Driving 6G Innovation with OpenAirInterface

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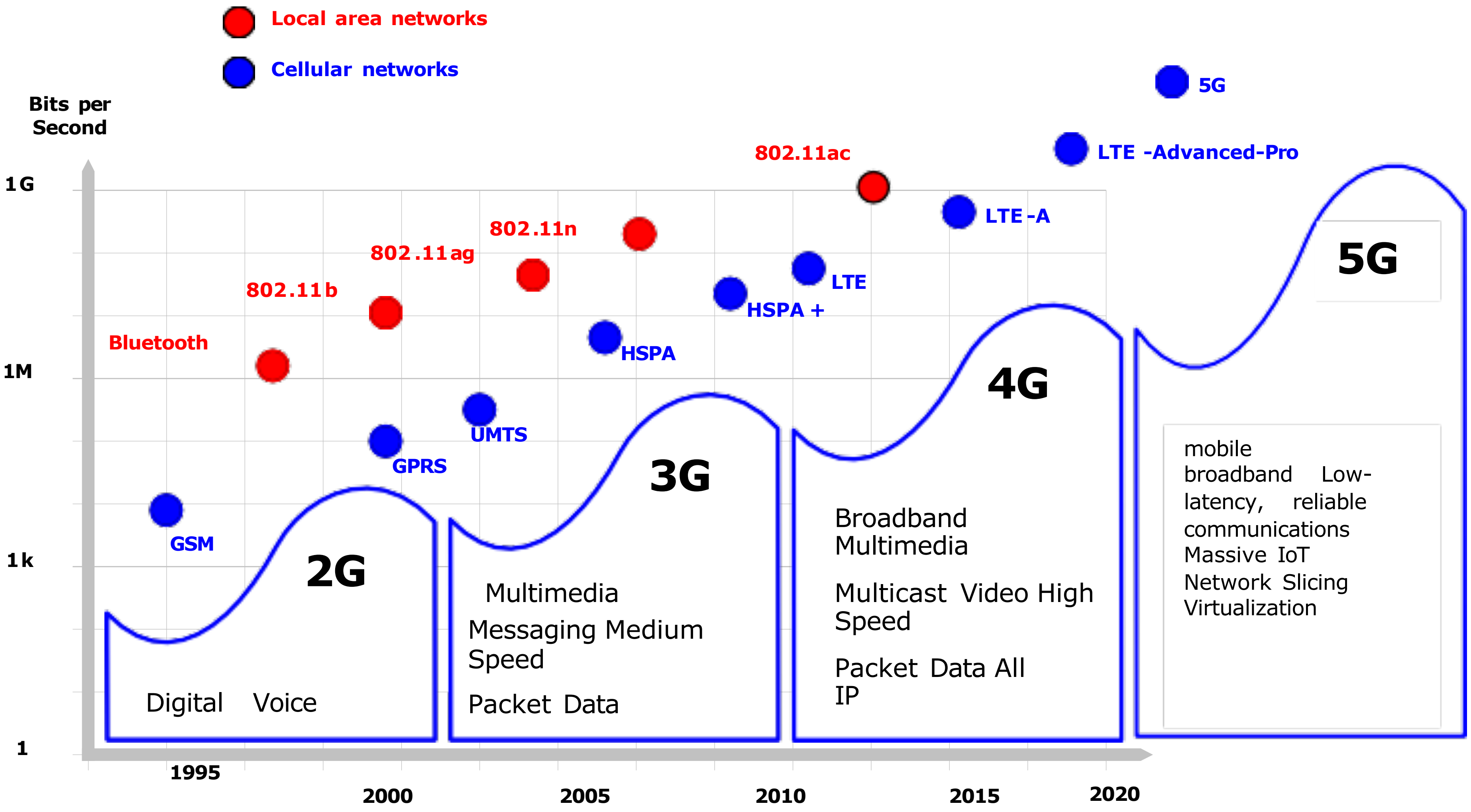
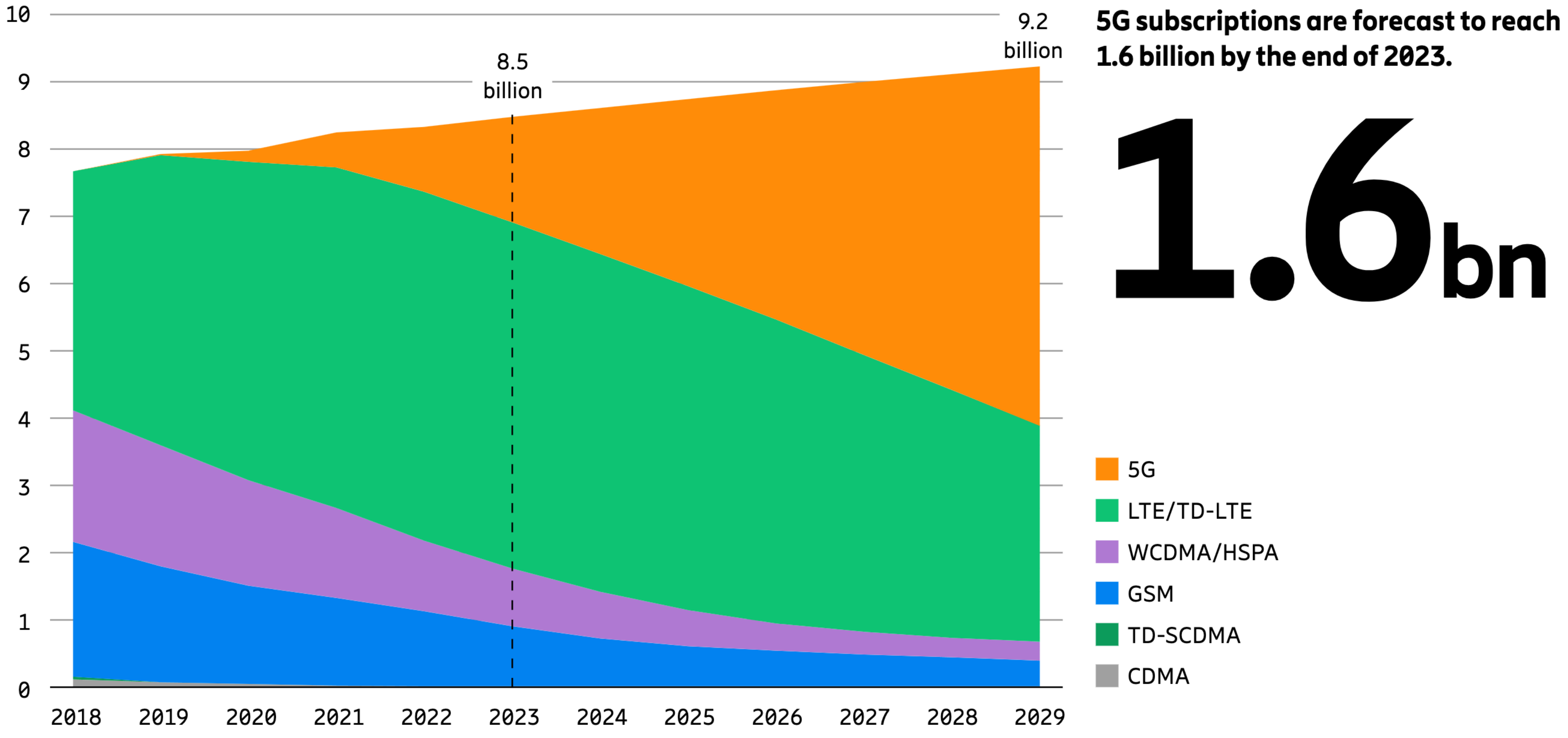
Evolution of Wireless Standards

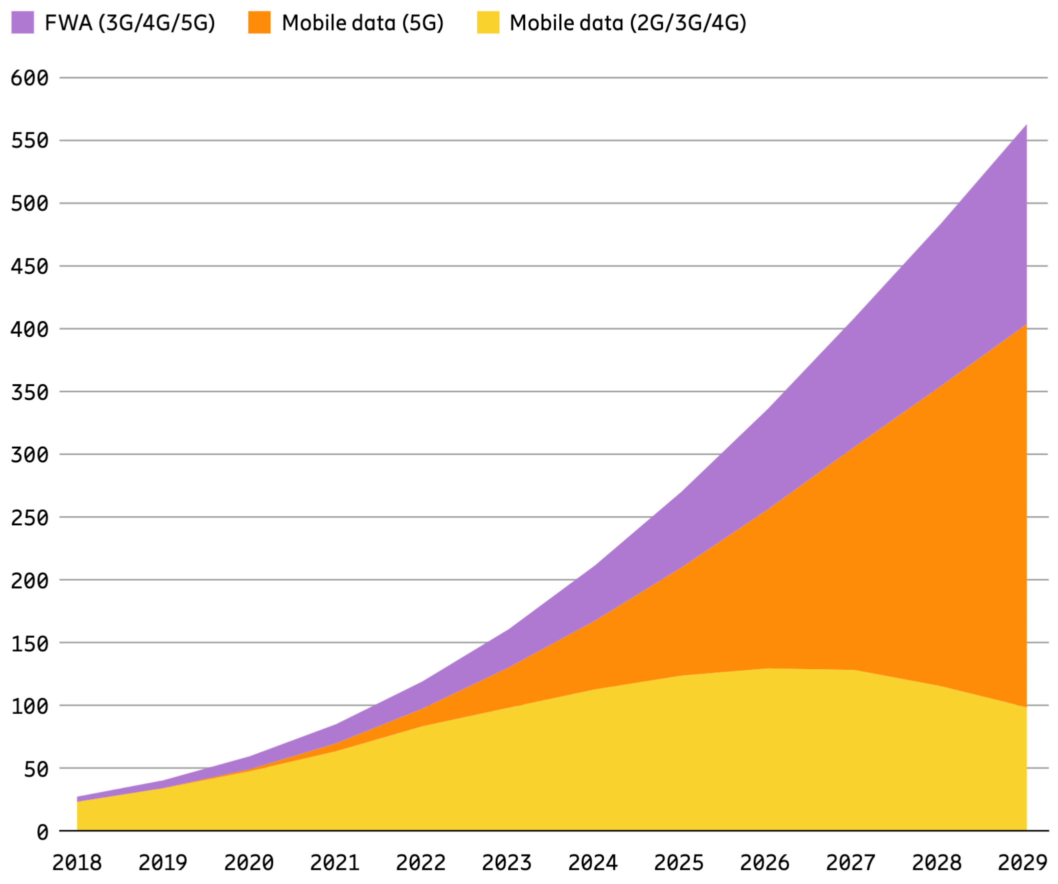


5G Market Share



Source: “ericsson-mobility-report-november-2023.pdf”

Traffic demand is still growing

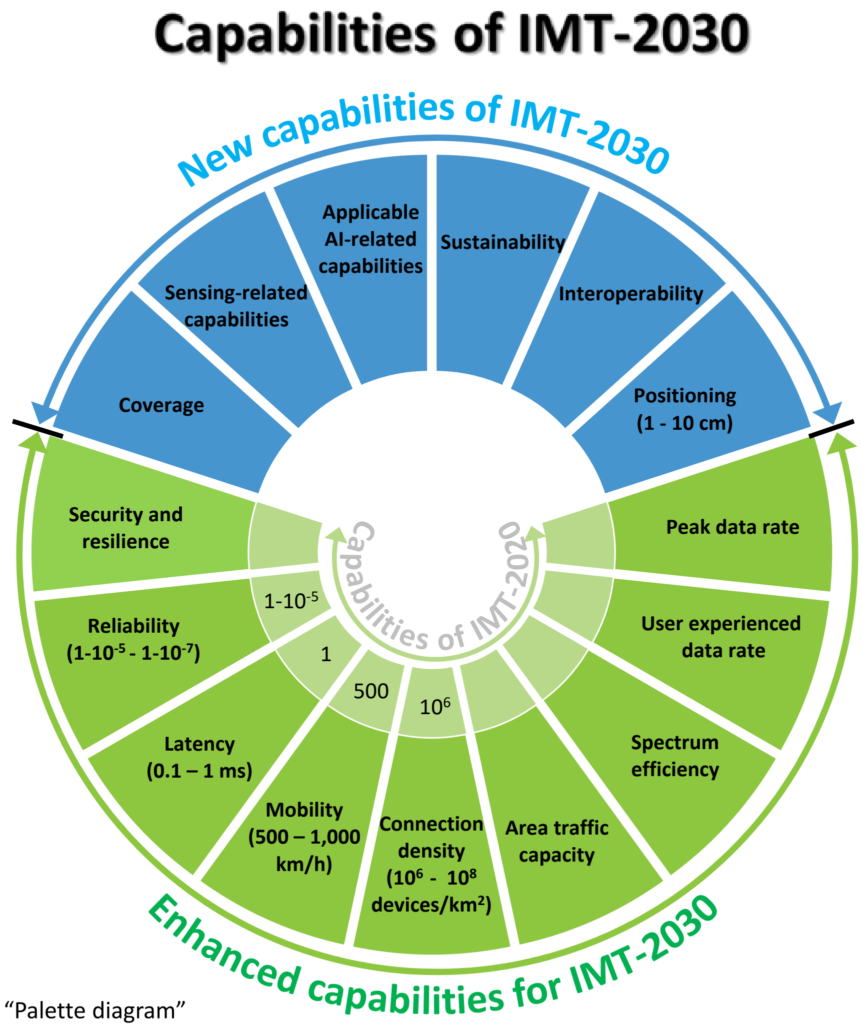


Globally, average monthly mobile data usage per smartphone is expected to reach 56 GB, rising from 21 GB at the end of 2023.

56GB

Source: “ericsson-mobility-report-november-2023.pdf”

6G requirements



So called “Palette diagram”

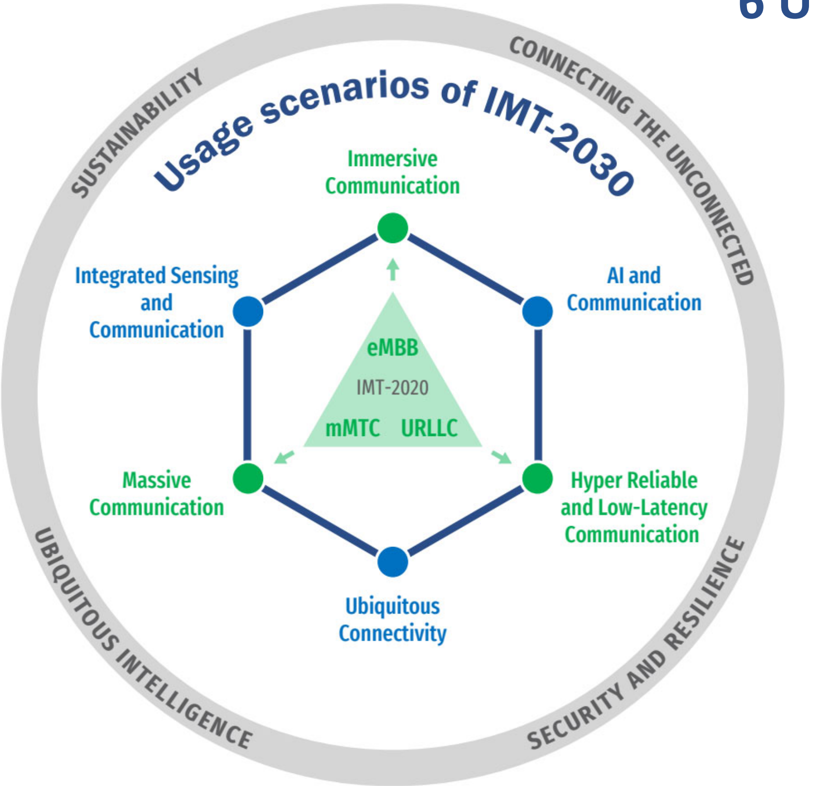
The range of values given for capabilities are estimated targets for research and investigation of IMT-2030.

All values in the range have equal priority in research and investigation.

For each usage scenario, a single or multiple values within the range would be developed in future in other ITU-R Recommendations/Reports.

6G Usage scenarios

Usage scenarios



So called "Wheel diagram"
Source: Document 5/131 and edited in SG 5

6 Usage scenarios

Extension from IMT-2020 (5G)

eMBB ➡ Immersive Communication

mMTC ➡ Massive Communication

URLLC ➡ HRLLC (Hyper Reliable & Low-Latency Communication)

New

Ubiquitous Connectivity

AI and Communication

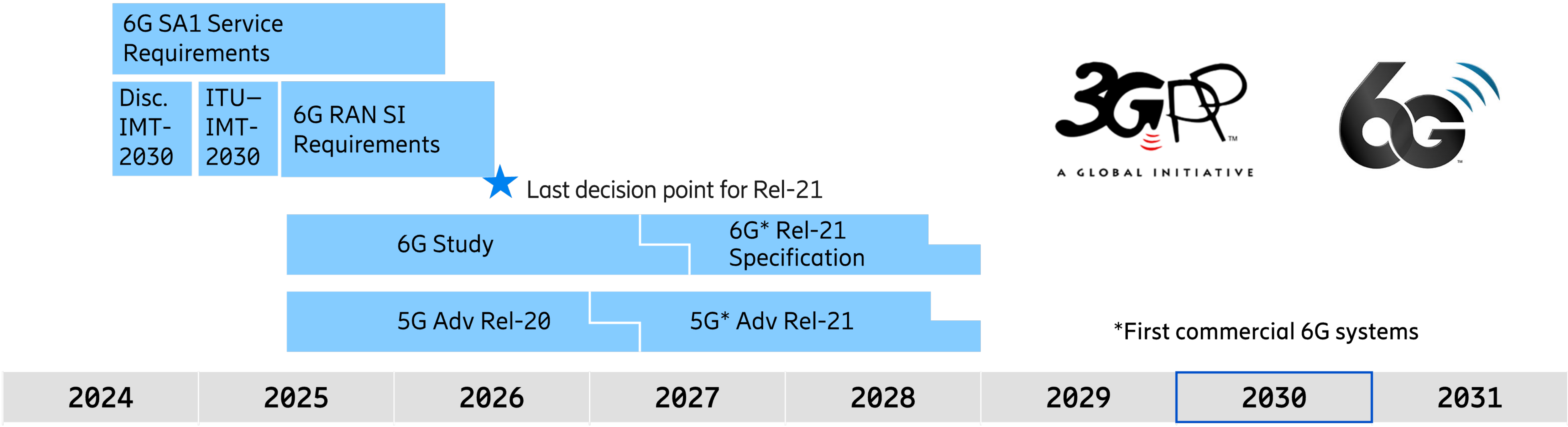
Integrated Sensing and Communication

4 Overarching aspects:

act as design principles commonly applicable to all usage scenarios

Sustainability, Connecting the unconnected,
Ubiquitous intelligence, Security/resilience

6G roadmap



* Indicative timeline Ericsson view

Principles for 6G design

- Key verticals
  - low-power wide area (LPWA) IoT,
  - fixed wireless access (FWA),
  - non-terrestrial networks (NTN),
  - dependable and time-critical communication
- Spectrum
  - 6G should support operation in a wide range of spectrum allocations including FR1, FR2, and the cm-wave range.
  - Highly efficient multi-RAT spectrum sharing (MRSS) between 5G and 6G is essential
- Evolution
  - 6G RAN should connect to an evolution of the 5G core network.
  - 6G should support stand-alone operation only
  - 6G should include open interfaces

The road to 6G…

- … is paved with good intentions
- There are many candidate technologies that could become building blocks of 6G
- Most of them have been researched in a contained environment (simulations, simplifications)
- Need to test these algorithms on real systems and at scale
- Today there are many open source tools to build such systems
- Today we are going to focus on OpenAirInterface

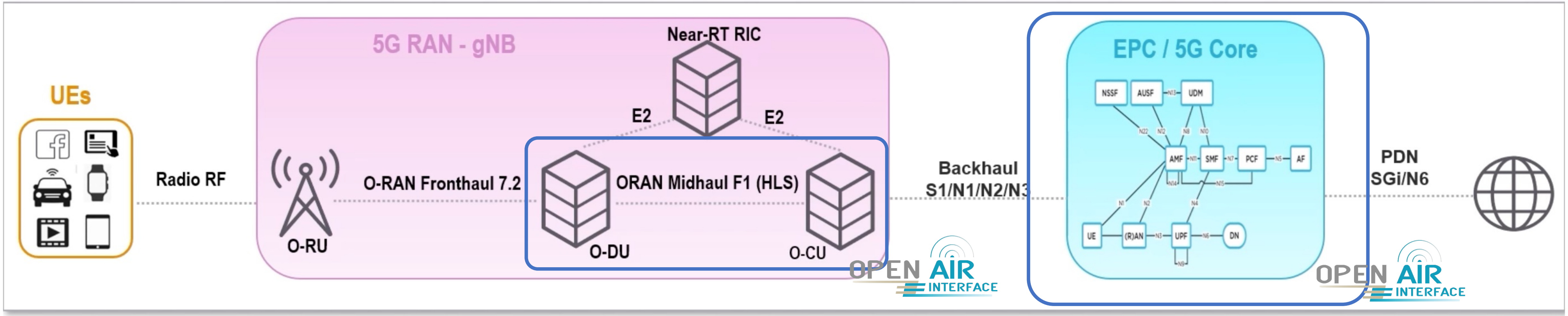
Agenda

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

What is OpenAirInterface?

- OpenAirInterface (OAI) is the most complete, open-source implementation of 3GPP 4G/5G RAN and EPC/5GC
- The OAI public license is based on Apache 2.0 but allows patent owners to contribute and keep their patents under 3GPP FRAND rules
- Community driven development supported by the OpenAirInterface Software Alliance and its strategic members

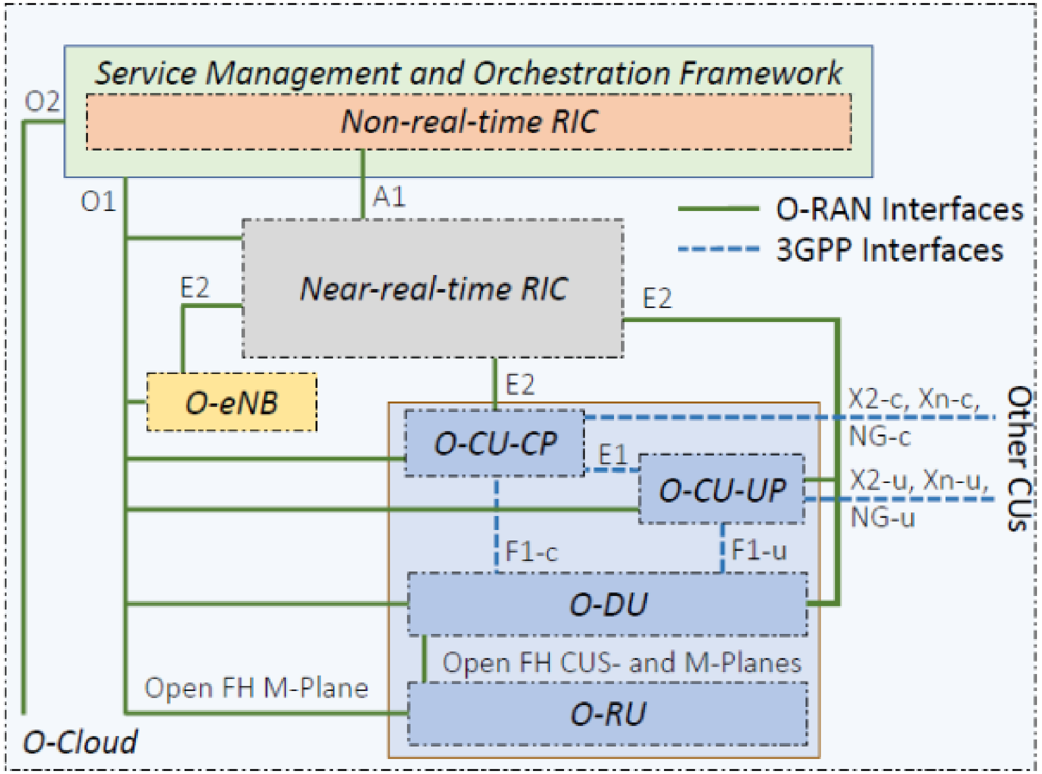
5G Network Architecture



- OpenAirInterface provides virtual network functions (software) for DU, CU, and most core network functions (AMF, SMF, UPF, etc).
- Runs on x86 hardware, with optional hardware accelerators.
- L2 and above also runs on ARM

Open RAN is transforming mobile networks

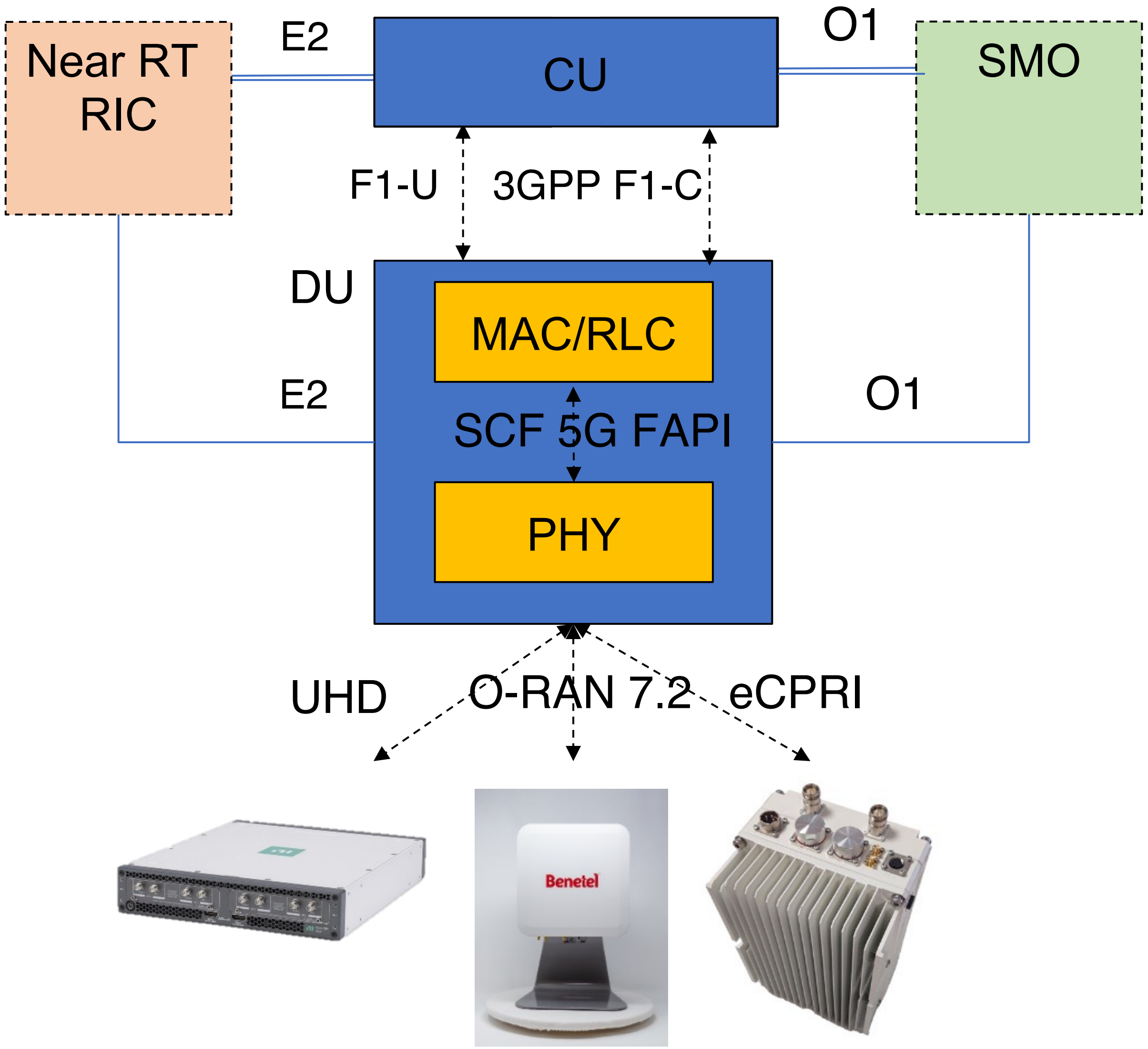
- O-RAN Alliance specifics open interfaces for
  - Fronthaul
  - RAN Intelligent Controller
  - Service Management and Orchestration
  - O-Cloud infrastructure
- Allows for
  - Virtualized & disaggregated deployments
  - AI/ML optimization of networks
  - Multi-vendor deployments



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)

Features

- 5G standalone (SA) and non-standalone (NSA)
- Duplexing: Static TDD, FDD
- Subcarrier spacings: 15 and 30kHz (FR1), 120kHz (FR2)
- Bandwidths: 10, 20, 40, 60, 80, 100MHz
- MIMO: 2-layer DL (4 under test) and 2-layer UL
- Highly efficient 3GPP compliant channel encoder and decoder (turbo, LDPC, polar)
- Support for UL transform precoding (SC-FDMA)
- O-RAN
  - 7.2 through OSC FHI library
  - E2 agent with KPM v2.03/v3.0 and RC v1.03
  - O1 interface with ONAP
- Full list of features: https://gitlab.eurecom.fr/oai/openairinterface5g/-/blob/develop/doc/FEATURE_SET.md

OAI gNB performance

gNB – **Max Downlink Throughput**, Band n41, TDD: DDDFU

DL		Bandwidth (MHz)/Number of PRBs @ 30kHz												
(Mbps)		5/11	10/24	15/38	20/51	25/65	30/78	40/106	50/133	60/162	70/189	80/217	90/245	100/273
Layers	1				**72**			**152**		**233**		**310**		**400**
	2				**143**			**304**		**466**		**622**		**800**
	4													

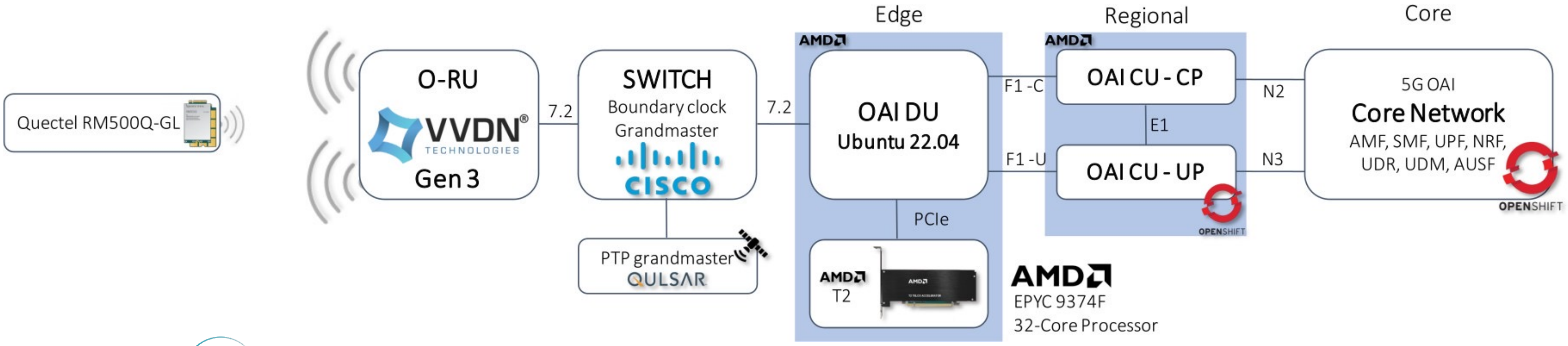
gNB – **Max Uplink Throughput**, Band n41, TDD: DDFUU

UL		Bandwidth (MHz)/Number of PRBs @ 30kHz												
(Mbps)		5/11	10/24	15/38	20/51	25/65	30/78	40/106	50/133	60/162	70/189	80/217	90/245	100/273
Layers	1				**39**			**81**		**123**		**80**		**101**
	2				**65**			**154**		**175**		**140**		**120**
	4													

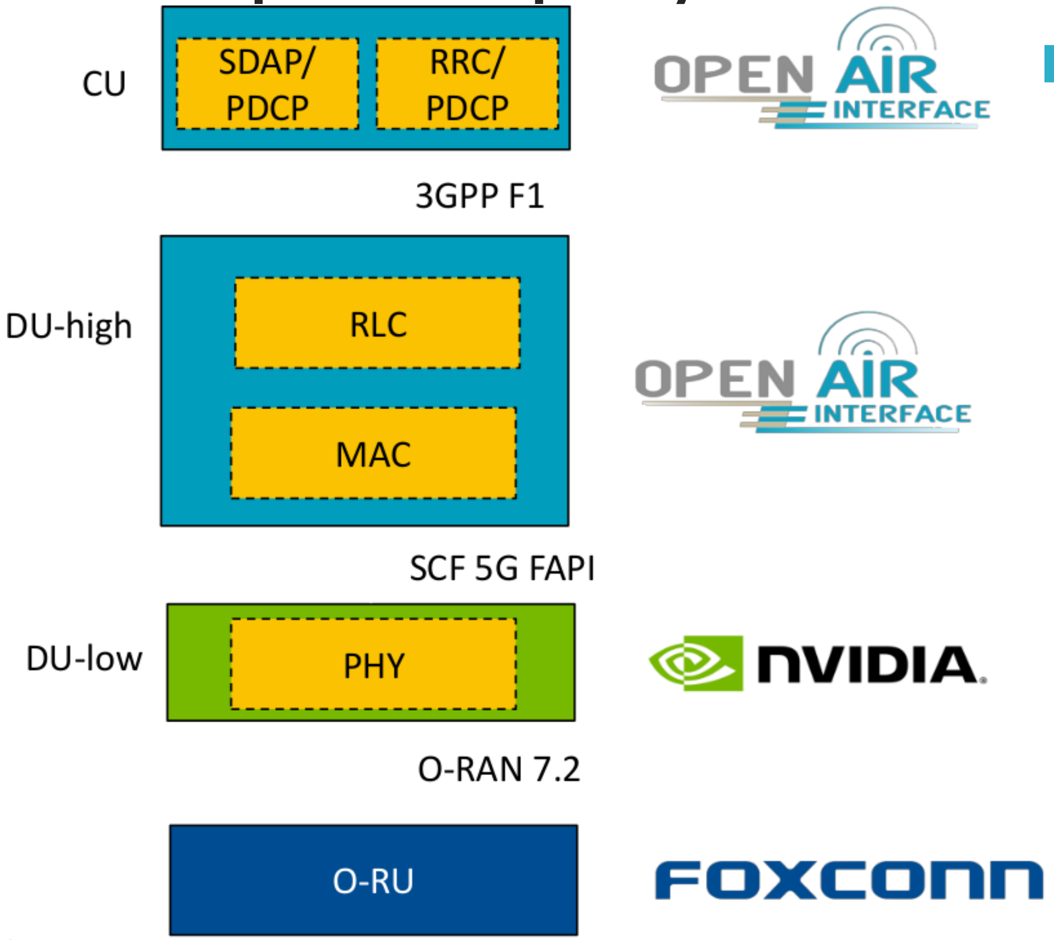
(Measurements in AllBeSmart lab, gNB/N310+`--tune-offset`, UE/Quectel RM500Q-GL)

Sample Deployment: O-RAN 7.2 Fronthaul with T2-Telco Card

- OAI 5GC and CU-CP/UP deployed in OpenShift Cluster
- 3GPP F1 and E1 midhaul splits between OAI CU-CP/CU-UP/DU
- O-RAN 7.2 fronthaul split using OSC fronthaul interface library (FHI, E release)
- Optionally: AMD T2 Lookaside Accelerator card
- Integration with O-RUs, 100MHz BW: Benetel, LITEON, VVDN; 500 Mbps throughput in DL



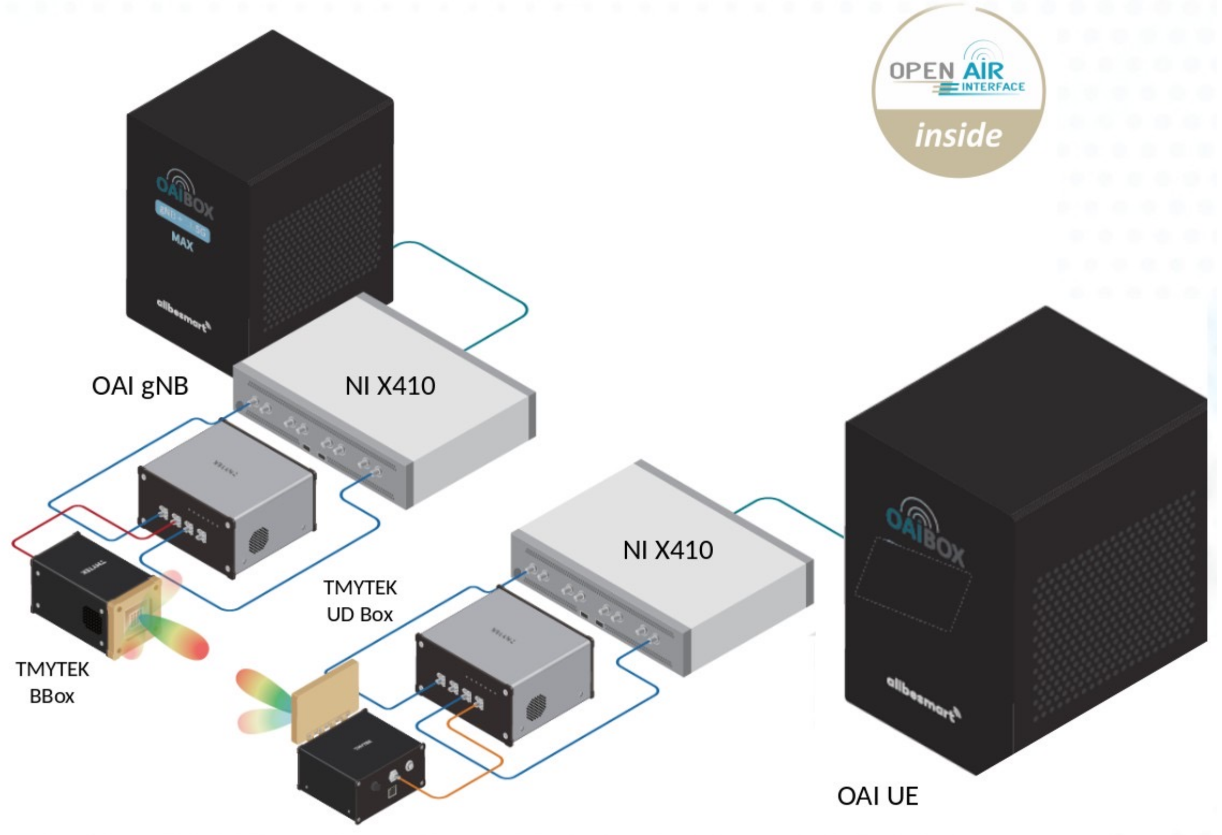
Sample Deployment: Nvidia Aerial ARC Setup



- Nvidia Aerial: GPU used as inline L1 accelerator
- L2/L3 from OpenAirInterface, Interface via SCF 5G FAPI
- DU Layer 1 southbound interface: O-RAN 7.2, Foxconn O-RU
- DU can be combined with CU in a single executable/container
- 300Mbps Downlink and 30Mbps Uplink

Status on FR2 SA with OAI UE

- FR2 Connection establishment with OAI UE
- Using USRP x400 and TMYTEK BBox
- Operating at 28GHz, 100MHz and 200MHz bandwidth
- Note: FR2 with COTS UE demo at MWC 2024, 200Mbps DL/40 UL
- Roadmap: UE: further performance improvements
- Roadmap: beam tracking



Positioning and Localization

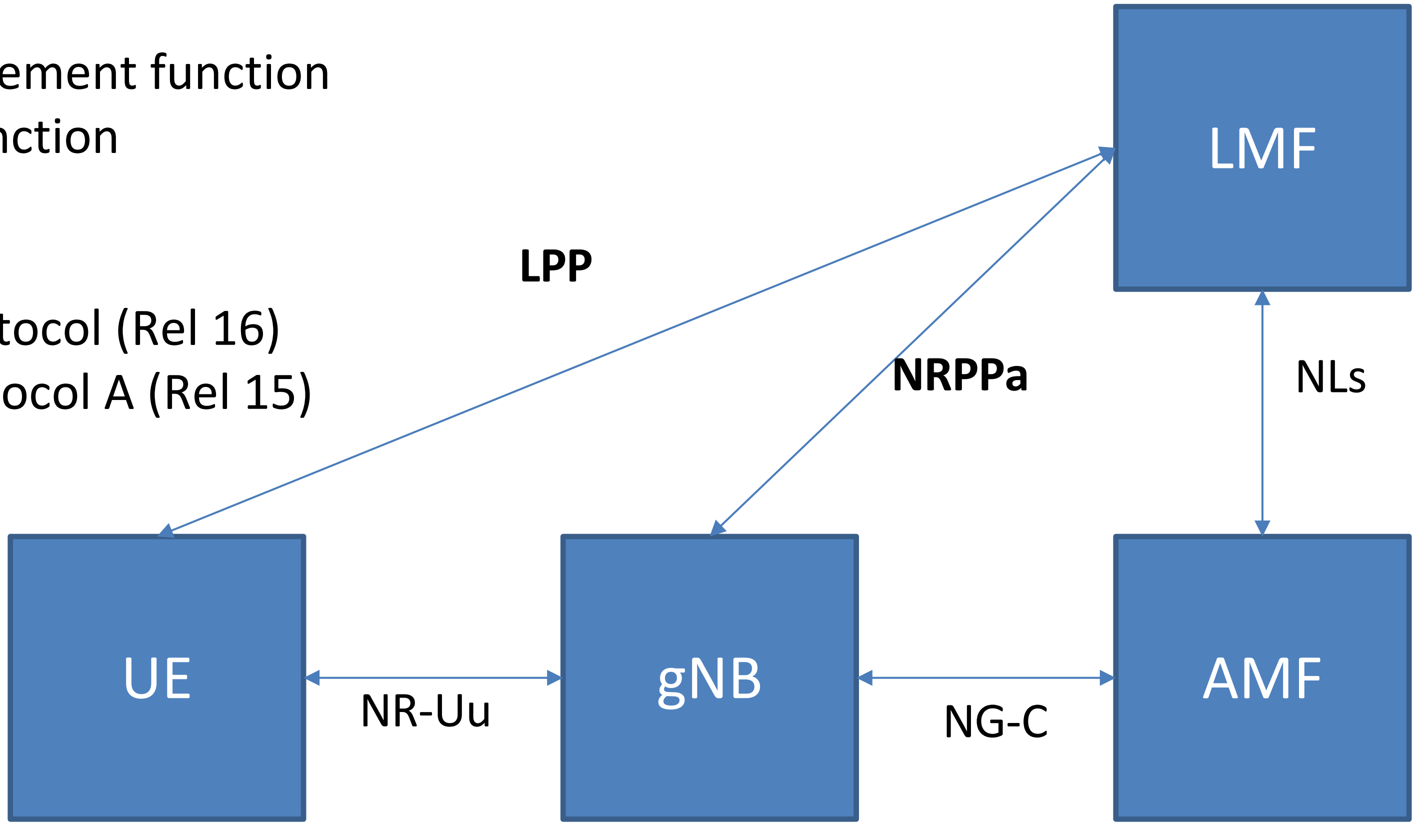
With help from Adeel Malik, Mohsen Ahadi, Rakesh Mundlamuri

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 communication performance, e.g.,
  - 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

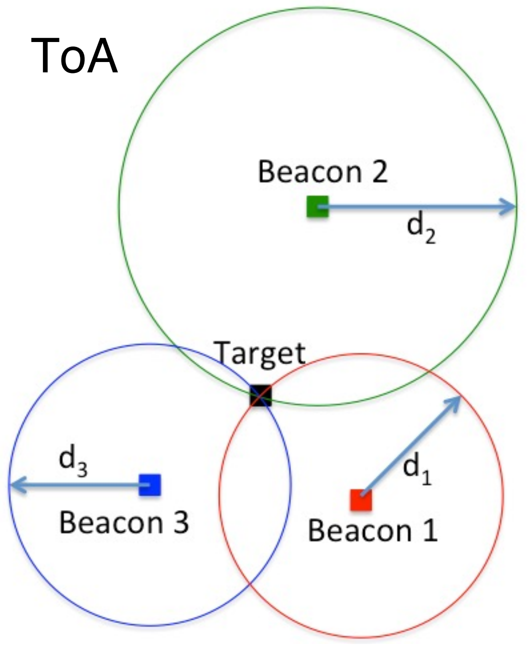
- Network based and UE based localization
- Hybrid positioning using GNSS, Bluetooh, Wifi, other sensors
- Positioning methods that rely only on 5G NR signals (and signaling)
  - Rel 15: Enhanced cell ID, UL-TDoA, UL-AoA
  - Rel 16: DL-TDoA, DL-AoD, Multi-RTT (Round-trip-time)
- mm-wave spectrum attractive 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

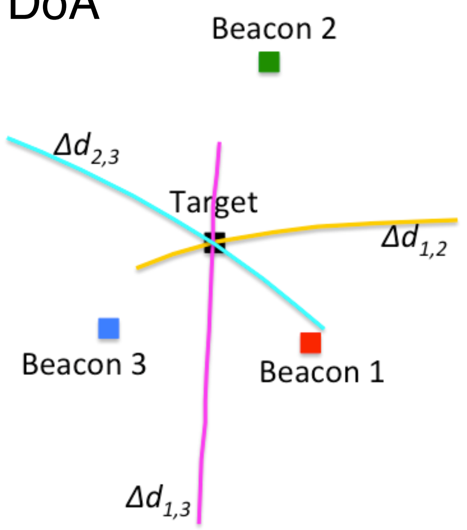
Basics of Localization

- Input: position of beacons (antennas)
- Absolute Time of Arrival (ToA)
  - Target on intersection of circles
- Time difference of arrival (TDoA)
  - Target on intersection of hyperbolas
- Angle of Arrival/Departure (AoA/AoD)
  - Target in intersection of lines
- Overdetermined system of equations with errors can be solved by
  - [Linear | Weighted | Non-linear] least squares
  - Kalman Filters
  - Particle Swarm Optimization
- Accuracy depends on availability of Line-of-Sight (LoS)
  - Non-LOS measurements can be identified (and discarded)

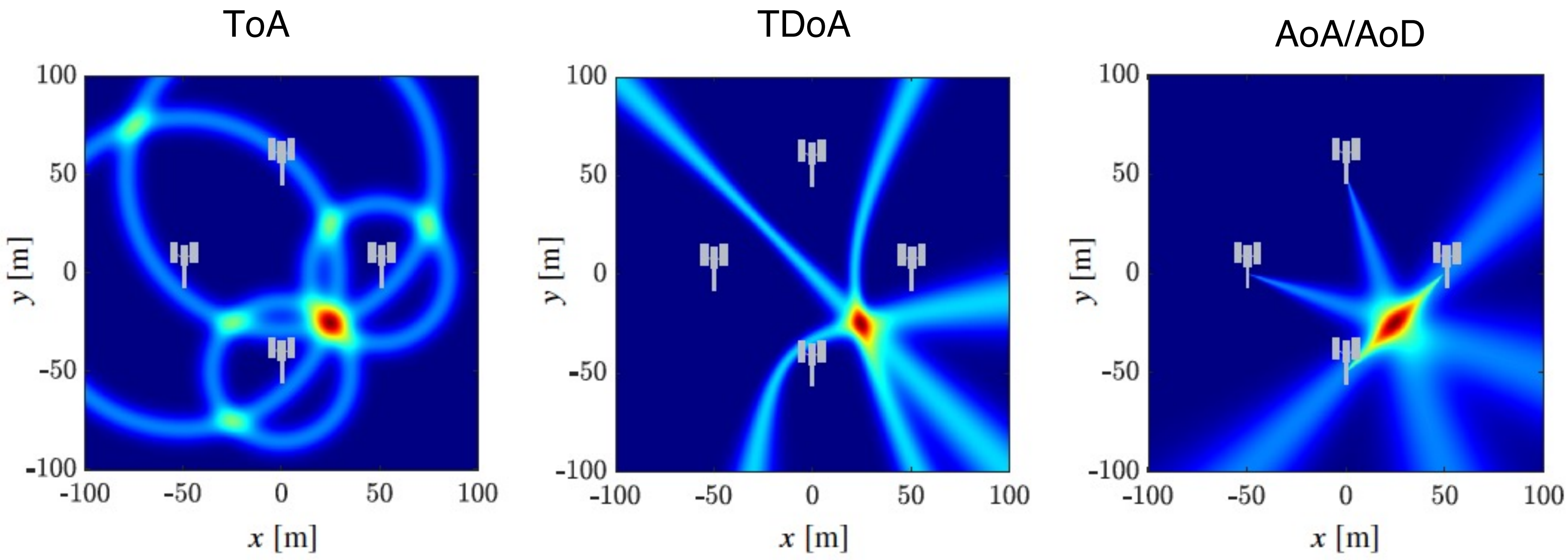
ToA



TDoA



Basics of Localization



Source: Italiano, Lorenzo, et al. "A tutorial on 5G positioning." *arXiv preprint arXiv:2311.10551* (2023).

Some notes on synchronization

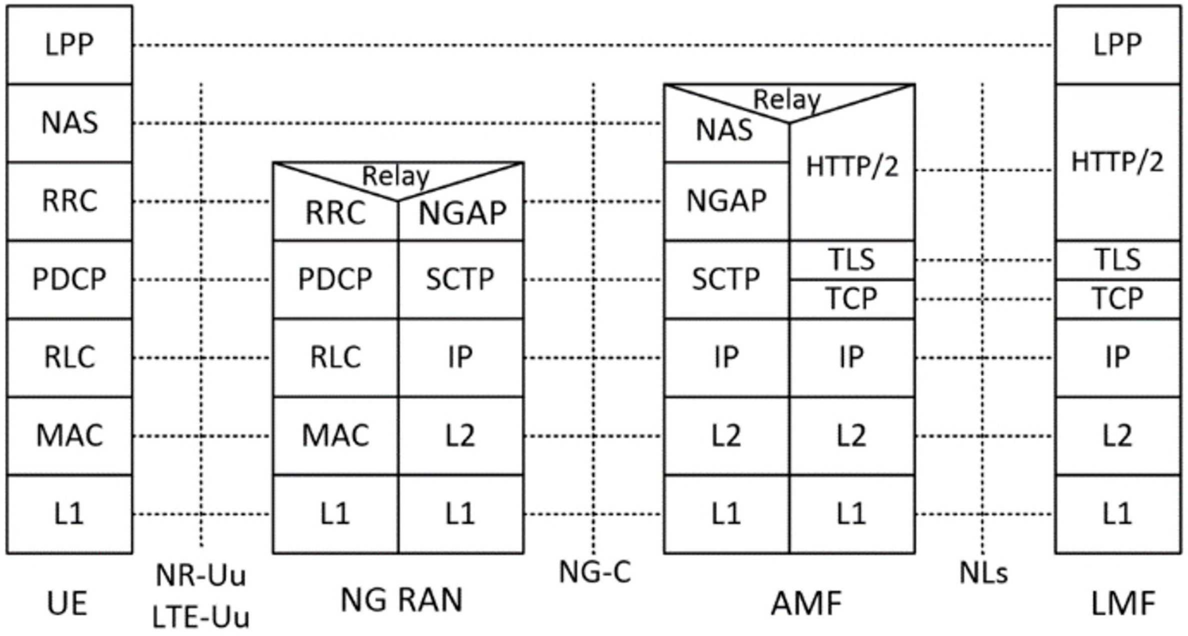
- Exact ToA can only be obtained in perfectly synchronized network (gNBs and UEs)
- TDoA only requires gNBs to be synchronized
  - Can be achieved with GPS (outdoor) or PTP+SyncE (indoor, O-RAN)
  - But residual sync error remains
- Sync Errors can be reduced using multi round-trip-time (multi-RTT) method at the expense of added signaling (Release 16)
- Colosseum radios (USRPs) are fully synchronized using octoclocks providing
  - Pulse-per-second (pps) for time sync
  - 10MHz sine wave for frequency sync
- New: OpenAirInterface can make use of this sync

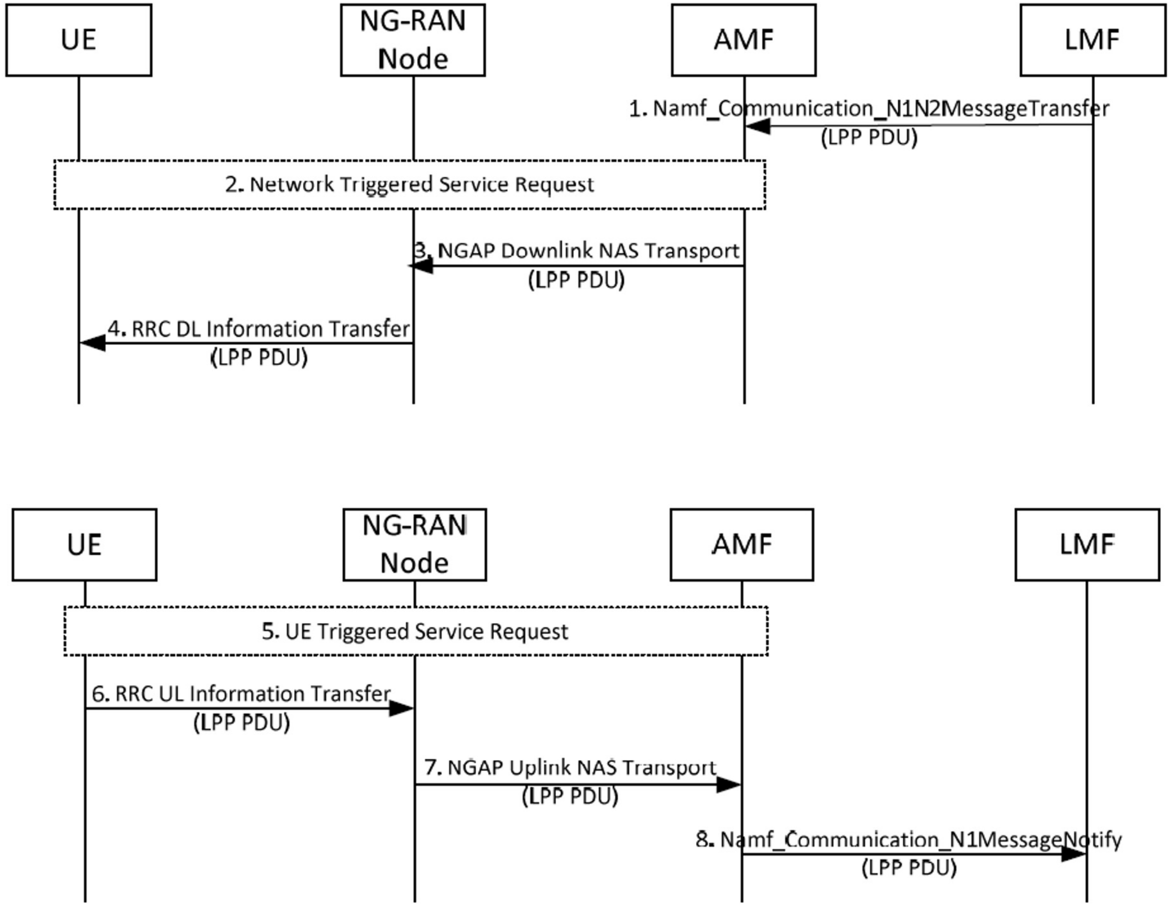
5G NR signals used for localization

- Known signals used for channel estimation
- Sounding reference signals (UL)
  - Also used for power control, scheduling, and MIMO
  - Can be received by neighboring gNBs
  - Periodic or on demand
- Positioning reference signals (DL)
  - Orthogonal between multiple gNBs
  - Periodic
- Both implemented in OpenAirInterface

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

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

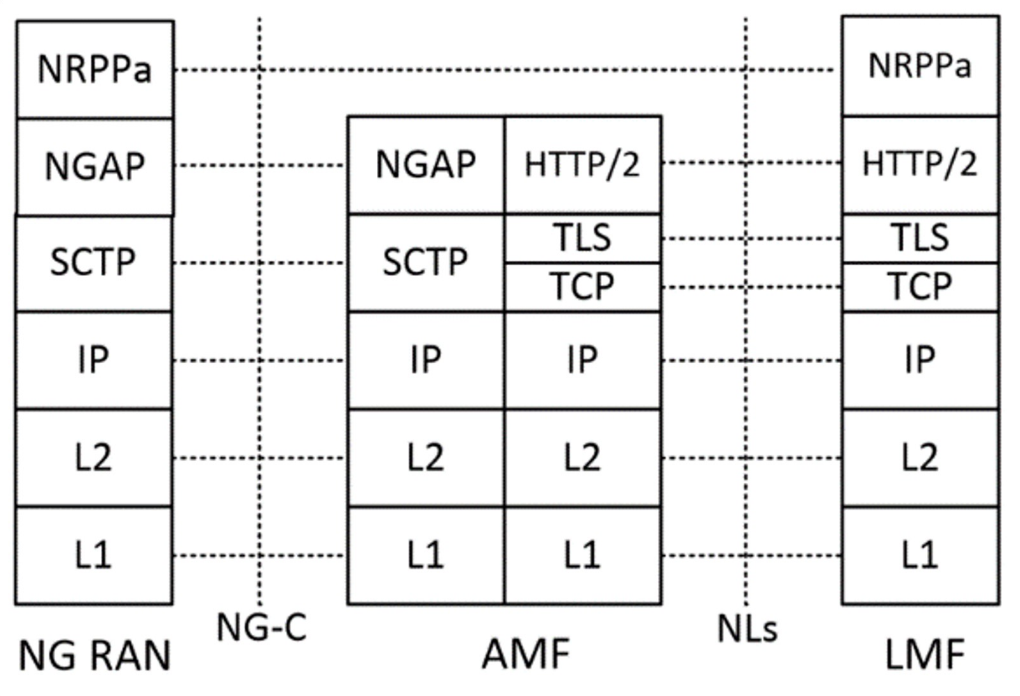


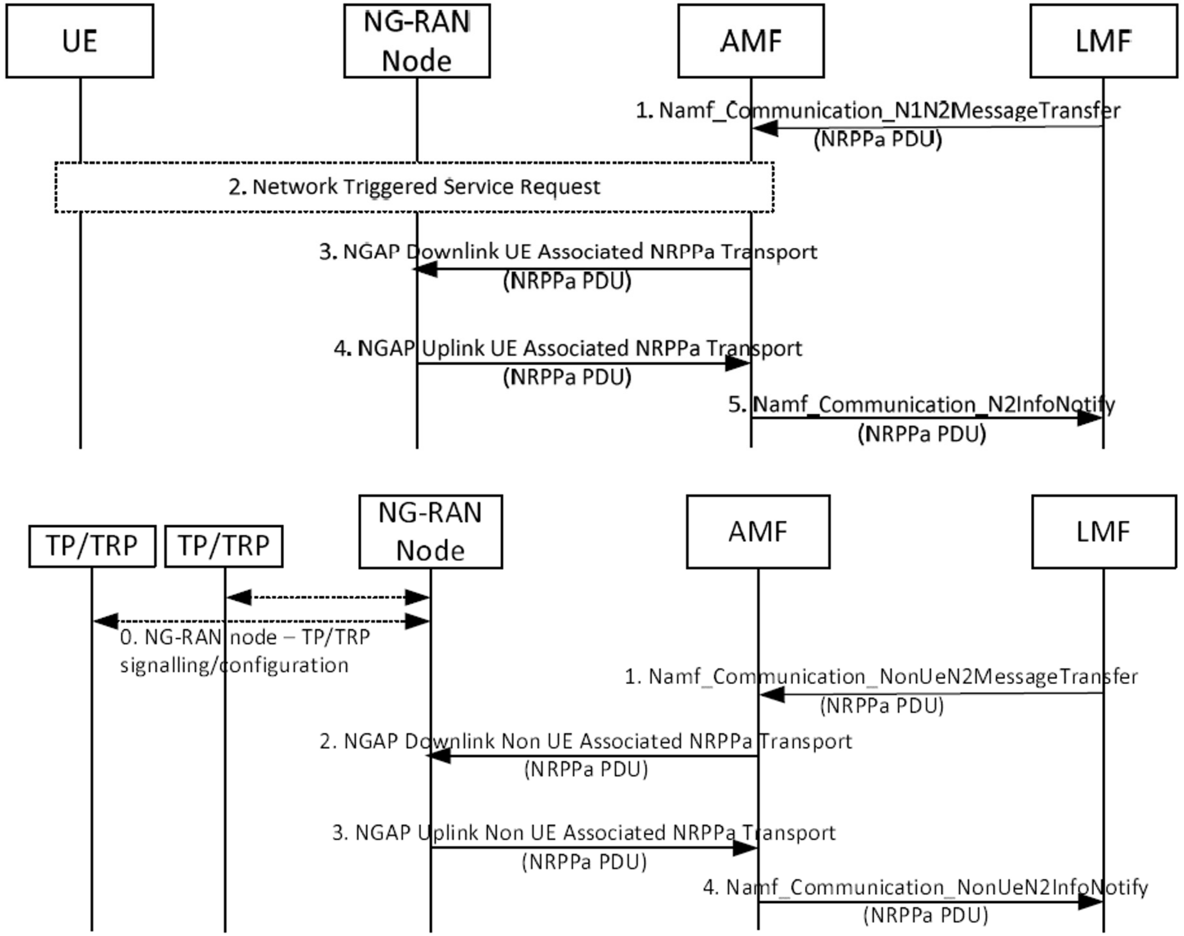


LPP PDU transfer between LMF and UE (network- and UE-triggered cases)

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

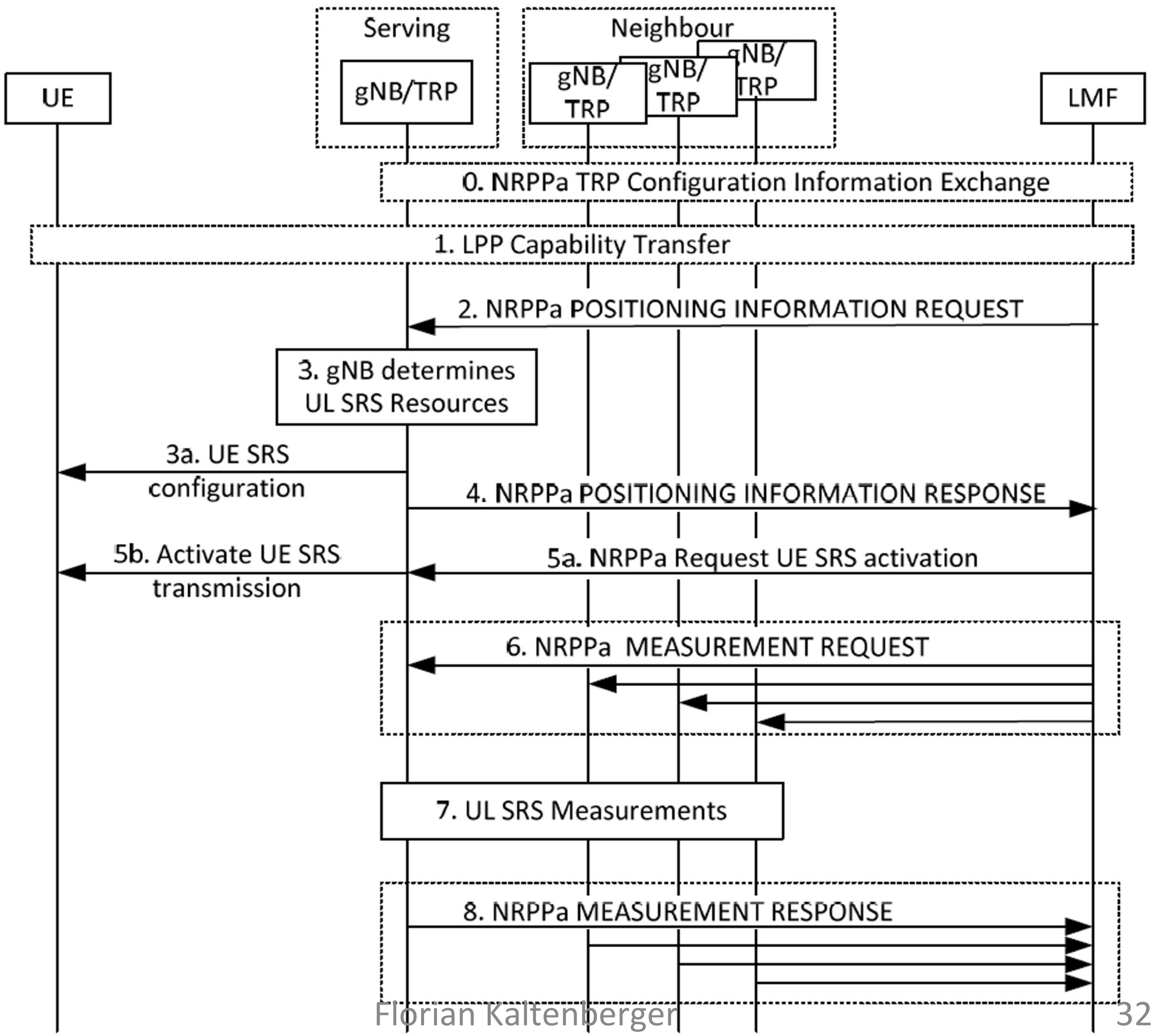
Protocol Layering for LMF to NG-RAN Signalling(Section 6.5 TS 38.305)





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]



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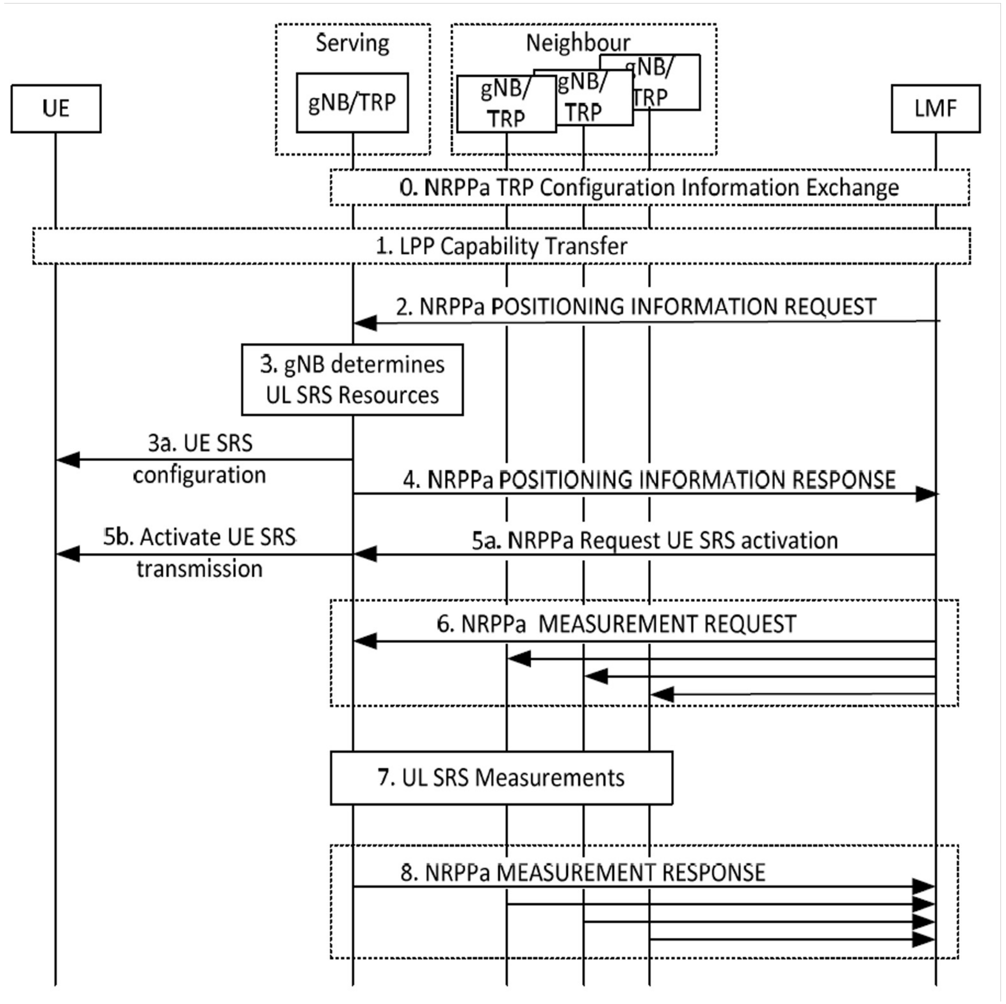
OAI Support for NG-RAN-assisted UL-TDOA Positioning Method

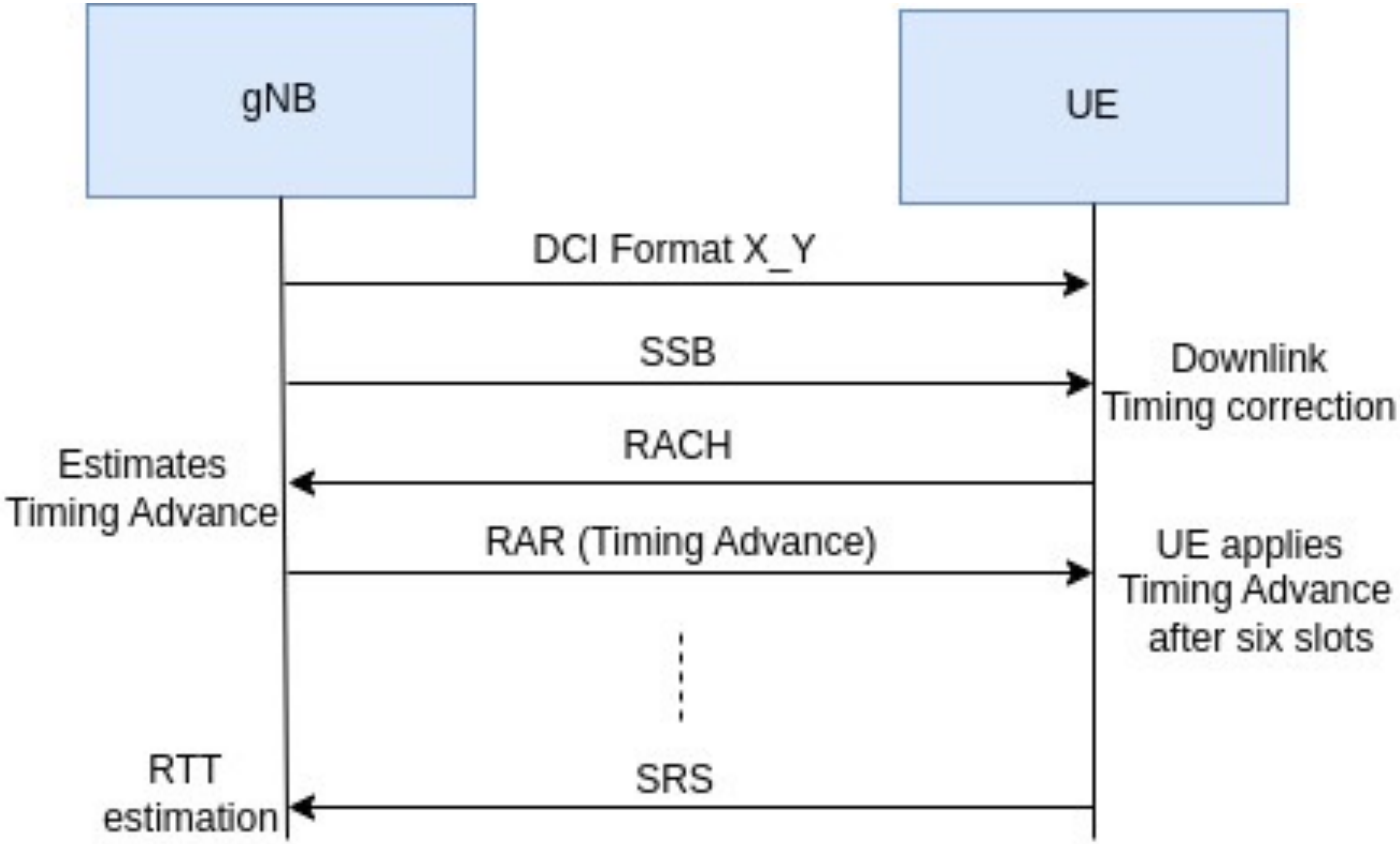
- LMF
  - LMF Procedures (TS 29.572)
  - NRPPa Functionalities (TS 38.455)
  - NRPPa PDU Transfer protocol between AMF/LMF ((TS 29.518)
- AMF
  - NRPPa PDU Transfer protocol between AMF/LMF (TS 29.518)
  - NRPPa PDU Transfer protocol between AMF/gNB (TS 38.413)
- RAN
  - NRPPa Functionalities (TS 38.455)
  - NRPPa PDU Transfer protocol between AMF/gNB (TS 38.413)



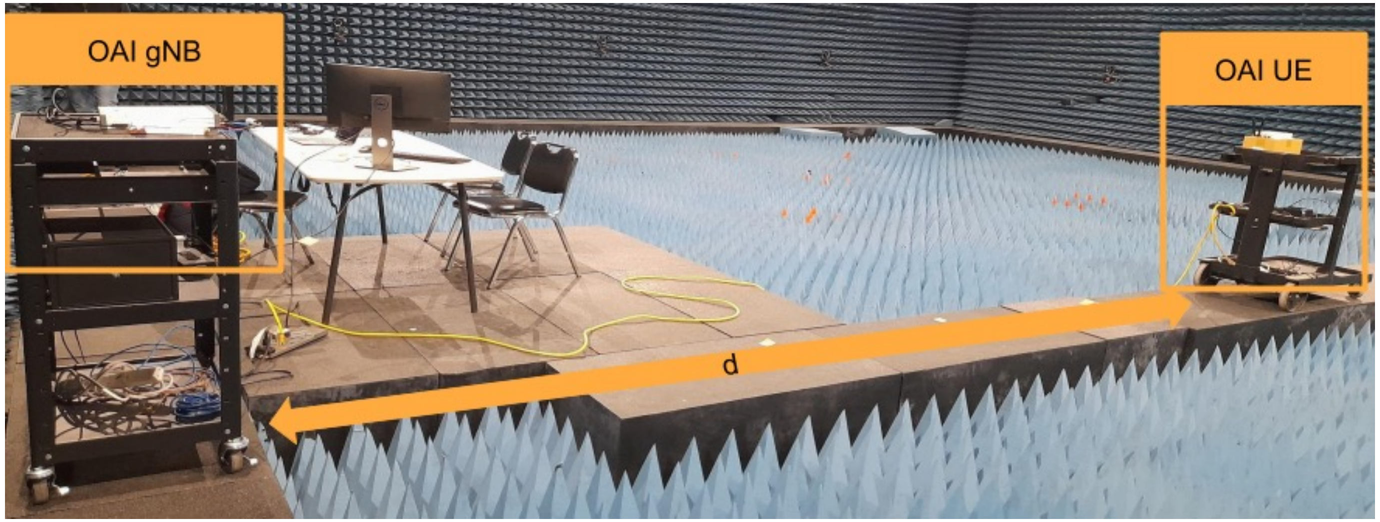
Novel RTT estimation method

- Sync Errors between gNBs decrease accuracy in TDoA
- Multi-RTT overcomes this problem by measuring exact time-of-flight
  - But comes at the expense of additional protocol overhead
- Course RTT can also be estimated from RACH procedure (timing advance),
  - but accuracy not good enough for positioning
- Idea: send SRS immediately after PRACH to improve estimate
  - This can be triggered by a new DCI command

Novel RTT estimation method

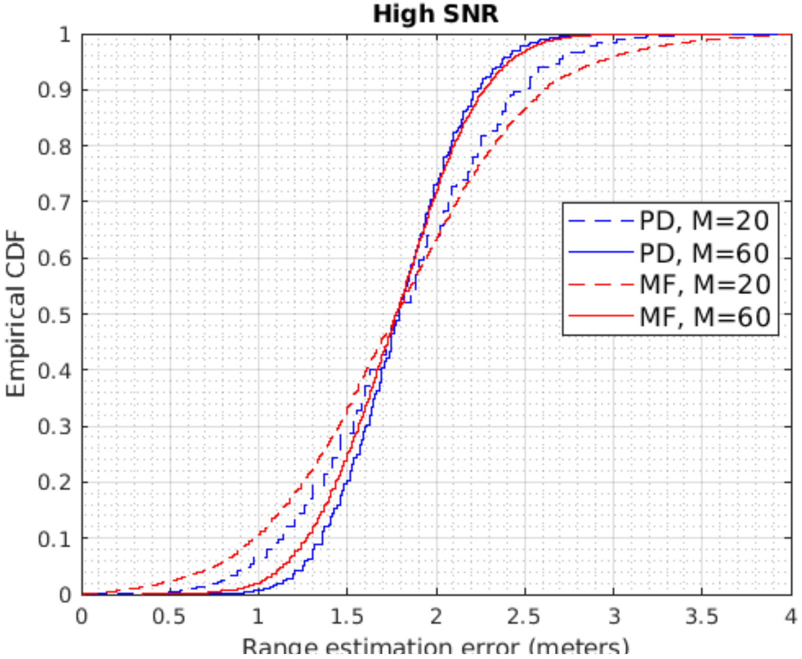


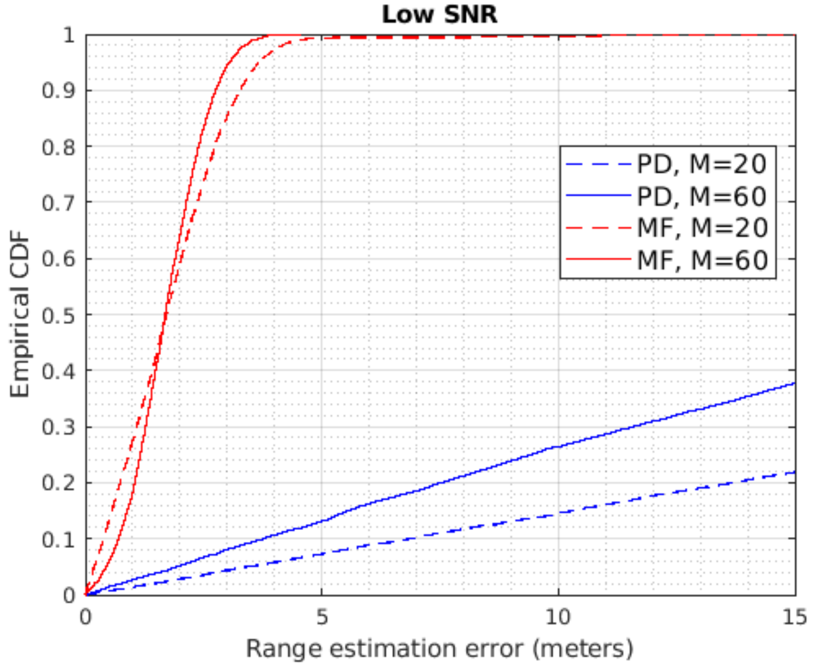
Measurement results



Parameters	Values
Bandwidth	40 MHz
Subcarrier Spacing (SCS)	30 KHz
Centre frequency	3.6 GHz
FFT size (K)	1536
Cyclic prefix	132
K_c	2

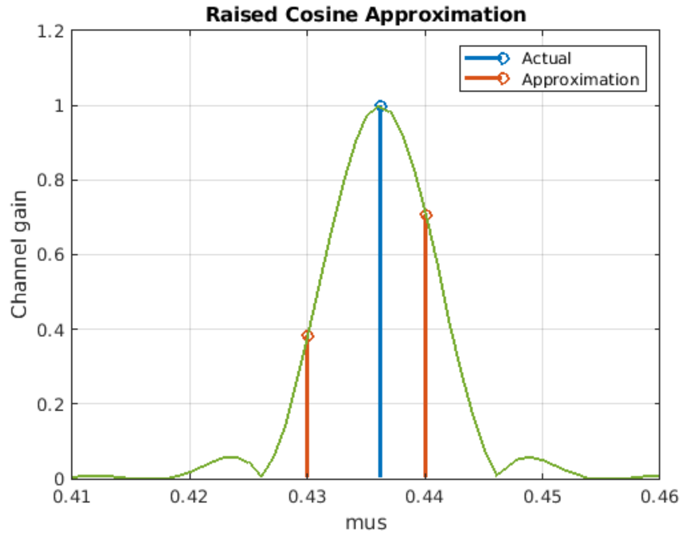
Mundlamuri, Rakesh; Gangula, Rajeev; Kaltenberger, Florian; Knopp, Raymond, "**Novel round trip time estimation in 5G NR,**" Submitted to Globecom 2024, 30 April 2024 (arXiv:2405.04357)

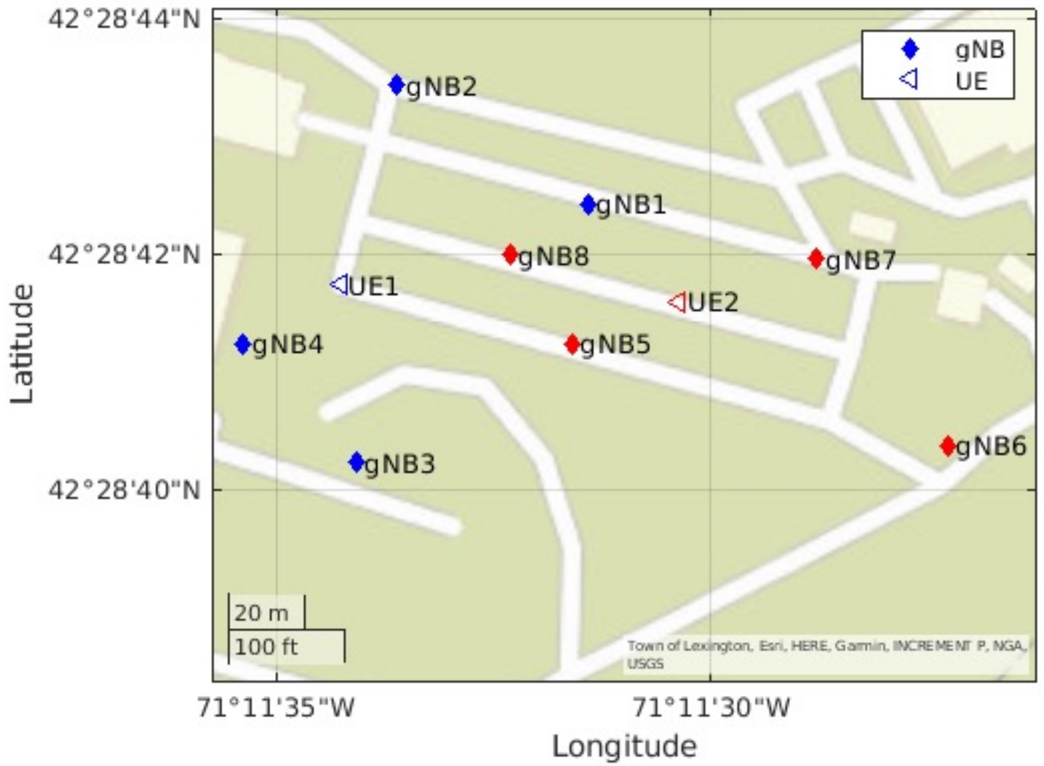




Experiments on Colosseum

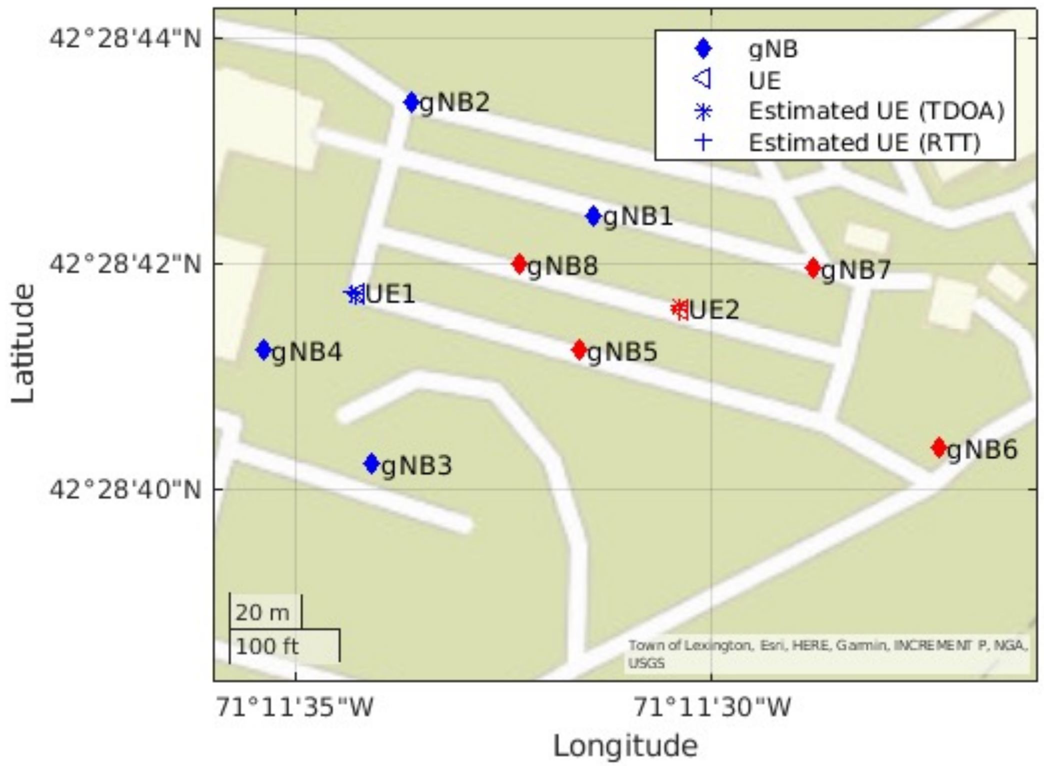
- A single Line-of-sight path with 0dB path loss.
- Sampling rate : 100 MHz
- Maximum Taps : 4
- FIR filter size : 512
- Channel approximation using raised cosine filter.





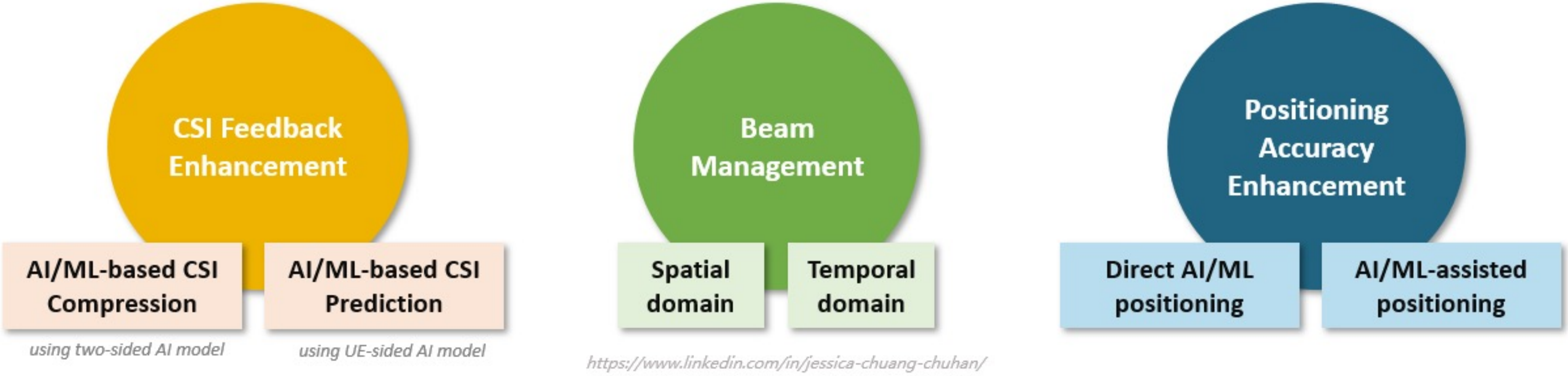
Colosseum: Preliminary Results

- RTT
  - UE1 : 1.71m
  - UE2 : 0.44m
- DL TDOA
  - UE1 : 0.34m
  - UE2 : 0.93m



Localization and Machine Learning

AI/ML for Air Interface



Goal of Using AI/ML Techniques

1. Reduce CSI feedback overhead
2. Improve CSI feedback accuracy

Goal of Using AI/ML Techniques

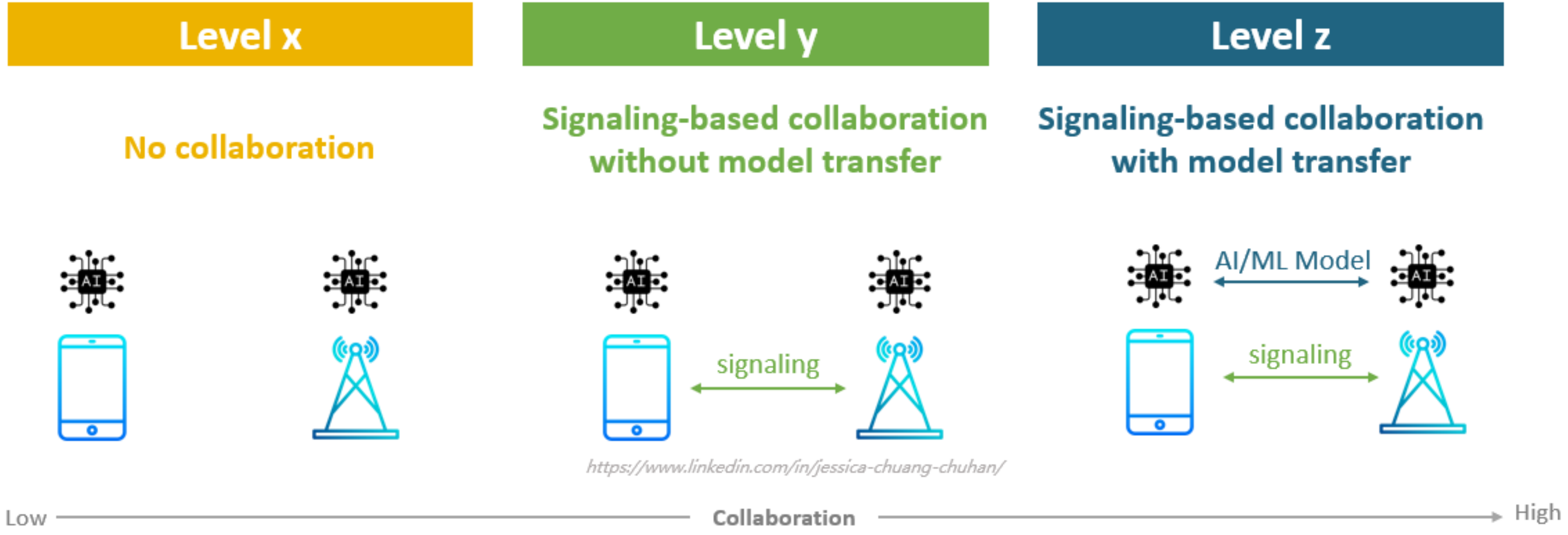
1. Reduce overhead
2. Minimize latency
3. Improve the accuracy of beam selection

Goal of Using AI/ML Techniques

1. Improve positioning accuracy

Source: 3GPP TR38.843 (v1.0.0) 2023-09

Collaboration Level Between UE-side & Network-side



Source: 3GPP TR 38.843 V1.0.0 (2023-09)

Level X Examples (no collaboration)

- Supervised fingerprinting neural networks with labeled data
- Semi-supervised Channel Charting methods with a subset of labeled data
- Self-supervised methods using antenna positions in real-world coordinates

Global Scale Self-Supervised Channel Charting with Sensor Fusion

- Taking the high dimensional CSI of M TRPs as well as ToAs in a dimensionality reduction method
- Similar CSIs should have similar distance in a 2D latent space
- Assuming ToA (near TRPs) < ToA (far TRPs), taking TRPs known locations into account to transform the 2D space
- Incorporating laser scanner data only during the training phase
- Optimize the combined objective function by a Deep Neural Network
- Recreating 2 Fraunhofer IIS 5G Dataset with laser scanner and Ray-Tracing in MATLAB with only 2 LoS antennas

TABLE II: 2 TRPs Comparison of Our Model with State-of-the-Art over Datasets 1 and 2

	CT		TW		CE90 [m]	
Model	1	2	1	2	1	2
Classical PSO	0.987	0.978	0.986	0.984	1.59	1.45
Siamese [12]	0.996	0.994	0.994	0.991	3.08	2.24
Triplets [13]	0.993	0.994	0.992	0.994	2.29	1.35
Triplets+Bilat. [18]	0.991	0.980	0.990	0.964	24.14	22.16
Ours (no Laser)	0.995	0.992	0.995	0.991	3.98	3.81
Ours	0.998	0.996	0.997	0.995	0.94	0.97

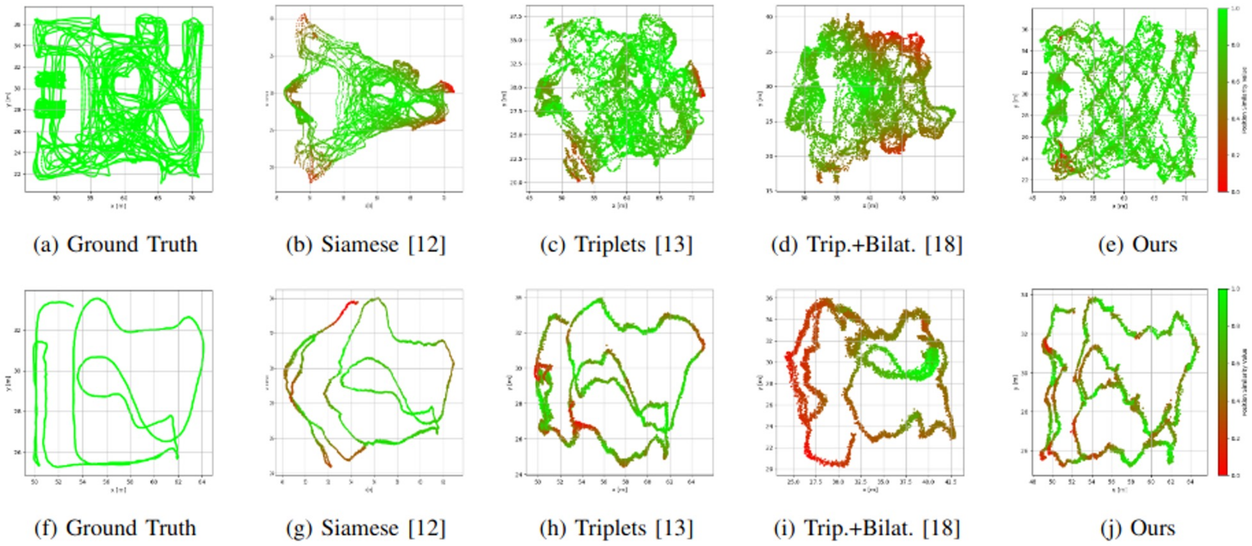


Fig. 3: Figures (a) to (e) are the results for test Dataset 1, and figures (f) to (j) are the results for test Dataset 2.

Esrafilian, Omid; Ahadi, Mohsen; Kaltenberger, Florian; Gesbert, David, "**Global scale self-supervised channel charting with sensor fusion,**" Submitted to GLOBECOM 2024, IEEE Global Communications Conference, 8-12 December 2024, Cape Town, South Africa (arXiv:2404.19618)

Conclusions

- 6G is coming fast
- 6G will be more of an evolution (of 5G) rather than a revolution
- AI/ML and Integrated Sensing and Communication will be part of 6G
- Need to bring ideas from paper to reality
- Open-source tools and testbeds are essential for that

Thank you!

https://www.openairinterface.org

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OPEN AIR interface

Quarter 1 2024

- Handling of Multiple RUs per DU
- LDPC Encoding and Decoding Offload on T2
- FR2 Basic SA Interoperability with COTS UE
- Support for O-RAN Through OSC's FHI Release F
- Inline Acceleration with Aerial

Quarter 2 2024

- OAI UE Initial Access Procedures with 3rd Party gNB
- DL MIMO: 4 Layers
- NRPP Support in gNB
- 2-step RACH Rel16
- F1 Handover
- Sidelink Rel16

Quarter 3 2024

- Support for Short-Data Transmission Rel17
- QoS Aware Scheduler
- Support of 5G RAN Slicing
- Basic NTN Support Rel17
- N2 Handover Procedures

Quarter 4 2024

- Xn Handover Procedures
- Multi UE Bandwith Part Handling
- Beamforming Procedures for FR2