Accelerating O-RAN adoption with OpenAirInterface

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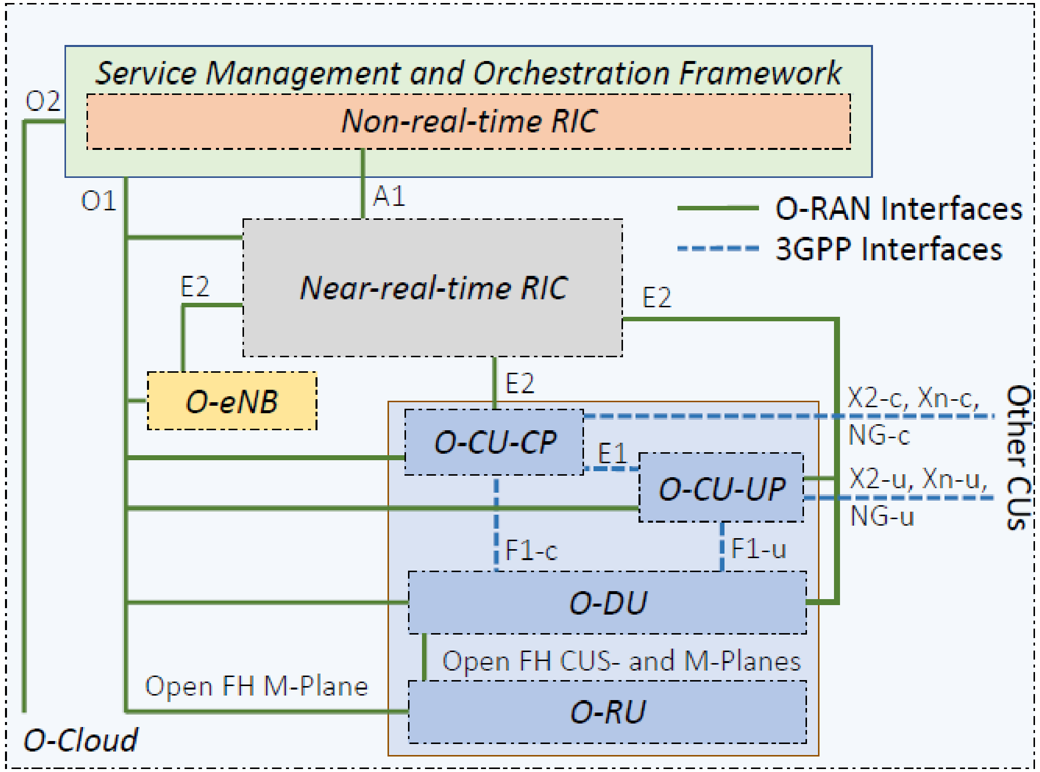
Agenda

- Part 1: O-RAN and OpenAirInterface
- Part 2: Use case: positioning and localization in 5G NR
- Discussion and conclusions

Open RAN is transforming mobile networks

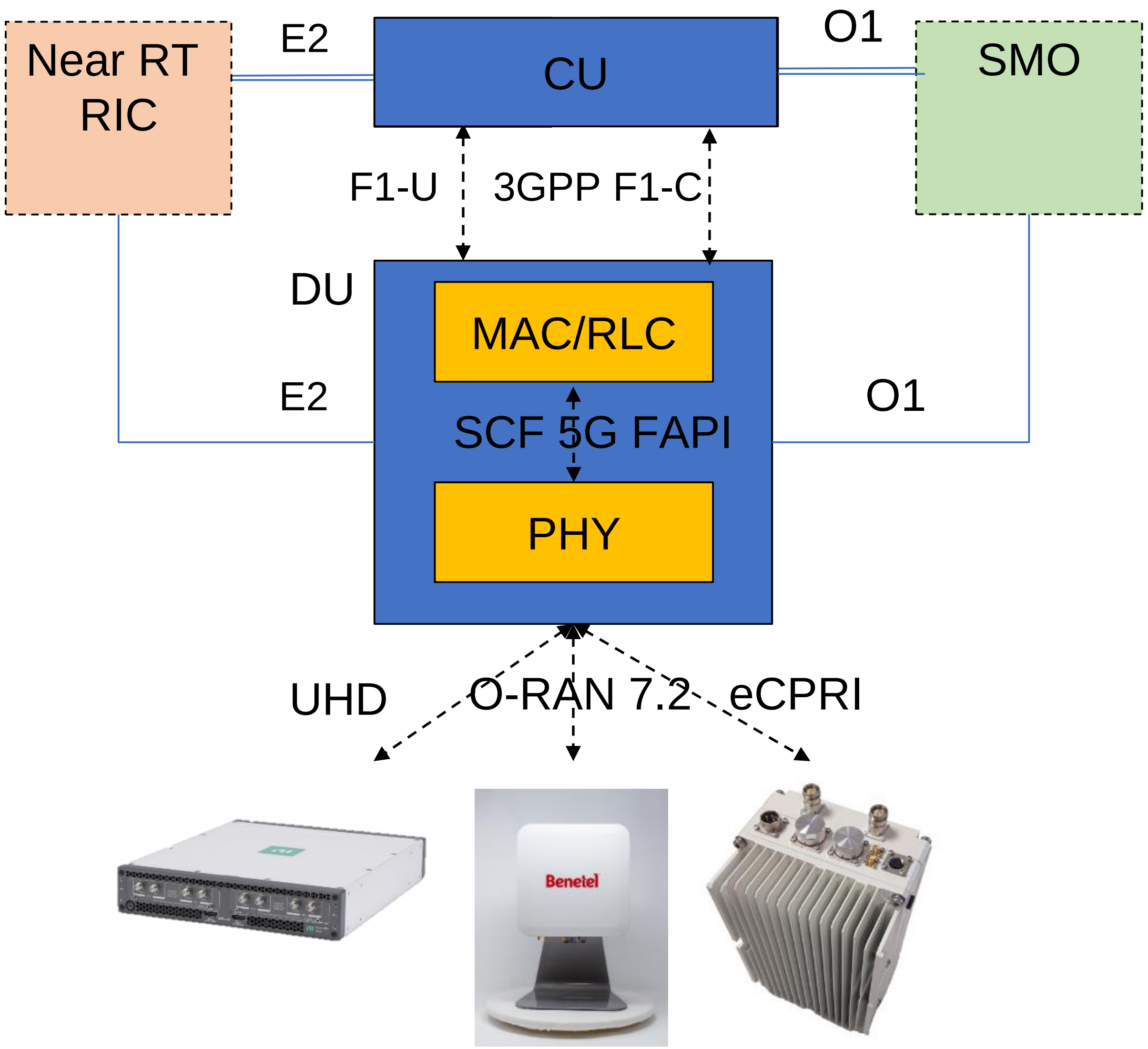
- O-RAN Alliance specifics open interfaces for
  - Fronthaul
  - RAN Intelligent Controller
  - Service Management and Orchestration
  - O-Cloud infrastructure
- Allows for
  - Virtualized & disaggregated deployments
  - AI/ML optimization of networks
  - Multi-vendor deployments



Open RAN and Open Source

- Open-source software is a big enabler for open RAN networks
  - Brings down costs
  - Increase security and trust
  - No vendor lock-in
  - Easier market entry for new players
  - Network sovereignty
- The O-RAN Software Community is a Linux Foundation project supported and funded by O-RAN to lead the implementation of the O-RAN specifications in Open Source, e.g.
  - Fronthaul library
  - RAN intelligent controller
  - Service Management and Orchestration
- OpenAirInterface (OAI) is a community-driven open-source project supported by the OpenAirInterface Software Alliance implementing
  - 4G and 5G Radio Access Network
  - 4G and 5G Core Network
  - 5G User Equipment
- Memorandum of Understanding between O-RAN ALLIANCE and OpenAirInterface Software Alliance (OSA) was signed in March 2023 to accelerate the integration of the two projects

OpenAirInterface and open RAN

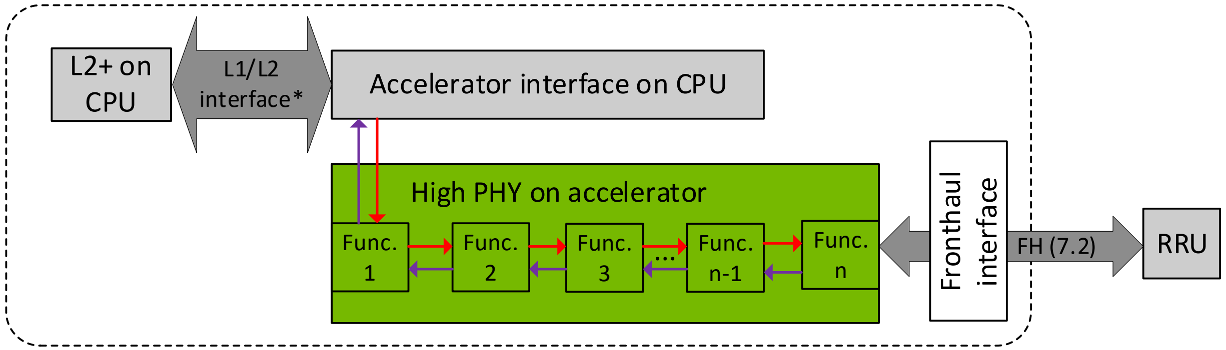


- **F1-C and F1-U**
  - OAI DU tested with Acceleran CU
  - Multiple DU per CU support
  - F1 handover under integration
- **E1 interface**
  - Available, interoperability testing ongoing
- **E2 interface**
  - E2 agent interoperable with different RICs
- **5G FAPI**
  - Compliant with SCF 5G FAPI 222.10.02
  - OAI L2 tested with Nvidia L1
  - 5G nFAPI
- **Fronthaul**
  - UHD with USRP (Split 8)
  - eCPRI with AW2S (Split 8)
  - O-RAN 7.2 CUS-plane (Split 7.2) tested with VVDN, LiteOn (others ongoing)
- **O1 interface**
  - Ongoing work (2023)

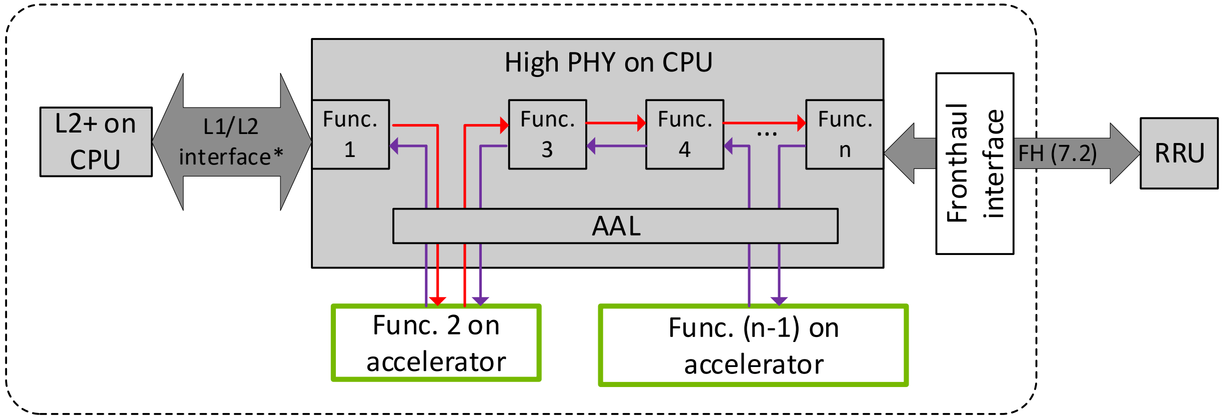
Hardware Acceleration and Offloading

- To deploy virtualized open RAN at scale, hardware acceleration is needed
- Layer 1, especially PHY channel en/de-coding, is the most computationally expensive (90% of total computation time)

Inline Offloading



Look-aside Offloading



Hardware Accelerators Examples

Look-aside Accelerators

NXP Layerscape

5G OPERA

AMD/Xilinx T1 & T2 cards

OPEN AIR INTERFACE

Intel FlexRAN

Inline Accelerators

Nvidia Aerial (Melanox NIC + A100 GPU)

OPEN AIR INTERFACE

Kalray MPPA

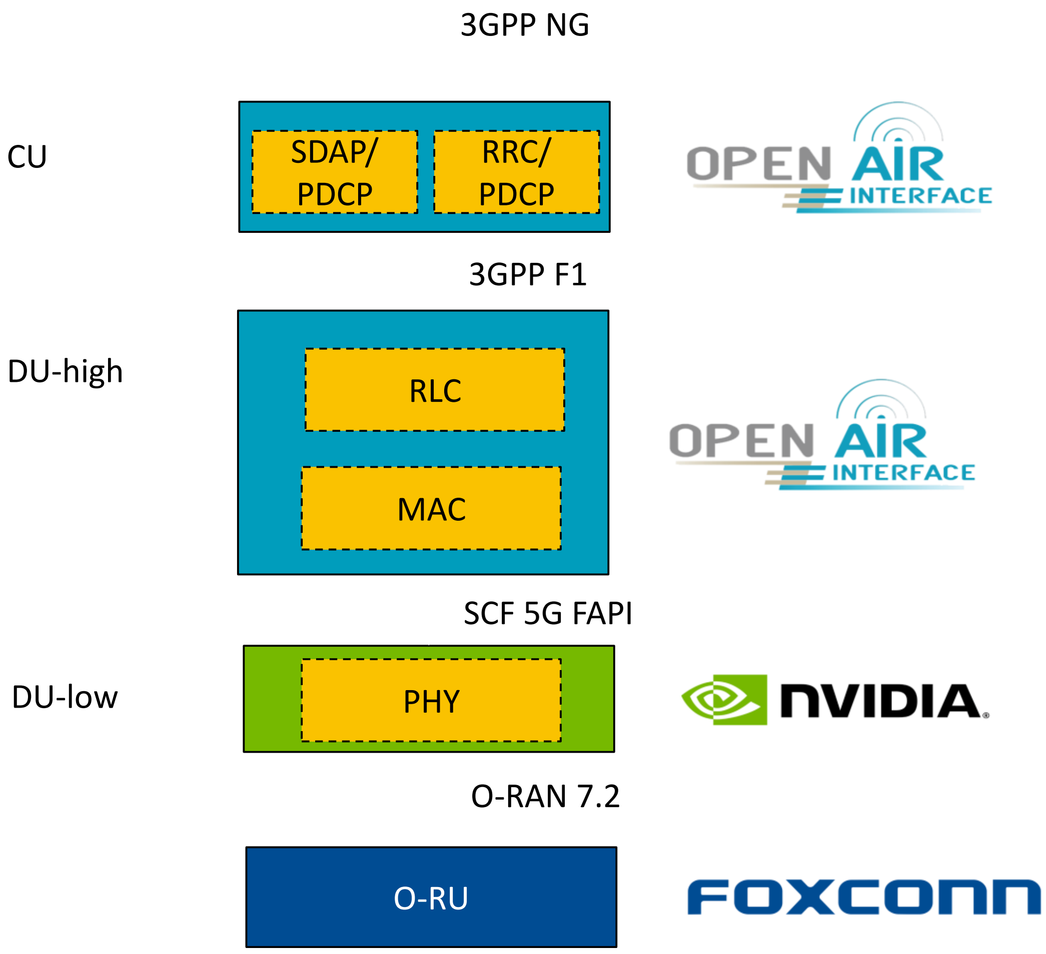
5G OPERA

Qualcomm X100

NVIDIA Aerial SDK

- NVIDIA Aerial provides inline layer 1 offloading on COTS hardware
  - A100 GPU for signal processing acceleration
  - Melanox CX6-DX NIC for fronthaul
- Interfaces with L2 Using SCF222.10.02 FAPI standard
- Interfaces with commercial O-RU radios using O-RAN 7.2
- Nvidia gives access to source code (but not classical open source)
- https://developer.nvidia.com/aerial-sdk
- https://docs.nvidia.com/aerial/aerial-research-cloud/index.html

Integration of Aerial with OpenAirInterface

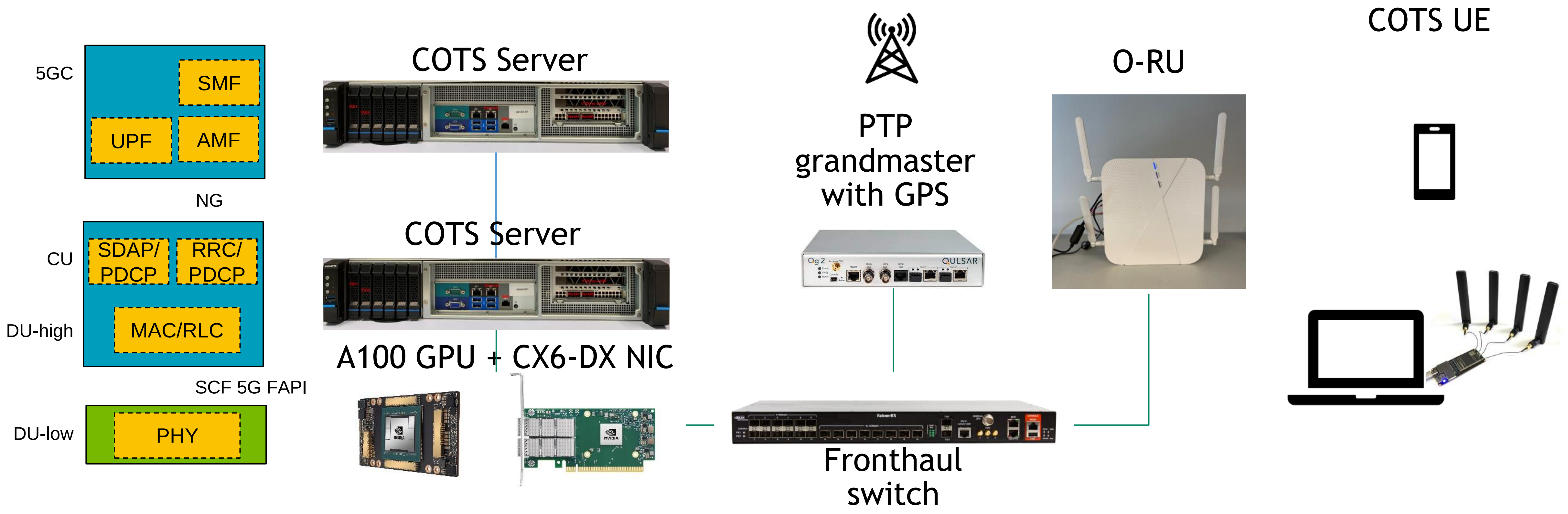


- Nvidia Aerial is used as an inline L1 accelerator
- DU-high (Layer 2) from OpenAirInterface
- Interface realized using 5G FAPI defined by Small Cell Forum
- Both run in individual docker containers
- Traces can be analyzed with Wireshark

- DU Layer 1 southbound interface: O-RAN 7.2
- DU Layer 2 northbound interface: 3GPP F1
- DU can be combined with CU in a single executable/container

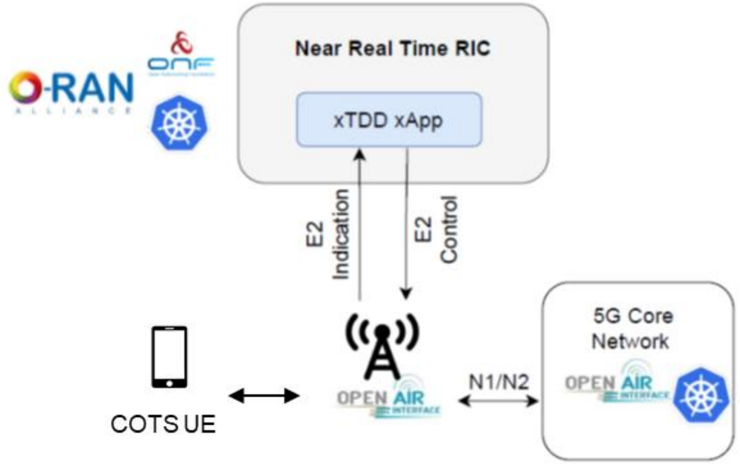
Inline GPU acceleration of the entire L1 improves performance and extends features of OAI DU to multiple cell deployments and other advanced configurations

Aerial Research Cloud Setup

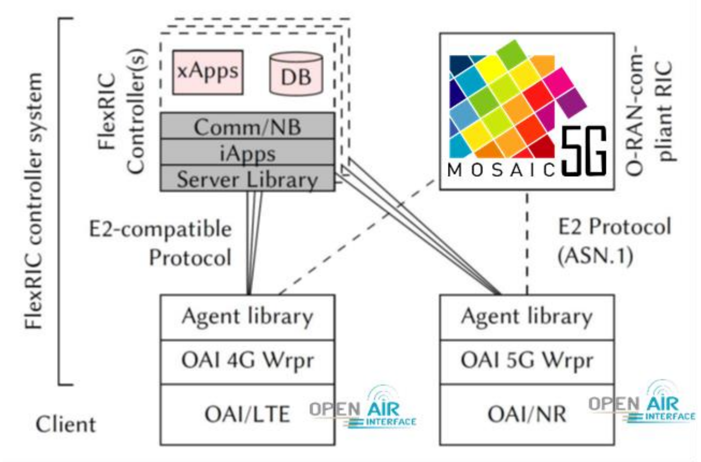


Demo available at O-RAN virtual exhibition: https://www.virtualexhibition.o-ran.org
Presentation at GTC: https://www.nvidia.com/en-us/on-demand/session/gtcfall20-a21527/

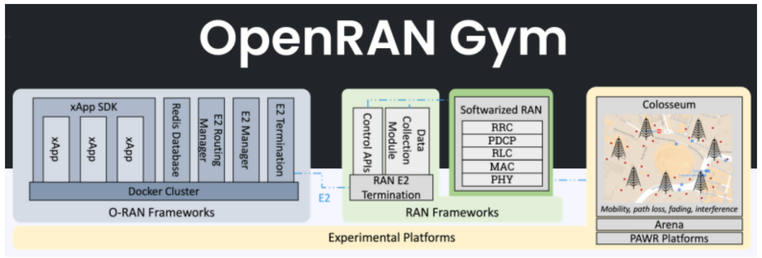
E2 integration examples



Dynamic TDD by reinforcement learning
Based on µONOS RIC from ONF



Slicing, traffic control based on FlexRIC
from Mosaic5G project



OpenRAN Gym leverages the OSC RIC for
Data-driven O-RAN experimentation at scale

EURECOM Sophia Antipolis

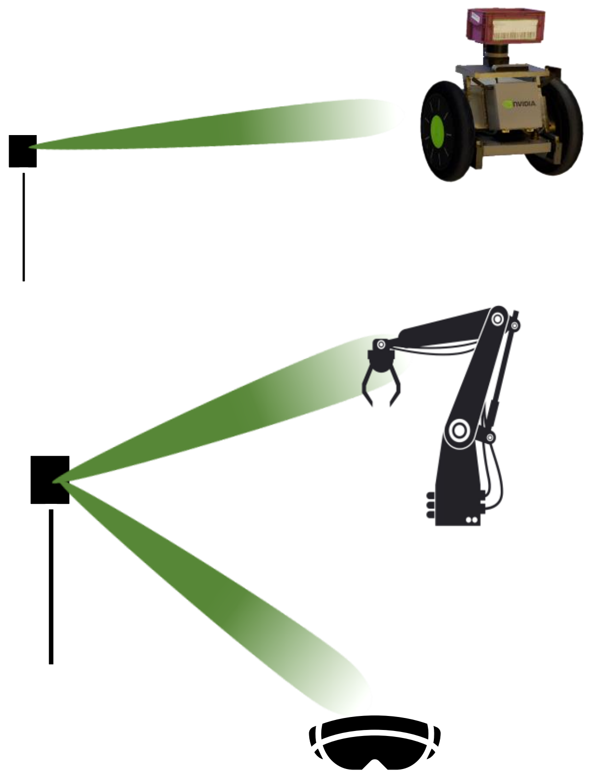
EURECOM Sophia Antipolis

Institute for the Wireless Internet of Things at Northeastern University

- Schmidt, Robert; Irazabal, Mikel; Nikaein, Navid, "**FlexRIC: An SDK for next-generation SD-RANs,**" CONEXT 2021, 17th International Conference on Emerging Networking EXperiments and Technologies, 7-10 December 2021, Munich, Germany (Virtual Conference)
- Ksentini, Adlen, "**On using AI for dynamic TDD configuration in OpenAirInterface (OAI): An O-RAN approach,**" O-RAN next Generation Research Group (nGRG) Workshop, 19-20 October 2022, Madrid, Spain
- L. Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia, "**OpenRAN Gym: AI/ML Development, Data Collection, and Testing for O-RAN on PAWR Platforms**," Computer Networks, vol. 220, pp. 1-11, January 2023

AI/ML use case examples

Dynamic optimization of 5G networks for **industrial control**



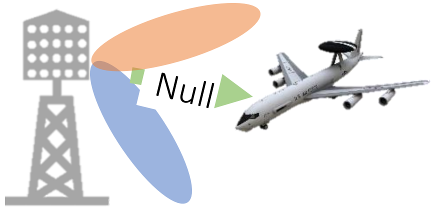
AI-based channel and interference estimation

slicing and dynamic resource allocation

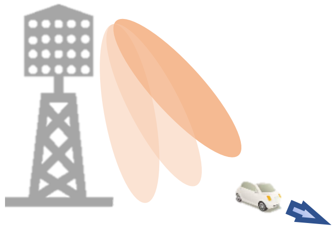
Load balancing and mobility management

Institute for the Wireless Internet of Things at Northeastern University

AI enhanced MIMO operation



Radar Detection and Co-existence



Beam Selection and Tracking

Deep Learning-based Massive MIMO Detection

RICE UNIVERSITY

Positioning and Localization

With help from Adeel Malik, Mohsen Ahadi, Rakesh Mundlamuri

Positioning and Localization

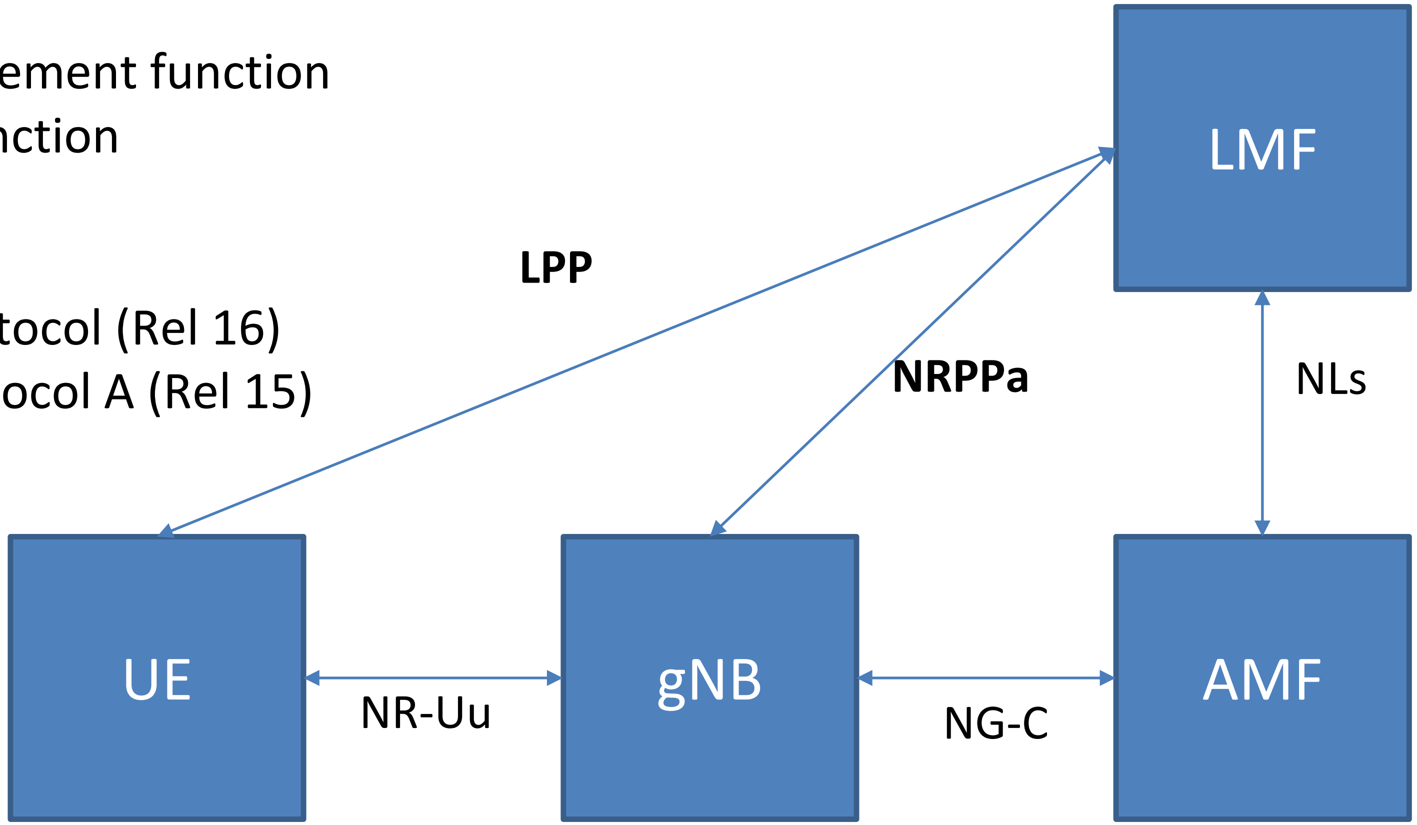
- Use cases
- 5G NR Localization Architecture
- 5G NR supports many positioning and localization methods
- Current implementation status in OAI
- Demos
- O-RAN localization support via E2
- Conclusions

Use case: indoor 5G localization

- Industrial Automation
  - Precise localization of tools and products
  - Automated guided vehicles
  - Geofencing
- Logistics and Transport
- Position information of UEs can greatly enhance commu
  - Enhanced beam management
  - Enhanced mobility procedures
- One network for 2 purposes

Localization Architecture in 5G NR

LMF	Localization management function
AMF	Access Mobility Function
gNB	next gen node B
UE	User Equipment
LPP	LTE Positioning Protocol (Rel 16)
NRPPa	NR Positioning Protocol A (Rel 15)



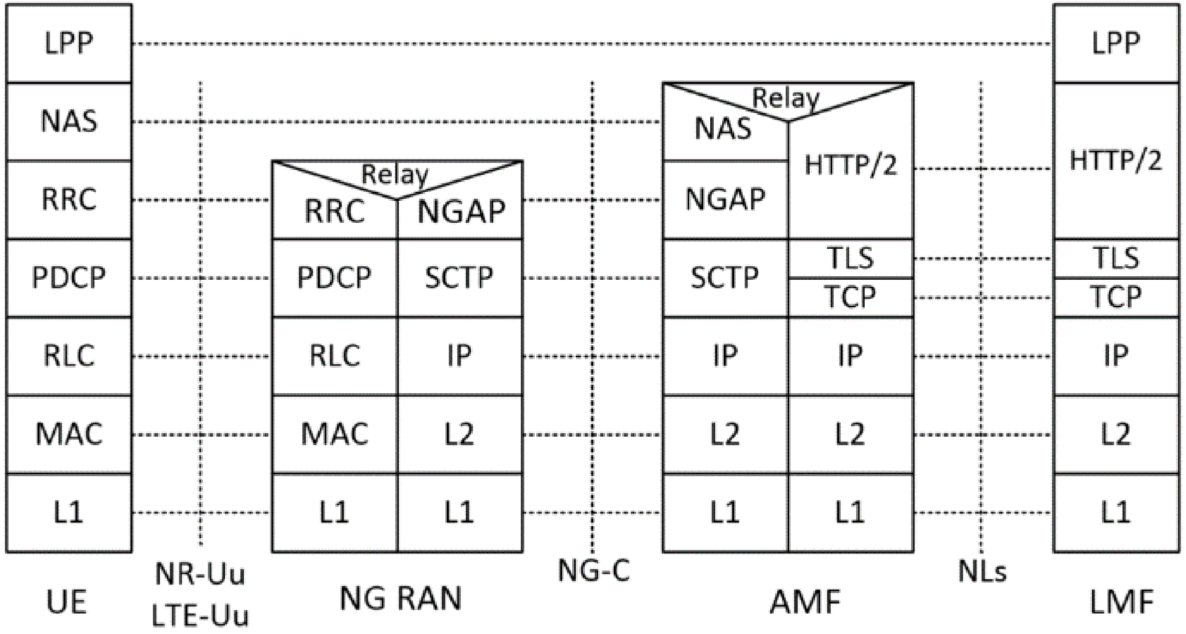
Support for localization in 5G NR

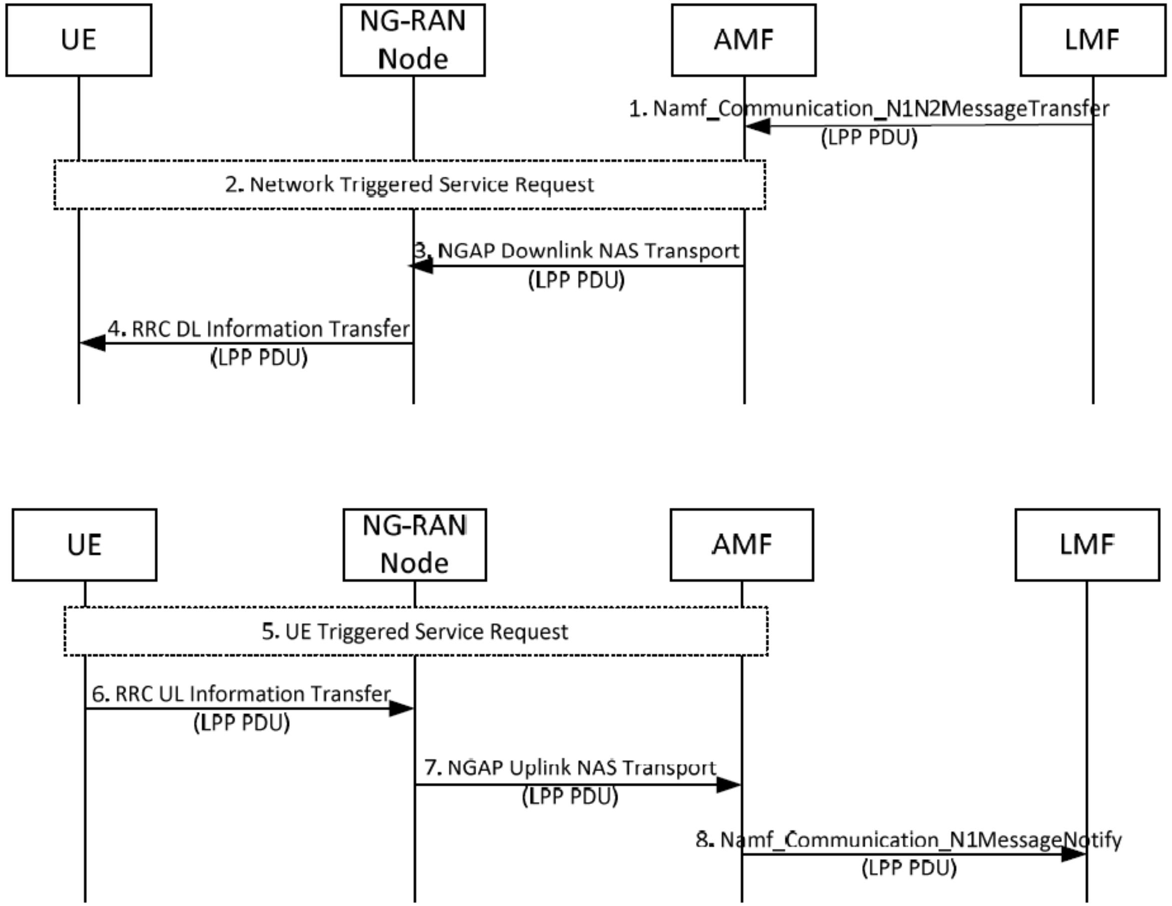
- Network based and UE based localization
- Hybrid positioning using GNSS, Bluetooh, Wifi, other sensors
- Positioning methods that rely only on 5G NR signals (and signaling)
  - Rel 15: Enhanced cell ID, UL-TDoA, UL-AoA
  - Rel 16: DL-TDoA, DL-AoD, Multi-RTT (Round-trip-time)
- mm-wave spectrum attractive for localization
  - High bandwidths → higher accuracy
  - AoA/AoD information can be derived from beam indices
  - Can achieve sub-meter accuracy in theory*

*Ahadi, Mohsen; Kaltenberger, Florian, "5G NR indoor positioning by joint DL-TDoA and DL-AoD," COST CA20120 Interact, CA20120 TD(22)02029, 2nd Technical meeting, 13-15 June 2022, Lyon, France

Protocol Layering (LPP): Localization Architecture in 5G NR

Protocol Layering for LMF to UE Signalling
(Section 6.4 TS 38.305)

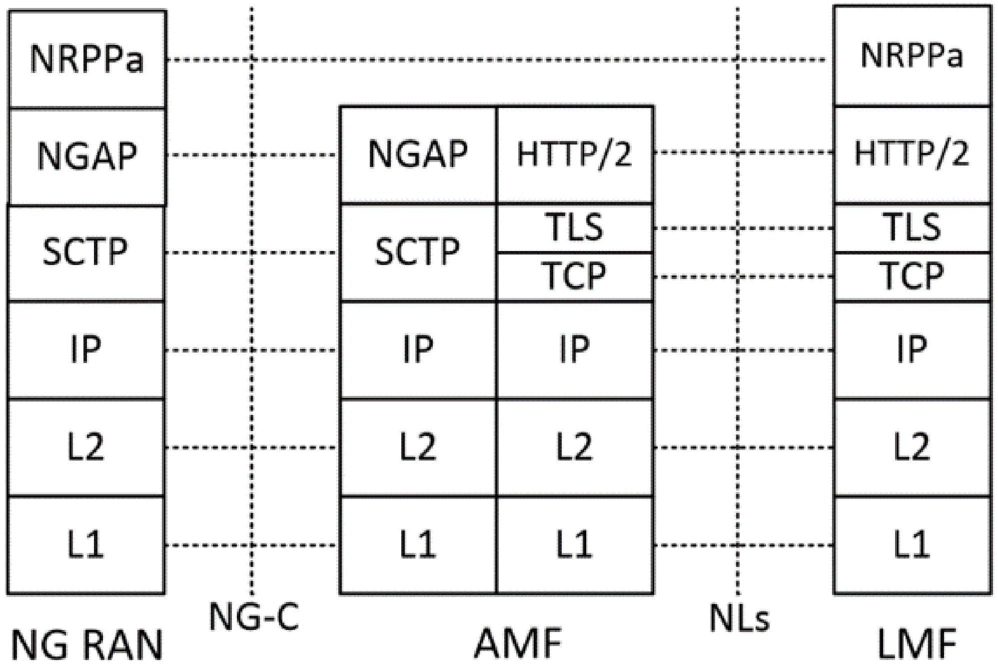


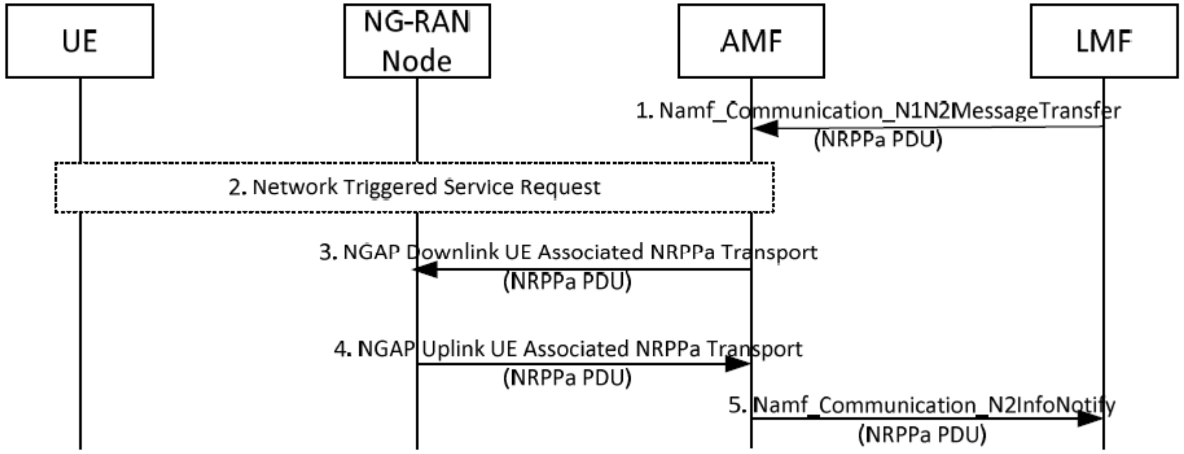


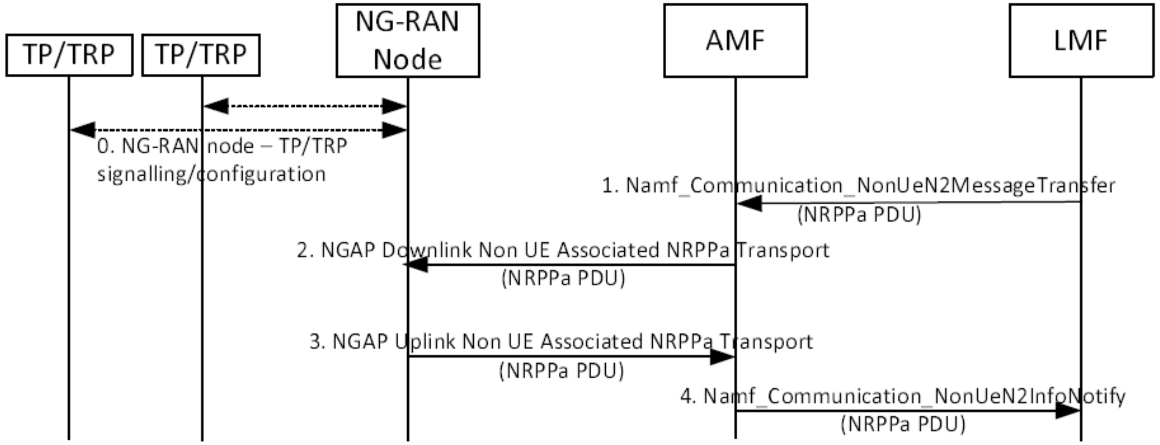
LPP PDU transfer between LMF and UE (network- and UE-triggered cases)

Protocol Layering (NRPPa): Localization Architecture in 5G NR

Protocol Layering for LMF to NG-RAN Signalling(Section 6.5 TS 38.305)

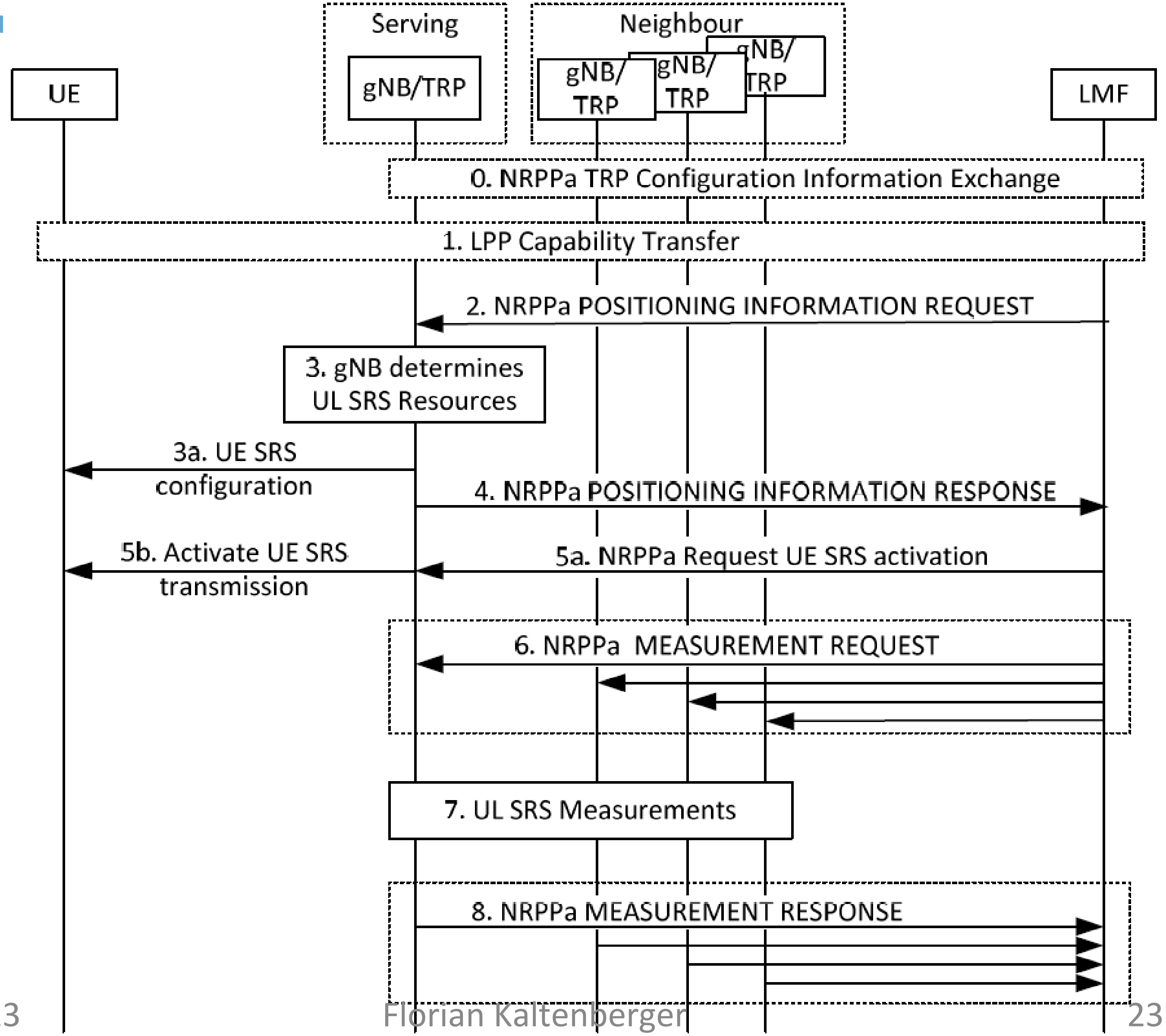






NRPPa PDU Transfer between an LMF and NG-RAN Node

Example: NG-RAN-assisted UL-TDOA Positioning Method [Section 8.13 of TS 38.305]



Required OAI Support for NG-RAN-assisted UL-TDOA Positioning Method

LMF

In Progress

- LMF Procedures ([TS 29.572])
- NRPPa Functionalities ([TS 38.455])

Completed

- NRPPa PDU Transfer protocol between AMF/LMF (([TS 29.518])

AMF

Completed

- NRPPa PDU Transfer protocol between AMF/LMF ([TS 29.518])
- NRPPa PDU Transfer protocol between AMF/gNB ([TS 38.413])

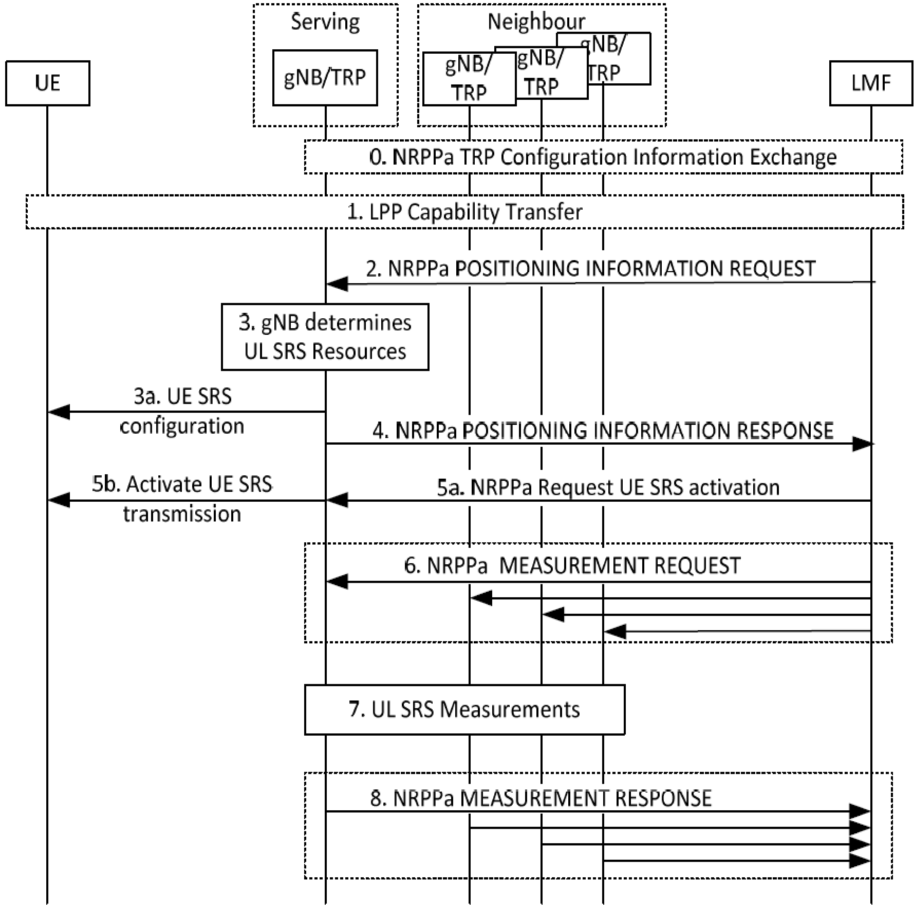
RAN

In Progress

- NRPPa Functionalities ([TS 38.455])

Completed

- NRPPa PDU Transfer protocol between AMF/gNB ([TS 38.413])



Status of Integration in OAI

Status (RAN): NRPPA Support for NG-RAN-assisted UL-TDOA Positioning Method

RAN (Working branch: NRPPA_Procedures)
Contributors: Eurecom (Team Prof. Florian)

- **NRPPa Functionalities** (In Progress)
  - Positioning Information Transfer
    - Positioning Information Request (done)
    - Positioning Information Response (done)
    - Positioning Information Failure (done)
  - TRP Information Transfer
  - Measurement Information Transfer

- **NRPPa PDU Transfer protocol between AMF/gNB (NGAP)** (done)
  - NGAP Upnlink UE Associated NRPPa Transport (done)
  - NGAP Uplink Non UE Associated NRPPa Transport (done)
  - NGAP Downlink UE Associated NRPPa Transport (done)
  - NGAP Downlink Non UE Associated NRPPa Transport (done)

Status (LMF): NRPPA Support for NG-RAN-assisted UL-TDOA Positioning Method

LMF (Working branch: [oai-cn5g-lmf branch: initial](#))

Contributor: IITH Team

- **LMF Procedures** (In Progress)
  - DetermineLocation: Retrieve UE Location
    - Functionalities: Process InputData, build_request_location_lpp_pdu, build_positioning_information_request_nrppa_pdu (done)
  - CancelLocation: Cancel Periodic or Triggered Location

- **NRPPa Functionalities** (In Progress)
  - Positioning Information Transfer
    - Positioning Information Request (done)
  - TRP Information Transfer
    - TRP Information Request (done)
  - Measurement Information Transfer
- NRPPa PDU Transfer protocol between AMF/LMF (NAMF) (done)

Status (AMF): NRPPA Support for NG-RAN-assisted UL-TDOA Positioning Method

AMF (Working branch: oai-cn5g-amf branch: feat_downlink_ue_assoc_nrrpa) (DONE)

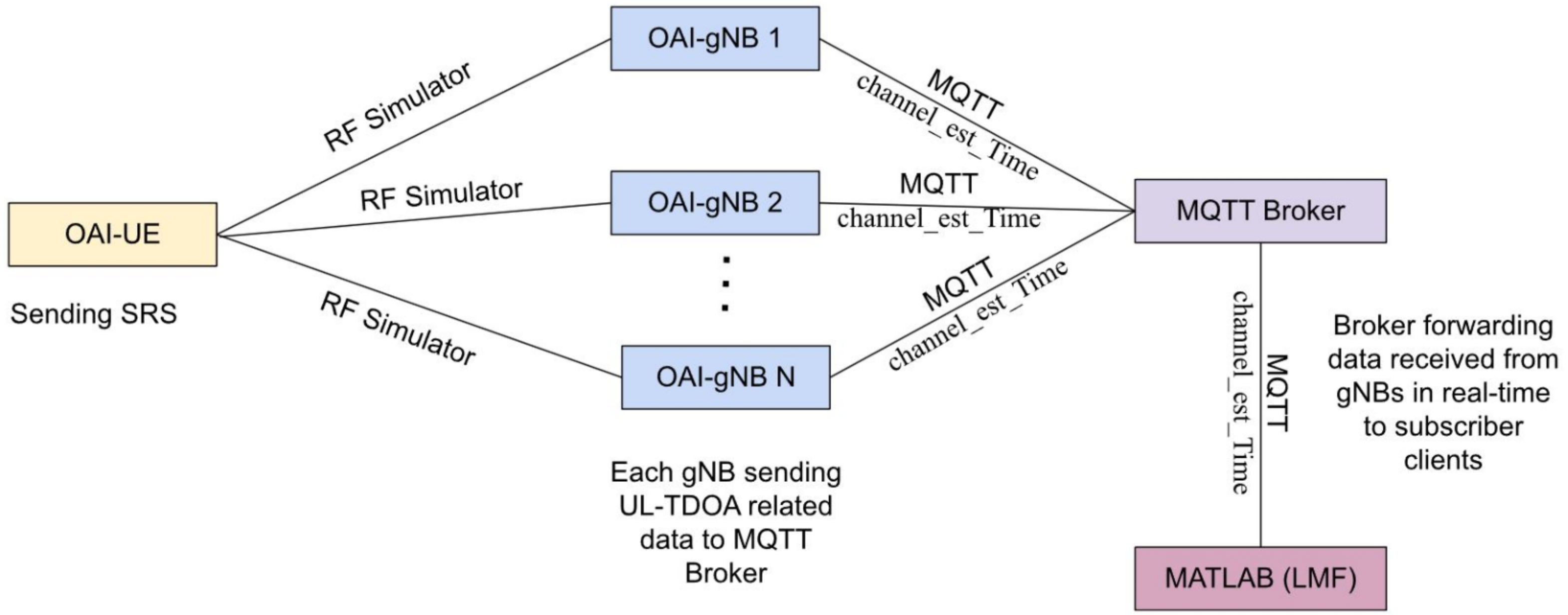
Main Contributors: OAI Team, IITH Team

- **NRPPa PDU Transfer protocol**
  - NRPPa PDU Transfer protocol between AMF/LMF (NAMF) (done)
  - NRPPa PDU Transfer protocol between AMF/gNB (NGAP) (done)

Demos

OAI Rfsimulator-based UL-TDOA Positioning Demo

We developed the first prototype of the system that allows us a quick simulation of a simple positioning using UL TDoA based on SRS.



Network Environment: We use a simulated environment **(rfsimulator)** with a simplified channel model that only models the channel as AWGN with a propagation delay between the UE and the gNBs.

- We configure gNBs in such a way that they can **simultaneously receive the SRS signals** from target UE.
- Simultaneous reception of SRS signals at multiple gNBs is currently supported in **phy-test mode**.

OAI Rfsimulator-based Positioning Demo

Emulating LMF-Related Functionalities: We implement the localization algorithms in **MATLAB** and emulate the functionalities of LMF by interfacing Matlab with all the gNBs directly.

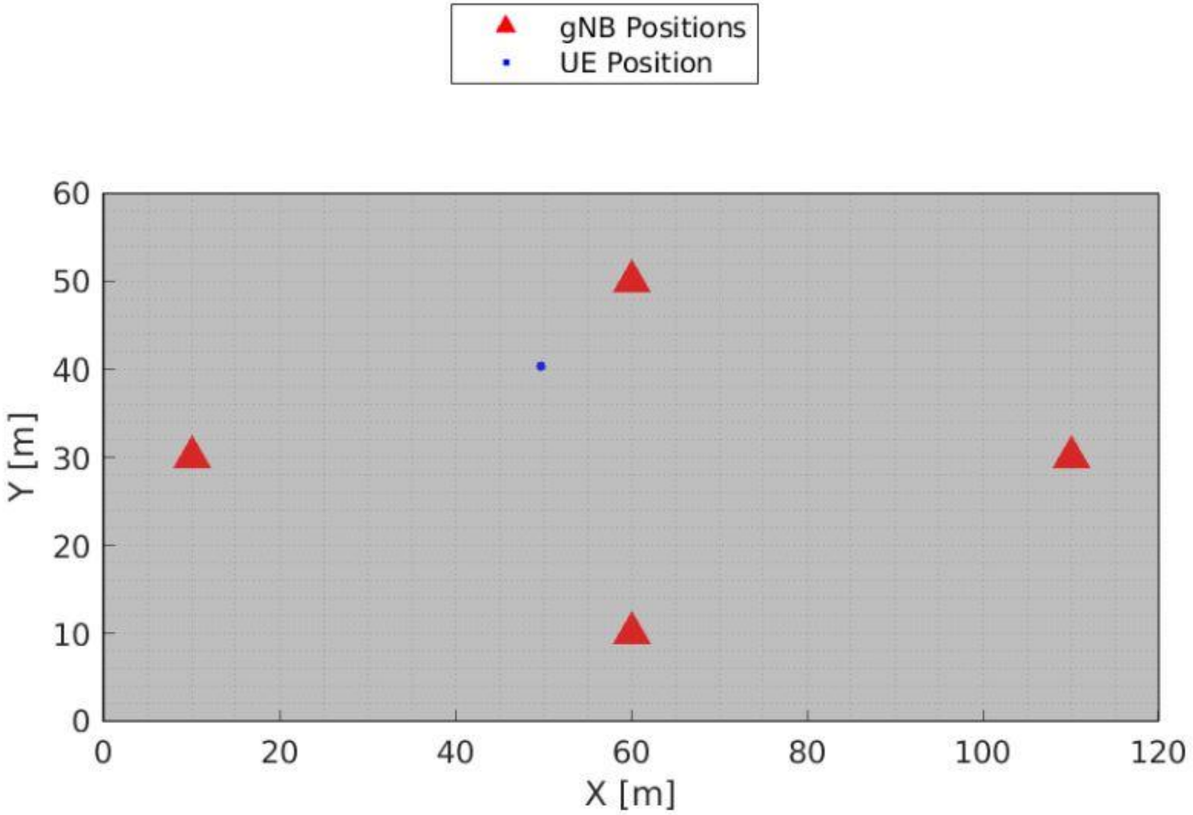
Emulating NRPPa-Related Functionalities: We use the **MQTT framework** as an interface between Matlab (LMF) and gNB and emulate the NRPPa functionalities for real-time processing.

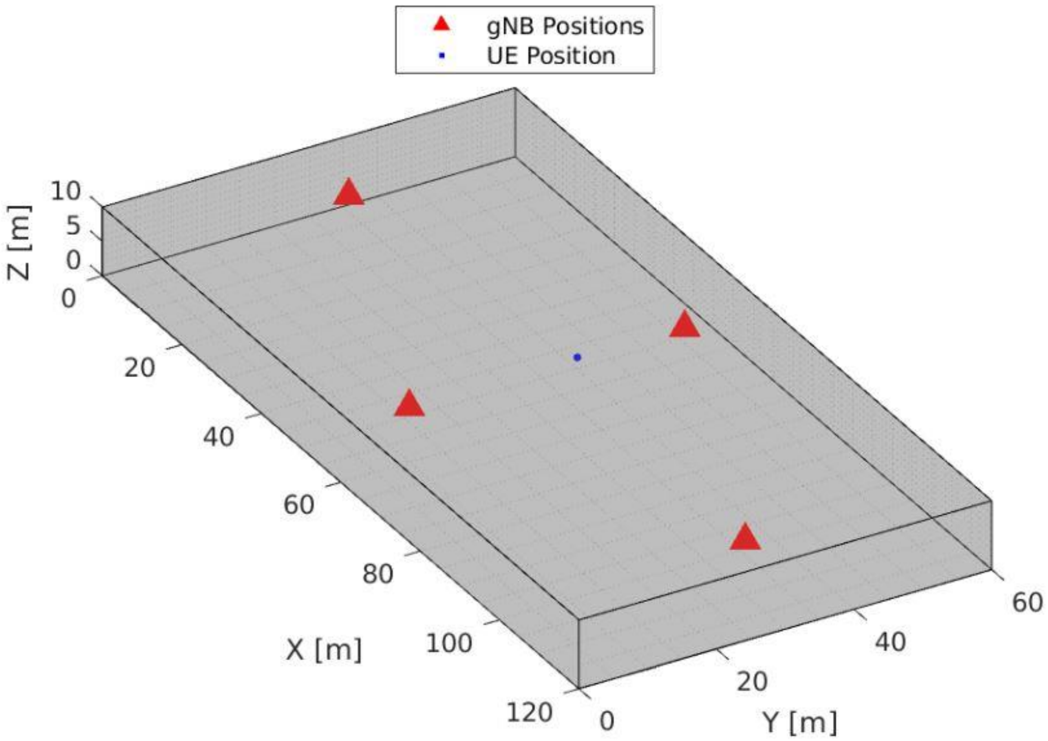
- Using the MQTT framework, each gNB can send its UL-ToA measurements to Matlab (LMF) in real time which can be used to do position calculations.
- The key components of the MQTT framework are the following.
  - Setting up MQTT broker and enabling MQTT functionalities in OAI code
  - Integrating MQTT publisher client at each OAI-gNB
    - Each gNB act as a publisher client and sends a message containing the following five elements, gNB ID, peak index, peak power, time domain channel estimate, and FFT size.
  - Integrating MQTT subscriber client in MATLAB
    - The LMF run as an MQTT subscriber client in MATLAB and subscribed to the message with the topic name “channel_est_Time”.

Emulating Real-Time Mobility: We use the **OAI telnet server facility** to emulate the mobility in our simulated environment.

- The OAI telnet server enables us to change several parameters of the channel model on the run.
- To emulate mobility, our setup supports a predefined range of delays (or ue positions) that can be added on the run using a telnet server

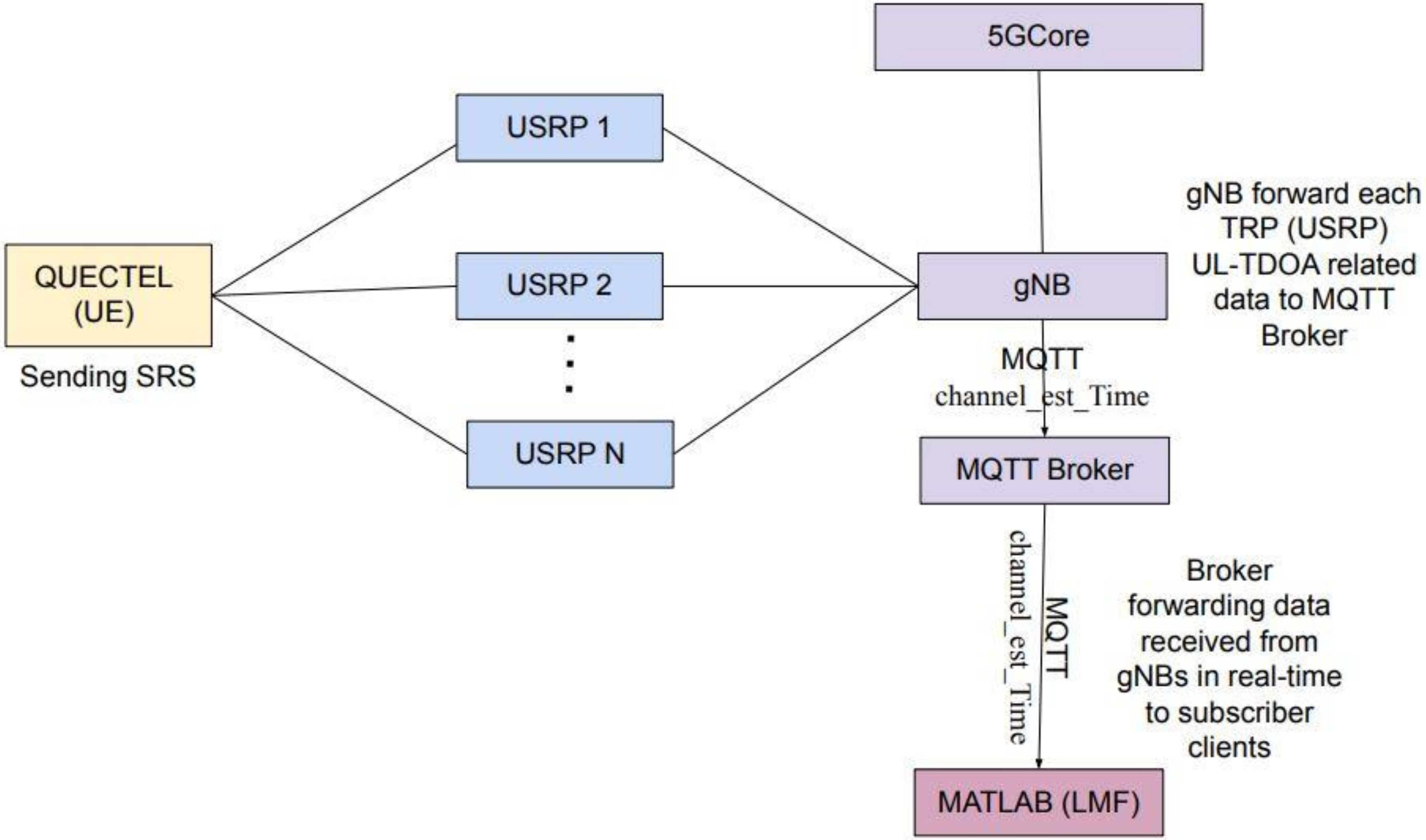
OAI Rfsimulator-based Positioning Demo





[Demo video]

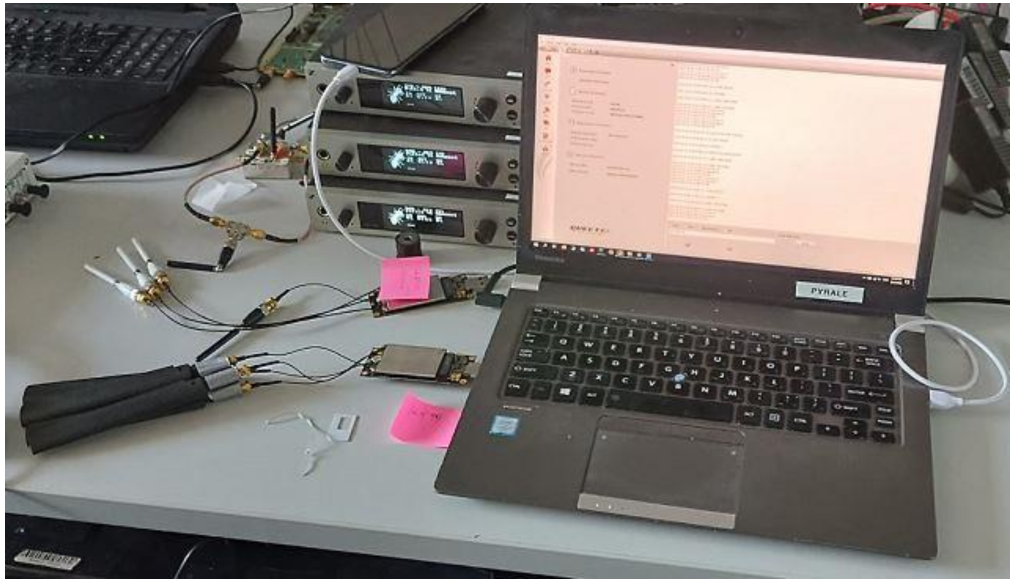
Multi-USRP based UL-TDOA Positioning Demo

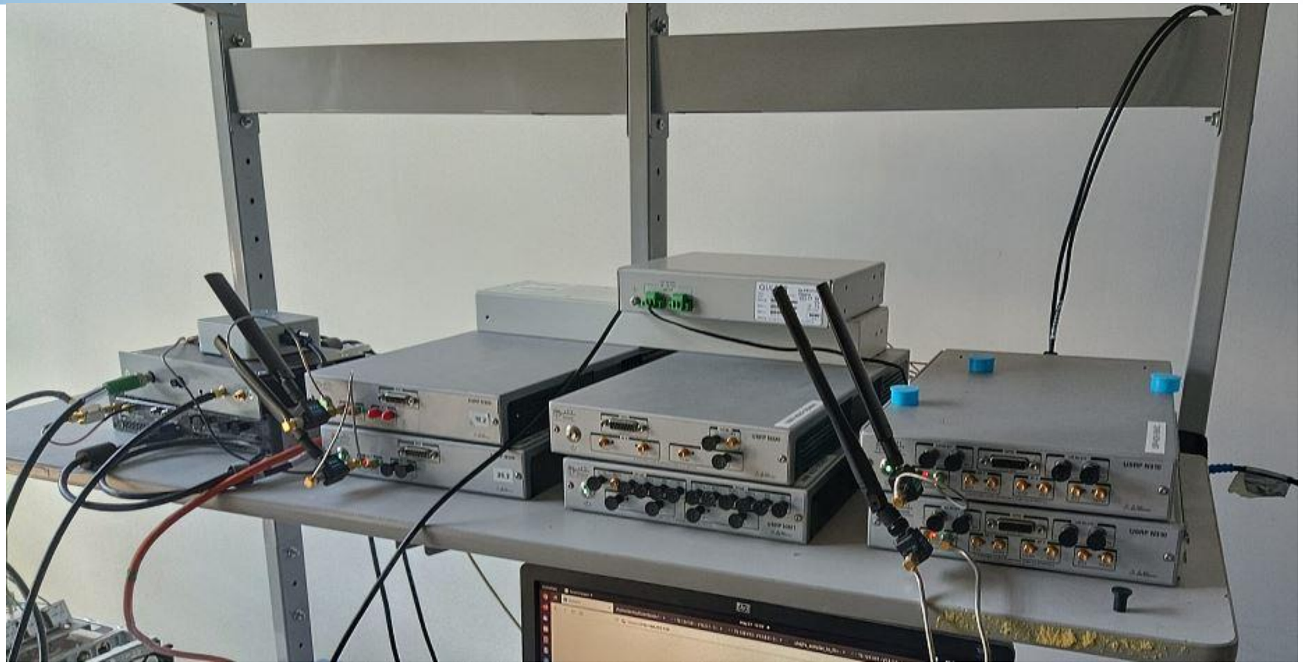


Multi-USRP based UL-TDOA Positioning

- Single gNB with a distributed antenna system based on USRPs
  - Easier than synchronizing multiple gNBs
- Some USRP devices (X3x0, N3x0, X4x0) are capable of being grouped to form a single, virtual device.
  - Changes in RU configuration
    - sdr_addrs = "addr0=192.168.10.2,addr1=192.168.20.2,addr2=192.168.30.2,addr3=192.168.40.2,clock_source=external,time_source=external";
    - tx_subdev = "A:0"
    - rx_subdev = "A:0“
  - Synchronization achieved with octoclock (pps & 10MHz referene)
    - GPSDO is also possible

Multi-USRP based UL-TDOA Positioning

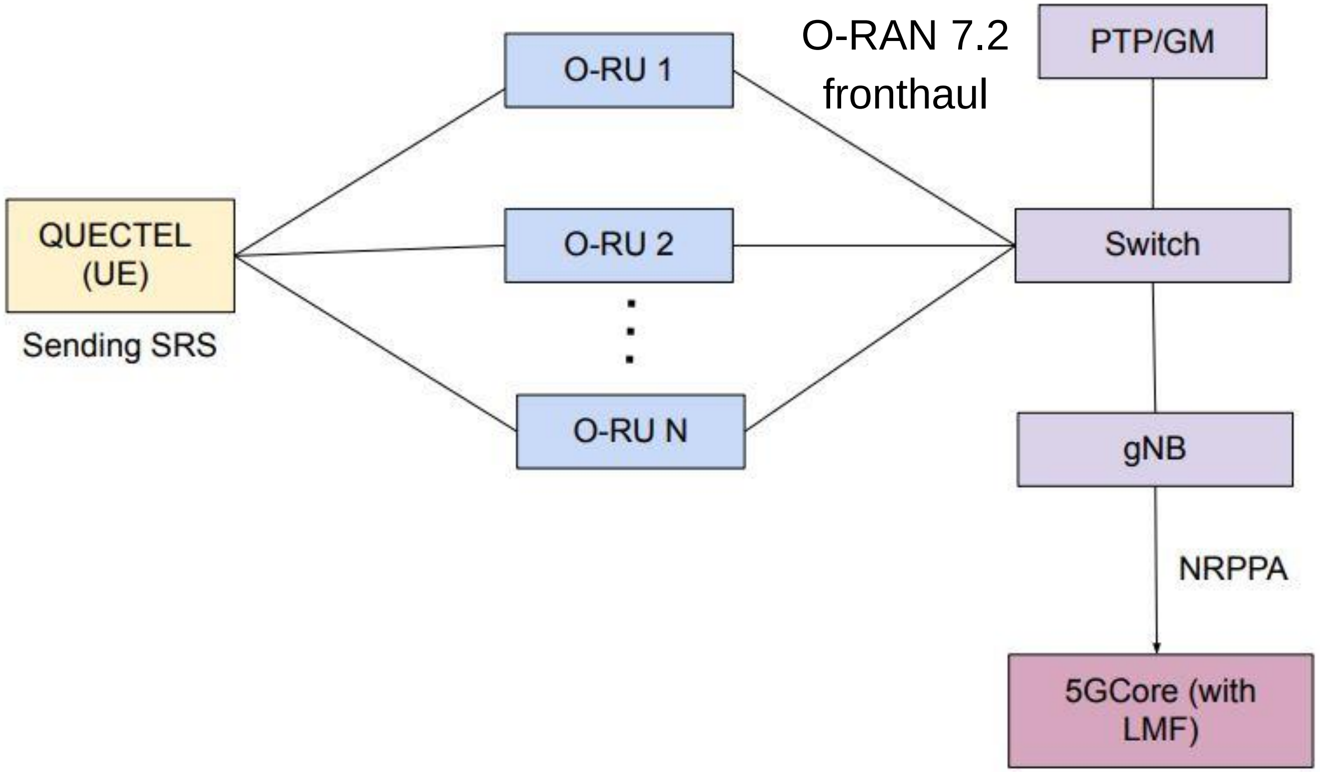




Demo Video

Extension and Future Plan

- Use O-RAN 7.2 fronthaul
  - Provides sync through S-plane
- Integrate and test the Functionalities of NRRPa at gNB and LMF
- Integrate basic localization algorithms in LMF
- Deploy and test in a relevant environment (factory hall)



O-RU based Positioning with LMF/NRPPa integrated OAI 5GCore

Some food for thoughts/discussions

From O-RAN WG1 Use Case Specification:

3.13 Use case 13: Local Indoor Positioning in RAN

This use case provides the background and motivation for the O-RAN architecture to support local indoor positioning.

3.13.1 Background and goal of the use case

Real-time indoor positioning based on cellular network has aroused attention with the development of 5G vertical industries, individuals and operators. NR positioning is introduced by 3GPP Rel.16. The location management function (LMF) resides in core network request the NG-RAN node to report positioning measurements, which is used by LMF to compute the location of UE. The messages between LMF and the NG-RAN need the AMF to route transparently. However, this long route messages between the NG-RAN node and centralized LMF may suffer network jitters and leads to un-real-time UE location results.

The main objective is to ensure local positioning be supported within the O-RAN architecture and its open interfaces. In the context of O-RAN architecture, the positioning function can be deployed as a positioning xApp in the Near-RT RIC. The positioning xApp computes the UE location and optional velocity based on the positioning measurement obtained via the E2 interface. The local indoor positioning results can be acquired via positioning xApp to support positioning applications (e.g., indoor navigation, electric security fence, etc.).

Some food for thoughts/discussions

- It would be relatively straightforward to adapt OAI code to deliver positioning based measurements via E2.
- Can we exploit this information in an xAPP?
- Can we use this data to in non-real-time RIC for training of AI/ML models?
- What kind of use cases would this be beneficial for?
- What is the advantage over classical 3GPP architecture?
- Can we do some localization experiments on Colloseum?

Conclusions

- Industry is moving towards open and virtualized RAN
- Many trials and small scale deployments are ongoing
- But we have yet to exploit the full potential of open RAN
- Many use cases can benefit from RIC xAPPs leveraging AI/ML optimization
  - Maybe even for or using localization information
- Hardware acceleration is a necessity for virtualized open RAN networks
- Open source projects can accelerate innovation
- Localization and positioning are important use cases for industrial 5G networks
  - Still challenging to achieve high accuracy

Thank you!

https://www.openairinterface.org

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OpenAirInterface Projects Roadmap

- Focus on scalability
  - Throughput improvements (> 1Gbps DL, 300Mb UL)
  - Support for large number of users (>64)
- Focus on mobility
  - Deployment of multiple DUs (multi-cell) and RUs (cell-free MIMO)
  - Handover (F1 and Xn)
- Indoor localization for industrial 5G networks (GEO-5G project)
- Time-sensitive networking (STIC-5G project)
- Non-terrestrial networks (ESA LEO project)
- Integrated access and backhaul

Quarter 1 2023

- O-RAN 7.2 Fronthaul Support
- E1AP and CU-UP Separation
- UL MIMO Support 2x2
- nFAPI Interoperability Testing with NVIDIA Aerial

Quarter 2 2023

- DL MIMO: 4 Layers
- F1 Handover
- NRPP Support in gNB
- F1 Extended Interoperability Testing
- Handling Multiple DUs per CU
- FR2 Basic NSA Interoperability
- Support for Non-terrestrial Networks (Rel.17)
- OAI UE Initial Access Procedures with 3rd Party gNB
- QoS Aware Scheduler

Quarter 3 2023

- 2-step RACH (Rel.16)
- FR2 SA
- System Measurements (Intrafrequency)
- Integrated Access and Backhaul
- Multi UE Bandwith Part Handling
- OAI UE Interoperability with 3rd Party gNB
- FR2 NSA Interoperability: Beamforming Procedures
- Support for short-data Transmission (Rel.17)

Quarter 4 2023

- E1AP Interoperability
- FR2 OAI UE
- Xn Handover Procedures
- Handling of Multiple RUs per DU (cell-free MIMO)
- Handling Multiple Carriers in L2 (with L1 Accelerator)

Productization of OpenAirInterface

- OAI is used in other open-source projects
- More and more startups are building products based on OpenAirInterface
- Several projects dedicated to open RAN and code improvements