tsdsi India's Telecom SDO 10 Years of developing ICT Standards celebrating

NCC

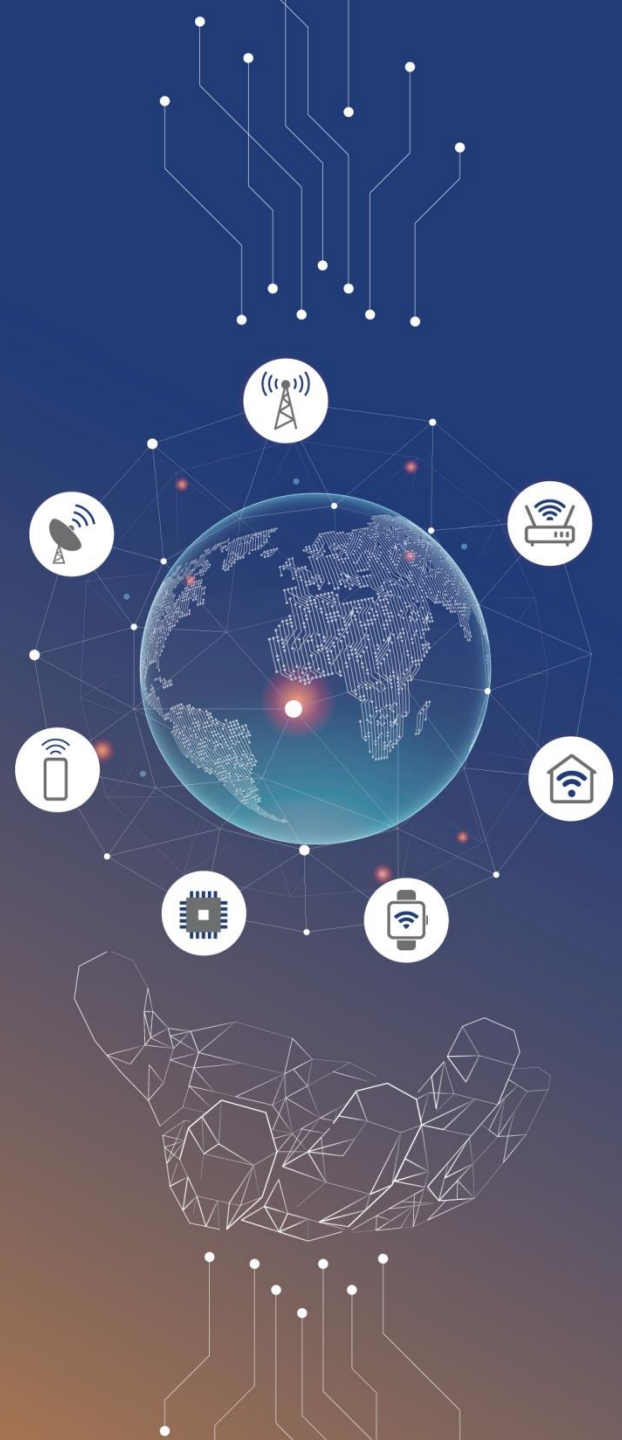
Workshop on

Standards-driven Research @ NCC 2024

28th February 2024

09:00 to 17:30 IST

IIT Madras



\Orchestrating a brighter world NEC

Workshop on Standards-driven Research @NCC 2024

O-RAN (Open RAN) Standardization and Associated Research Challenges

By

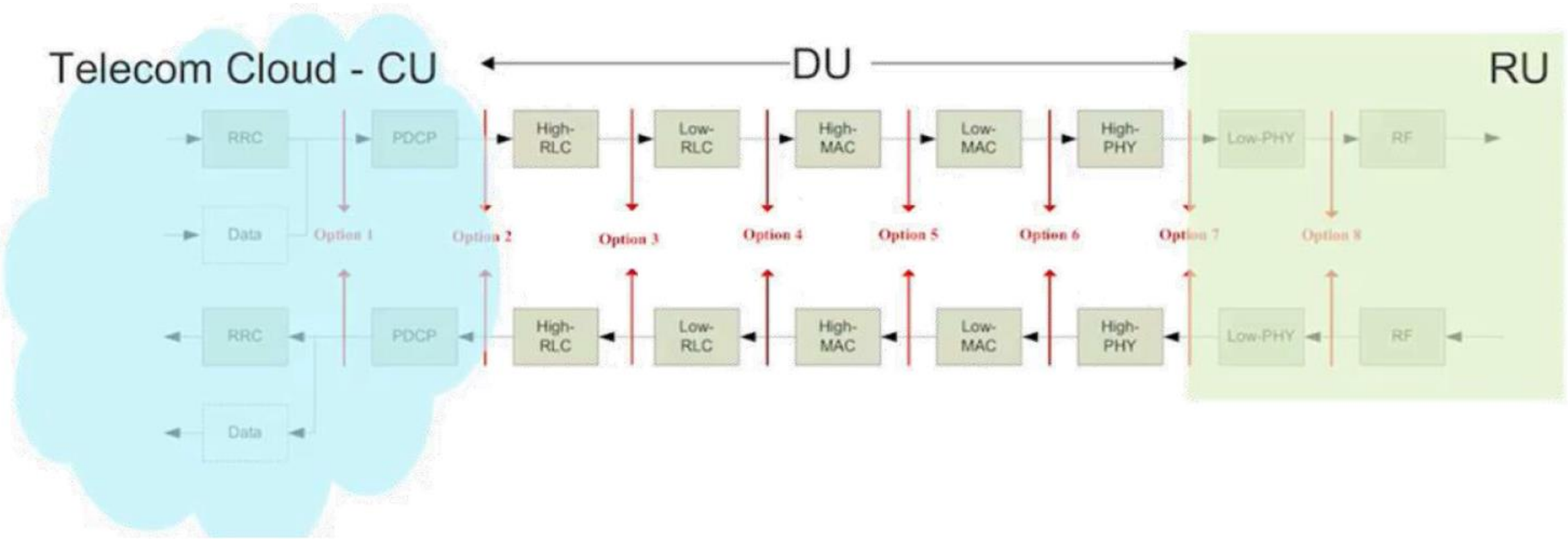
Dr. Manikantan Srinivasan
Kokila Jagadeesan

NEC Corporation India Private Limited

Agenda

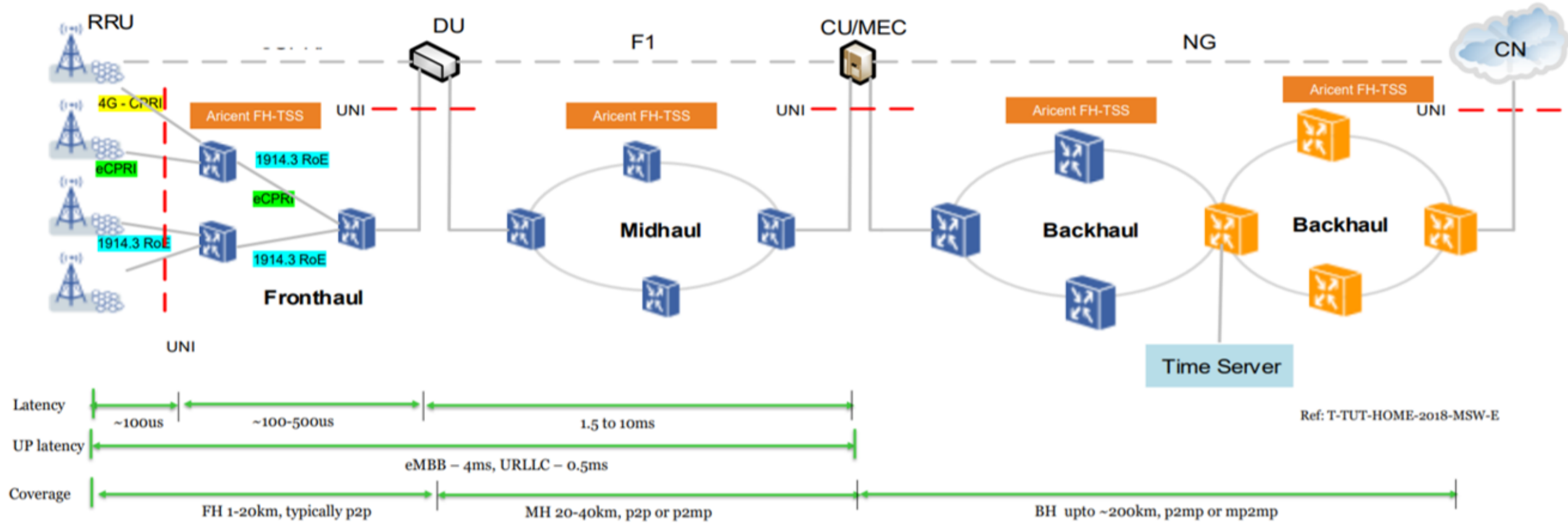
- Open RAN – overview
- O-RAN Alliance
  - Introduction to the O-RAN alliance, O-RAN Working Groups
- Deep dive research challenges following Working Groups
  - WG4 – Open Fronthaul interfaces work group
  - WG5 – Open F1/W1/E1/X2/Xn interface Workgroup
  - WG11 – Security Working Group
  - SuFG – Sustainability Focus Group
  - nGRG – next Generation Research Group
  - Academic Research and O-RAN
- Open RAN & O-RAN Research, Open Source Support for Research
- A shot demo of Open Source 5G Solution - OAI

Mobile networks: 5G Functional Splits



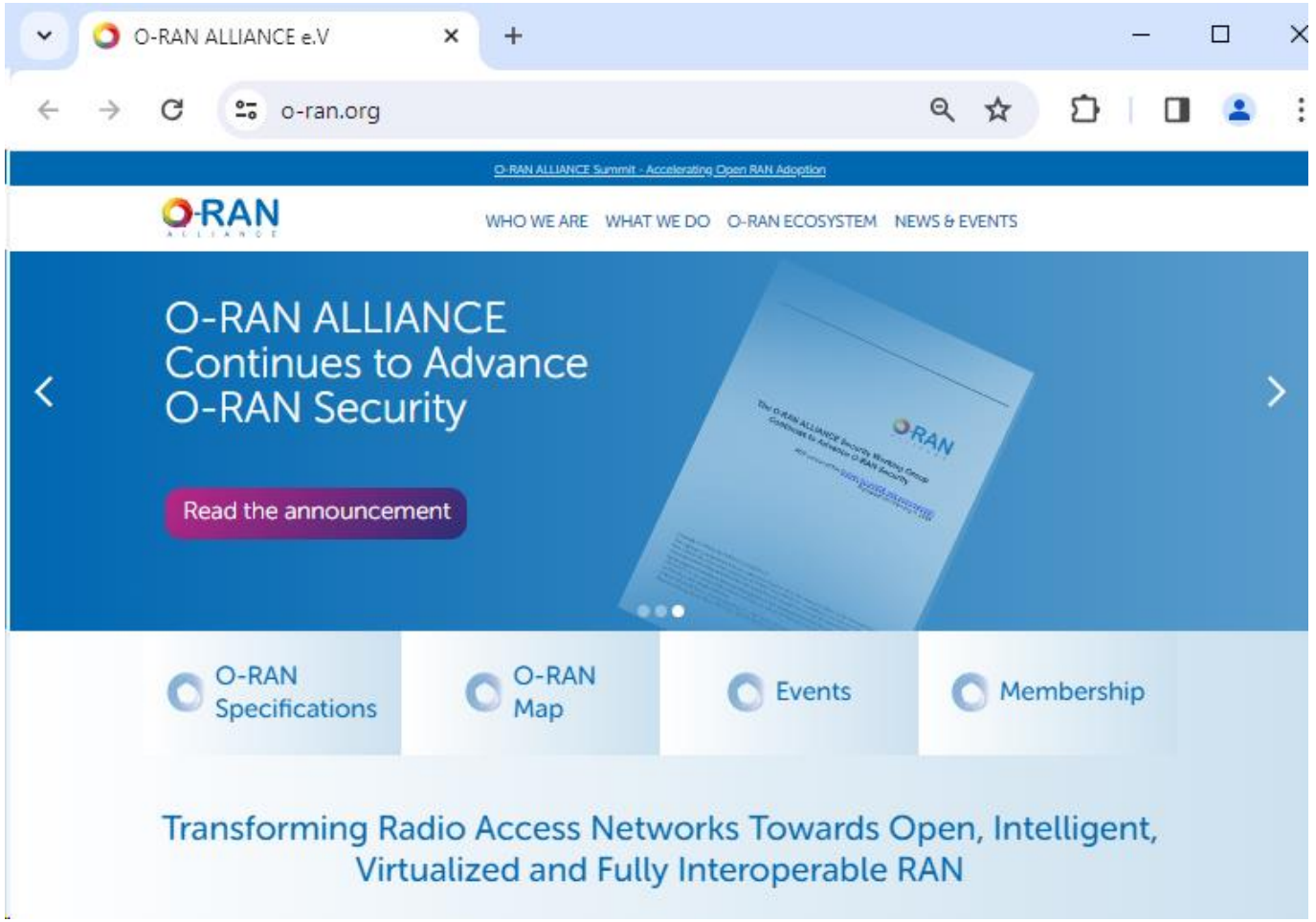
Open RAN network deployments based on the **3GPP defined 7.2 Low level splits**, along with well defined Open Interfaces and AI/ML application support, ushers in a performance optimized 5G networks.

Mobile networks: Open RAN Deployment



- ✓ Fronthaul – Network between RRU/RU (Remote Unit) and DU (Distributed Unit) – can be CPRI or eCPRI or IEEE 1914.3
- ✓ Midhaul – Network between DU and CU (Centralized Unit) – "F interface"
- ✓ Backhaul – Network between CU and 5G NGC (and EPC)

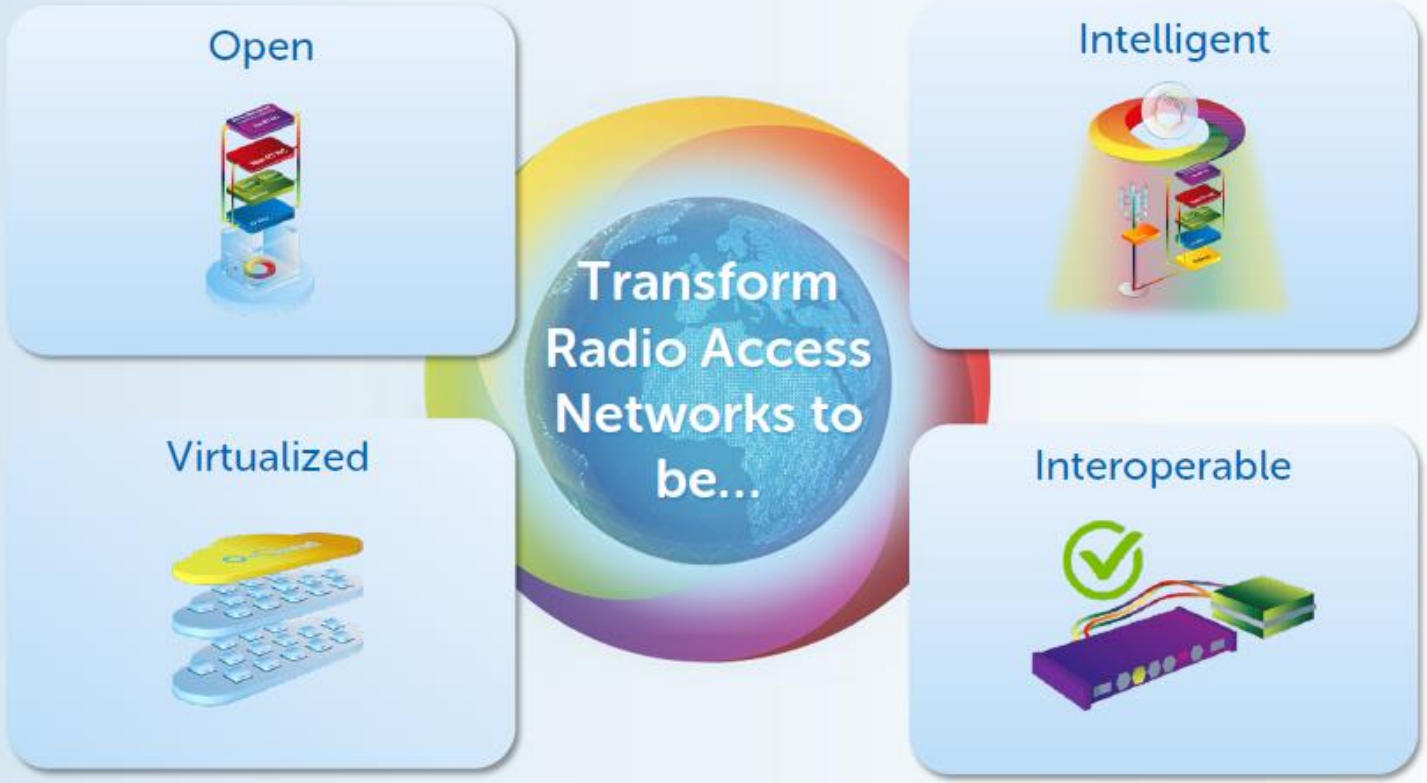
O-RAN ALLIANCE



O-RAN ALLIANCE
- Overview

Source: https://mediastorage.o-ran.org/white-papers/O-RAN.Overview-of-the-O-RAN-ALLIANCE-presentation.pdf, Copyright: O-RAN Alliance

O-RAN ALLIANCE Mission



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O-RAN ALLIANCE Foundation in 2018

O-RAN ALLIANCE has been established as a German entity in August 2018

Merging C-RAN Alliance and XRAN Foundation

C-RAN Alliance

XRAN.org

O-RAN ALLIANCE

5 founding Members

AT&T | 中国移动 China Mobile | docomo | orange | T

Source: https://mediastorage.o-ran.org/white-papers/O-RAN.Overview-of-the-O-RAN-ALLIANCE-presentation.pdf, Copyright: O-RAN Alliance

O-RAN Ecosystem with Over 300 Participants

Since its foundation, O-RAN ALLIANCE has become a world-wide community of mobile network operators, vendors, and research & academic institutions operating in the Radio Access Network (RAN) industry.

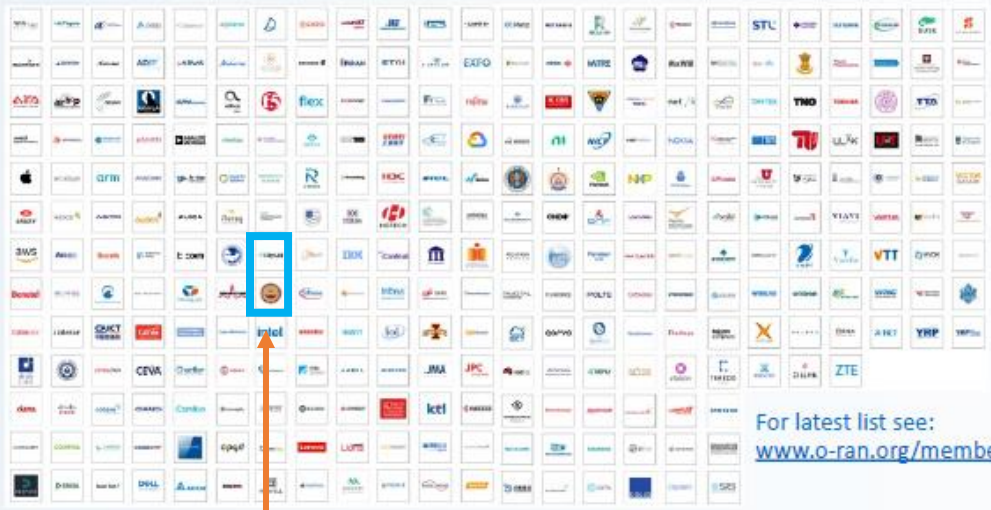
Diverse community

- Academia
- Application developers
- Chipset makers
- Cloud providers
- Government agencies
- Hyperscalers
- Network Equipment Manufacturers
- Operators
- Research institutes
- Security
- Service providers
- System integrators
- Test and measurements
- Test labs
- Transport networks

Members*

Led by MNOs serving over 5B subscribers around the world

Contributors and Academic Contributors*



For latest list see: www.o-ran.org/membership

IIT-Madras, IIT-Hyderabad are O-RAN Alliance Academic Contributors

Source: https://mediastorage.o-ran.org/white-papers/O-RAN.Overview-of-the-O-RAN-ALLIANCE-presentation.pdf, Copyright: O-RAN Alliance

3 Main Thrusts

O-RAN Specification Effort

O-RAN specifications define all aspects of the O-RAN Architecture and are available to everyone

Testing, Integration and Certification

O-RAN supports its Members and Contributors in testing, integration and certification of their O-RAN implementations

PlugFest

Open Testing and Integration Centre

O-RAN CERTIFIED

O-RAN INTEROPERABLE

O-RAN E2E - TESTED

O-RAN Software Community

In collaboration with the Linux Foundation, supports the creation of open software for the RAN

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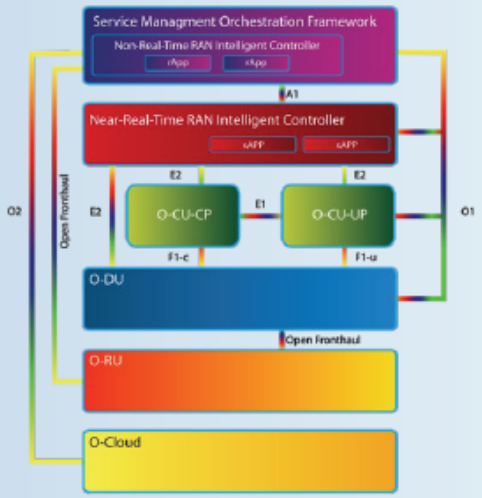
Specification Effort

O-RAN Specifications set the foundation for telecom industry towards open and intelligent RAN

- O-RAN specifications are available to the general public at https://www.o-ran.org/specifications

O-RAN Architecture



Roadmap Definition by MVP-C

Top-down planning of releases, feature packages, work items. Aligned with operators' requirements for Minimum Viable Plan (MVP) and future development based on operators' priorities.

Bottom-up specification effort

Work Groups

- WG1: Use Cases and Overall Architecture Work Group
- WG2: The Non-Real-Time RIC and A1 Interface Work Group
- WG3: The Near-Real-Time RIC and E2 Interface Work Group
- WG4: The Open Fronthaul Interfaces Work Group
- WG5: The Open F1/W1/E1/X2/Xn Interface Work Group
- WG6: The Cloudification and Orchestration Work Group
- WG7: The White-box Hardware Work Group
- WG8: Stack Reference Design Work Group
- WG9: Open X-haul Transport Work Group
- WG10: OAM Work Group
- WG11: Security Work Group

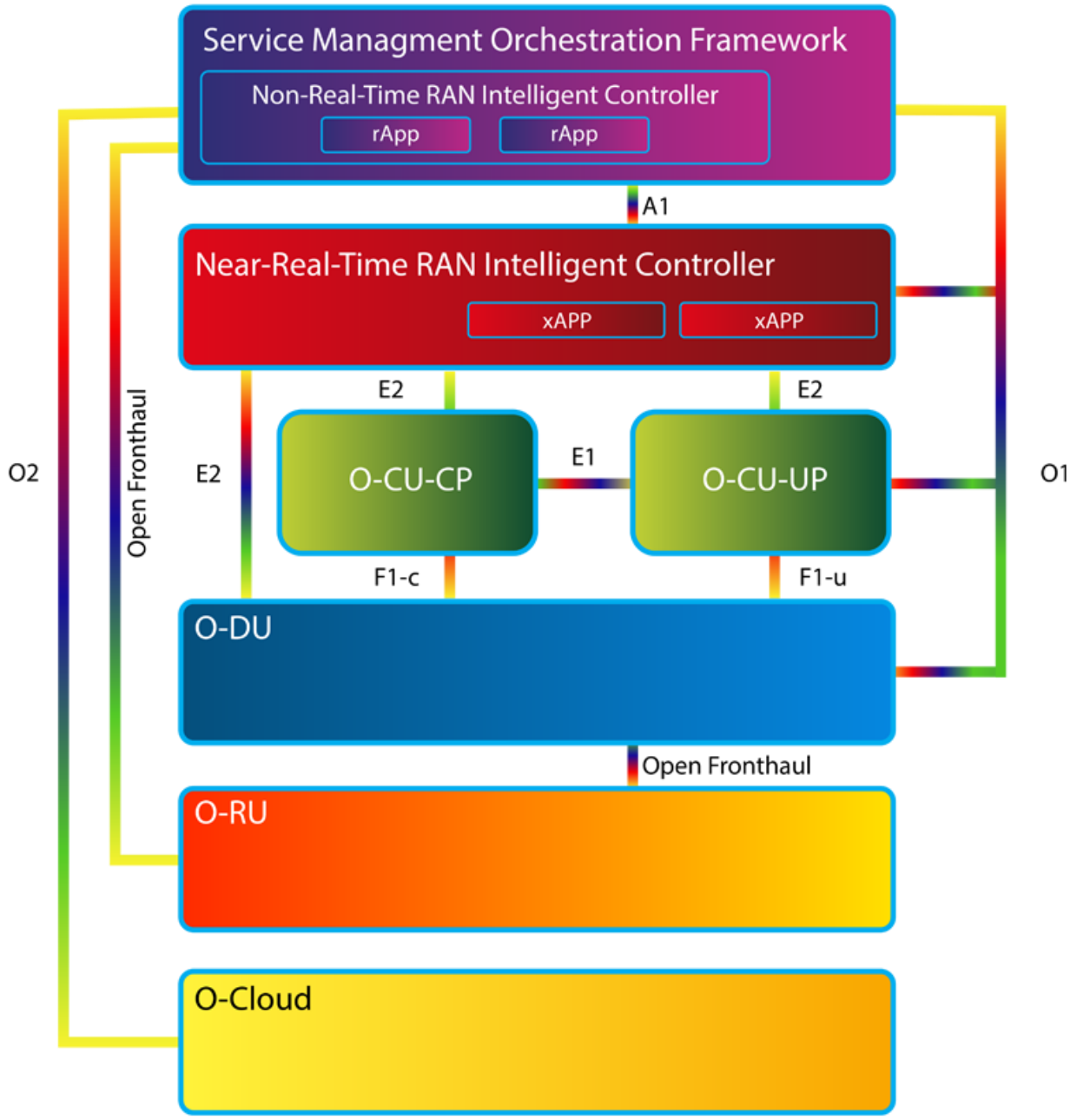
Focus and Research Groups

- IEFG: Industry Engagement Focus Group
- OSFG: Open Source Focus Group
- SDFG: Standard Development Focus Group
- SuFG: Sustainability Focus Group
- TIFG: Testing and Integration Focus Group
- nGRG: next Generation Research Group

For details see our website

Source: https://mediastorage.o-ran.org/white-papers/O-RAN.Overview-of-the-O-RAN-ALLIANCE-presentation.pdf, Copyright: O-RAN Alliance

O-RAN Architecture



Source: About us (o-ran.org) Copyright: O-RAN Alliance

WG4 – Open Fronthaul Interfaces Work Group

WG4: Open Fronthaul Interfaces Work Group

Work Group charter

- WG4 will specify the open fronthaul interface between O-DU/SMO and O-RU, and the cooperative transport interface between O-DU and TN. WG4 will also specify relevant test specifications

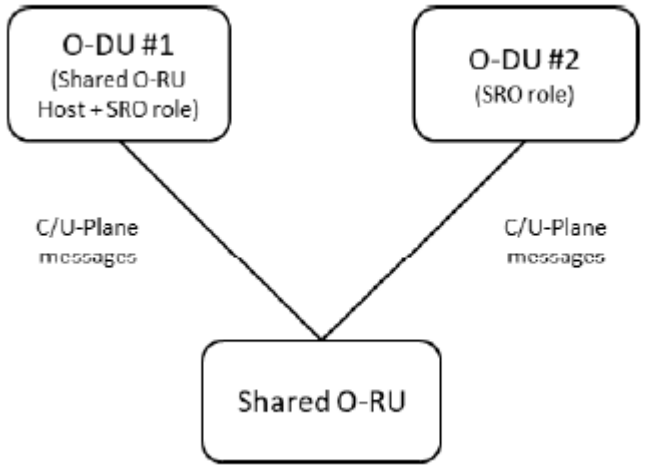
Work Group Scope

- Developing open fronthaul interface specifications for the lower layer split
  - Control, User and Synchronization (C/U/S) plane protocols
  - Management (M) plane protocols and associated YANG models
- Develop open fronthaul test specifications
  - Conformance Test specifications
  - IOT specifications including IOT profiles

Work items in WG4

Shared O-RU

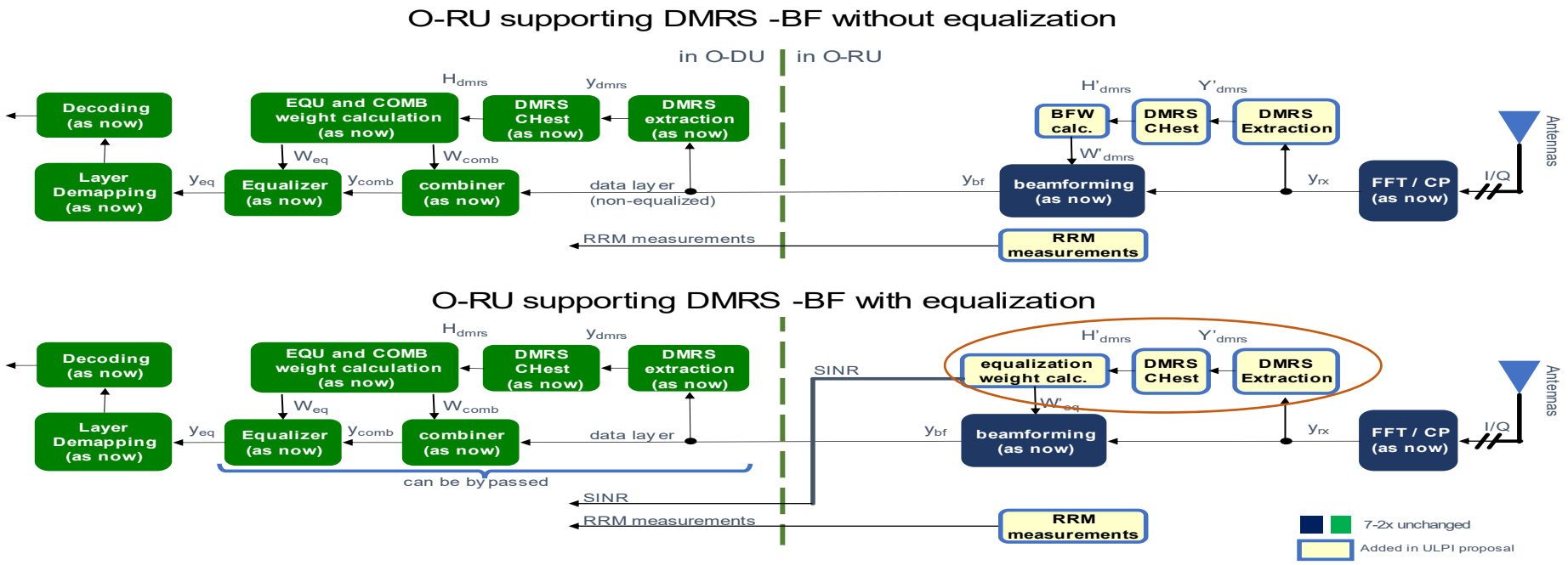
- Considering various RAN sharing use cases e.g. MORAN, Neutral host, DAS, Network Slicing, shared O-RU support across MNOs becomes inevitable to fulfill end to end support for such use cases.
- Each of these options pose common challenges related to defining sharing policies across MNOs and applying the negotiated policies to the shared O-RU.
- This work item intends to focus on identifying and making the required changes in the fronthaul CUS and M-Plane specifications to clearly segregate the common and shared resource specific management on fronthaul.



Work items in WG4

ULPI

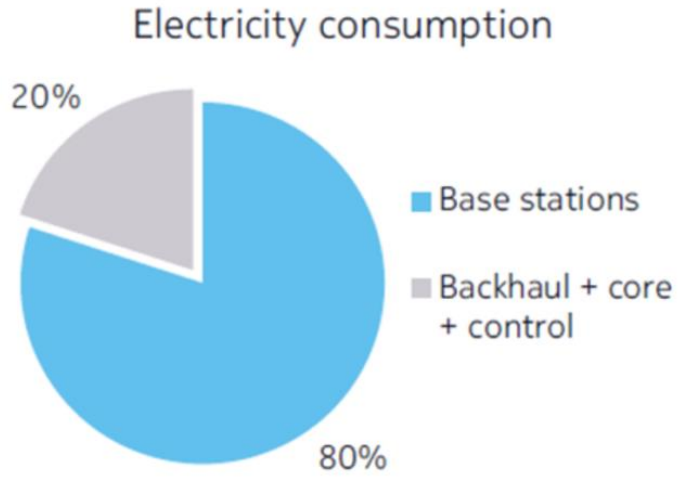
- An interest in investigating the uplink performance for the current O-RAN WG4 Lower Layer Split functional division between O-DU and O-RU and possibly introducing an additional functional division between O-RU and O-DU
- Currently this work item is agreed and normative work is in progress for creating CRs to relevant WG4 specifications.



Work items in WG4

Network Energy saving

- The RAN is responsible for a major part of the Energy Consumption (EC) of a mobile network, and the O-RU accounts for the largest part of the energy consumption of the RAN
- EC can be reduced by improving the Energy Efficiency (EE) of the network, and by introducing different Energy Saving (ES) mechanisms
- Use cases considered: Carrier and cell switch off/on ES, RF channel reconfiguration ES, Advanced Sleep Mode ES
- In WG4, the scope of work is to define the fronthaul interface requirements for various energy saving use cases



WG5 – Open F1/W1/E1/X2/Xn Interface work group

WG5: Open F1/W1/E1/X2/Xn Interface Work Group

Work Group charter

- Profile 3GPP-specified higher layer split interfaces to be truly inter-operable between vendors (focus on X2, F1, Xn, E1 and W1 interfaces), including the definition of the relevant management models for operation & maintenance support, and interoperability test cases, as applicable. WG5 also defines a transport specification to enhance openness at transport level for the network elements within its scope (higher layer split interfaces).

Work Group scope

- Profile specifications
  - Describe e.g., definition of IEs, general behavior of each node, etc. which will not be specified in 3GPP specifications
- O&M specifications
  - Describe CU/DU O&M functions (e.g. alarms, configurations, monitoring,…)
  - Should be consistent with the overall O&M framework established by WG10
- IOT specification
  - Specification for inter-operability testing of higher layer split profiled use cases
- Potential enhancements of 3GPP specifications (F1/E1/W1/X2/Xn)
  - Gap analysis between 3GPP spec and fully operable multi-vendor spec
  - If needed (i.e. in critical cases) identify and propose functions to be added to the 3GPP spec (O-RAN individual companies may decide to submit proposals to 3GPP)

Work items in WG5

- **Energy saving**
  - The RAN is responsible for a major part of the Energy Consumption (EC) of a mobile network, and the O-RU accounts for the largest part of the energy consumption of the RAN
  - EC can be reduced by improving the Energy Efficiency (EE) of the network, and by introducing different Energy Saving (ES) mechanisms
  - Use cases considered: Carrier and cell switch off/on ES, RF channel reconfiguration ES, Advanced Sleep Mode ES
  - In WG5, the scope is to define O1 interface requirements for various energy saving use cases, O-CU/O-DU energy efficiency KPIs, O-CU/O-DU energy consumption reporting

SuFG – Sustainability Focus group

SuFG – Sustainability Focus group

- Focus Group charter
  - The Sustainability Focus Group (SuFG) of the O-RAN Alliance works with MVP-C to coordinate initiatives with all O-RAN Work/Focus groups to: optimize energy consumption, reduce environmental impact, and create more energy-efficient and environmentally friendly mobile Networks
- Focus Group scope
  - Pushes, prioritizes and provides leadership on energy efficiency and sustainability activities in alignment with MVP-C procedures and release plans
  - Develops White papers and Technical Reports to advance O-RAN Energy Efficiency and Sustainability goals
  - Emphasizes focus on high-priority items to enable Energy Efficiency and Sustainability objectives to be met

Task Groups in SuFG

- TG1: Accelerate software energy optimization
  - Replicate existing PSFs on traditional RAN and 3GPP
  - Socialize and prioritize missing and/or new PSFs
  - Push PSFs prioritization development/availability
  - Use AI/ML to optimize energy consumption

- TG2: Standardization of energy measures
  - Identify configuration/design parameters with impact on energy consumption per: O-CU/DU, O-RU and O-Cloud
  - Define energy efficiency [counters & KPIs] and their respective monitoring through SMO
  - Define energy consumption metrics and measurement scenarios
  - EE & Power Consumption KPIs via real-time metering

Task Groups in SuFG

- TG3: Improve hardware energy efficiency
  - Identify specific components on the O-CU/DU, O-RU and O-Cloud with potential impact on energy consumption
  - Define energy optimization UCs applicable to each component
  - Define energy efficiency ratios at hardware level
  - Limit idle mode energy consumption
  - Massive MIMO needs power efficient HW underpinning it, with ability to turn off parts of the equipment
- TG4: Circularity on network equipment
  - Define and apply common guidelines to evaluate the circularity of network equipment to provide transparent information on its environmental impact, enabling circularity to be a criteria to be considered in purchasing decisions by operators

WG11 – Security Work Group

WG11 – Security Work Group

Work Group charter

- Responsible for defining the requirements and specifying the architectures and protocols for security and privacy in O-RAN systems.
- Collect the security requirements and solutions from all other WGs, negotiate as necessary to ensure uniform requirements and designs among the relevant WGs, thereby allowing a standardized security architecture.
- Specify security requirements, architectures and frameworks in support of the open interfaces defined by other O-RAN WGs. This includes security guidelines that span across the entire O-RAN architecture.

Work Group scope

- Specify O-RAN Security Architecture and protocols, Develop Security Requirements for O-RAN systems
- Specify Security Protocol specific profiles, Specify Security Test Cases
- O-RAN Coordinated Vulnerability Disclosure (CVD) Program
- Development of O-RAN Open-Source Community (OSC) security guidelines / requirements
- Development of an O-RAN Open Test and Integration Center (OTIC) / integration and validation of security use cases / capabilities with TIFG
- WG specific security analysis – Threats, risks assessment, specific countermeasure
- Study and if feasible specify adoption of blockchain technologies in O-RAN Security architecture

WG11 – Security Work Group

Work Items

- WG11-WI Security Testing
- WG11-WI AI/ML Security
- WG11-WI Fronthaul C/U/S-Plane Security
- WG11-WI Near RT RIC - xApps Security
- WG11-WI O-Cloud Security
- WG11-WI O-RU Centralized User Management
- WG11-WI Certificate Management Framework
- WG11-WI App LCM Security
- WG11-WI Security Log Management
- WG11-WI Shared O-RU Security
- WG11-WI SMO Security
- WG11-WI OAuth 2.0 Security
- WG11-2024-01 Zero Trust Architecture (ZTA)

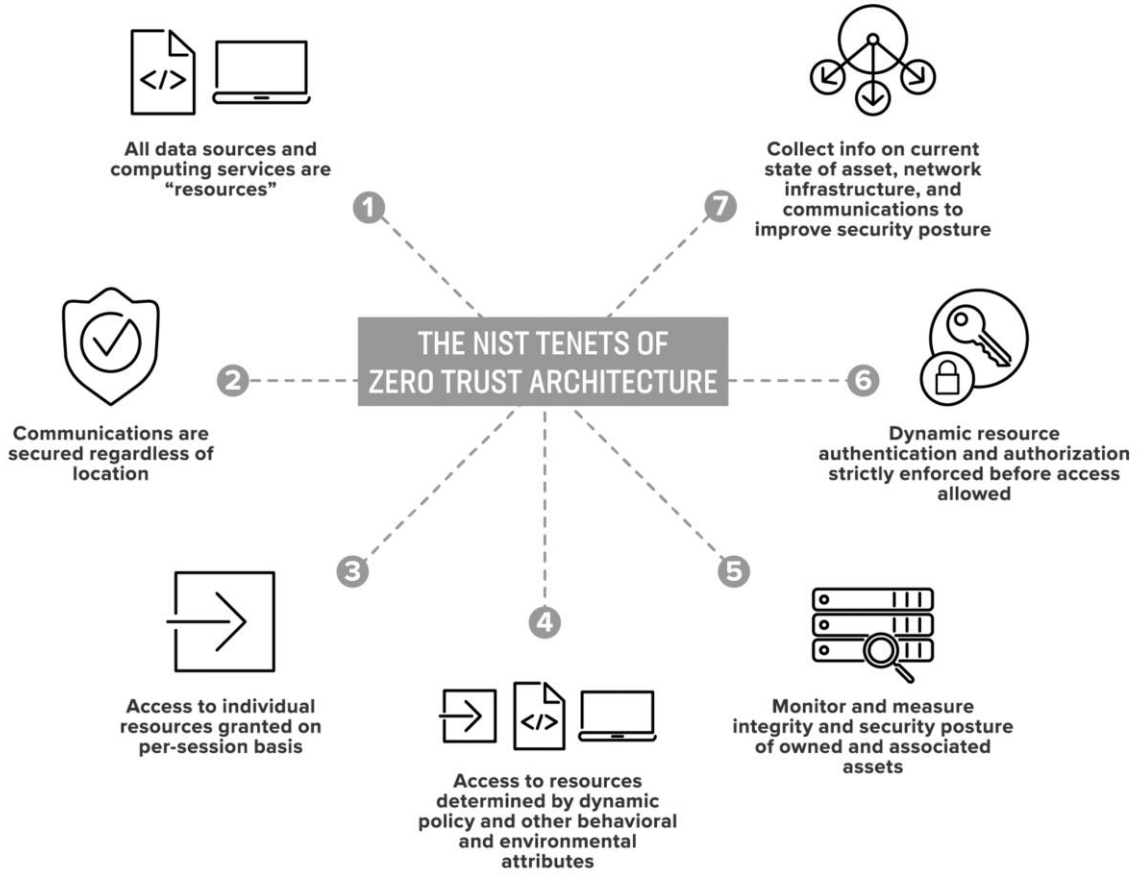
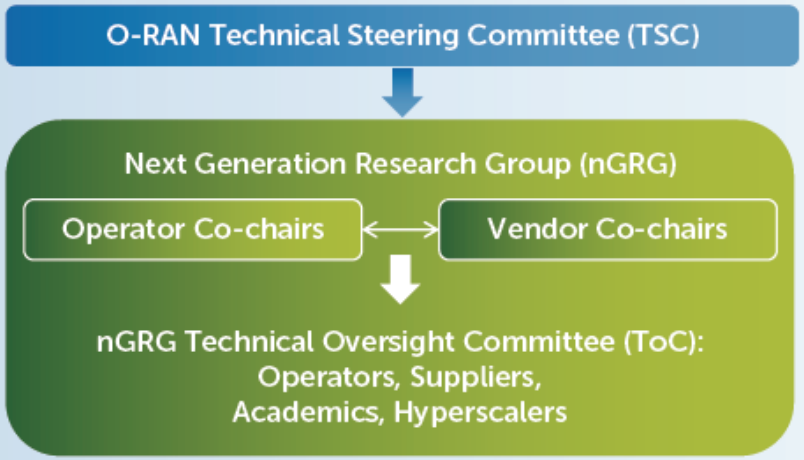


Image Source: [What Is Zero Trust Architecture (ZTA)? | F5 Labs]

nGRG – Security Work Group

O-RAN Next Generation Research Group (nGRG) Structure and Research Streams

The nGRG focuses on research of open and intelligent RAN principles in 6G and future network standards



	Research Streams
RS01	6G use cases and standard gap analysis
RS02	Architecture towards 6G O-RAN
RS03	Native AI and cross domain AI
RS04	Native security
RS08	nG Research Platform

Source: https://mediastorage.o-ran.org/white-papers/O-RAN.Overview-of-the-O-RAN-ALLIANCE-presentation.pdf, Copyright: O-RAN Alliance

O-RAN nGRG – Research opportunities

Work Group Charter

- Provide a forum to facilitate O-RAN related 6G research efforts and to publish research findings
- Leverage industry and academic 6G research efforts and determine how O-RAN may evolve to support 6G and beyond, considering regional research efforts, ITU-R, and 3GPP development
- Achieve O-RAN sustainability from 4G/5G to 6G and beyond
- Consider the impact of 6G on O-RAN areas of interest and work with Industry Partners to unify the 6G technology path/timeline to avoid incompatibility b/w O-RAN and other SDOs
- Define the O-RAN nG research agenda and key priorities
- Establish research streams based on defined research priorities, and solicit research items under corresponding research streams
- Organize regular discussions and reviews of the progress/outcomes of research streams
- Publish white papers and research reports based on the outcomes of the studies in the Group
- Recommend appropriate actions through white papers
- Sponsor topical workshops, seminars, and summits with appropriate partners

Work Group Scope

- **Near term (2022-2025):** Align with Industry Partners and perform a high-level impact analysis of potential 6G technology trends and the ITU-R Vision for the next IMT on the O-RAN architecture and establish research items based on defined research priorities and the outputs include white papers and research reports.
- **Mid term (2025-2027):** Based on the research findings, provide inputs to O-RAN WGs/FGs to prepare for O-RAN 6G standards studies and coordinate O-RAN 6G collaborations with other SDOs.
- **Long term (beyond 2027):** Align with other 6G research organizations, SDOs, and programs through liaisons via O-RAN SDFG and collaborate with O-RAN TIFG/IEEE/NSF etc. on potential 6G testbeds.

@Athens F2F meeting – 22nd Feb 2024:
O-RAN 6G Workshop: Architecture Evolution, Digital Twin, and Convergence of Communications and Computing in 6G Era

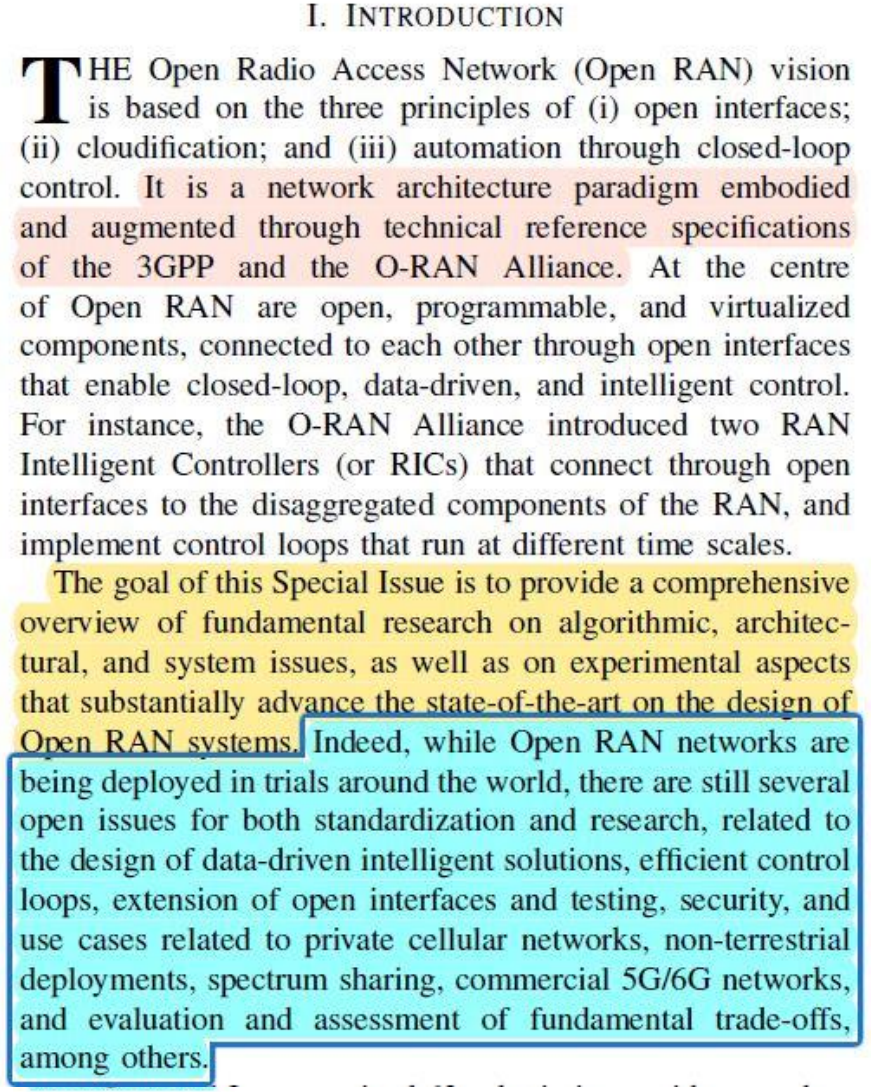
Academic Research : Open RAN based on O-RAN Specifications; A brief

Academic Research on Open RAN / O-RAN

- Extensive Academic research for Open RAN / O-RAN is being pursued across the globe
- A Pinnacle – IEEE Journal on Selected Areas in Communication - Feb 2024 – Issue on Open RAN

  Polese et.al., in the Introduction to the Guest Editorial "*Open RAN: A New Paradigm for Open, Virtualized, Programmable, and Intelligent Networks*" state

  - Vison of Open RAN, and its realization by the combination of technical specifications form – 3GPP and O-RAN Alliance
  - The ongoing fundamental research that is advancing the state-of-the-art on design of Open RAN Systems
  - And, the extensive "Open Issues" that are still to be addressed for standardization and research.



I. INTRODUCTION

THE Open Radio Access Network (Open RAN) vision is based on the three principles of (i) open interfaces; (ii) cloudification; and (iii) automation through closed-loop control. It is a network architecture paradigm embodied and augmented through technical reference specifications of the 3GPP and the O-RAN Alliance. At the centre of Open RAN are open, programmable, and virtualized components, connected to each other through open interfaces that enable closed-loop, data-driven, and intelligent control. For instance, the O-RAN Alliance introduced two RAN Intelligent Controllers (or RICs) that connect through open interfaces to the disaggregated components of the RAN, and implement control loops that run at different time scales.

The goal of this Special Issue is to provide a comprehensive overview of fundamental research on algorithmic, architectural, and system issues, as well as on experimental aspects that substantially advance the state-of-the-art on the design of Open RAN systems. Indeed, while Open RAN networks are being deployed in trials around the world, there are still several open issues for both standardization and research, related to the design of data-driven intelligent solutions, efficient control loops, extension of open interfaces and testing, security, and use cases related to private cellular networks, non-terrestrial deployments, spectrum sharing, commercial 5G/6G networks, and evaluation and assessment of fundamental trade-offs, among others.

Academic Research on Open RAN / O-RAN

OPEN RAN: A NEW PARADIGM FOR OPEN, VIRTUALIZED, PROGRAMMABLE, AND INTELLIGENT CELLULAR NETWORKS
M. Polese, M. Dohler, F. Dressler, M. Erol-Kantarci, R. Jana, R. Knopp, and T. Melodia

(Contents Continued on Back Cover)

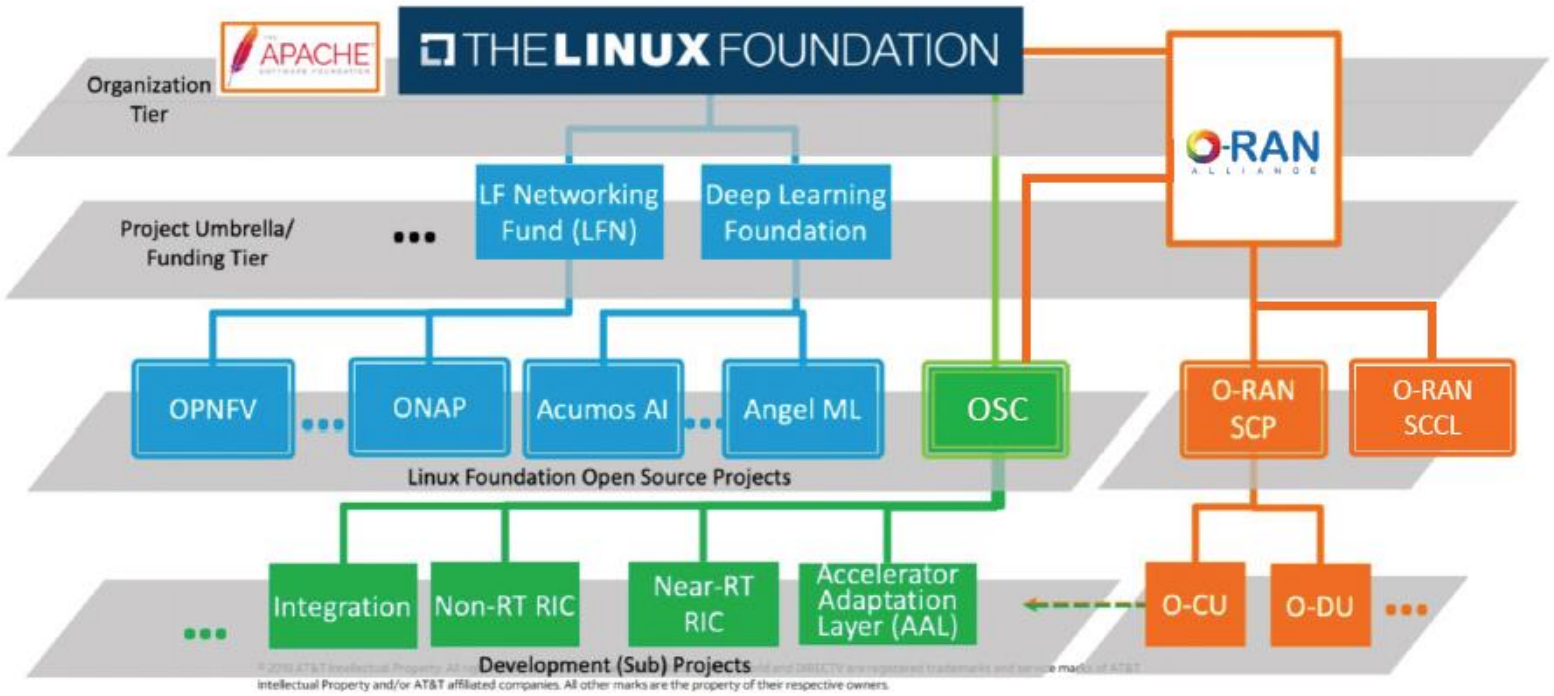
1. RAN slicing and management of the spectrum resources
2. Multiple Input Multiple Output (MIMO) systems optimization
3. RAN control use cases associated to traffic steering, flowcontrol, and security.
4. Orchestration and virtualization:
5. Lessons learnt from validation of multiple xApps and trials.

- 10 out of the 16 articles in Open RAN research aligned / based on O-RAN architecture / approach

Academic Research : Open Source Software & Options

O-RAN Software Community (OSC) and Related Linux Foundation Projects

A collaboration between O-RAN and Linux Foundation to develop software for RAN as per O-RAN specification and architecture



- O-RAN Software Community:
  - A collaborative effort between the O-RAN ALLIANCE and the Linux Foundation.
  - Mission - support the creation of software for the Radio Access Network (RAN)
  - O-RAN SC is sponsored by the O-RAN ALLIANCE and aims to enable the development of open source software for modular, open, intelligent, efficient, and agile disaggregated radio access networks.
- O-RAN Specification Code Project (SCP):
  - Objective: Allow contributions that will acknowledge essential patents.
- O-RAN Standards Collaboration Copyright License (SCCL):
  - To simplify the process of producing open source SW based on standards, by defining a license that will make it easier for the open source community to use code-like sections of O-RAN specifications in their implementations

Source: https://mediastorage.o-ran.org/white-papers/O-RAN.Overview-of-the-O-RAN-ALLIANCE-presentation.pdf, Copyright: O-RAN Alliance

O-RAN SC Releases & contributions by Academia

https://wiki.o-ran-sc.org/display/REL/Releases

Confluence Spaces

O-RAN SC | TOC | Committees | Projects | Software | Documentation | Events | Meetings | Releases | Partnerships | Participate

Releases

Pages

Blog

PAGE TREE

- Amber Release (Nov 2019)
- Bronze Release (Jun 2020)
- Cherry Release (Dec 2020)
- D release (Jul 2021)
- E Release (Dec 2021)
- F Release
- G Release
- H Release
- I Release
- J Release
- K Release
- Release Checklist
- Vote Release Name

Space tools

Pages

Releases

Created by Farheen Cefalu, last modified by David Kinsey on Jan 18, 2024

- Amber Release (Nov 2019)
- Bronze Release (Jun 2020)
- Cherry Release (Dec 2020)
- D release (Jul 2021)
- E Release (Dec 2021)
- F Release
- G Release
- H Release
- I Release
- J Release
- K Release
- Release Checklist
- Vote Release Name

Release Name	Current Phase	Release Date	Next Phase	Timeline	RSAC requirements at release start
K Release	Planning	Dec 2024	Requirements definition	timeline	
J Release	Requirements definition	Jun 2024	Development	timeline	
I Release	Current release	Dec 2023	EOL	timeline	

- O-RAN SC Releases:
  - Planned every six months
  - Feature implementation aligned to standards
  - Academia can play a Significant Role in providing Code Contributions thereby enabling releases with more features
- Contribution opportunities to
  - Non-Real-time RIC (NONRTRIC)
  - Near-Real-time RIC X-APPs (RICAPP)
  - Near-Real-time RAN Intelligent Controller Platform (E2 Interface) (RICPLT)
  - Operation and Maintenance (OAM)
  - O-RAN Central Unit (OCU)
  - O-DU High (ODUHIGH)
  - O-DU Low (ODULOW)
  - Simulators (SIM)
  - Service Management and Orchestration Layer (SMO)
  - Infrastructure (INF)
  - Integration and Test (INT)
  - AIML Framework (AIMLFW)
  - Documentation (DOC)

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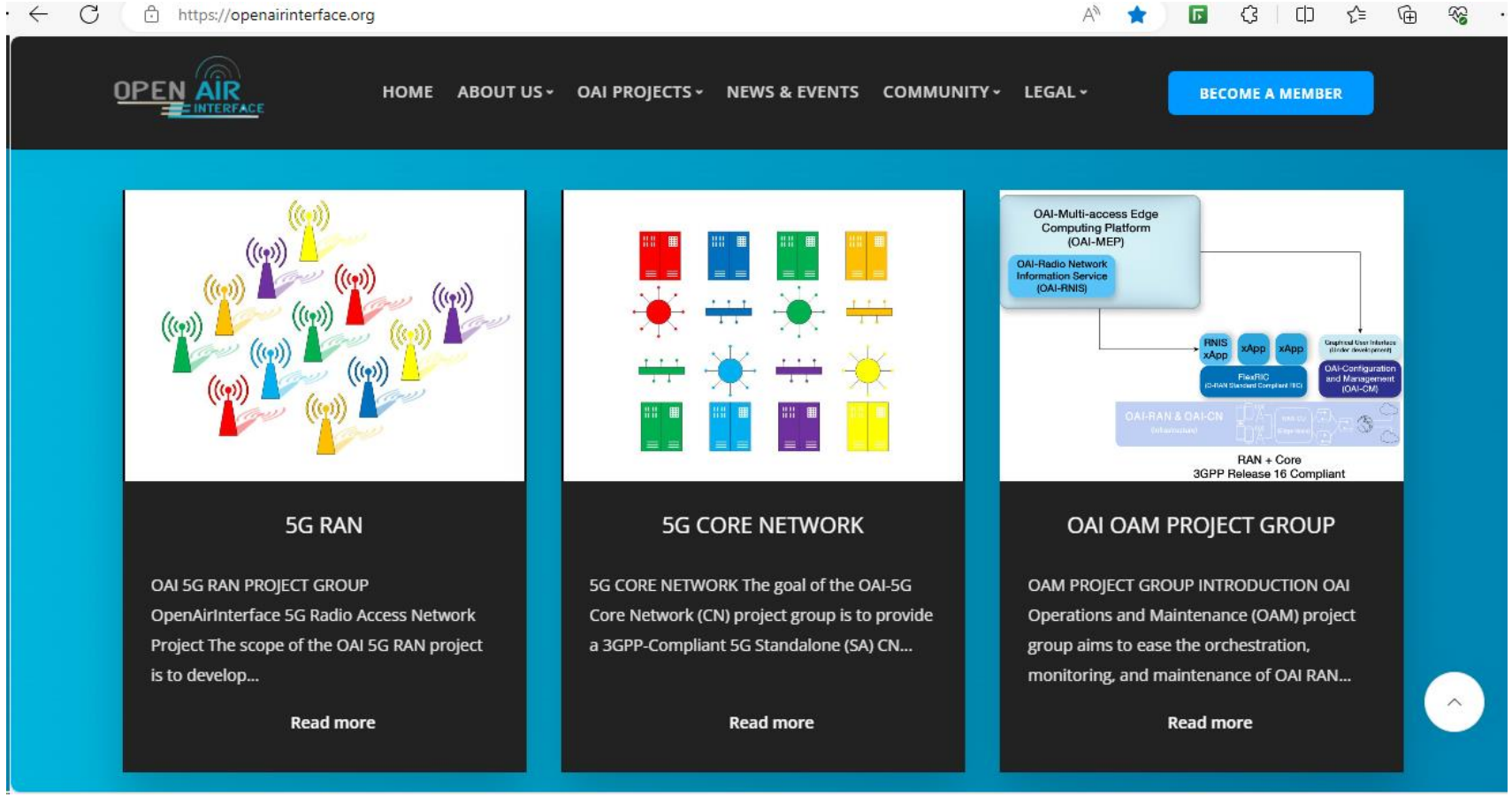
Open Source for Open RAN: OpenAirInterface Software Alliance (OSA)



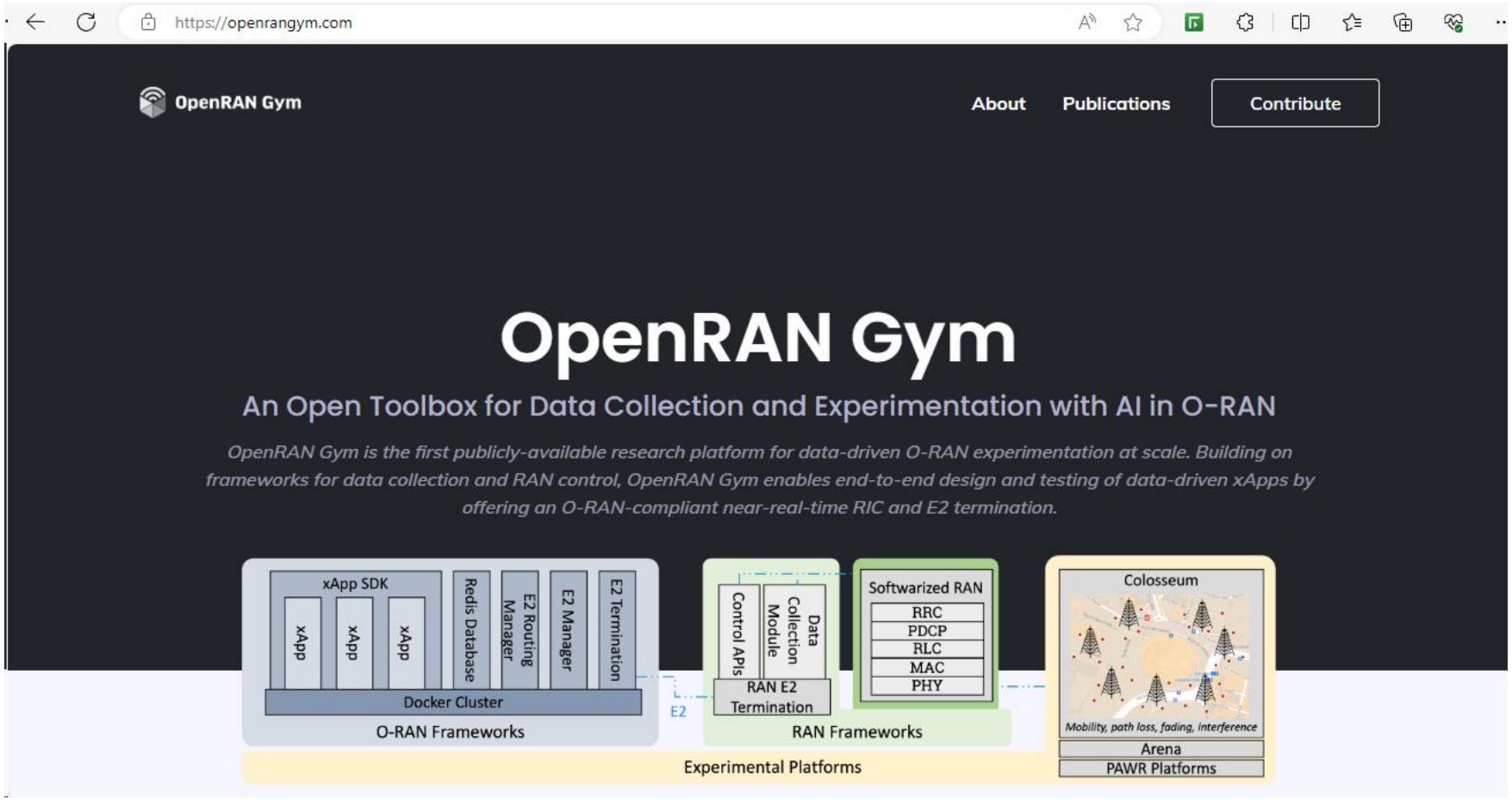
O-RAN ALLIANCE and OpenAirInterface Software Alliance Expand Cooperation on Developing Open Software for the RAN

EURECOM
Sophia Antipolis

- Established in 2014, the OSA is a French non-profit organization (“Fonds De Dotation”), funded by corporate sponsors.
- OSA is the home of OpenAirInterface, an open software that gathers a community of developers from around the world, who work together to build wireless cellular Radio Access Network (RAN) and Core Network (CN) technologies

Open Source for Open RAN: OpenRAN Gym

OpenRAN Gym: AI/ML Development, Data Collection, and Testing for O-RAN on PAWR Platforms: [2207.12362.pdf (arxiv.org)]



The OpenRAN Gym main components

i. publicly- and remotely-accessible experimental wireless platforms for collecting data, prototyping, and testing solutions in heterogeneous environments. Example of these are the Colosseum wireless network emulator [10], the Arena testbed [12], and the platforms of the PAWR program [13];

ii. a softwarized RAN implemented through open protocol stacks for cellular networks, such as srsRAN [22] and OpenAirInterface [23];

iii. a data collection and control framework, such as SCOPE [11], that exposes Application Programming Interfaces (APIs) to extract relevant Key Performance Measurements (KPMs) from the RAN, and dynamically control it at run-time, and

iv. an O-RAN control architecture, such as ColO-RAN [8], able to connect to the RAN through open and standardized interfaces (e.g., the ORAN E2 interface), receive the run-time KPMs from the RAN, and control it through AI/ML solutions running, for instance, as xApps/rApps.

Open Source a comparison – JSAC Feb 24

COMPARISON OF EACH PLATFORM'S OPEN-SOURCE IMPLEMENTATIONS AND EXEMPLAR XAPPS

	OAI	OSC	ONF	OAIC
CN	• OAI CN	• No CN or EPC	• OMEC CN	• LTE EPC
RAN	• Better CPU and memory utilization than srsRAN [17] • Multiple UE simulation • MOSAIC5G E2 agents • No O1 interface implementation	• Radisys CU lacks integration with open-source CU and RU implementations • DU and DU App • O1 interface	• Leverages OAI's RAN modules • ONF's own RAN simulator with more features and capability to simulate a large number of UEs	• Easier to modify [17] • POWDER [12] E2 agents within srsRAN stack • Single UE simulation • No F1 interface for CU/DU split • No O1 interface
RIC	• Better CPU, memory utilization, and latency than OSC's RIC [7] • Recursive agent library for the abstraction of underlying topology • iApps have less overhead than xApps	• Completely O-RAN compliant • All O-RAN components including Non-RT RIC • Requires more resources due to containerization and microservice structure	• μONOS-RIC using ONOS modules • Code used in previous SDN activities and is therefore reliable • Good documentation • Latest version is fully O-RAN compliant	• Uses OSC's RIC
xApps	• Key performance metrics (KPMs) monitoring, slice monitoring and control, and traffic controller	• Anomaly detection, HelloWorld xApp, HW-go xApp, KPM monitoring, QoE predictor, RIC APP ML, RIC Measurement Campaign xApp, traffic steering, and GS-lite stream processing engine [18]	• onos-kpimon (KPM monitoring), onos-rsm (slice management), onos-mho (mobile handover for mobility management), onos-mlb (load balancing between cells), onos-pci (for managing PCI resources)	• Besides the xApps provided by OSC, OAIC introduced their own KPI monitor and slice control xApps
Lang. Lic.	• *C/C++* • OAIPL1.1	• *Python*, *Go* , and *C/C++* • ALV2 mostly besides CCLA4I	• *Go* • ALV2	• *C/C++* • GAGPLV3

'Hoffman et.al., Open RAN xApps Design and Evaluation: Lessons Learnt and Identified Challenges: https://ieeexplore.ieee.org/document/10329915

- ONF: Open Networking Foundation
- OAIC: Open AI Cellular

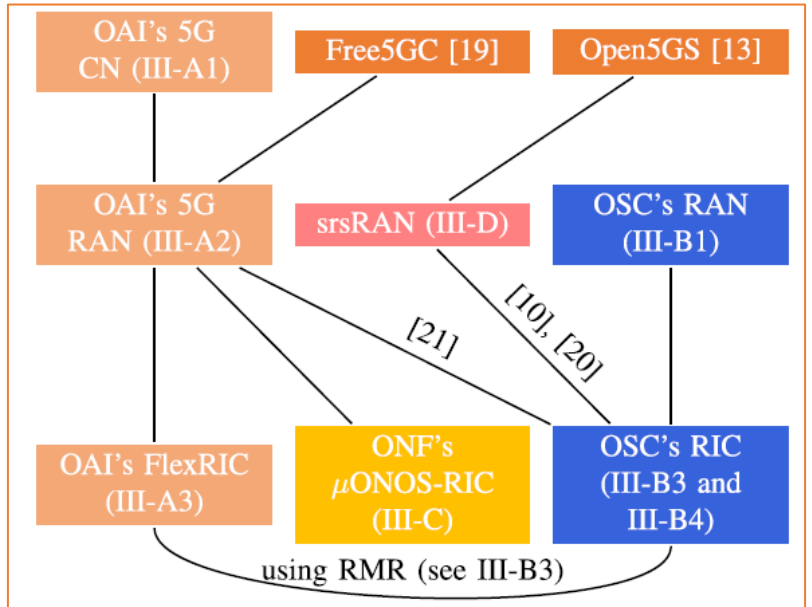
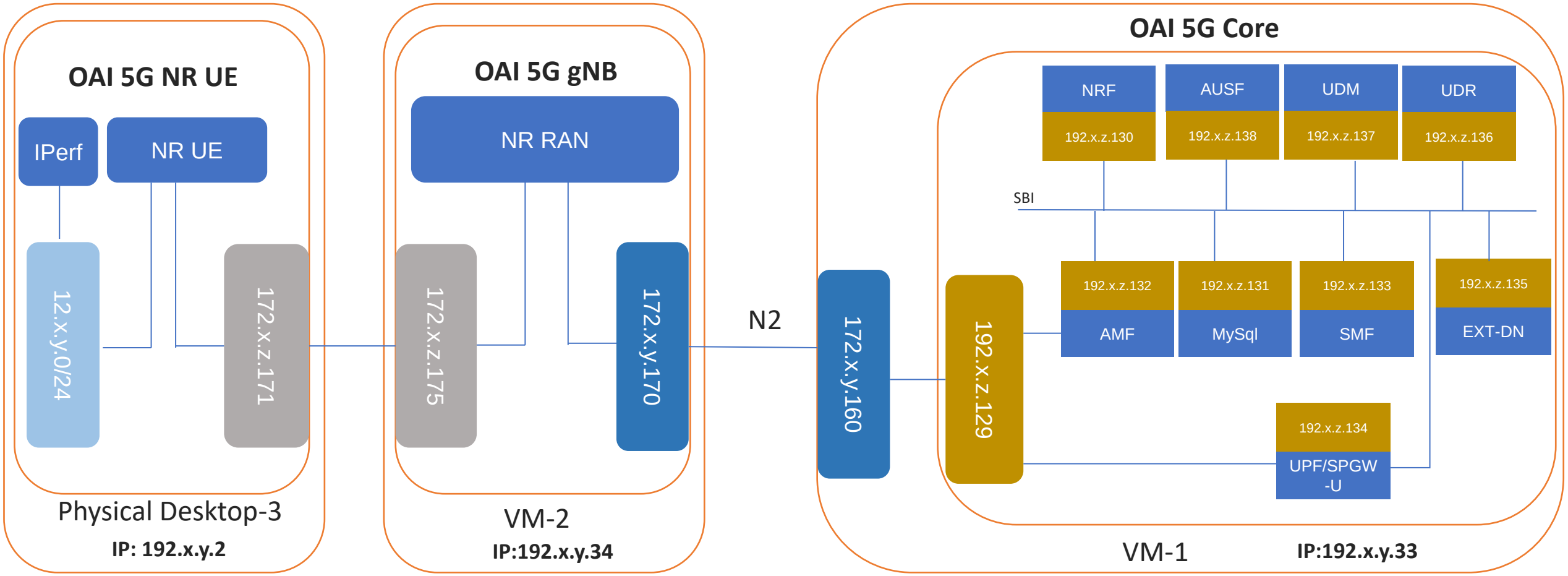


Fig. 2. Projects for building and testing a complete end-to-end 5G system with Open RAN functionalities and their compatibility. Starting from the top, the first row lists 5G CN projects, the second row mentions 5G RAN implementations, and the last row lists RIC implementations. Colors indicate the vendor: OAI (light orange); OSC (blue); ONF (yellow); srsRAN (red), and other vendors (dark orange).

A Short Demo – Use of Open Air Interface, enabling a 5G network

OAI TEST-SETUP ARCHITECTURE – Phy layer emulation (VM-1: Core , VM-2: RAN , PD-1: UE)



Throughput Results:

- DL: Core->1.2 Gbps , UE->35 to 45 Mbps
- UL: UE ->100 Mbps , Core -> 3.93 Mbps

OAI CORE NETWORK PATH & POD DEPLOYMENT

- CORE NETWORK VM DETAILS-(IP:192.x.y.33)
- Change directory to below path where CN files are located

  /home/oaiuser/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn
- Run the below command to activate the CN PODs

  #docker compose -f docker-compose.yml up –d

```
oaiuser@VM1OAICORE:~/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn$ pwd
/home/oaiuser/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn
oaiuser@VM1OAICORE:~/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn$ sudo docker compose -f docker-compo
se.yml up -d
[+] Running 9/0
 ✔ Container oai-ext-dn  Running                                                                                    0.0s
 ✔ Container oai-nrf     Running                                                                                    0.0s
 ✔ Container mysql       Running                                                                                    0.0s
 ✔ Container oai-udr     Running                                                                                    0.0s
 ✔ Container oai-udm     Running                                                                                    0.0s
 ✔ Container oai-ausf    Running                                                                                    0.0s
 ✔ Container oai-amf     Running                                                                                    0.0s
 ✔ Container oai-smf     Running                                                                                    0.0s
 ✔ Container oai-spgwu   Running                                                                                    0.0s
oaiuser@VM1OAICORE:~/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn$
```

- Commands to check AMF and SMF logs:

  #sudo docker logs -f oai-amf

  #sudo docker logs -f oai-smf

OAI CORE NETWORK – POD STATUS CHECK

- Command to check POD HEALTH status:

  #docker compose -f docker-compose.yml ps –a

```
oaiuser@VM1OAICORE:~/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn$ sudo docker compose -f docker-compose.yml ps -a
NAME         IMAGE                                       COMMAND
                                                                                SERVICE              CREATED       STATUS                  PORTS
mysql        mysql:8.0                                   "docker-entrypoint.sh mysqld"
                                                                                mysql                13 days ago   Up 13 days (healthy)    3306/tcp, 33060/
tcp
oai-amf      oaisoftwarealliance/oai-amf:v1.5.1          "python3 /openair-amf/bin/entrypoint.py /openair-amf/bin/oai_amf -c /openair-amf/etc/amf.conf -
o"                                                                              oai-amf              13 days ago   Up 13 days (healthy)    80/tcp, 9090/tcp
, 38412/sctp
oai-ausf     oaisoftwarealliance/oai-ausf:v1.5.1         "python3 /openair-ausf/bin/entrypoint.py /openair-ausf/bin/oai_ausf -c /openair-ausf/etc/ausf.c
onf -o"                                                                         oai-ausf             13 days ago   Up 13 days (healthy)    80/tcp
oai-ext-dn   oaisoftwarealliance/trf-gen-cn5g:latest     "/bin/bash -c ' ip route add 12.1.1.0/24 via 192.168.70.134 dev eth0; ip route; iperf3 -s -D; s
leep infinity' /bin/bash -c 'trap : SIGTERM SIGINT; sleep infinity & wait'"     oai-traffic-server   13 days ago   Up 13 days (healthy)
oai-nrf      oaisoftwarealliance/oai-nrf:v1.5.1          "python3 /openair-nrf/bin/entrypoint.py /openair-nrf/bin/oai_nrf -c /openair-nrf/etc/nrf.conf -
o"                                                                              oai-nrf              13 days ago   Up 13 days (healthy)    80/tcp, 9090/tcp
oai-smf      oaisoftwarealliance/oai-smf:v1.5.1          "python3 /openair-smf/bin/entrypoint.py /openair-smf/bin/oai_smf -c /openair-smf/etc/smf.conf -
o"                                                                              oai-smf              13 days ago   Up 13 days (healthy)    80/tcp, 8080/tcp
, 8805/udp
oai-spgwu    oaisoftwarealliance/oai-spgwu-tiny:v1.5.1   "python3 /openair-spgwu-tiny/bin/entrypoint.py /openair-spgwu-tiny/bin/oai_spgwu -c /openair-sp
gwu-tiny/etc/spgw_u.conf -o"                                                    oai-spgwu            13 days ago   Up 13 days (healthy)    2152/udp, 8805/u
dp
oai-udm      oaisoftwarealliance/oai-udm:v1.5.1          "python3 /openair-udm/bin/entrypoint.py /openair-udm/bin/oai_udm -c /openair-udm/etc/udm.conf -
o"                                                                              oai-udm              13 days ago   Up 13 days (healthy)    80/tcp
oai-udr      oaisoftwarealliance/oai-udr:v1.5.1          "python3 /openair-udr/bin/entrypoint.py /openair-udr/bin/oai_udr -c /openair-udr/etc/udr.conf -
o"                                                                              oai-udr              13 days ago   Up 13 days (healthy)    80/tcp
oaiuser@VM1OAICORE:~/oai/slicing-with-nssf/oai-cn5g-fed/charts/oai-5g-core/summerworkshop2023/cn$
```

OAI RAN SOURCE FILES PATH AND RAN EXECUTION

- RAN VM DETAILS-(IP:192.x.y.34)
- Change directory to below path where RAN source files are located

  /home/oaiuser/openairinterface5g/cmake_targets/ran_build/build/
- Run the below command to activate RAN and to establish NGAP connection between RAN & core network

  sudo -E RFSIMULATOR=server ./nr-softmodem --rfsim --sa -O /home/oaiuser/openairinterface5g/cmake_targets/ran_build/build/summerworkshop2023-main-ran/ran/conf/gnb.sa.band78.106prb.rfsim.conf

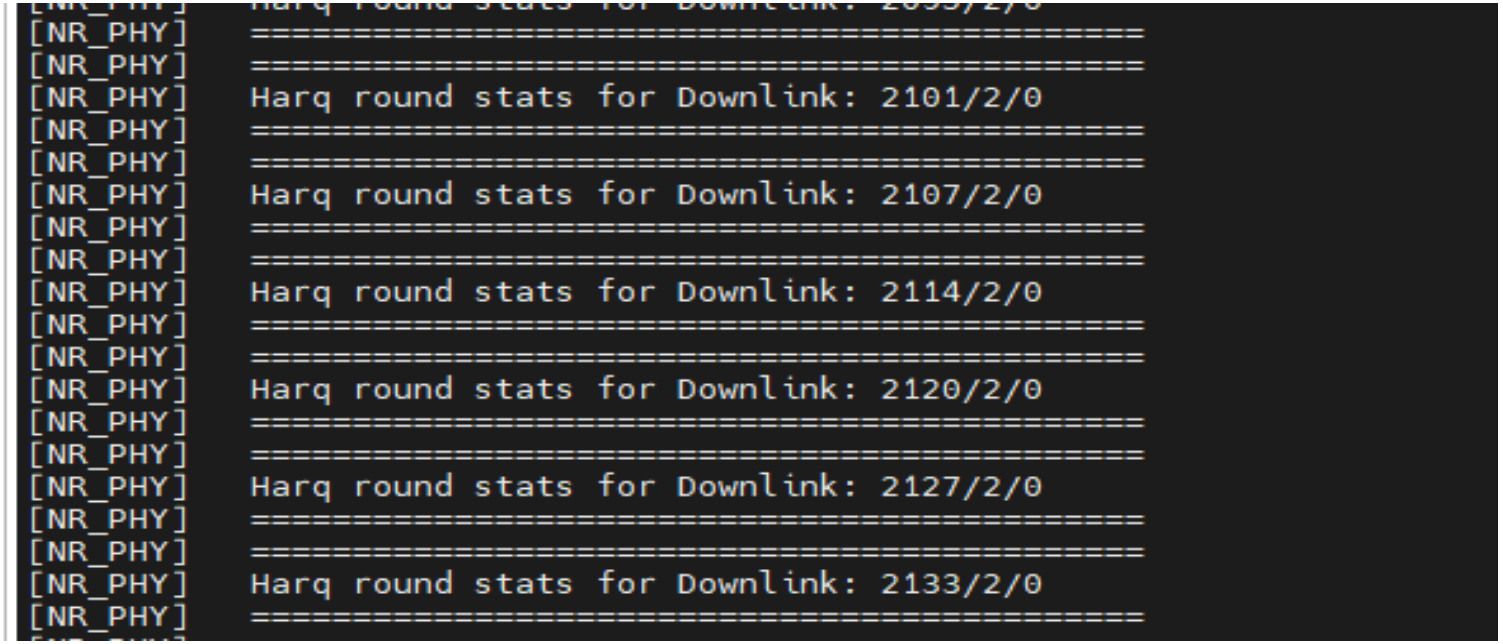
```
[UTIL]   Creating thread Tpool6_-1 with affinity -1 and priority 50
create a thread for core -1
[UTIL]   Creating thread Tpool7_-1 with affinity -1 and priority 50
[PHY]   Creating thread for TX reordering and dispatching to RU
[UTIL]   Creating thread thread_tx_reorder with affinity -1 and priority 97
[UTIL]   Creating thread L1_stats with affinity -1 and priority 1
waiting for sync (L1_stats_thread,-1/0x55e3c0cc82d4,0x55e3c16011c0,0x55e3c1601180)
ALL RUs ready - ALL gNBs ready
Sending sync to all threads
Entering ITTI signals handler
TYPE <CTRL-C> TO TERMINATE
got sync (L1_stats_thread)
got sync (ru_thread)
[PHY]   RU 0 rf device ready
[PHY]   RU 0 RF started opp_enabled 0
[HW]   No connected device, generating void samples...
[PHY]   tx_reorder_thread started
[NR_MAC]   Frame.Slot 128.0

[NR_MAC]   Frame.Slot 256.0

[NR_MAC]   Frame.Slot 384.0

[NR_MAC]   Frame.Slot 512.0

[NR_MAC]   Frame.Slot 640.0

[NR_MAC]   Frame.Slot 768.0

[NR_MAC]   Frame.Slot 896.0

[NR_MAC]   Frame.Slot 0.0
```

OAI UE SOURCE FILE PATH & EXECUTION

- UE-Physical machine details-(IP:192.x.y.2)
- Change directory to below path where UE source files are located

  /home/oaiuser/openairinterface5g/cmake_targets/ran_build/build
- Run the below command to activate UE

sudo -E rfsimulator.serveraddr=172.6.1.175 ./nr-uesoftmodem -r 106 --numerology 1 --band 78 -C 3619200000 --rfsim --sa --nokrnmod –O /home/necadmin/openairinterface5g/cmake_targets/ran_build/build/summerworkshop2023-main-ran/ran/conf/ue.conf



OAI 5G CONNECTED STATUS – CORE NETWORK

- After activating the GNB and UE, the 5G connection status can be verified in CORE NETWORK Host by executing below command

#sudo docker logs -f oai-amf

```
----------------------|
[2023-12-01 08:19:08.359] [amf_app] [info]
[2023-12-01 08:19:28.359] [amf_app] [info]
[2023-12-01 08:19:28.359] [amf_app] [info] |----------------------------------------------------------------------------------------------------
----------------------|
[2023-12-01 08:19:28.359] [amf_app] [info] |-----------------------------------------------------gNBs' information----------------------
----------------------|
[2023-12-01 08:19:28.359] [amf_app] [info] |    Index    |      Status      |       Global ID       |       gNB Name       |
    PLMN            |
[2023-12-01 08:19:28.359] [amf_app] [info] |      1      |    Connected     |         0xe000        |         gNB-Eurecom-5GNRBox
        |            001, 01            |
[2023-12-01 08:19:28.359] [amf_app] [info] |----------------------------------------------------------------------------------------------------
----------------------|
[2023-12-01 08:19:28.359] [amf_app] [info]
[2023-12-01 08:19:28.359] [amf_app] [info] |----------------------------------------------------------------------------------------------------
----------------------|
[2023-12-01 08:19:28.359] [amf_app] [info] |-----------------------------------------------------UEs' information----------------------
----------------------|
[2023-12-01 08:19:28.359] [amf_app] [info] | Index |      5GMM state      |      IMSI        |     GUTI      | RAN UE NGAP ID | AMF UE
ID |  PLMN   |Cell ID|
[2023-12-01 08:19:28.359] [amf_app] [info] |      1|       5GMM-REGISTERED|   001010000000101|               |               0|
  3| 001, 01 |14680064|
[2023-12-01 08:19:28.359] [amf_app] [info] |----------------------------------------------------------------------------------------------------
----------------------|
[2023-12-01 08:19:28.359] [amf_app] [info]
```

IPERF COMMAND TO VERIFY THE DOWNLINK THROUGHPUT

- Execute below iperf command in UE host to start iperf server.

  #iperf3 -s -B <UE-IP>

```
necadmin@CNDT-5GSIT03:~$ iperf3 -s -B 12.1.1.163
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 192.168.70.135, port 59564
[  5] local 12.1.1.163 port 5201 connected to 192.168.70.135 port 47918
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec  1.40 MBytes  11.7 Mbits/sec  0.734 ms  520/1533 (34%)
[  5]   1.00-2.00   sec  2.28 MBytes  19.1 Mbits/sec  0.589 ms  1610/3262 (49%)
[  5]   2.00-3.00   sec  3.28 MBytes  27.5 Mbits/sec  0.353 ms  1981/4357 (45%)
[  5]   3.00-4.00   sec  2.58 MBytes  21.6 Mbits/sec  0.509 ms  6511/8378 (78%)
[  5]   4.00-5.00   sec  5.16 MBytes  43.3 Mbits/sec  0.012 ms  237224/240961 (98%)
[  5]   5.00-6.00   sec  5.09 MBytes  42.7 Mbits/sec  0.020 ms  127304/130989 (97%)
[  5]   6.00-7.00   sec  5.12 MBytes  43.0 Mbits/sec  0.022 ms  105333/109043 (97%)
[  5]   7.00-8.00   sec  4.10 MBytes  34.4 Mbits/sec  0.024 ms  84295/87263 (97%)
[  5]   8.00-9.00   sec  5.12 MBytes  43.0 Mbits/sec  0.004 ms  105587/109297 (97%)
[  5]   9.00-10.00  sec  5.39 MBytes  45.2 Mbits/sec  0.003 ms  110540/114441 (97%)
[  5]  10.00-11.00  sec  4.10 MBytes  34.4 Mbits/sec  0.006 ms  84272/87241 (97%)
[  5]  11.00-12.00  sec  5.09 MBytes  42.7 Mbits/sec  0.003 ms  105288/108972 (97%)
[  5]  12.00-13.00  sec  5.11 MBytes  42.9 Mbits/sec  0.006 ms  105381/109085 (97%)
[  5]  13.00-14.00  sec  4.10 MBytes  34.4 Mbits/sec  0.003 ms  83727/86696 (97%)
[  5]  14.00-15.00  sec  5.13 MBytes  43.0 Mbits/sec  0.003 ms  105621/109336 (97%)
^C[  5]  15.00-15.74  sec  4.35 MBytes  49.3 Mbits/sec  0.010 ms  89428/92577 (97%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-15.74  sec  67.4 MBytes  35.9 Mbits/sec  0.010 ms  1354622/1403431 (97%)  receiver
iperf3: interrupt - the server has terminated
necadmin@CNDT-5GSIT03:~$ iperf3 -s -B 12.1.1.163
```

- Login to ”oai-ext-dn” POD in CORE NW HOST with the command

  #docker exec -it oai-ext-dn bash

- After entering pod execute below iperf command to trigger DL data.

  #iperf3 -c <UE-IP> -u -b 1200M -t 500

```
root@ab0e021347d6:/tmp# iperf3 -c 12.1.1.163 -u -b 1200M -t 500
Connecting to host 12.1.1.163, port 5201
[  5] local 192.168.70.135 port 47918 connected to 12.1.1.163 port 5201
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec   143 MBytes  1.20 Gbits/sec  103569
[  5]   1.00-2.00   sec   143 MBytes  1.20 Gbits/sec  103560
[  5]   2.00-3.00   sec   143 MBytes  1.20 Gbits/sec  103634
[  5]   3.00-4.00   sec   143 MBytes  1.20 Gbits/sec  103591
[  5]   4.00-5.00   sec   143 MBytes  1.20 Gbits/sec  103601
[  5]   5.00-6.00   sec   143 MBytes  1.20 Gbits/sec  103523
[  5]   6.00-7.00   sec   143 MBytes  1.20 Gbits/sec  103558
[  5]   7.00-8.00   sec   143 MBytes  1.20 Gbits/sec  103677
[  5]   8.00-9.00   sec   143 MBytes  1.20 Gbits/sec  103601
[  5]   9.00-10.00  sec   143 MBytes  1.20 Gbits/sec  103507
[  5]  10.00-11.00  sec   143 MBytes  1.20 Gbits/sec  103579
[  5]  11.00-12.00  sec   143 MBytes  1.20 Gbits/sec  103664
[  5]  12.00-13.00  sec   143 MBytes  1.20 Gbits/sec  103619
[  5]  13.00-14.00  sec   143 MBytes  1.20 Gbits/sec  103558
[  5]  14.00-15.00  sec   143 MBytes  1.20 Gbits/sec  103611
[  5]  14.00-15.00  sec   143 MBytes  1.20 Gbits/sec  103611
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-15.00  sec  2.19 GBytes  1.26 Gbits/sec  0.000 ms  0/1626699 (0%)  sender
[  5]   0.00-15.00  sec  0.00 Bytes  0.00 bits/sec  0.000 ms  0/0 (0%)  receiver
iperf3: error - the server has terminated
root@ab0e021347d6:/tmp# iperf3 -c 12.1.1.163 -u -b 100M -t 500 -R
```

IPERF COMMAND TO VERIFY THE UPLINK THROUGHPUT

- Execute below iperf command in UE host to start iperf server.

  #iperf3 -s -B <UE-IP>

```
necadmin@CNDT-5GSIT03:~$ iperf3 -s -B 12.1.1.163
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
Accepted connection from 192.168.70.135, port 37220
[  5] local 12.1.1.163 port 5201 connected to 192.168.70.135 port 57122
[ ID] Interval           Transfer     Bitrate         Total Datagrams
[  5]   0.00-1.00   sec  11.9 MBytes  99.9 Mbits/sec  8625
[  5]   1.00-2.00   sec  11.9 MBytes   100 Mbits/sec  8633
[  5]   2.00-3.00   sec  11.9 MBytes   100 Mbits/sec  8632
[  5]   3.00-4.00   sec  11.9 MBytes   100 Mbits/sec  8633
[  5]   4.00-5.00   sec  11.9 MBytes   100 Mbits/sec  8632
[  5]   5.00-6.00   sec  11.9 MBytes   100 Mbits/sec  8633
[  5]   6.00-7.00   sec  11.9 MBytes   100 Mbits/sec  8633
[  5]   7.00-8.00   sec  11.9 MBytes   100 Mbits/sec  8632
[  5]   8.00-9.00   sec  11.9 MBytes   100 Mbits/sec  8633
[  5]   9.00-10.00  sec  11.9 MBytes   100 Mbits/sec  8632
[  5]  10.00-11.00  sec  11.9 MBytes   100 Mbits/sec  8633
[  5]  11.00-12.00  sec  11.9 MBytes   100 Mbits/sec  8633
[  5]  12.00-13.00  sec  11.9 MBytes   100 Mbits/sec  8632
[  5]  13.00-14.00  sec  11.9 MBytes   100 Mbits/sec  8633
[  5]  14.00-15.00  sec  11.9 MBytes   100 Mbits/sec  8632
[  5]  15.00-16.00  sec  11.9 MBytes   100 Mbits/sec  8633
[  5]  16.00-17.00  sec  11.9 MBytes   100 Mbits/sec  8633
[  5]  17.00-18.00  sec  11.9 MBytes   100 Mbits/sec  8632
[  5]  18.00-19.00  sec  11.9 MBytes   100 Mbits/sec  8633
[  5]  19.00-20.00  sec  11.9 MBytes   100 Mbits/sec  8632
[  5]  20.00-21.00  sec  11.9 MBytes   100 Mbits/sec  8634
[  5]  20.00-21.00  sec  11.9 MBytes   100 Mbits/sec  8634
```

- Login to ”oai-ext-dn” POD in CORE NW HOST with the command

  #docker exec -it oai-ext-dn bash

- After entering pod execute below iperf command to trigger UL data.

  #iperf3 -c <UE-IP> -u -b 1200M -t 500 -R

```
root@ab0e021347d6:/tmp# iperf3 -c 12.1.1.163 -u -b 100M -t 500 -R
Connecting to host 12.1.1.163, port 5201
Reverse mode, remote host 12.1.1.163 is sending
[  5] local 192.168.70.135 port 57122 connected to 12.1.1.163 port 5201
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec   611 KBytes  5.00 Mbits/sec  2.717 ms  271/703 (39%)
[  5]   1.00-2.00   sec   479 KBytes  3.93 Mbits/sec  2.623 ms  0/339 (0%)
[  5]   2.00-3.00   sec   479 KBytes  3.93 Mbits/sec  2.682 ms  0/339 (0%)
[  5]   3.00-4.00   sec   479 KBytes  3.93 Mbits/sec  2.715 ms  0/339 (0%)
[  5]   4.00-5.00   sec   479 KBytes  3.93 Mbits/sec  2.673 ms  0/339 (0%)
[  5]   5.00-6.00   sec   479 KBytes  3.93 Mbits/sec  2.774 ms  0/339 (0%)
[  5]   6.00-7.00   sec   479 KBytes  3.93 Mbits/sec  2.751 ms  0/339 (0%)
[  5]   7.00-8.00   sec   479 KBytes  3.93 Mbits/sec  2.805 ms  0/339 (0%)
[  5]   8.00-9.00   sec   479 KBytes  3.93 Mbits/sec  2.863 ms  0/339 (0%)
[  5]   9.00-10.00  sec   479 KBytes  3.93 Mbits/sec  2.762 ms  0/339 (0%)
[  5]  10.00-11.00  sec   479 KBytes  3.93 Mbits/sec  2.867 ms  0/339 (0%)
[  5]  11.00-12.00  sec   479 KBytes  3.93 Mbits/sec  2.919 ms  0/339 (0%)
[  5]  12.00-13.00  sec   481 KBytes  3.94 Mbits/sec  3.062 ms  0/340 (0%)
[  5]  13.00-14.00  sec   479 KBytes  3.93 Mbits/sec  2.623 ms  0/339 (0%)
[  5]  14.00-15.00  sec   479 KBytes  3.93 Mbits/sec  2.648 ms  0/339 (0%)
[  5]  15.00-16.00  sec   479 KBytes  3.93 Mbits/sec  2.564 ms  0/339 (0%)
[  5]  16.00-17.00  sec   482 KBytes  3.95 Mbits/sec  2.936 ms  0/341 (0%)
[  5]  17.00-18.00  sec   479 KBytes  3.93 Mbits/sec  2.921 ms  0/339 (0%)
[  5]  18.00-19.00  sec   482 KBytes  3.95 Mbits/sec  2.579 ms  0/341 (0%)
[  5]  19.00-20.00  sec   325 KBytes  2.66 Mbits/sec  8.353 ms  1275/1505 (85%)
^C[  5]  20.00-20.51  sec   294 KBytes  4.74 Mbits/sec  0.900 ms  4273/4481 (95%)
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         Jitter    Lost/Total Datagrams
[  5]   0.00-20.51  sec  0.00 Bytes  0.00 bits/sec  0.000 ms  0/0 (0%)  sender
```

Conclusion

Conclusion – Research for Open RAN Standards

- We are in an threshold to bring in solutions for optimized next generation mobile networks
- The goal is to pursue and leverage optimal cloud based (virtual) deployments, open interfaces leveraging AI/ML based solutions for the next gen networks – 6G
- While research both in industry and academia is well progressing, there are still many issues to be addressed and standardized
- Standards bodies are working in a collaborative way to address the challenges for next gen networks
- Open source solutions are extensively available to both industry and academic researchers to enable their ground breaking and fundamental research
- For Indian Academia, the opportunity to contribute to O-RAN Alliance standardization is very high
  - Contribution to the O-RAN OSC – enabling new releases
  - O-RAN SCP enables contributions that are linked with patents (i.e. SEPs in O-RAN is applicable)
  - Contribution to the specifications development with participation in the Working Group meetings

Q&A, Thank You

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