressMIMO2 (discontinued)
  - USRP B200, X300, N300 (recommended)
  - Blade RF
  - LMS-SDR
  - Epiq Sidekiq (experimental)
  - Skylark Iris (experimental)
  - Syrtem (experimental)
- Host PC
  - A powerful x86 PC (recommended
    - Intel Core i5, i7, i9
    - Intel Xeon
    - Intel Atom
    - 4 cores, > 3GHz, SSE 4, AVX
  - Low-cost x86 PC
    - Up board (up2), Euclid board
  - ARM (experimental)
    - Odroid
- Antennas, Duplexers, etc

Comparison

*needs external RF elements
** depends on daughterboard
*** subjective to the author ☺

	USRP B210	USRP X310	USRP N310	Blade RF	LMS SDR
Data acquisition	USB3	Gbit EtherNet, PCIexpress	Gbit Ethernet	USB3	USB3
MIMO and bandwidth capabilities	2x1 MIMO 20MHz or 2x2 MIMO 10MHz	2x2 MIMO, 120MHz	4x4 MIMO 100MHz	1x1 SISO 20MHz	2x2 MIMO 20MHz
RF chip	AD9361	n/a**	AD9371 (x2)	LMS6002D	LMS7002M
Frequency range	70MHz - 6GHz	DC-6GHz (depends on daughterbrd)	10 MHz - 6GHz	300 MHz - 3.8GHz	300 MHz - 3.8GHz
Price	€1,130	~€5,000	~€10,000	$420	$299
Duplexing	FDD* or TDD*	FDD* or TDD*	FDD* or TDD	FDD*	FDD* or TDD*
Output power	10dBm	n/a**	12-18dBm	6dBm	10dBm
Noise figure	<8dB	n/a**	5.5-7.5dB	?	<7dB
EVM***	Very good	Excellent	???	Poor	Average
Open source	FGPA/driver	FPGA/driver	FPGA/Driver	All	All
Compatibility	4G	4G/5G (80MHz with ¾ sampling)	5G up to 100MHz	4G	4G

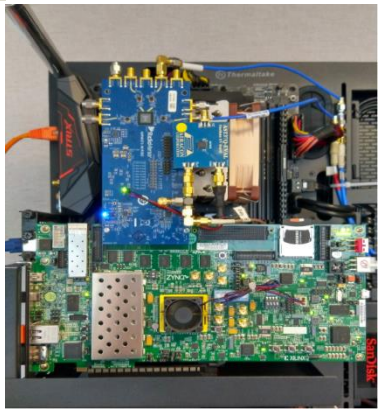
Epiq Sidekiq

- 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 independet 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

Other experimental targets

- CPRI - PCIexpress
  - 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

SYRTEM UED



Skylark Iris

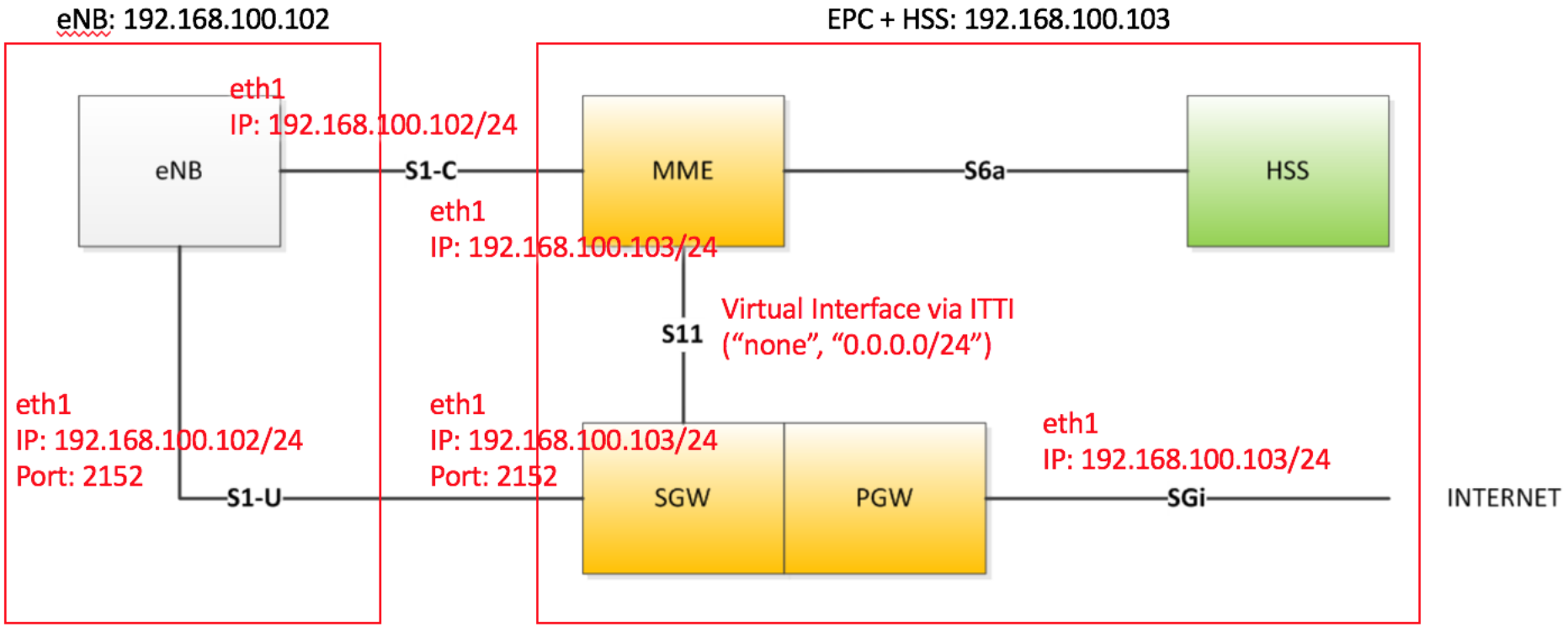
OAI EPC + OAI eNB + OAI UE

INSTALLATION

Software Requirements

- **Operating system**
  - Ubuntu 16.04.2, kernel 4.8
    - works for both openairinterface5g and openair-cn
    - For real-time operation, a low-latency kernel is recommended
    - For P/S-GW, gtp kernel module needs to be patched
    - See details on Wiki
  - CentOS Linux release 7.4.1708 (Core)
    - Better real-time performance than Ubuntu low-latency
- **Get code from our gitlab server**
  - RAN (eNB+UE): https://gitlab.eurecom.fr/oai/openairinterface5g
    - Branch master most stable
    - Branch develop latest features (recommended)
    - Several feature branches for cutting-edge developments
  - EPC: https://gitlab.eurecom.fr/oai/openair-cn
    - Tag 0.5.0 most stable (recommended)
    - Branch develop latest features

Example setup for eNB + EPC



OpenAirInterface5G directories

- cmake_targets
  - New directory for building all the targets
  - Contains “mother” build_oai script
- targets
  - Hardware specific code (drivers, tools, etc)
  - lte-softmodem, oaisim
- 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 located in
  - cd openairinterface5g/cmake_targets
- Compile lte-softmodem
  - ./build_oai
  - -I installs additional required software
  - -w <hw_target> select HW target
  - --eNB compiles the lte-softmodem (for UE and eNB)
  - -x compiles with support for xforms softscope
  - -V compiles with support for VCD debugging
  - --UE compiles UE specific NAS parts
  - --T-tracer compiles with T support
  - --lte-simulators compiles the unitary simulators
  - -h help
- This creates executables in
  - openairinterface5g/targets/bin

Compiling OAI EPC + HSS

- Top-level build script located in
  - cd openairCN/SCRIPTS
- For dedicated RB support
  - Install kernel sources
  - Patch kernel using patch in /build/tools
- Compile EPC
  - ./build_spgw
    - -i installs additional software packages*
  - ./build_mme
    - -i installs additional software packages*
    - requires FQDN to be set in /etc/hosts
  - ./build_hss
    - -i installs additional software packages*
    - -I installs database

*when asked to set password for root, use “linux” (or change it later in config file).

HSS and SIM card configuration

- Configuration file: /usr/local/etc/oai/hss.conf
- Use PHPmyadmin: http://yourhsshost/phpmyadmin
  - User: hssadmin, password: admin
- Add your MME
- Add your user
- Configure your SIM card
  - Use a blank SIM card, card reader and programming tool,
  - or a pre-programmed SIM card
- See Wiki for details

EPC and eNB configuration

- EPC configuration
  - /usr/local/etc/oai/mme.conf, /usr/local/etc/oai/spgw.conf
    - Check MCC, MNC, TAC
    - Check IP addresses for interfaces
    - Take care of S-GW list selection
- eNB configuration
  - targets/PROJECTS/GENERIC-LTE-EPC/CONF/
  - Select the config file that is most appropriate for your configuration (Band and Hardware)
  - Check
    - MCC, MNC, TAC
    - downlink_frequency
    - mme_ip_address
    - IP addresses of S1-MME and S1-U interfaces

Running OAI

- Running EPC
  - ./run_hss
  - ./run_mme
  - ./run_spgw
- Run eNB
  - sudo ./lte-softmodem -O <file.conf> -d -V
- Run UE
  - sudo ./lte-softmodem -U -C <freq> -r [25|50|100] --ue-scan-carrier --ue-txgain xx --ue-rxgain yy
- Have fun!

Troubleshooting

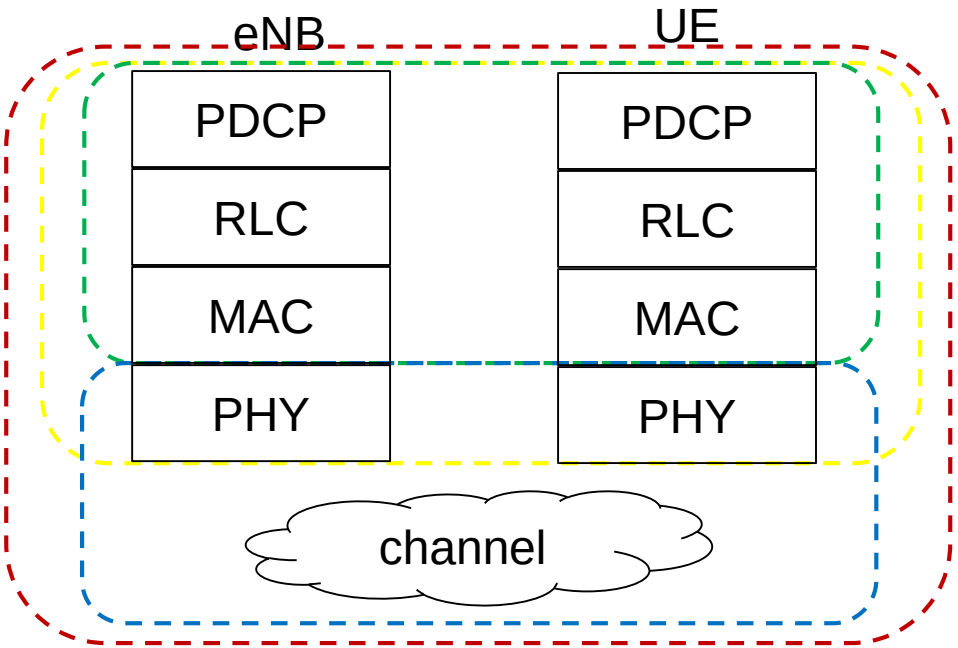
- eNB not connection to MME / RRH
  - Check IP addresses in config files
  - Check MCC, MNC matching
- I get a lot of UUUs and LLLs
  - Check the performance setting of CPU (C-states, CPU frequency)
  - Check USB3 connection (some cables are bad)
- Phone does not connect
  - Analyze S1AP messages in wireshark
  - Check keys in SIM card and HSS
  - …
- Throughput is very low
  - Check radio conditions: duplexer, antennas, interference

DEBUGGING TOOLS

Debug tools

- The T tracer
  - Monitor the eNB in real-time, simulation, or playback mode
- Telnet server
  - Monitor and change parameters of the eNB in real-time or simulation
- Simulators
  - ulsim/dlsim
  - Basic simulator
  - L1 simulator*
  - L2 FAPI simulator*

*being integrated into develop



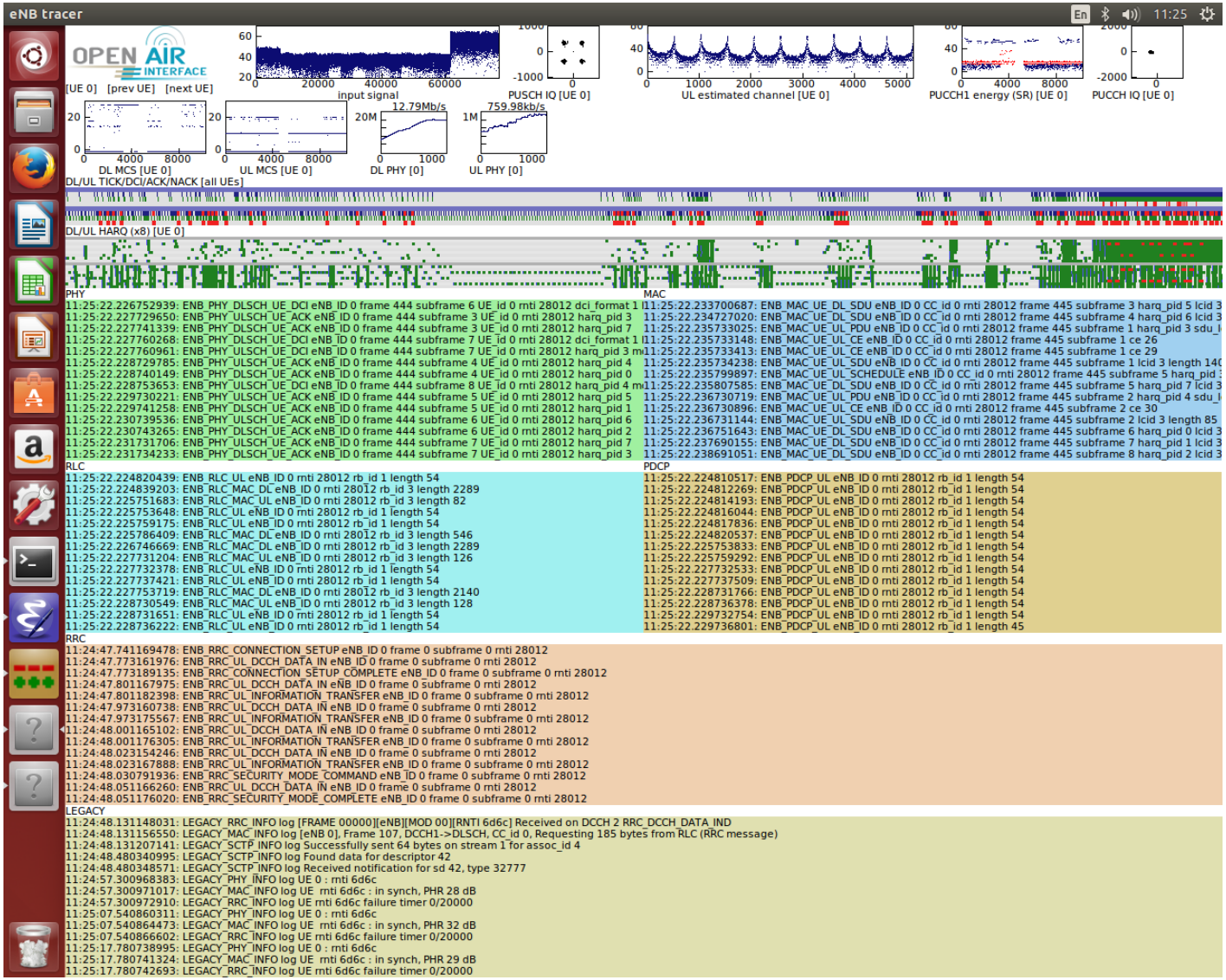
The T tracer

- The T tracer is a framework to debug and monitor the 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

- Compile eNB with -T-tracer option:
  - ./build_oai -w USRP -eNB -T-tracer
- Compile eNB GUI:
  - cd openairinterface5g/common/utils/T
  - make
- Run lte-softmodem normally
  - sudo ./lte-softmodem -O <…>
- Run T tracer GUI
  - ./enb -d ../T_messages

eNB GUI



- 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 -T-tracer
  - sudo ./lte-softmodem -O <…> --telnetsrv
  - Telnet 127.0.0.1 8080
  - Use online help

Simulators

- dlsim/ulsim
  - ./build_oai -phy_simulators
- Basic simulator
  - ./build_oai -basic-simulator
  - See targets/ARCH/tcp_bridge/README.tcp_bridge_oai
- L1 simulator (ex oaisim)
  - Based in IF5/IF4.5
  - ./build_oai --eNB -t ETHERNET --noS1
  - eNB: sudo ./lte-softmodem -O ../../../targets/PROJECTS/GENERIC-LTE-EPC/CONF/rcc.band7.tm1.if4p5.50PRB.lo.conf
  - ./build_oai --UE -t ETHERNET --noS1
  - UE: sudo ./lte-uesoftmodem -O ../../../targets/PROJETS/GENERIC-LTE-EPC/CONF/rru.oaisim.conf -A AWGN -r 50 -s 25 --siml1
- L2 simulator
  - Based on nFAPI (IF2)
  - Same build process as L1 simulator but config files for nFAPI
  - See targets/DOCS/nfapi-L2-emulator-setup.txt for details

BACKUP

Debug tools

- Spectrum Analyzer (UL and DL)
  - Shows RF performance and signal integrity
- Logs
  - Verbosity can be adjusted in config file
  - Shows L2/L3 events
- PHY scope
  - signals in time and frequency domain
  - Constellation plots of PUSCH, PUCCH
- Stats window
  - eNB measurements (noise, signal power, etc)
  - UE feedback (CQI, etc.)
  - UL and DL HARQ statistics
- VCD file
  - Analyze real-time behavior
  - gtkwave -a ~/openairinterface5g/targets/RT/USER/eNB_usrp.gtk
- Wireshark
  - To analyze messages over S1 interface
  - Can also analyze MAC, RLC, PDCP, RRC if enables (see twiki for details)
- Iperf/speedtest
  - Shows throughout for UDP and IP

OAI Packet tracer API
Interface wireshark

- Supported information
  - MAC_LTE_RNTI_TAG; MAC_LTE_UEID_TAG; MAC_LTE_SUBFRAME_TAG; MAC_LTE_PAYLOAD_TAG
- How to enable
  - Lte-softmodem
    - Wireshark: lte-softmodem -W (capture in localhost)
    - Pcap: lte-softmodem -P /tmp/oai.pcap
  - Oaisim
    - ./oaisim -P wireshark (capture in localhost)
    - ./oaisim -P pcap (output goes to /tmp/oai_opt.pcap)
- How to configure wireshark
  - try heuristics for the UDP protocol, MAC-LTE, RLC-LTE, and PDCP-LTE
- More information can be found at
  - https://gitlab.eurecom.fr/oai/openairinterface5g/wikis/IttiAnalyzer

Openairinterface5g LOG APIs

- LOG_X(COMPONENT, format_string, args …)
- Logs are formatted as follows :

  [COMPONENT][LOG LEVEL][FUNC][FILE][NODE ID][FRAME NUM] [CONTENT]
  - COMPONENT : RRC, PDCP, RLC, MAC, PHY, …
  - LOG LEVEL: Emerge, Alert, Critic, Error, Warning, Notice, Info, Debug, Trace
  - FUNC : name of the function inside which the log is called. This is optional
  - FILE: add the file name
  - NODE ID: eNB or UE with their ID
  - FRAME NUM: frame and subframe number
  - CONTENT: content of the log message
  - LOG_FULL include FILE line

- Log verbosity mask
  - LOG_LOW: include the component
  - LOG_MED includes include the level of the log
  - LOG_HIGH includes include function name
  - LOG_FULL include the file name

- LOG Level
  - LOG_EMERG :: LOG_G
  - LOG_ALERT :: LOG_A
  - LOG_CRIT :: LOG_C
  - LOG_ERR :: LOG_E
  - LOG_WARNING :: LOG_W
  - LOG_NOTICE :: LOG_N
  - LOG_INFO :: LOG_I
  - LOF_DEBUG :: LOG_D

Openairinterface5g LOG APIs How to configure

- Option “-l “ with the level as a number
  - 0 lowest
  - 9 highers
- Configuration file (for the moment, only valid for lte-softmodem)

```
log_config :
    {
      global_log_level                    ="trace";
      global_log_verbosity               ="medium";
 ..
}
```

- Manually in oaisim_config.c (func olg_config) or in lte-softmodem local variables
- oaisim with option “-c” and xml configuration file

```
<EMULATION_CONFIG>
 <LOG>  <!-- set the global log level -->
      <LEVEL>debug</LEVEL>
      <INTERVAL>1</INTERVAL>
    </LOG>
    <SEED_VALUE>1234</SEED_VALUE>       <!-- value 0 means randomly generated by OAI -->

  </EMULATION_CONFIG>
```

- Source files
  - openairinterface5g/openair2/UTIL/LOG/

Openair-CN Log API

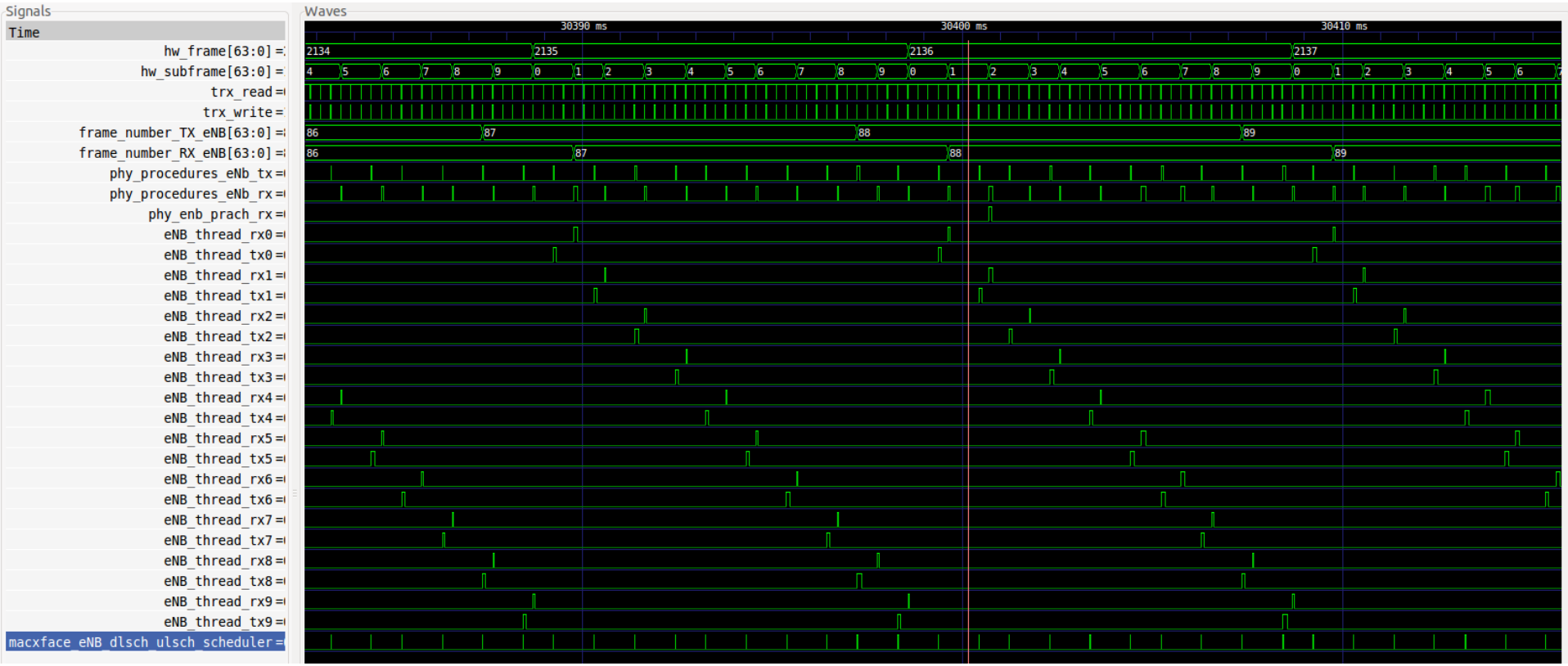
- OAILOG_FUNC_IN(pROTO)
- OAILOG_FUNC_RETURN(pROTO,RC)
- OAILOG_EMERGENCY(pROTO, args…)
- OAILOG_ALERT(pROTO, args…)
- OAILOG_CRITICAL(pROTO, args…)
- OAILOG_ERROR(pROTO, args…)
- OAILOG_WARNING(pROTO, args…)
- OAILOG_NOTICE(pROTO, args…)
- OAILOG_INFO(pROTO, args…)
- OAILOG_DEBUG(pROTO, args…)
- OAILOG_TRACE(pROTO, args…)

- Source
  - openair-cn/SRC/UTIL/

```
LOGGING :
    {
        # OUTPUT choice in { "CONSOLE"}
        # `path to file` must start with '.' or '/'
        # if TCP stream choice, then you can easily dump the
traffic on the remote or local host: nc -l `TCP port num` >
received.txt
        OUTPUT            = "CONSOLE";

        # COLOR choice in { "yes", "no" } means use of ANSI styling
codes or no
        COLOR             = "yes";
# TODO

        # Log level choice in { "EMERGENCY", "ALERT", "CRITICAL",
"ERROR", "WARNING", "NOTICE", "INFO", "DEBUG", "TRACE"}
        SCTP_LOG_LEVEL    = "TRACE";
        S1AP_LOG_LEVEL    = "TRACE";
        NAS_LOG_LEVEL     = "TRACE";
        MME_APP_LOG_LEVEL = "TRACE";
        S6A_LOG_LEVEL     = "TRACE";
        UTIL_LOG_LEVEL    = "TRACE";
        MSC_LOG_LEVEL     = "ERROR";
        ITTI_LOG_LEVEL    = "ERROR";

        # ASN1 VERBOSITY: none, info, annoying
        # for S1AP protocol
        ASN1_VERBOSITY    = "none";
    };
};
```

OAI time analyzer
Format: VCD Value Change Dump

- tracks the execution time of each function working as a common profiler for performance improvement.
  - code optimization, bottleneck detection, and processing time measurements
- Output format is read by gtkwave to view the signal transition and timin

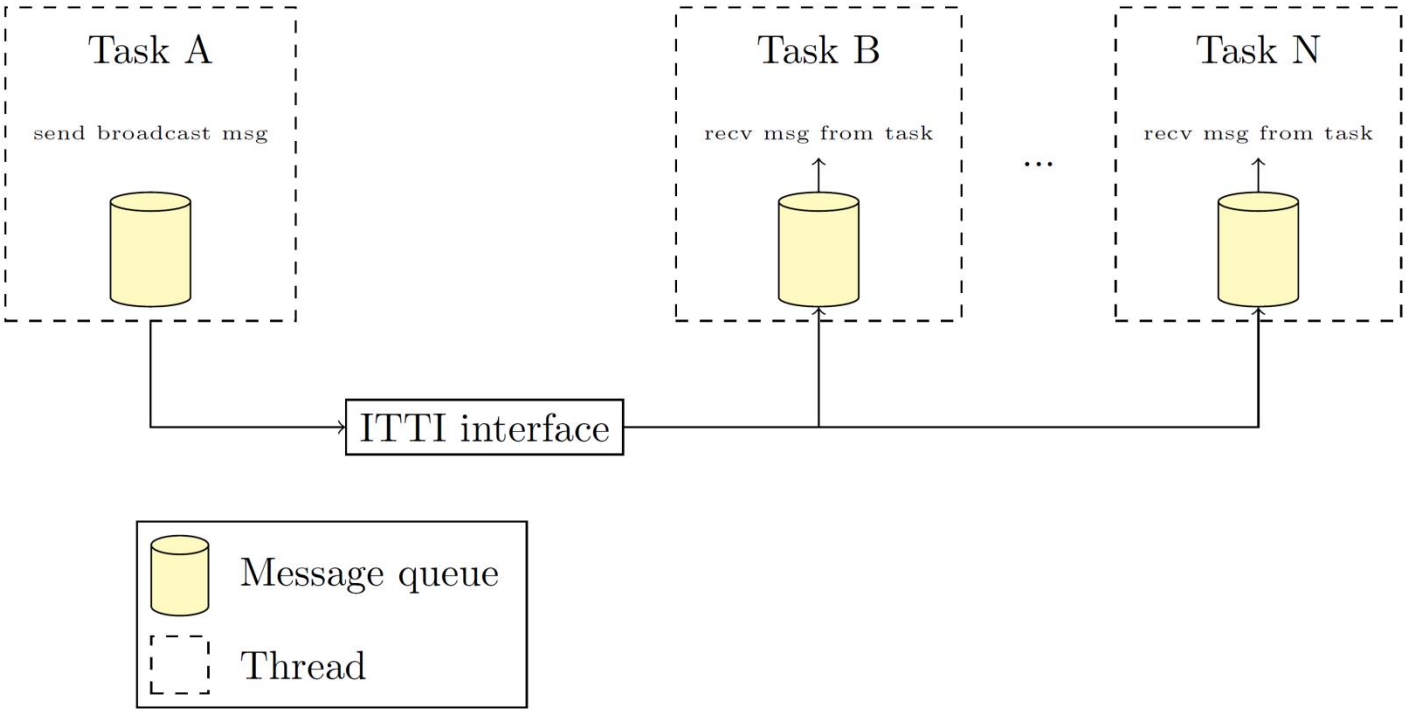


OAI time analyzer API
Format: VCD Value Change Dump

```
#include "UTIL/LOG/vcd_signal_dumper.h"
Main(){
VCD_SIGNAL_DUMPER_INIT("/tmp/openair_dump.vcd");
 VCD_SIGNAL_DUMPER_DUMP_VARIABLE_BY_NAME(VCD_SIGNAL_DUMPER_VARIABLES_HW_FRAME, frame);
 VCD_SIGNAL_DUMPER_DUMP_FUNCTION_BY_NAME(VCD_SIGNAL_DUMPER_FUNCTIONS_ENB_DLSCH_ULSCH_SCHEDULER,VCD_FUNCTION_IN);
…
 VCD_SIGNAL_DUMPER_DUMP_FUNCTION_BY_NAME(VCD_SIGNAL_DUMPER_FUNCTIONS_ENB_DLSCH_ULSCH_SCHEDULER,VCD_FUNCTION_OUT);

 VCD_SIGNAL_DUMPER_CLOSE();
}
```

- Two type of signals
  - variables
  - Functions
- Used with gtkwave to view the signal transition and timing
- Source code
  - Openair2/UTILS/LOG
- To enable use option “-V”, then open with gtkwave and precnfigured file
  - eNB_exmimo2.gtkw eNB_usrp.gtkw rrh.gtkw ue_exmimo2.gtkw

Inter-task interface (ITTI)



- Intra-process communication system through async message passing
- Source code:
  - common/utils/itti

Inter-task interface (ITTI)

- Task = thread + Queue intra-process communication
  - #define TASK_DEF(name of the task, priority , queue size)
- Thread management, Task priority, Timer service
- Message definitions

```
MESSAGE_DEF ( S1AP_SCTP_NEW_MESSAGE_IND ,
TASK_PRIORITY_MED , S1apSctpNewMessageInd
s1apSctpNewMessageInd )

Typedef struct {
uint8_t * buffer ; ///< SCTP buffer
3 uint32_t bufLen ; ///< SCTP buffer length
4 int32_t assocId ; ///< SCTP physical
} s1apSctpNewMessageInd
```

- ITTI can wait for
  - Messages
  - Timeout
  - External events such as sockets (FD)

Task message handling

```
void * s1ap_mme_thread ( void * args ) {
while (1) {
  receive_msg ( TASK_S1AP , & receivedMessage );
 assert ( receivedMessage != NULL );
 switch ( receivedMessage -> messageId ) {
    case S1AP_SCTP_NEW_MESSAGE_IND :
     // Some processing
     break ;
    default :
     S1AP_DEBUG (" Unkwnon message ID %d\n", receivedMessage -> messageId );
     break ;
    }
 free ( receivedMessage );
 receivedMessage = NULL ;
 }
return NULL ;
}
```

ITTI Analyzer
Analyzing protocols PDU/SDU logs

itti_analyzer "log"

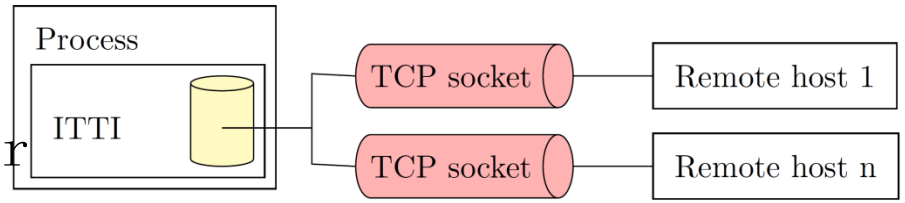
Filters | Messages | Auto | ip: 127.0.0.1 | port: 10006

Messages list | Terminal

MN	LTE Time	Message	From	To	Ins
1588	0.15	S1AP_DOWNLINK_NAS	TASK_S1AP	TASK_RRC_ENB	0
1590	0.15	RRC_DL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1591	0.15	RRC_DCCH_DATA_REQ	TASK_RRC_ENB	TASK_PDCP_ENB	0
1594	0.17	RRC_DCCH_DATA_IND	TASK_PDCP_ENB	TASK_RRC_ENB	0
1596	0.17	RRC_UL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1597	0.17	S1AP_UPLINK_NAS	TASK_RRC_ENB	TASK_S1AP	0
1598	0.17	S1AP_UPLINK_NAS_LOG	TASK_S1AP	TASK_UNKNOWN	DEF
1599	0.17	SCTP_DATA_REQ	TASK_S1AP	TASK_SCTP	0
1606	0.13	SCTP_DATA_IND	TASK_SCTP	TASK_S1AP	DEF
1608	0.13	S1AP_INITIAL_CONTEXT_SETUP_LOG	TASK_S1AP	TASK_UNKNOWN	DEF
1609	0.13	S1AP_INITIAL_CONTEXT_SETUP_REQ	TASK_S1AP	TASK_RRC_ENB	0
1611	0.13	GTPV1U_ENB_CREATE_TUNNEL_REQ	TASK_S1AP	TASK_GTPV1_U	0
1613	0.13	GTPV1U_ENB_CREATE_TUNNEL_RESP	TASK_GTPV1_U	TASK_RRC_ENB	0
1615	0.13	RRC_DL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1617	0.13	RRC_DCCH_DATA_REQ	TASK_RRC_ENB	TASK_PDCP_ENB	0
1626	0.11	RRC_DCCH_DATA_IND	TASK_PDCP_ENB	TASK_RRC_ENB	0
1628	0.11	RRC_UL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1630	0.11	RRC_DL_CCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1632	0.11	RRC_DCCH_DATA_REQ	TASK_RRC_ENB	TASK_PDCP_ENB	0
1636	0.15	RRC_DCCH_DATA_IND	TASK_PDCP_ENB	TASK_RRC_ENB	0
1638	0.15	RRC_UL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1640	0.15	S1AP_UE_CAPABILITIES_IND	TASK_RRC_ENB	TASK_S1AP	0
1641	0.15	S1AP_UE_CAPABILITY_IND_LOG	TASK_S1AP	TASK_UNKNOWN	DEF
1642	0.15	SCTP_DATA_REQ	TASK_S1AP	TASK_SCTP	0
1643	0.15	RRC_DL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1646	0.15	RRC_DCCH_DATA_REQ	TASK_RRC_ENB	TASK_PDCP_ENB	0
1651	0.11	RRC_DCCH_DATA_IND	TASK_PDCP_ENB	TASK_RRC_ENB	0
1653	0.11	RRC_UL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1660	0.11	S1AP_INITIAL_CONTEXT_SETUP_RESP	TASK_RRC_ENB	TASK_S1AP	0
1661	0.11	S1AP_INITIAL_CONTEXT_SETUP_LOG	TASK_S1AP	TASK_UNKNOWN	DEF
1662	0.11	SCTP_DATA_REQ	TASK_S1AP	TASK_SCTP	0
1669	0.13	RRC_DCCH_DATA_IND	TASK_PDCP_ENB	TASK_RRC_ENB	0
1671	0.13	RRC_UL_DCCH	TASK_RRC_ENB	TASK_UNKNOWN	0
1672	0.13	S1AP_UPLINK_NAS	TASK_RRC_ENB	TASK_S1AP	0
1673	0.13	S1AP_UPLINK_NAS_LOG	TASK_S1AP	TASK_UNKNOWN	DEF
1674	0.13	SCTP_DATA_REQ	TASK_S1AP	TASK_SCTP	0

```
.ittiMsg = msg_t, msg_s |
  .rrc_dl_dcch = IttiMsgText,
<DL-DCCH-Message>
    <message>
        <c1>
            <rrcConnectionReconfiguration>
                <rrc-TransactionIdentifier>0</rrc-TransactionIdentifier>
                <criticalExtensions>
                    <c1>
                        <rrcConnectionReconfiguration-r8>
                            <dedicatedInfoNASList>
                                <DedicatedInfoNAS>
                                    27 9C 97 C2 02 02 07 42 02 4A 06 20 02 F8 29 00
                                    01 00 31 52 01 C1 01 09 09 08 6F 70 65 72 61 74
                                    6F 72 05 01 C0 AC 00 02 5E 04 FE FE 9E 0D 27 14
                                    80 80 21 10 02 00 00 10 81 06 C0 A8 0C 64 83 06
                                    C0 A8 0C 64 50 0B F6 02 F8 29 80 00 01 00 00 01
                                    20 17 2C
                                </DedicatedInfoNAS>
                            </dedicatedInfoNASList>
                            <radioResourceConfigDedicated>
                                <drb-ToAddModList>
                                    <DRB-ToAddMod>
                                        <eps-BearerIdentity>5</eps-BearerIdentity>
                                        <drb-Identity>1</drb-Identity>
                                        <pdcp-Config>
                                            <discardTimer><infinity/></discardTimer>
                                            <rlc-UM>
                                                <pdcp-SN-Size><len12bits/></pdcp-SN-Size>
                                            </rlc-UM>
                                            <headerCompression>
                                                <notUsed></notUsed>
                                            </headerCompression>
                                        </pdcp-Config>
                                        <rlc-Config>
                                            <um-Bi-Directional>
                                                <ul-UM-RLC>
                                                    <sn-FieldLength><size10/></sn-FieldLength>
                                                </ul-UM-RLC>
                                                <dl-UM-RLC>
                                                    <sn-FieldLength><size10/></sn-FieldLength>
```

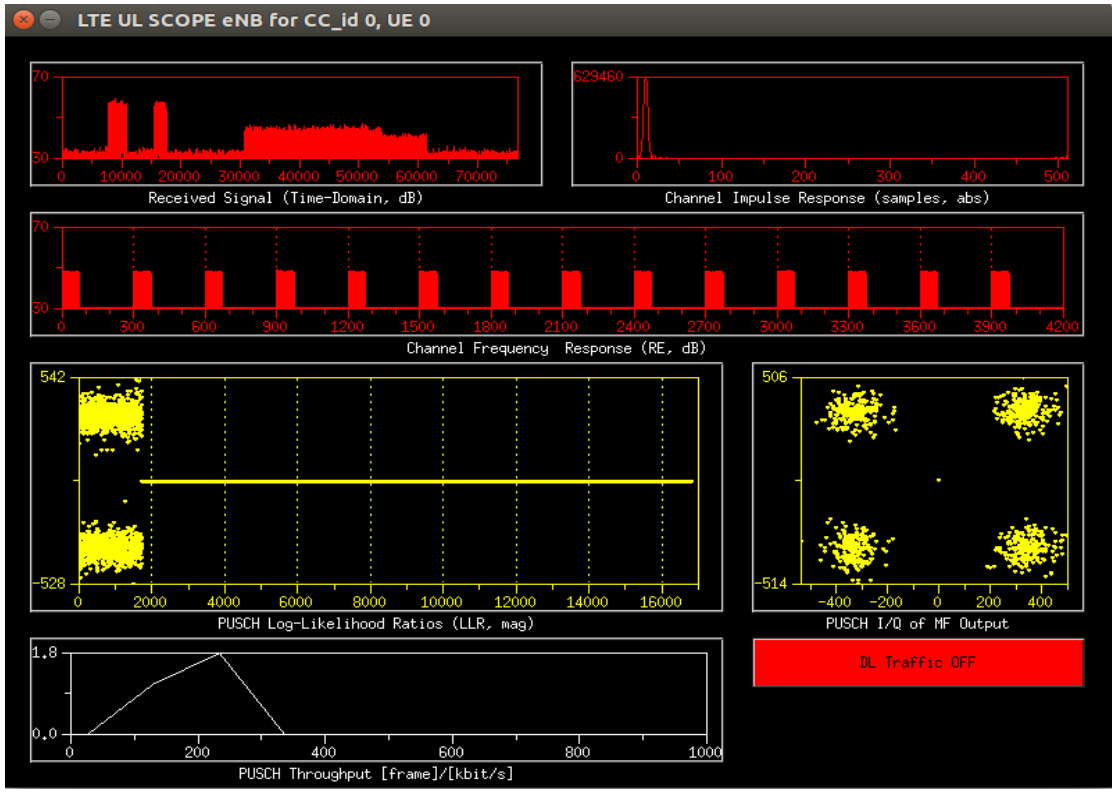
- Complementary to Wireshark
- source file
  - common/utils/itti_analyzer



Softscope

- Monitor PHY layer for both eNB and UE
- The tool plots
  - received signal power, channel impulse response, channel frequency response, channel frequency response, LLRs, throughput and I/Q components (e.g., 4-QAM constellation)

- source file
  - openair1/PHY/TOOLS



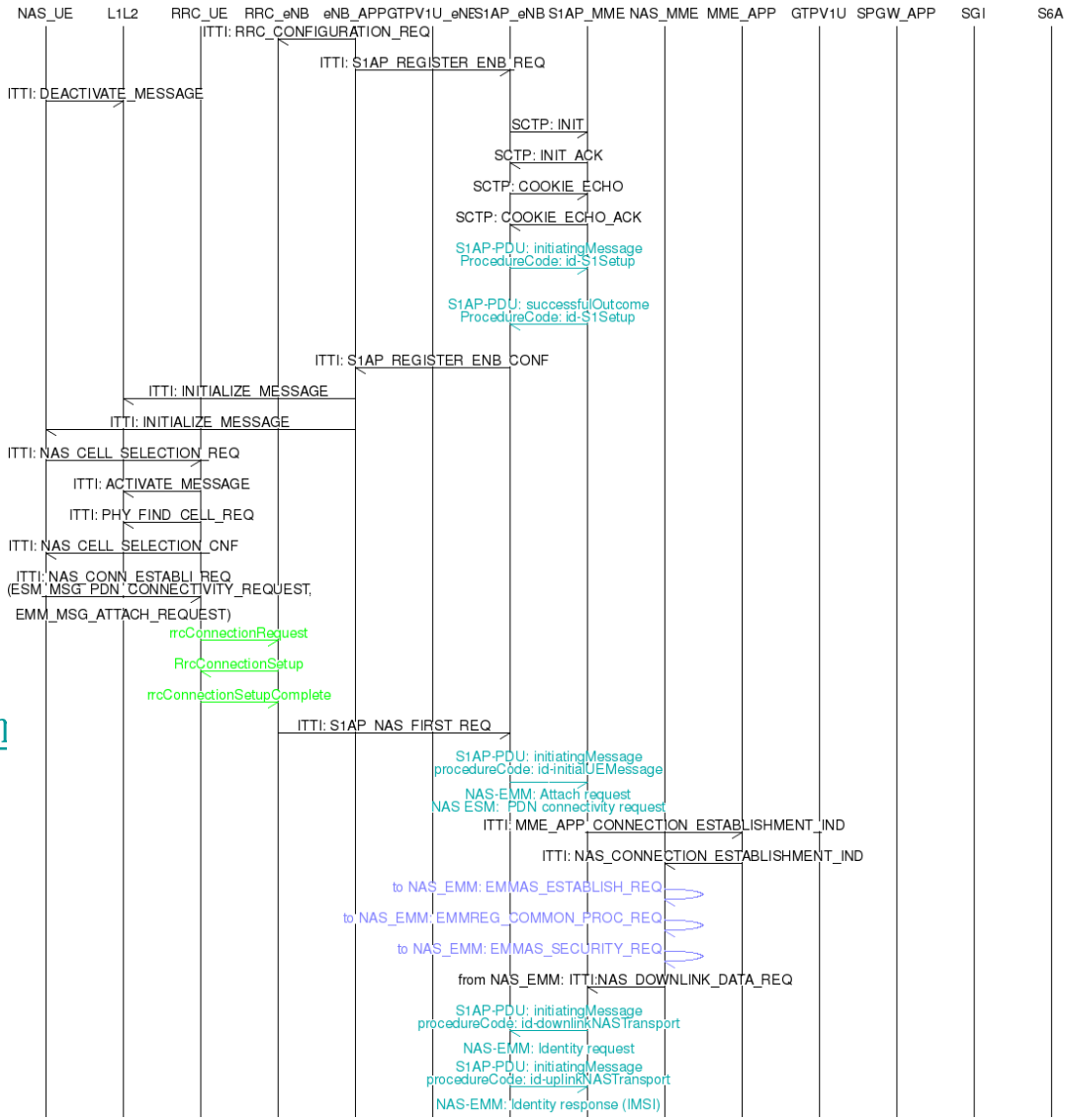
MAC/PHY statistics

- Online statistics for the status of the network
  - successful transmissions, errors per HARQ per round, average throughput, ULSCH/DLSCH errors per HARQ process (8 in LTE FDD) per round (4 is maximum).
- Source file
  - Openair1/PHY/LTE_TRANSPORT/print_stats.c
  - Openair2/LAYER2/openair2_proc.c

```
[eNB PROC] eNB 0/1 Frame 134: RX Gain 120 dB, I0 -97 dBm (23,0) dB
[eNB PROC] Subband I0:  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

[eNB PROC] PERFORMANCE PARAMETERS
[eNB PROC] Total DLSCH bits successfully transmitted 12 kbits in 135 frame(s)
[eNB PROC] Total DLSCH average system throughput 0 kbps
[eNB PROC] Total DLSCH successful transmissions 25 in 135 frame(s)

[eNB PROC] UE 0 (c7b4) Power: (46,0) dB, Po_PUSCH: (-91,0) dBm, Po_PUCCH (-85/-108) dBm, Po_PUCCH1 (-96,-109) dBm,  PUCCH1 Thres -108 dBm
   harq 0: DL mcs 28, UL mcs 10, UL rb 6, delta_TF 269
   harq 1: DL mcs 22, UL mcs 9, UL rb 3, delta_TF 269
   harq 2: DL mcs 0, UL mcs 10, UL rb 6, delta_TF 269
   harq 3: DL mcs 0, UL mcs 10, UL rb 6, delta_TF 269
   harq 4: DL mcs 0, UL mcs 10, UL rb 6, delta_TF 269
   harq 5: DL mcs 0, UL mcs 10, UL rb 6, delta_TF 269
   harq 6: DL mcs 0, UL mcs 10, UL rb 6, delta_TF 269
   harq 7: DL mcs 0, UL mcs 10, UL rb 6, delta_TF 197
[eNB PROC] Wideband CQI: (0,0) dB
[eNB PROC] Subband CQI:    0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
[eNB PROC] DL TM 1, DL_cqi 15, DL_pmi_single 0
[eNB PROC] DL Subband CQI: 15 15 15 15 15 15 15  0  0  0  0  0  0
[eNB PROC] Timing advance 12 samples (3 16Ts), update -1
[eNB PROC] Mode = PUSCH(3)
[eNB PROC] UE_id_mac = 0, RRC status = 4
[eNB PROC] SR received/total: 3922/4139 (diff 217)
[eNB PROC] ULSCH errors/attempts per harq (per round):
   harq 0: 1/2068 (fer 0) (1/2068, 1/1, 1/1, 1/1)
   harq 1: 0/2070 (fer 0) (0/2070, 0/0, 0/0, 0/0)
   harq 2: 1/2068 (fer 0) (1/2068, 1/1, 1/1, 1/1)
   harq 3: 0/2070 (fer 0) (0/2070, 0/0, 0/0, 0/0)
   harq 4: 0/2070 (fer 0) (0/2070, 0/0, 0/0, 0/0)
   harq 5: 0/2071 (fer 0) (0/2071, 0/0, 0/0, 0/0)
   harq 6: 0/2071 (fer 0) (0/2071, 0/0, 0/0, 0/0)
   harq 7: 0/2071 (fer 0) (0/2071, 0/0, 0/0, 0/0)
[eNB PROC] ULSCH errors/attempts total 2/16559 (2/16559, 2/2, 2/2, 2/2):
[eNB PROC] DLSCH errors/attempts per harq (per round):
   harq 0: 0/19 (19/0/19, 0/0/0, 0/0/0, 0/0/0)
   harq 1: 0/6 (6/0/6, 0/0/0, 0/0/0, 0/0/0)
   harq 2: 0/0 (0/0/0, 0/0/0, 0/0/0, 0/0/0)
   harq 3: 0/0 (0/0/0, 0/0/0, 0/0/0, 0/0/0)
   harq 4: 0/0 (0/0/0, 0/0/0, 0/0/0, 0/0/0)
   harq 5: 0/0 (0/0/0, 0/0/0, 0/0/0, 0/0/0)
   harq 6: 0/0 (0/0/0, 0/0/0, 0/0/0, 0/0/0)
   harq 7: 0/0 (0/0/0, 0/0/0, 0/0/0, 0/0/0)
[eNB PROC] DLSCH errors/attempts total 0/25 (0/25, 0/0, 0/0, 0/0):
[eNB PROC] DLSCH total bits from MAC: 12kbit
[eNB PROC] DLSCH total bits ack'ed: 12kbit
[eNB PROC] DLSCH Average throughput (100 frames): 0kbps
[eNB PROC] Transmission Mode 1
[eNB PROC] RB Allocation on Sub-bands: 1 0 0 0 0 0 0
[eNB PROC] Total Number of Allocated PRBs = 2
```

Message Sequence Chart API

- Represents the internal function calls across layers and entities in a form of chart
- It is an ITTI task
- Make use of MSC lib
  - http://www.mcternan.me.uk/mscgen/

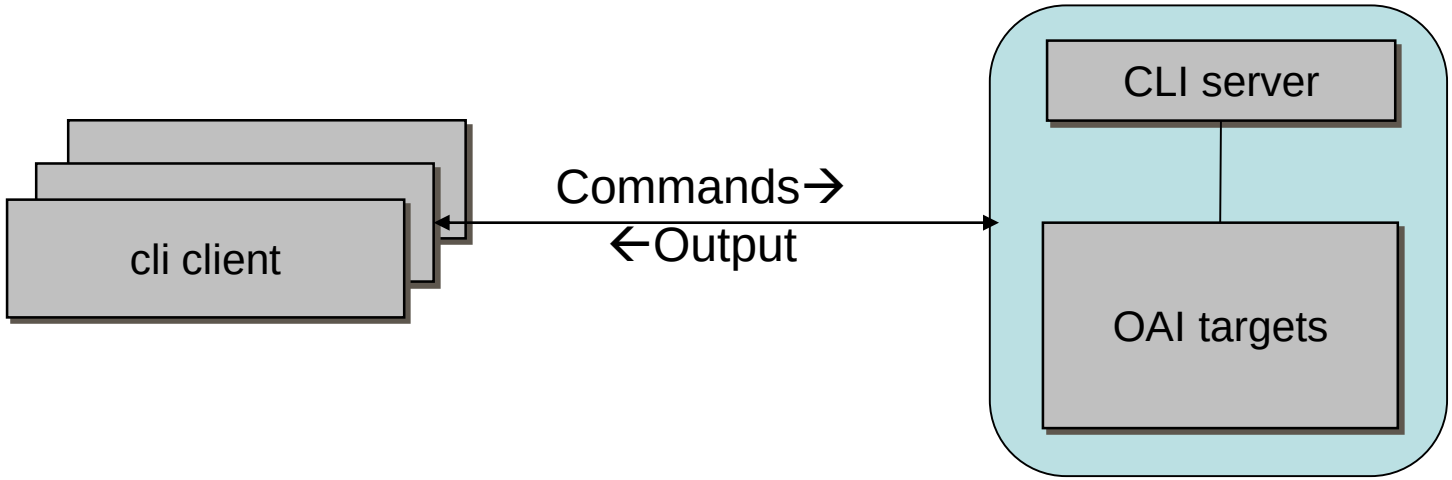


MSC API

- MSC_LOG_EVENT(pROTO, fORMAT, aRGS...)
  - Failure events, new UE attached, congestion, ….
- MSC_LOG_RX_MESSAGE(rECEIVER, sENDER, bYTES, nUMbYTES, fORMAT, aRGS...)
- MSC_LOG_RX_DISCARDED_MESSAGE(rECEIVER, sENDER, bYTES, nUMbYTES, fORMAT, aRGS...)
- MSC_LOG_TX_MESSAGE(sENDER, rECEIVER, bYTES, nUMbYTES, fORMAT, aRGS...)
- MSC_LOG_TX_MESSAGE_FAILED(sENDER, rECEIVER, bYTES, nUMbYTES, fORMAT, aRGS...)
- Example
  - MSC_LOG_TX_MESSAGE(MSC_S1AP_ENB, MSC_S1AP_MME,NULL,0,
    MSC_AS_TIME_FMT" S1AP_NAS_FIRST_REQ eNB %u UE %x",
    MSC_AS_TIME_ARGS(ctxt_pP),
    ctxt_pP->module_id,
    ctxt_pP->rnti);
- Usage
  - usage: msc_gen [-h] [--dir DIR] [--profile PROFILE] [--no_message NO_MESSAGE][--no_pdu NO_PDU] [--no_event NO_EVENT] [--type TYPE]
    - Dir:Directory where msc logs can be found
    - Profile : E-UTRAN, EPC
    - type: 'png', 'eps', 'svg' or 'ismap'
- Source code
  - Openair-cn/SRC/UTIL/MSC/ and openair-cn/SCRIPTS/msc_gen
  - Openairinterface5g/ommon/util/msc and openairinterface5g/targets/SCRIPTS/msc_gen

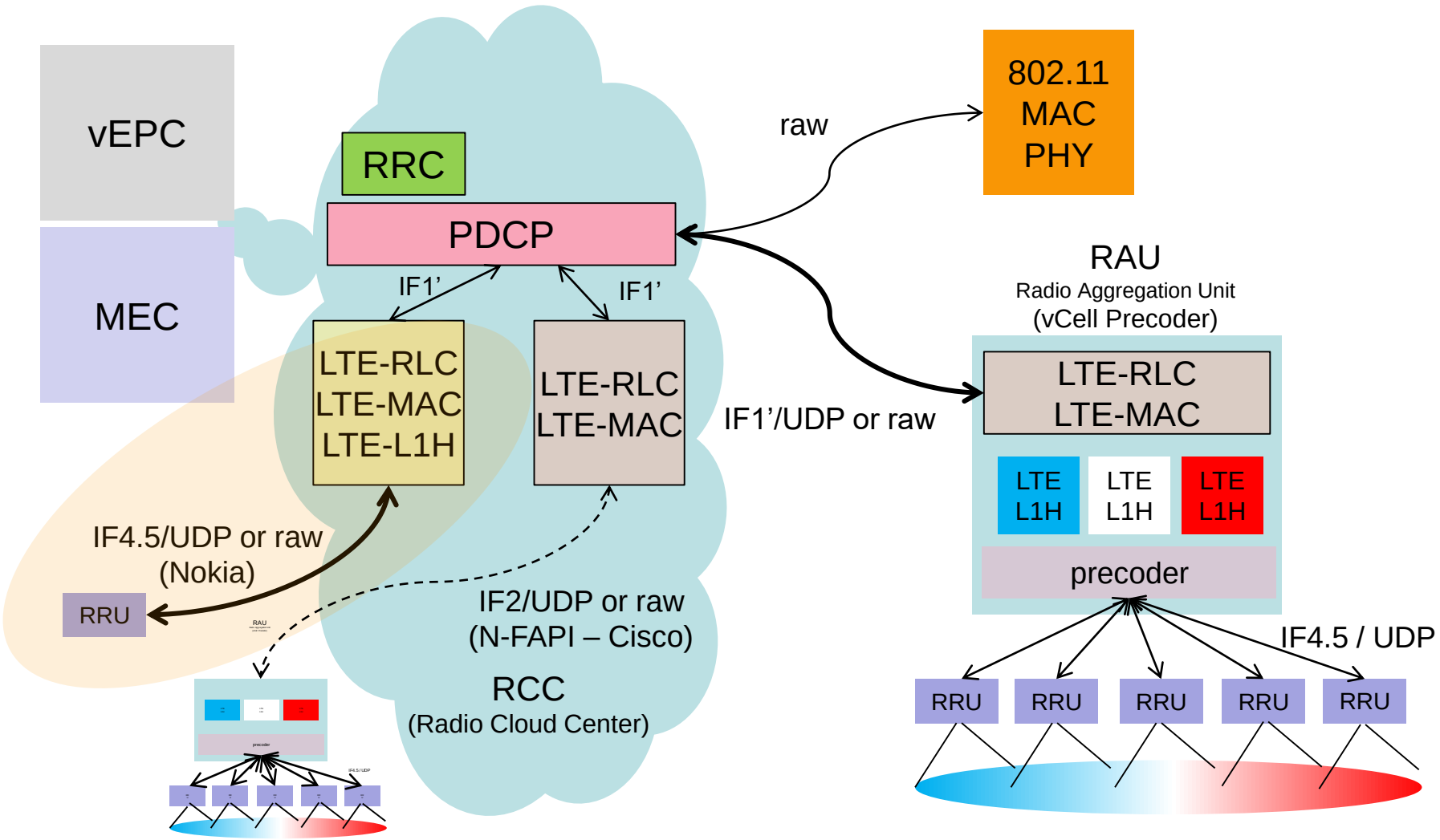
CLI

- Allow interactive interface with the OAI
  - Debugging
  - Monitoring
  - Configuration
- Now only available in oaisim with limited commands
- Plans
  - Extend the commands
  - Apply to all OAI targets: lte-softmodem, RRH



BACKUP

Splits under construction in OAI Community



Key Ingredients (How does OAI work)

- Real-time extensions to Linux OS
  - Today we rely on the lowlatency kernel provided by Ubuntu (since Ubuntu 14.04)
  - In earlier Ubuntu versions RTAI was used
- Real-time data acquisition to/from PC
  - ExpressMIMO uses DMA to transfer signals in and out of PC memory without hogging CPU -> very efficient
  - USRP transfers data over USB and therefore requires extra CPU time for (de-)packetization of signals
- Highly optimized DSP routines running on Intel GPP
  - Exploiting vector processing (SIMD)
  - 64-bit MMX → 128-bit SSE2/3/4 → 256-bit AVX2
  - OAI features fastest FFT and Turbo decoder of its kind
- Multi-threaded parallel processing

OSA Strategic Areas