國立陽明交通大學
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An Introduction to O-RAN

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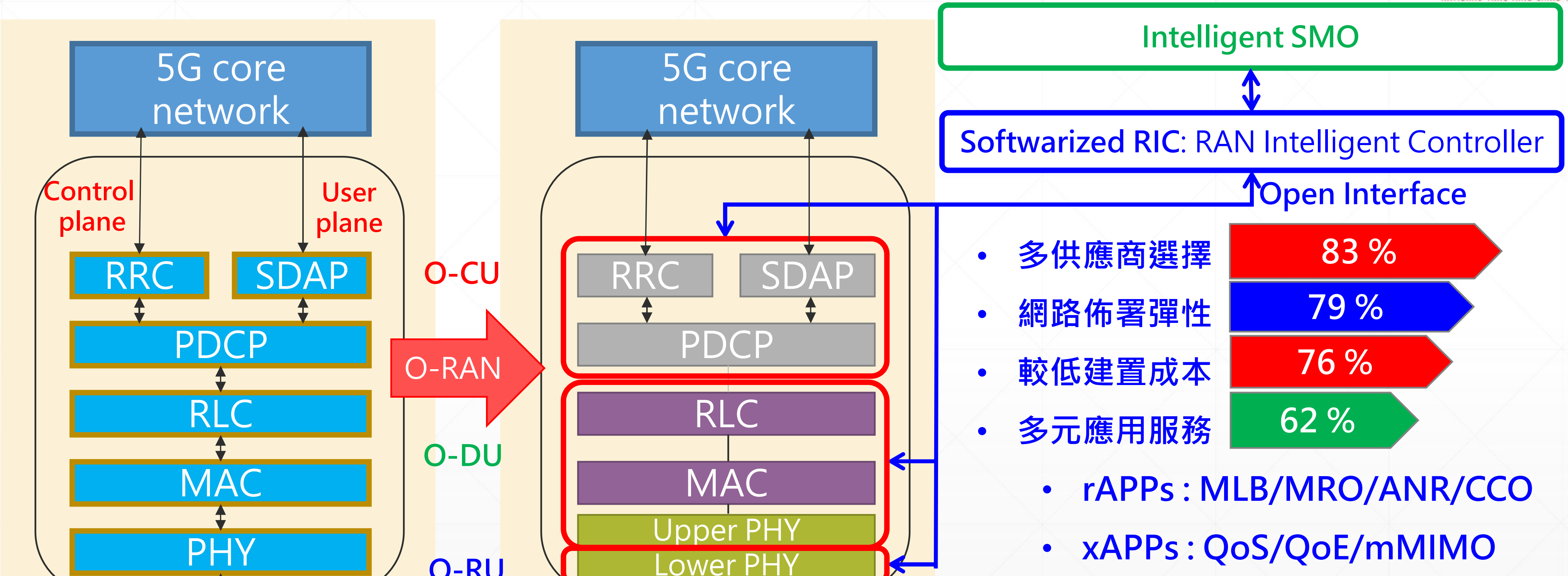
The O-RAN Alliance

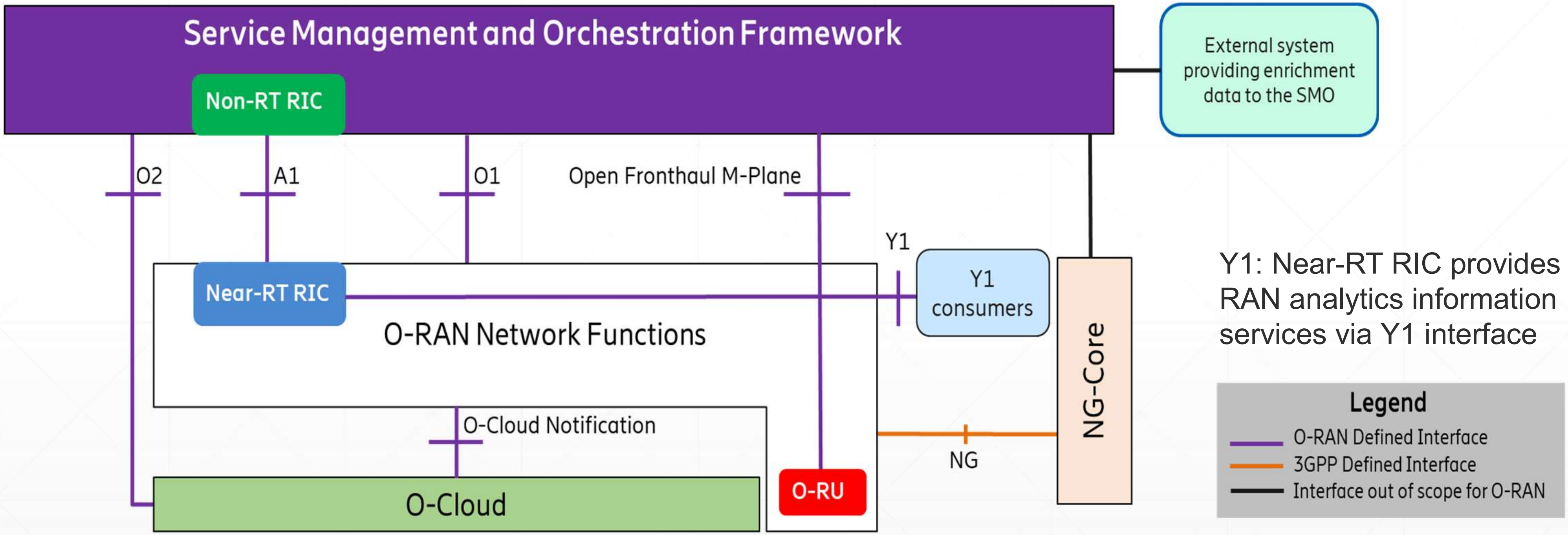
- Founded in February 2018 by AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO and Orange
- To re-shape the RAN industry towards a more intelligent, open, virtualized and fully interoperable mobile network
  - Extending RAN standards towards openness and intelligence
  - Development of open software for the RAN
  - Supporting members companies in testing and integration of their O-RAN implementations

What Are The Key Features of O-RAN?



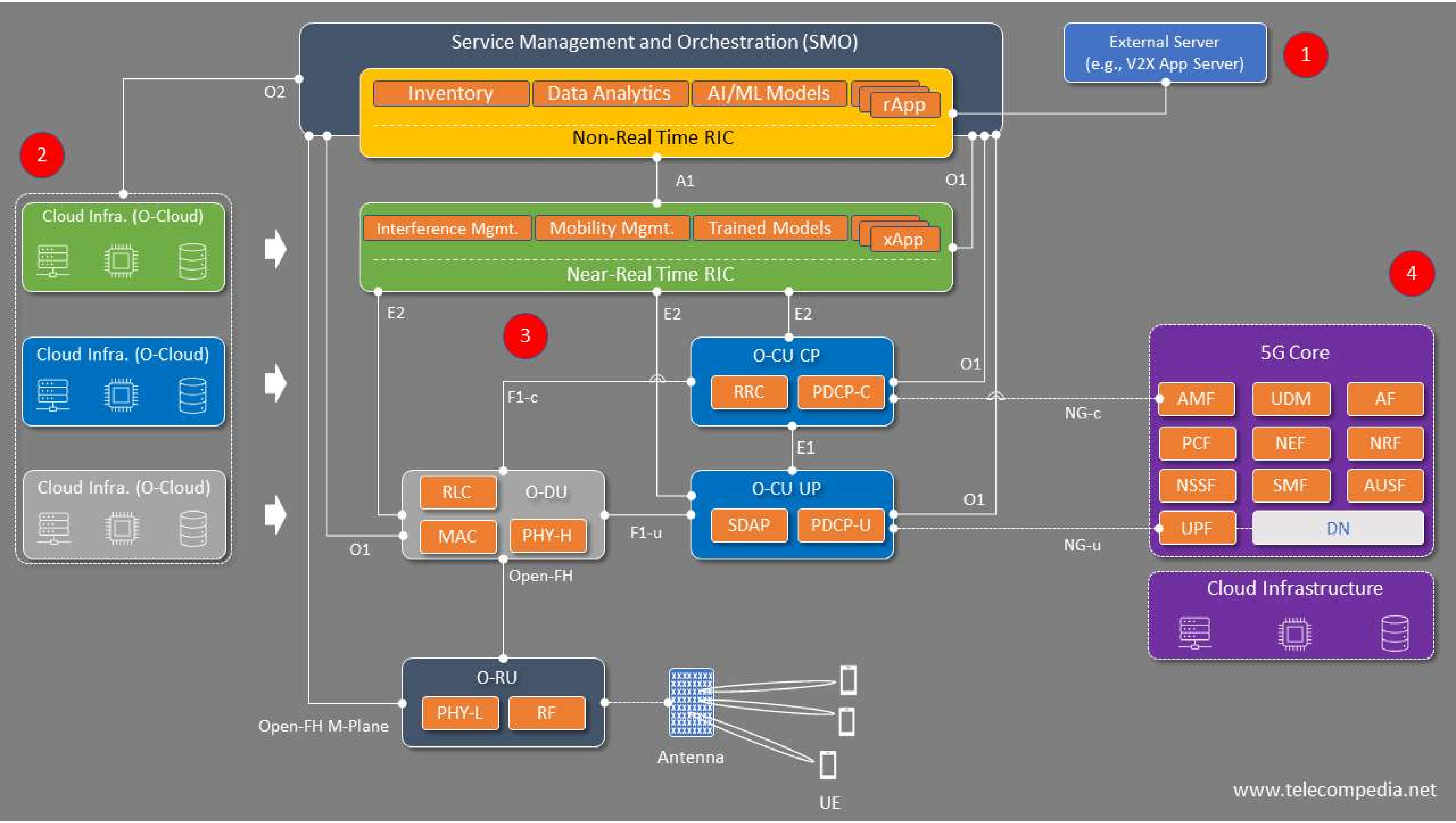
SMO* : Service Management and Orchestration
RRC* : Radio Resource Control
SDAP*: Service Data Adaptation Protocol
PDCP*: Packet Data Convergence Protocol

The Architecture of O-RAN

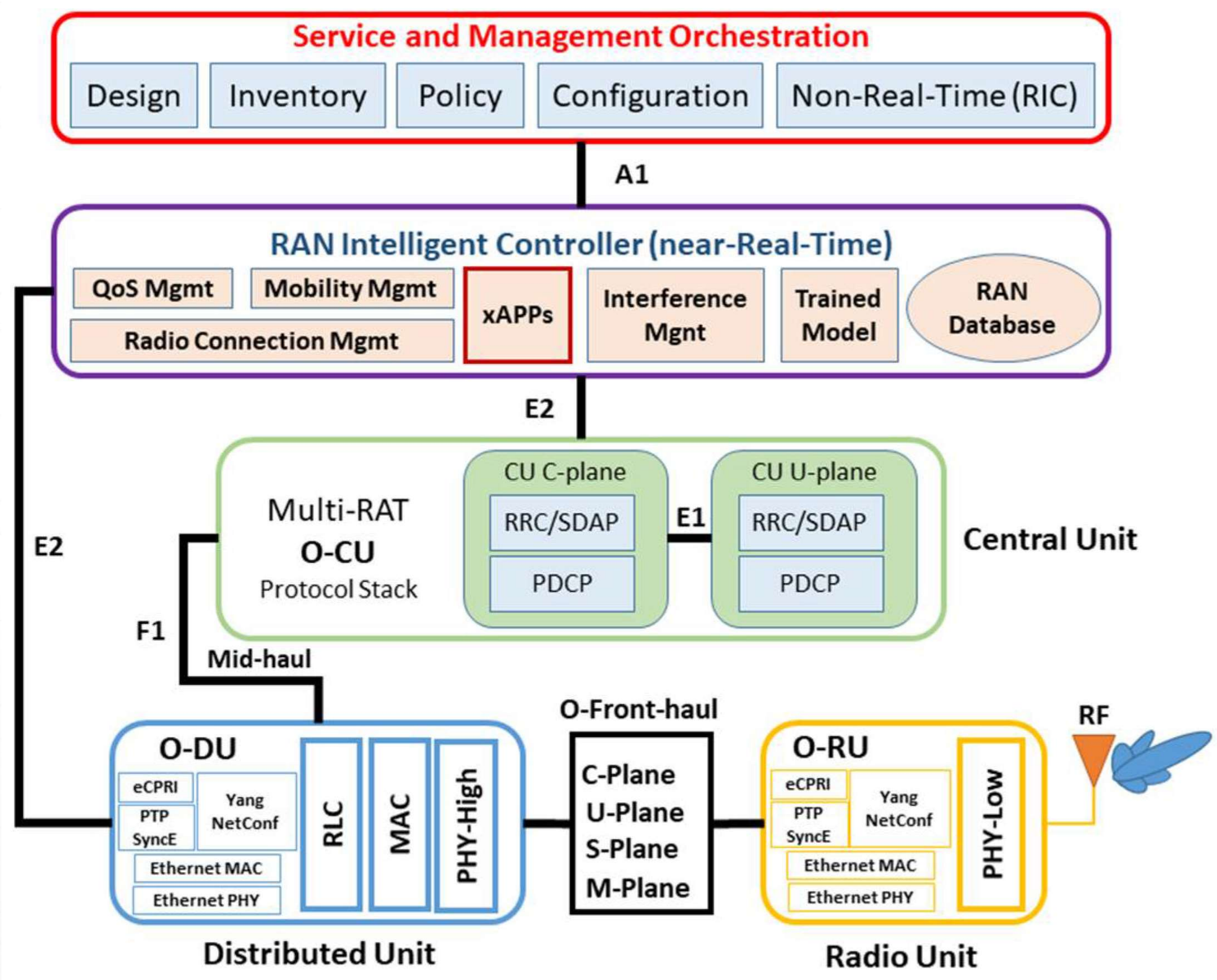


Y1: Near-RT RIC provides RAN analytics information services via Y1 interface

- The O-Cloud is a cloud platform that comprises nodes to host the functions of Near-RT RIC, O-DU, O-CU-CP, O-CU-UP, VM monitor, container runtime etc.



Service Management and Orchestration (SMO)
Inventory
Data Analytics
AI/ML Models
rApp
Non-Real Time RIC
External Server
(e.g., V2X App Server)
1
O2
2
A1
O1
Cloud Infra. (O-Cloud)
Cloud Infra. (O-Cloud)
Cloud Infra. (O-Cloud)
Interference Mgmt.
Mobility Mgmt.
Trained Models
xApp
Near-Real Time RIC
4
E2
E2
E2
3
O-CU CP
RRC
PDCP-C
O1
5G Core
F1-c
AMF
UDM
AF
NG-c
PCF
NEF
NRF
E1
NSSF
SMF
AUSF
RLC
O-DU
O-CU UP
O1
MAC
PHY-H
F1-u
SDAP
PDCP-U
UPF
DN
O1
NG-u
Open-FH
Cloud Infrastructure
O-RU
PHY-L
RF
Open-FH M-Plane
Antenna
UE
www.telecompedia.net

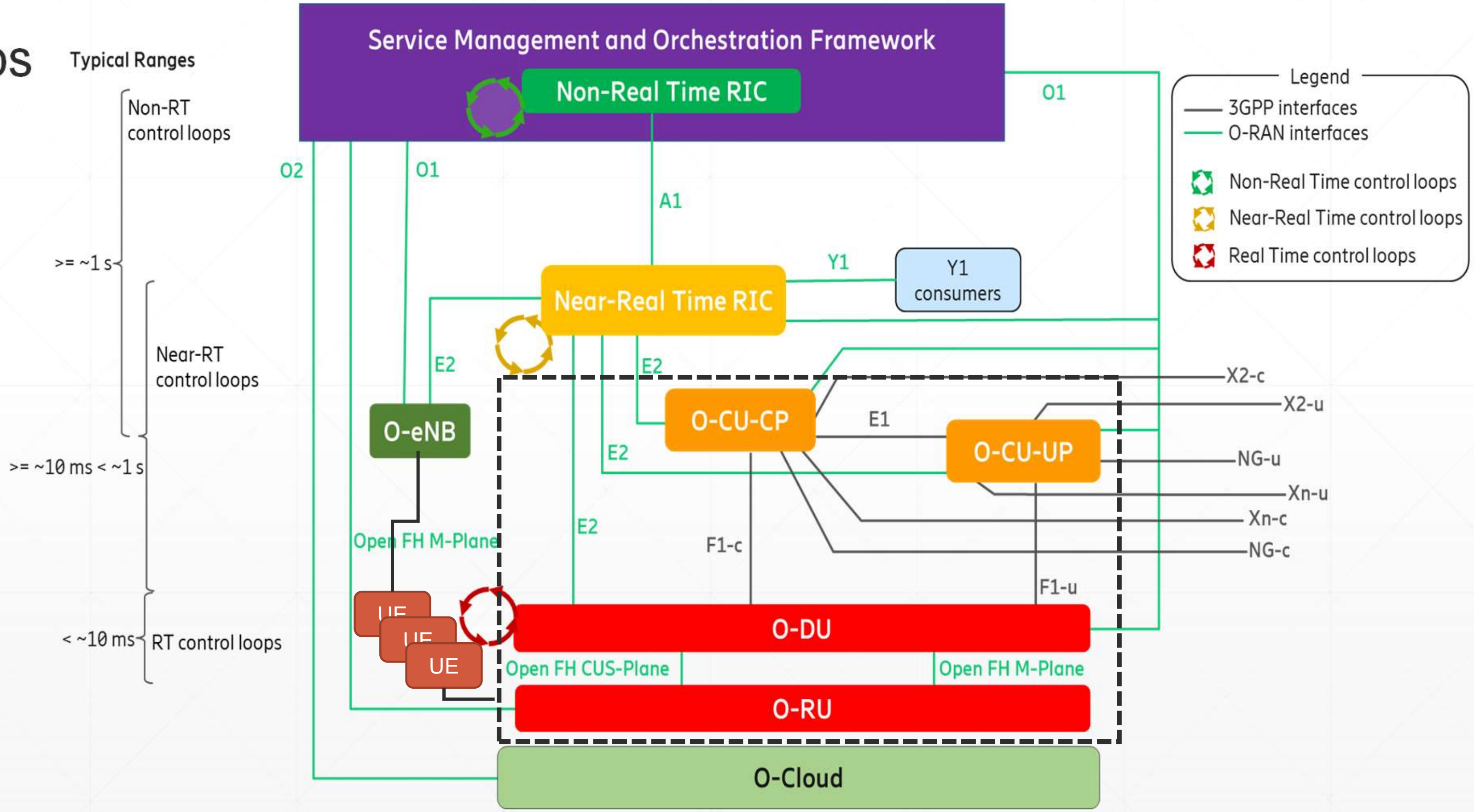


WG1: Overall architecture, use-cases & O1
Chairs: AT&T, CMCC
- **WG2: Non-RT RIC and A1 interface**
Chairs: AT&T, CMCC, Ericsson
- **WG3: Near-RT RIC and E2 interface**
Chairs: DT, CMCC, Nokia
- **WG4: Open Fronthaul**
Chairs: Verizon, Docomo, Nokia, Cisco
- **WG5: Open 3GPP interfaces (HLS)**
Chairs: Orange, Docomo, Ericsson
- **WG6: RAN virtualization**
Chairs: AT&T, Orange, Lenovo
- **WG7: White box hardware**
Chairs: AT&T, CMCC, Qualcomm, Baicells
- **WG8: Software reference design**
Chairs: AT&T, CMCC, Intel, Radisys

Mohsin et al, On Analyzing Beamforming Implementation in O-RAN 5G, *Electronics* **2021**, *10*(17), 2162

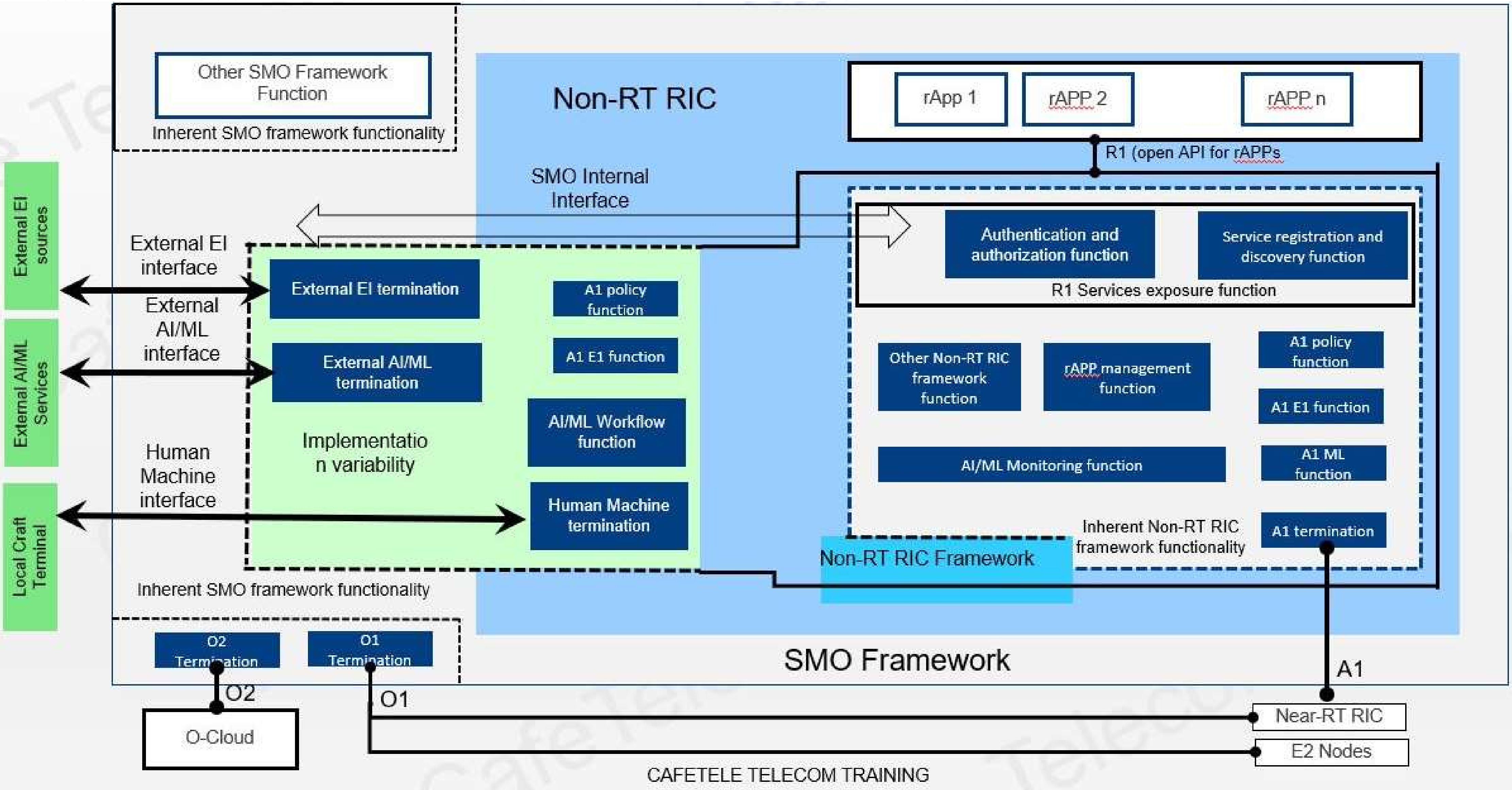
Service Loops of O-RAN

- Control loops
  - Non-RT
  - Near-RT
  - RT



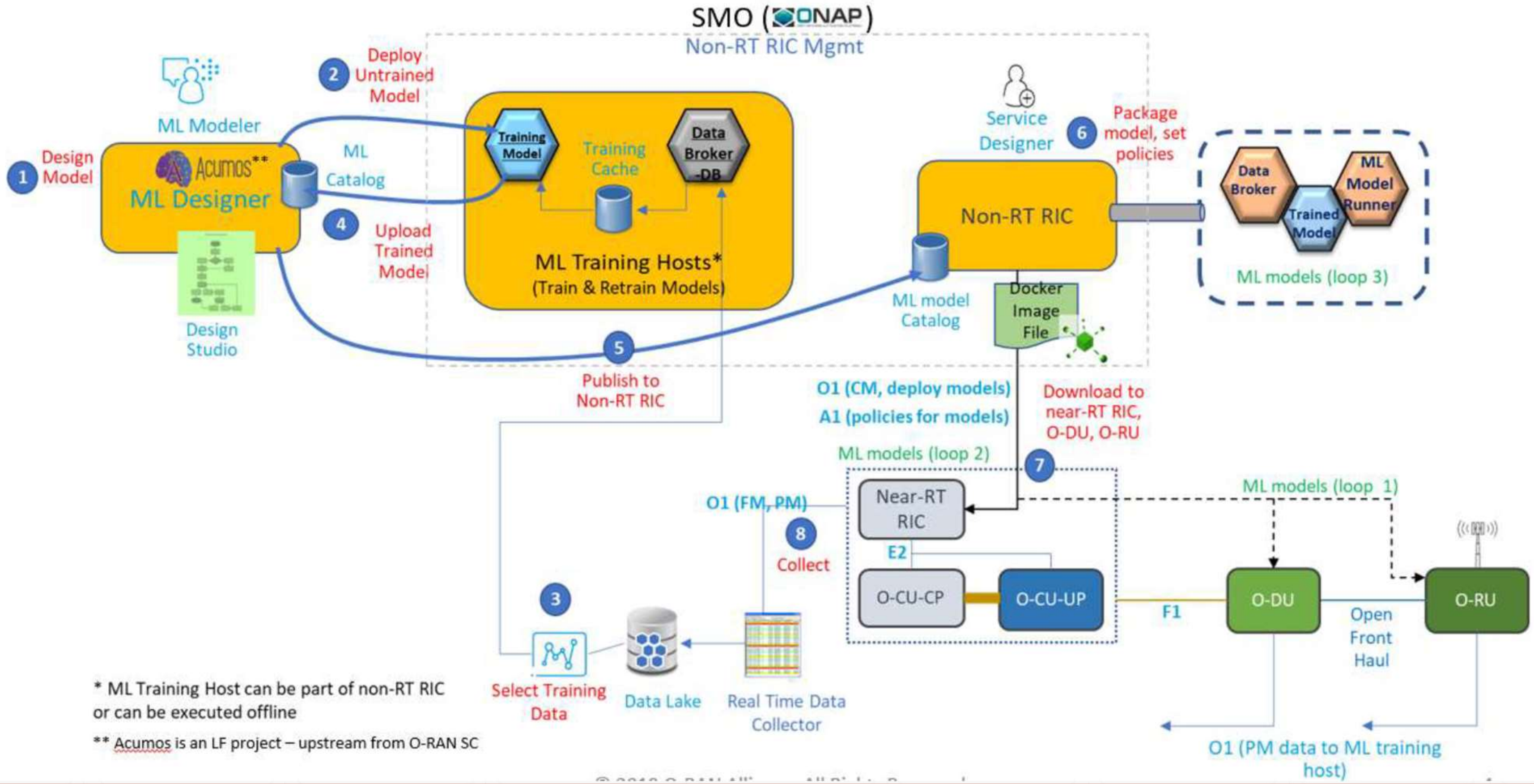
Functions of SMO

- SMO is responsible for RAN domain management,
  - Not for Core, transport, and End to End slice management
- The key capabilities of the SMO for O-RAN
  - Non-RT RIC for RAN optimization
  - FCAPS interface to O-RAN Network Functions
  - O-Cloud Management, Orchestration and Workflow Management
- The SMO performs these services through
  - A1 interface between the Non-RT RIC in SMO and the Near-RT RIC for RAN optimization
  - O1 between SMO and O-RAN or Open FH M-plane interface between SMO and RU for FCAPS
  - O2 between SMO and the O-Cloud to provide platform resource and workload management



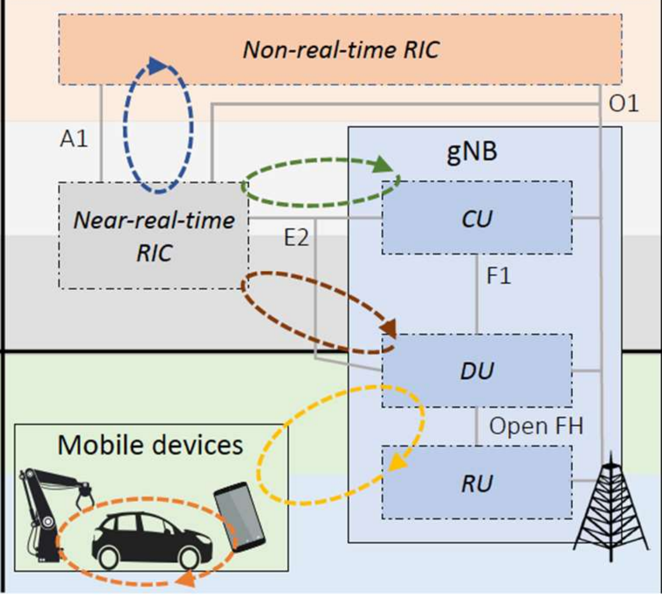
Other SMO Framework Function
Inherent SMO framework functionality
Non-RT RIC
rApp 1
rAPP 2
rAPP n
R1 (open API for rAPPs
SMO Internal Interface
Authentication and authorization function
Service registration and discovery function
R1 Services exposure function
External EI sources
External EI interface
External EI termination
A1 policy function
External AI/ML Services
External AI/ML interface
External AI/ML termination
A1 E1 function
Other Non-RT RIC framework function
rAPP management function
A1 policy function
A1 E1 function
AI/ML Workflow function
Implementation variability
AI/ML Monitoring function
A1 ML function
Local Craft Terminal
Human Machine interface
Human Machine termination
Inherent Non-RT RIC framework functionality
A1 termination
Non-RT RIC Framework
Inherent SMO framework functionality
O2 Termination
O1 Termination
SMO Framework
A1
O2
O1
O-Cloud
Near-RT RIC
E2 Nodes
CAFETELE TELECOM TRAINING

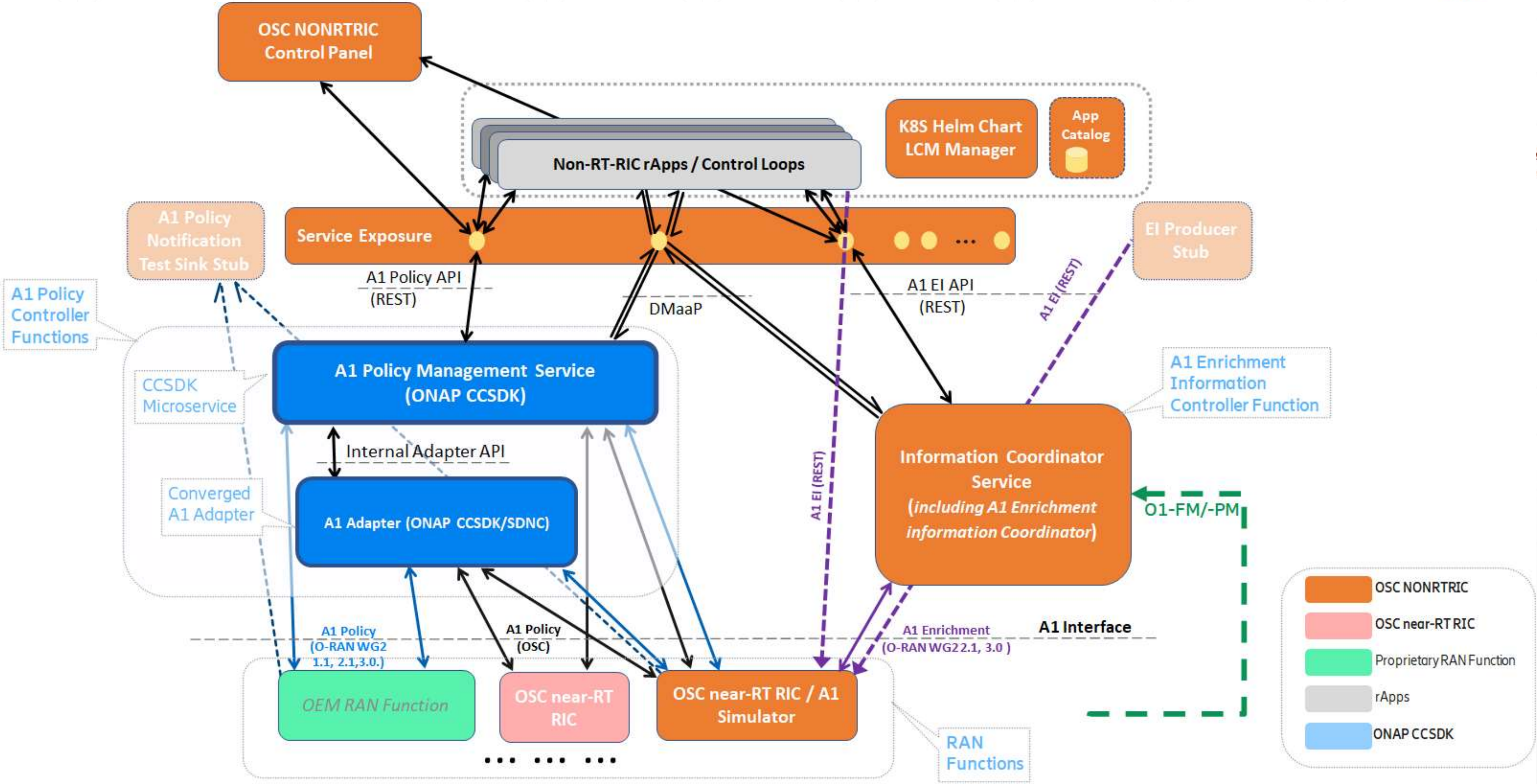
Management of AI Models



RIC Functions and Service Hierarchies

Control and learning objective	Scale	Input data	Timescale	Architecture	Challenges and limitations	
Policies, models, slicing	> 1000 devices	Infrastructure-level KPMs	Non-real-time > 1 s		Orchestration of large scale deployments with multiple near-RT RICs, RAN nodes	Supported by O-RAN
User Session Management e.g., load balancing, handover	> 100 devices	CU-level KPMs e.g., number of sessions, PDCP traffic	Near-real-time 10-1000 ms		Process streams from multiple CUs and sessions	Supported by O-RAN
Medium Access Management e.g., scheduling policy, RAN slicing	> 100 devices	MAC-level KPMs e.g., PRB utilization, buffering	Near-real-time 10-1000 ms		Operate at small time scales, make decisions involving several DUs/UEs	Supported by O-RAN
Radio Management e.g., resource scheduling, beamforming	~10 devices	MAC/PHY-level KPMs e.g., PRB utilization, channel estimation	Real-time < 10 ms		Deployment of AI/ML models at the DU is not supported	For further study
Device DL/UL Management e.g., modulation, interference, blockage detection	1 device	I/Q samples	Real-time < 1 ms		Require device- and/or RU-level standardization	For further study




OSC NONRTRIC Control Panel
Non-RT-RIC rApps / Control Loops
K8S Helm Chart LCM Manager
App Catalog
A1 Policy Notification Test Sink Stub
Service Exposure
...
EI Producer Stub
A1 Policy Controller Functions
A1 Policy API (REST)
DMaaP
A1 EI API (REST)
A1 EI (REST)
A1 Policy Management Service (ONAP CCSDK)
CCSDK Microservice
A1 Enrichment Information Controller Function
Internal Adapter API
Information Coordinator Service (including A1 Enrichment information Coordinator)
Converged A1 Adapter
A1 Adapter (ONAP CCSDK/SDNC)
A1 EI (REST)
O1-FM/-PM
A1 Policy (O-RAN WG2 1.1, 2.1,3.0.)
A1 Policy (OSC)
A1 Enrichment (O-RAN WG2 2.1, 3.0)
A1 Interface
OEM RAN Function
OSC near-RT RIC
OSC near-RT RIC / A1 Simulator
... ...
RAN Functions
OSC NONRTRIC
OSC near-RT RIC
Proprietary RAN Function
rApps
ONAP CCSDK

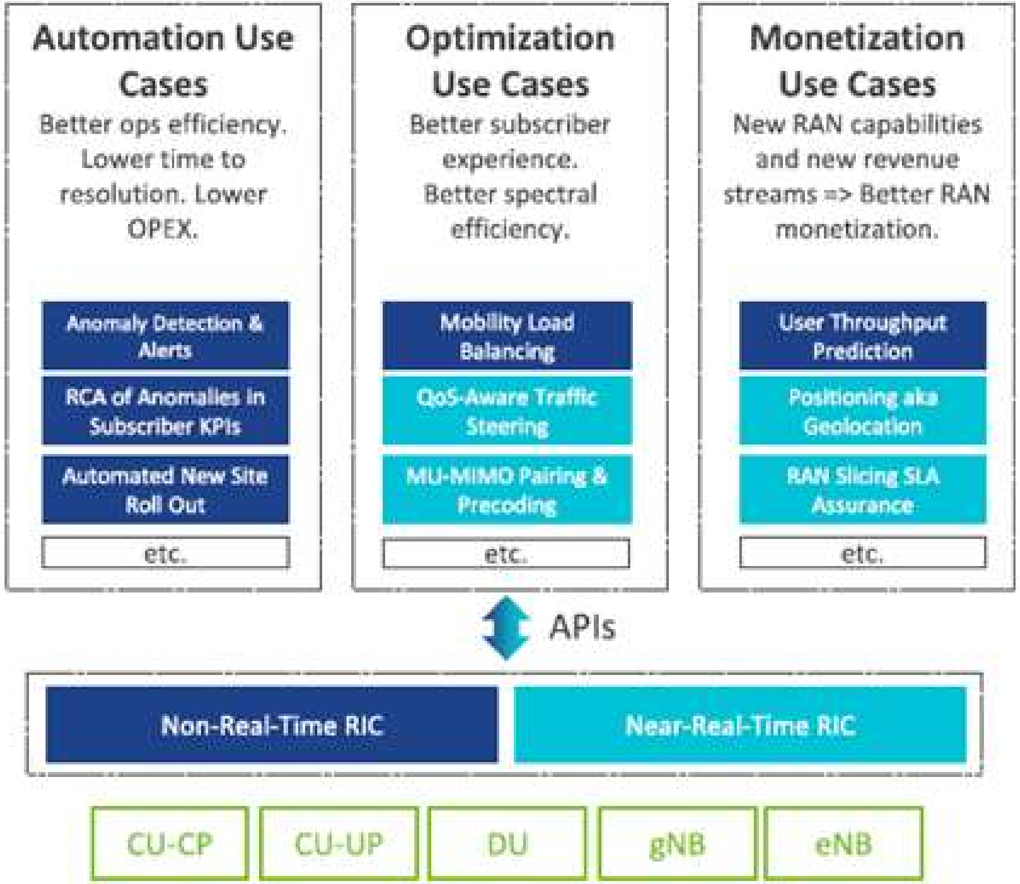
Use Cases of RIC Functions

- Use cases serve the purposes of implementation, open source codes and testing of main RIC functions, and provide
  - Analysis report
  - Detailed specifications
- Cases of most viable plans
  - Traffic Steering
  - QoS and QoE Optimization
  - Massive MIMO Optimization
  - RAN Slicing and SLA Assurance

1	Context-Based Dynamic HO Management for V2X	3
2	Flight Path Based Dynamic UAV Radio Resource Allocation	3
3	Radio Resource Allocation for UAV Application Scenario	3
4	QoE Optimization	1
5	Traffic Steering	1
6	Massive MIMO Beamforming Optimization	1
7	RAN Sharing	2
8	QoS Based Resource Optimization	2
9	RAN Slice SLA Assurance	1
10	Multi-Vendor Slices	2
11	Dynamic Spectrum Sharing	3
12	NSSI Resource Allocation Optimization	2
13	Local Indoor Positioning in RAN	3
14	Massive SU/MU-MIMO Grouping Optimization	2
15	O-RAN Signalling Storm Protection	3
16	Congestion Prediction and Management	2
17	Industrial IoT Optimization	3
18	BBU Pooling to achieve RAN Elasticity	3

Purposes of O-RAN Use Cases

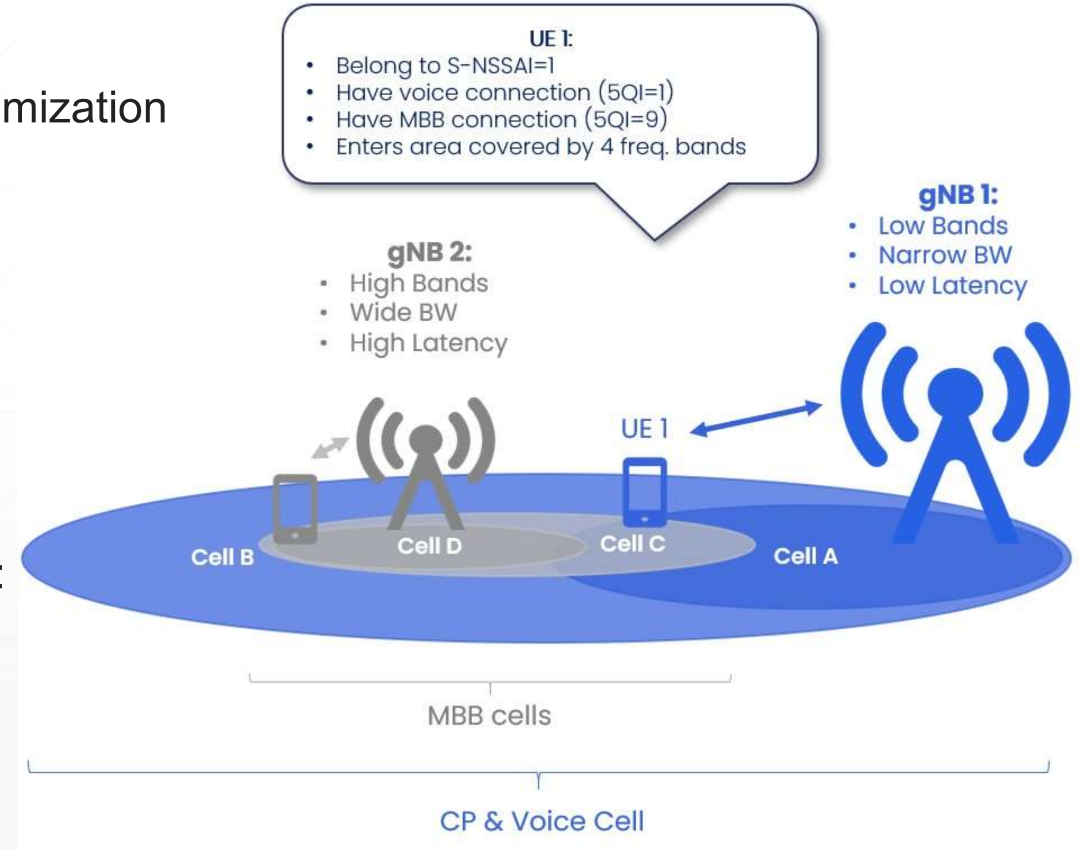
- Non-Real Time RIC
  - Automation use
  - Optimization
- Near Real Time RIC
  - Optimization
  - Monetization



[Making RIC Innovation a Reality in Multi-Vendor 5G Networks: Diving into the Vodafone RIC Trial - VMware Telco Cloud Blog]

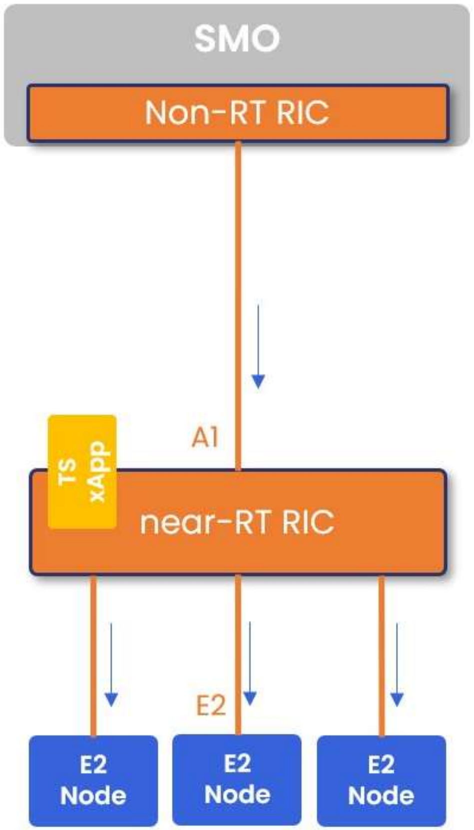
O-RAN QoS-Aware Traffic Steering

- Objectives
  - Customization of UE-centric strategies and optimization
- Direct traffics to specific cells
  - Limited to adjusting the cell reselection, handover parameters, cell priorities
- Example:
  - UE1 has two services, voice and MBB (5QI=9)
  - The non-RT sends two policies to near RT RIC:
    - Steer voice services to be served by cell B
    - Prevent MBB services to be served by cells A, B, and direct them to cells C, D



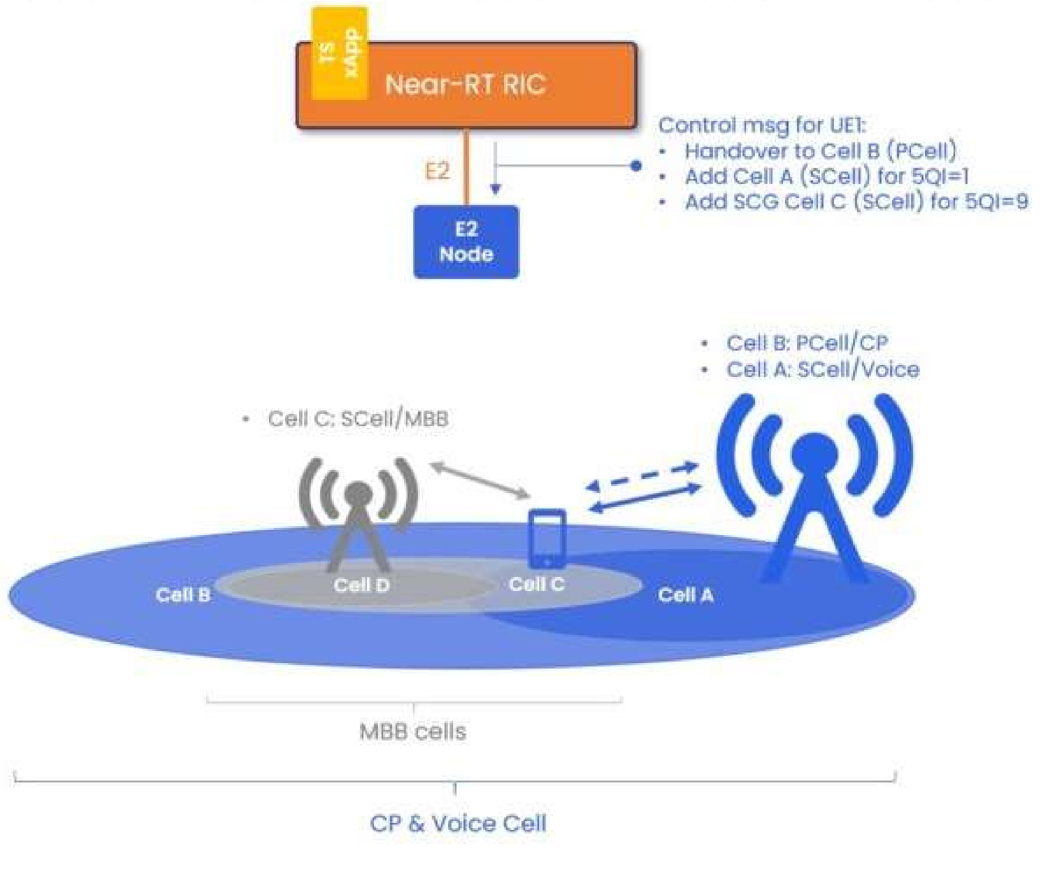
RIC Functions for Traffic Steering (TS)

- Non-RT RIC
  - Define and update policies to guide the behavior of TS xAPP
  - Perform statistical analysis to provide enrichment info for nRT RIC (e.g. RF fingerprints based on RSRP/RSRQ/CQI) to assist TS
  - Send policies and enrichment info to nRT RIC & measurement configuration to RAN nodes
- Near-RT RIC
  - Interprets and enforces policies from Non-RT RIC
  - Uses enrichment info to optimize control function, e.g.
    - Use RF fingerprint to predict inter-frequency cell measurement based on the intra-frequency cell measurement to speed up the TS



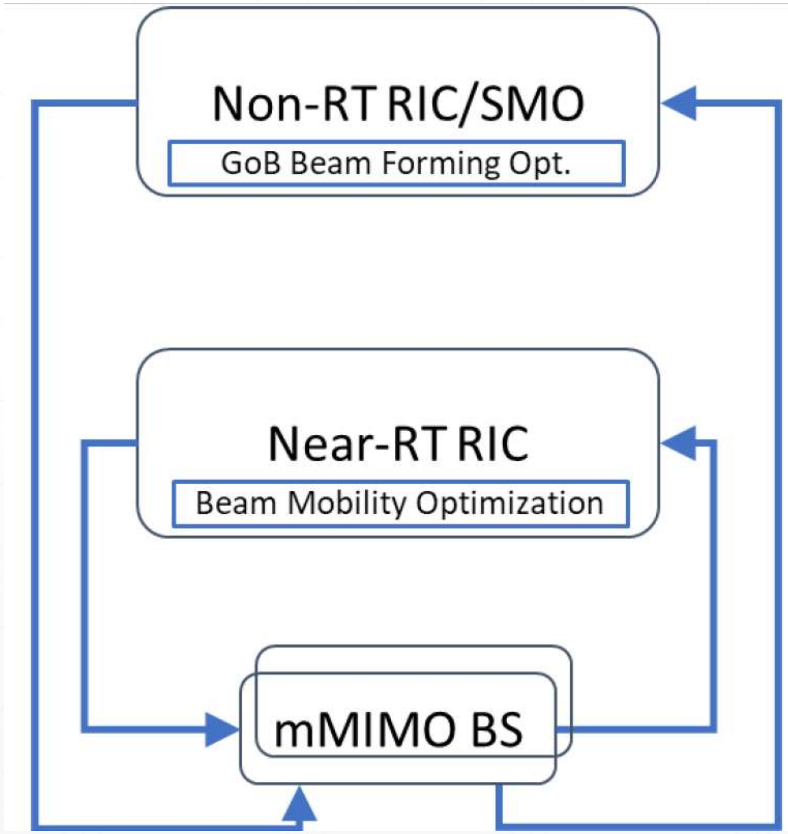
Executions of A1 Policies for TS

- The near-RT RIC locates the UE and enforces the assigned policies by
  - Inform the BS to execute RRC commands:
    - Perform handover to cell B, which becomes the Primary cell (Pcell) and handles control plan (CP) traffics
    - Add secondary cell (Scell) A to the carrier aggregation for voice services (5QI=1)
    - Add secondary gNB to be used for handling MBB (5QI=9)



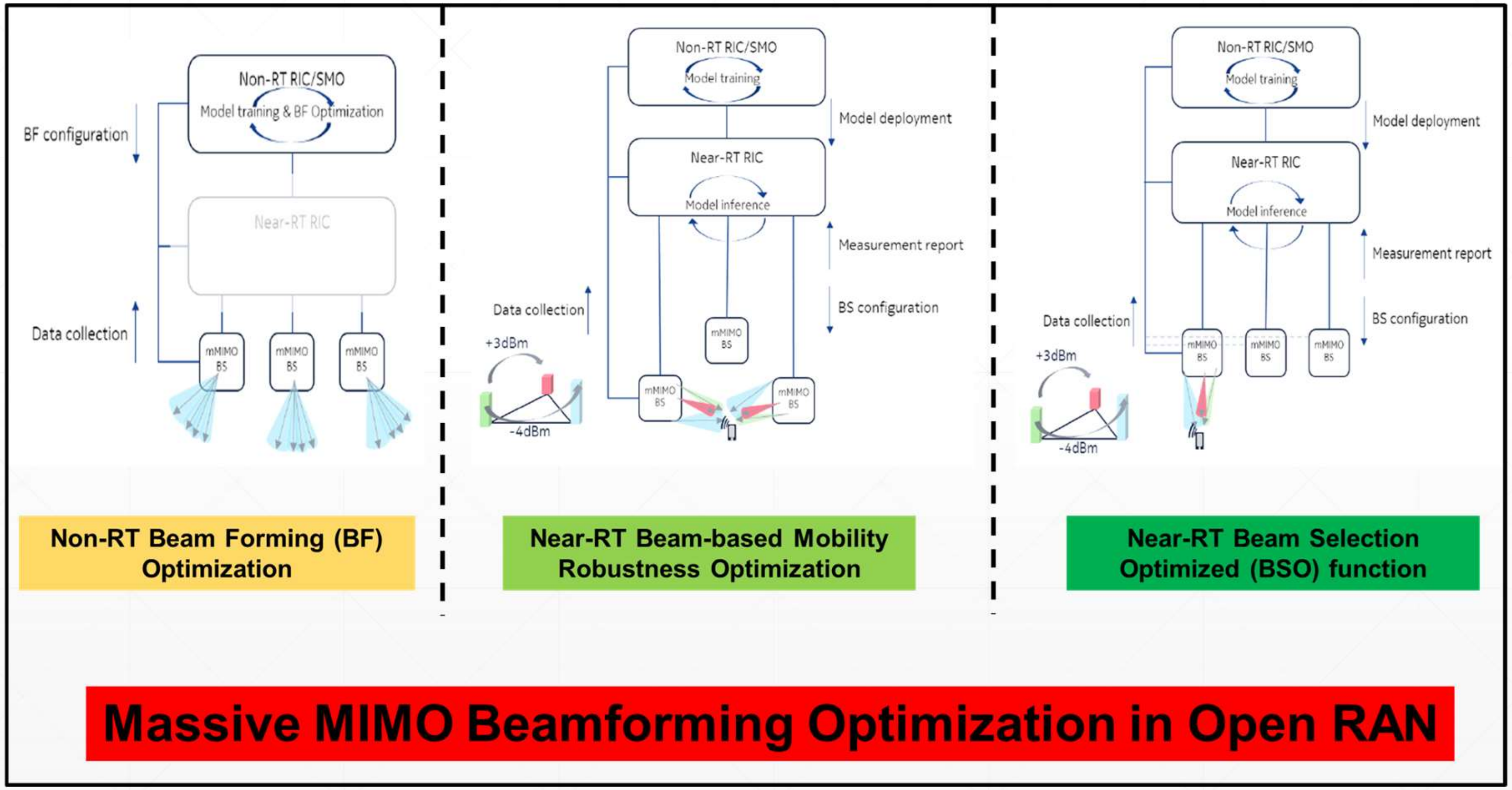
O-RAN Massive MIMO Use Case

- Purpose of massive MIMO (mMIMO)
  - Improve signal quality or number of data streams
  - Spatially filtering the interferences and neighboring cell
  - Fully digital beamforming for sub-6 GHz
    - Extend cell coverage, maximize cell capacity, etc
    - Grid of beam (GoB): Selective coverages of intertests
    - Beam-based load balancing
    - Beam-based mobility robustness optimization
- Objective
  - Enhance the aforementioned performance metrics by **beam configurations**



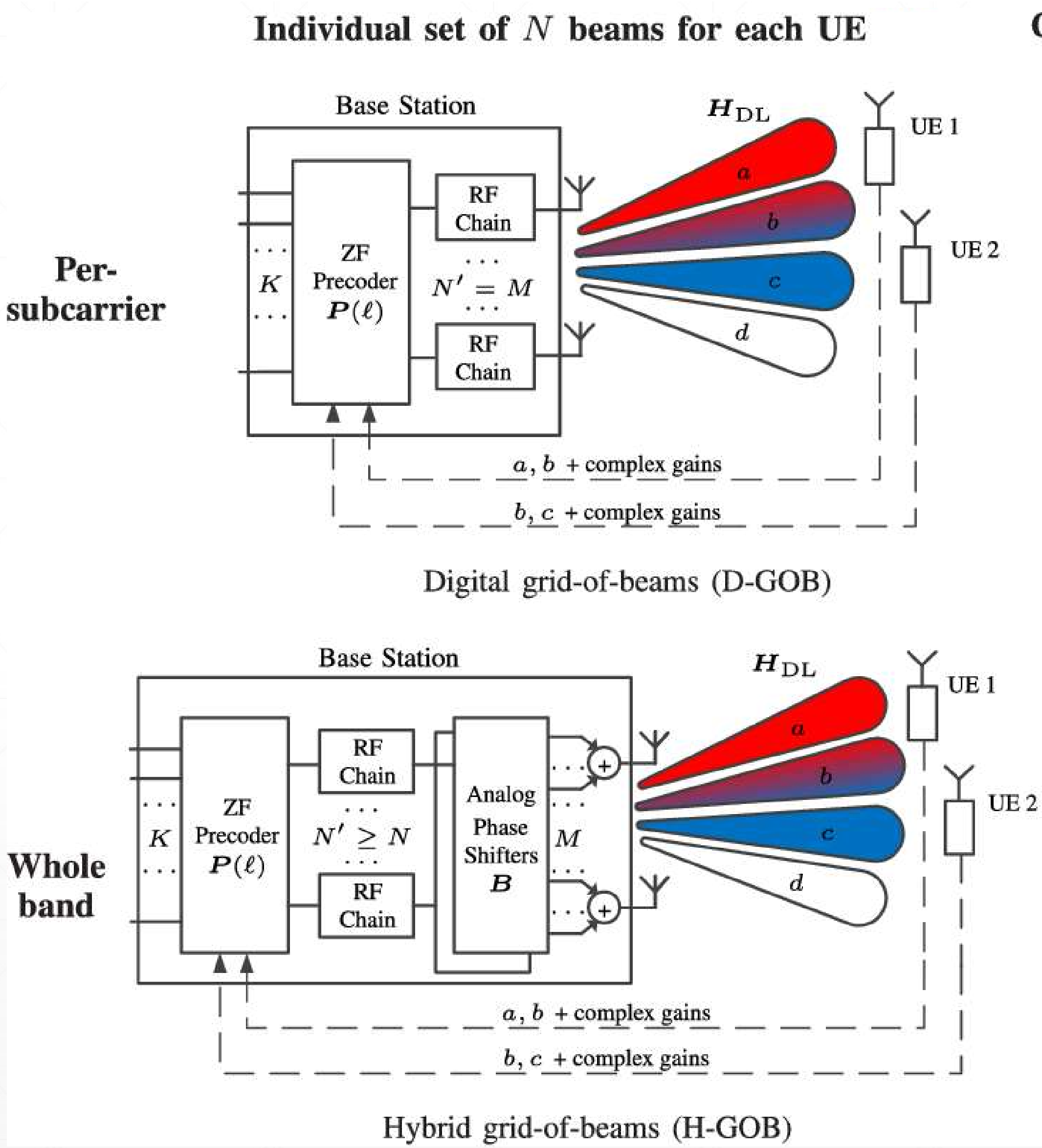
Massive MIMO Beamforming Optimization

- Beam configuration
  - Number of beams
  - Beam boresights
  - Beam widths
  - Beam black/white lists
  - Beam mobility thresholds
- Optimization loops
  - Outer loop
    - Non-RT GoB
  - Inner loop
    - nRT Beam–based MRO (bMRO)
    - nRT BSO



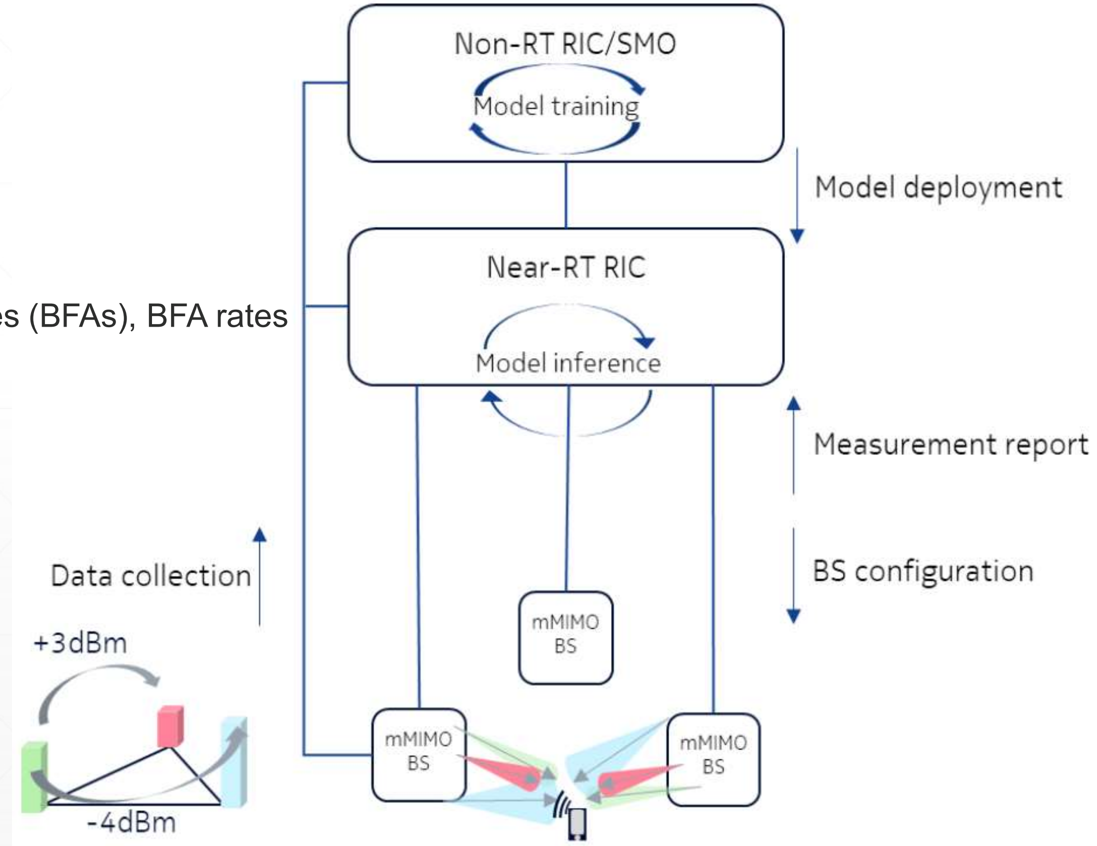
Non-Real Time GoB

- Design objectives
  - Cell-edge throughput
  - Cell geometry (SSB beams)
  - Cell capacity (CSI-RS beams)
- Task: collect, process, and analyze
  - Antenna array parameters
  - Cell performance KPIs
  - UE mobility/spatial density and Traffic density data
  - Beamforming gain/RSRP data
- Output optimized BF configurations
  - Number of beams
  - Beam elevations, horizontal or vertical widths
  - Power allocations of beams



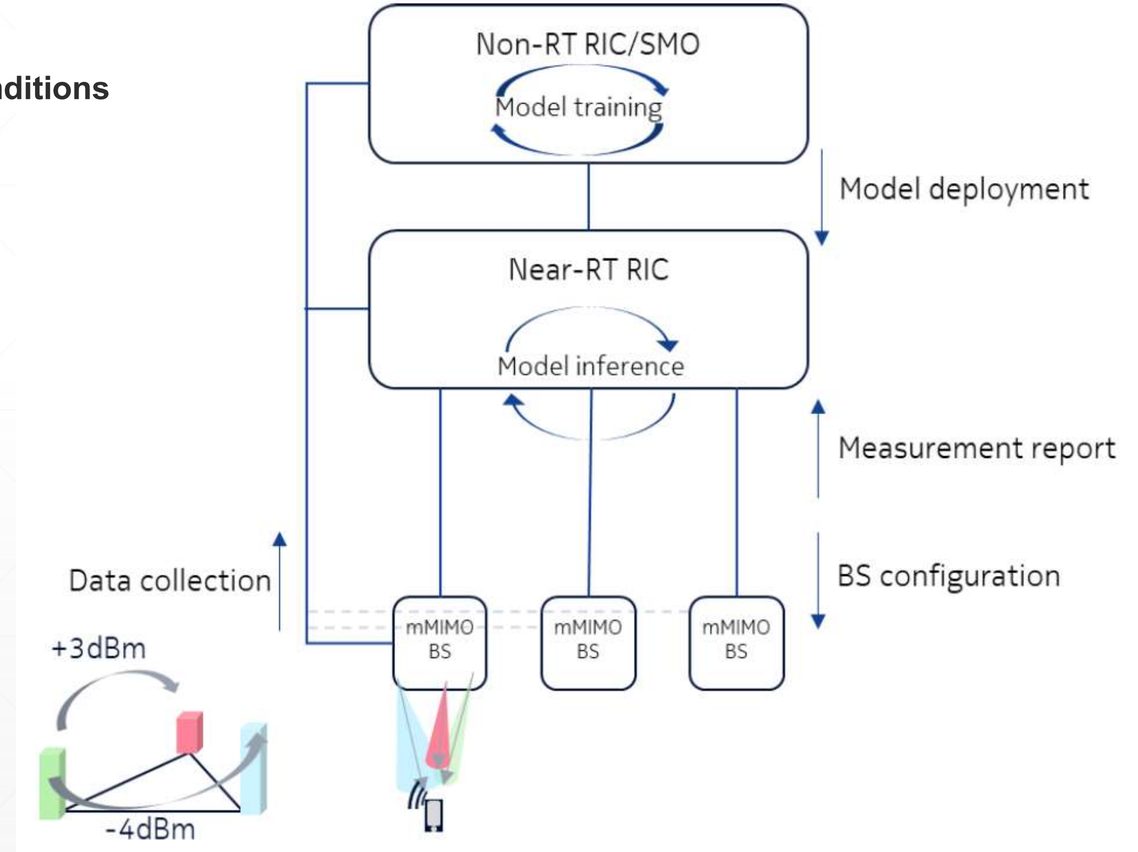
Near-Real Time Beam-Based MRO

- Objective: **Inter-cell beam-based** MRO (bMRO)
- Tasks include inner and outer loops:
  - Non-RT RIC: collect and analyze data for ML training
    - Underlying GoB configuration
    - Beam mobility and failure statistics
      - Early or late HOs, HO failures, numbers of beam failures (BFAs), BFA rates
    - L1/L2 RSRP, SINRs
    - Potential source-target beam pairs
    - Neighboring cells' beams/interference information
  - Near-RT; ML inference reset upon the change of GoB
    - Monitor potential source-target beam pairs
    - Managing beam pairs for beam mobility optimization
- Output
  - Candidate source-target beam pairs
  - Beam individual offsets



Near-Real Time BSO

- Objective: **Intra-cell beam mobility**
  - **Configure parameters for intra-cell beam switching conditions**
- Tasks include inner and outer loops:
  - Non-RT RIC: collect and analyze data for ML training
    - Underlying GoB configuration
    - Beam mobility and failure statistics
    - Per-user measurements of RSRP, SINRs
    - Potential source-target beam pairs
    - Neighboring cells' beams/interference information
  - Near-RT; ML inference reset upon the change of GoB
    - Monitor potential source-target beam pairs
    - Managing beam pairs for beam mobility optimization
- Output
  - Candidate source-target beam pairs
  - Beam individual offsets

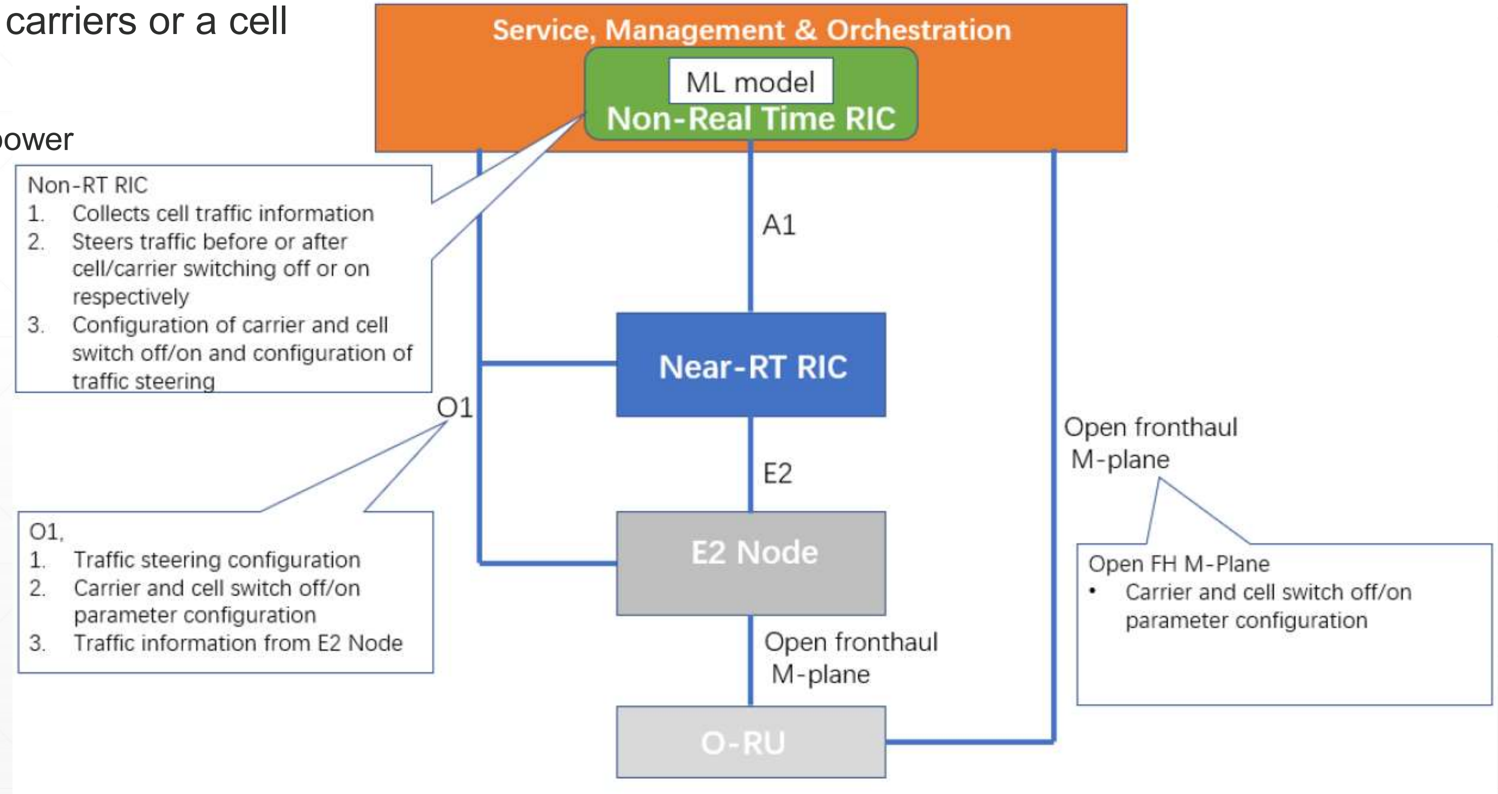


O-RAN Energy Saving Use Case

- Energy saving (ES) modes include
  - Deep sleep mode (shut downs of BS or technology) yet to be discussed in R-18
  - Non-RT Carrier and cell switch off/on ES
  - Near-RT/Non-RT RF switch off/on ES
  - Advanced Sleep Mode ES

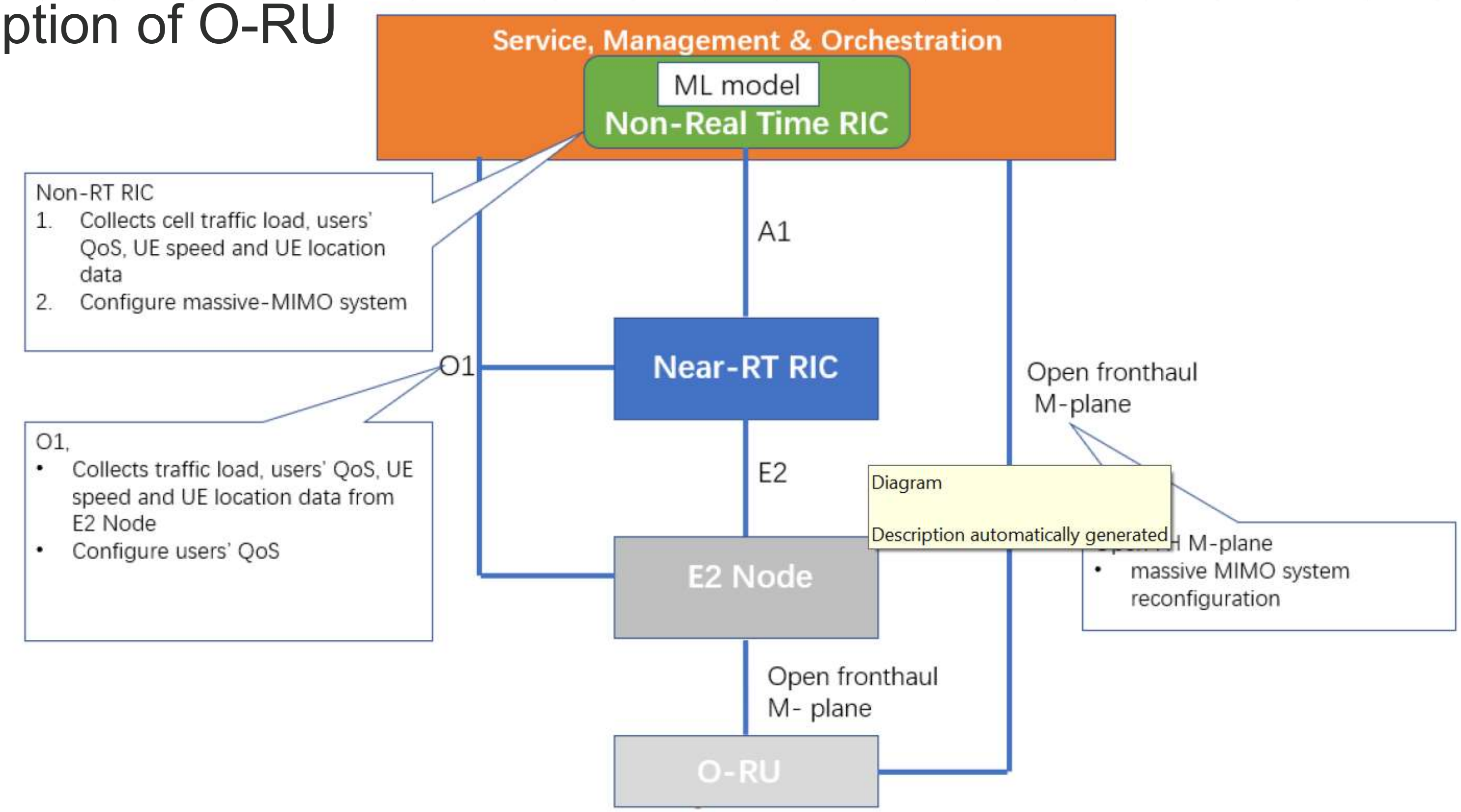
Carrier and Cell Switch Off/On ES

- Reducing power consumption of O-CU/DU/RU by switching on/off one or more carriers or a cell of a technology
  - Hibernate mode with minimum RF power
  - Complete switch off
- AI/ML assisted non-RT RIC to control the traffic load of a carrier
- Automatic switch on/off via O1/Open FH M-Plane
- Accompanied with **traffic steering** to ensure service continuity



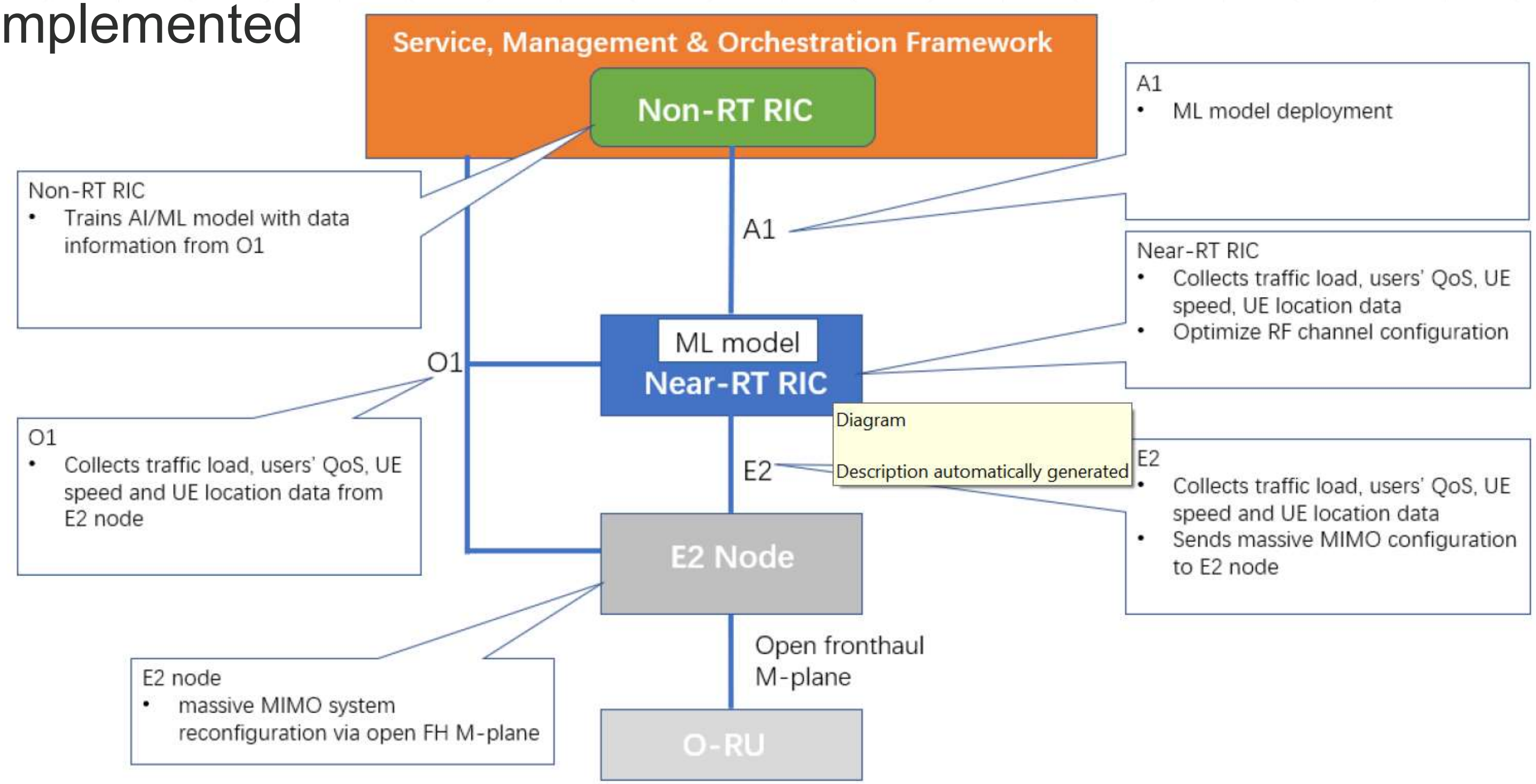
Non-RT RF Channel Switch Off/On ES

- Reduce power consumption of O-RU
- Switch off part of RF channels in mMIMO
- Configure the mMIMO system to minimize the impact on users' QoS



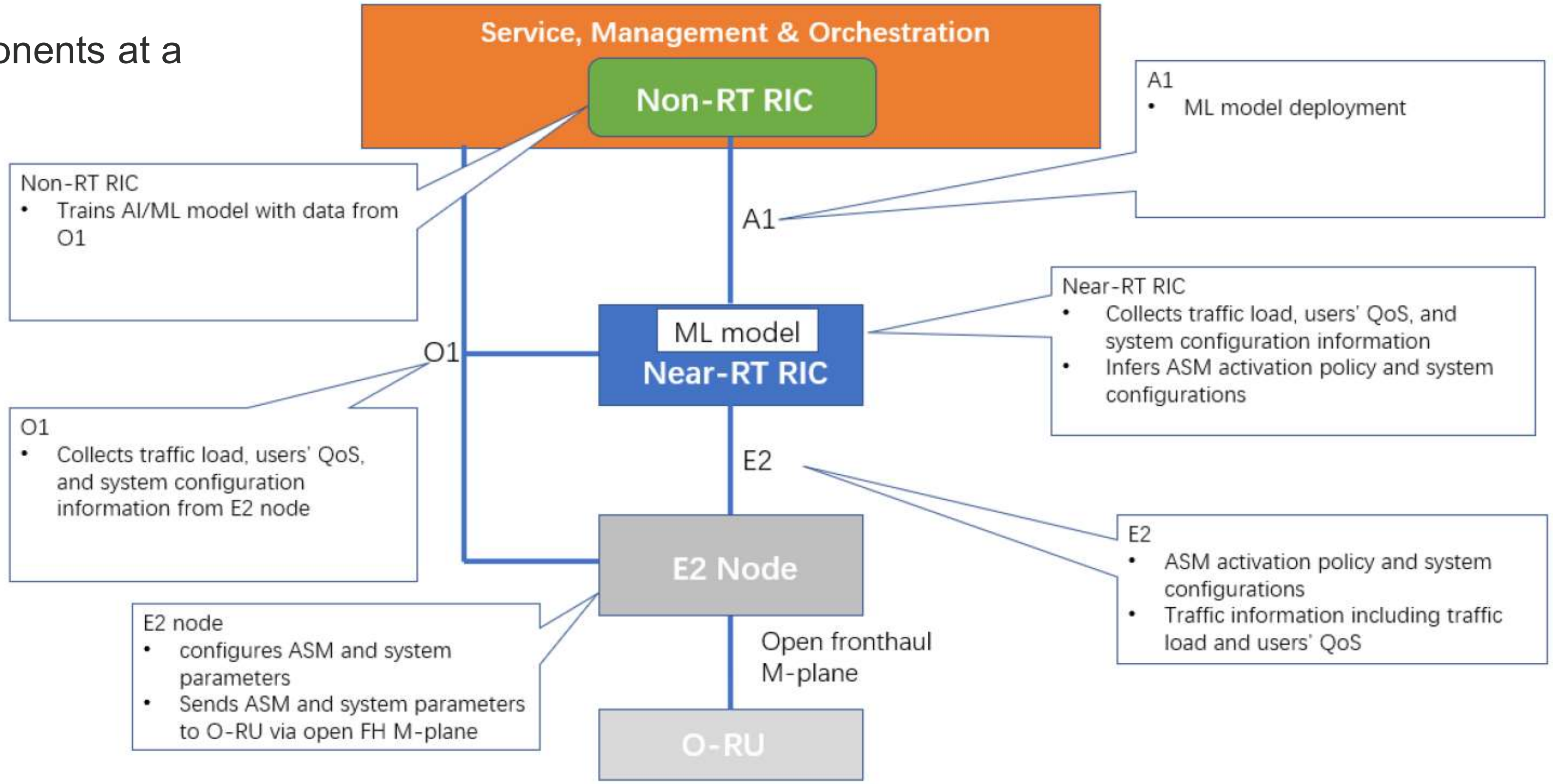
Near-RT RF Channel Switch Off/On ES

- The same purpose implemented with xAPPs
- AI/ML model trained based on data collected from O1, e.g. cell traffics, users' QoS, speed or geolocation



Advanced Sleep-Mode ES

- Reduce power consumption by partially switching off O-RU components at a duration of
  - A symbol (ASM1)
  - A slot (ASM2)
  - A frame (ASM3)
- Goal: maximize ASMs durations in which O-RU is turned off
- AI/ML model to achieve optimal tradeoff between ES and QoS, e.g. latency



O-RAN AI/ML Deployment

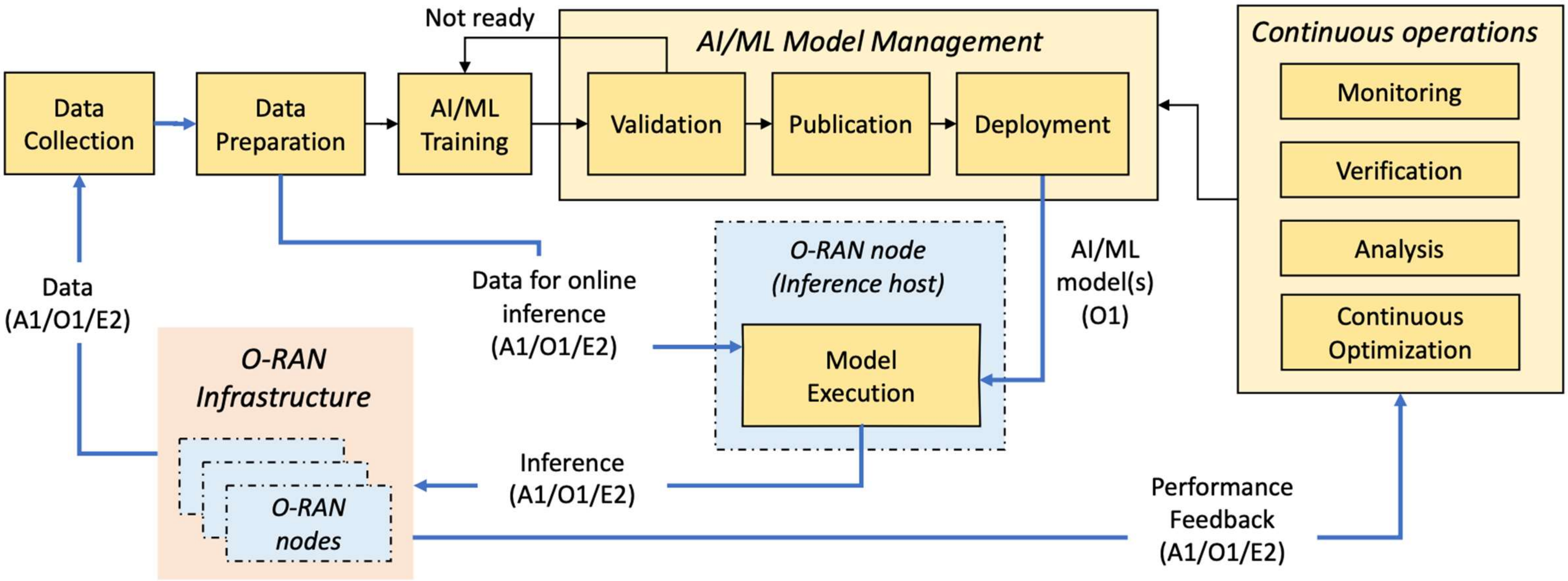


Fig. 13: AI/ML workflow in the O-RAN architecture.

O-RAN AI/ML Deployment Scenarios

- Scenarios 1.1

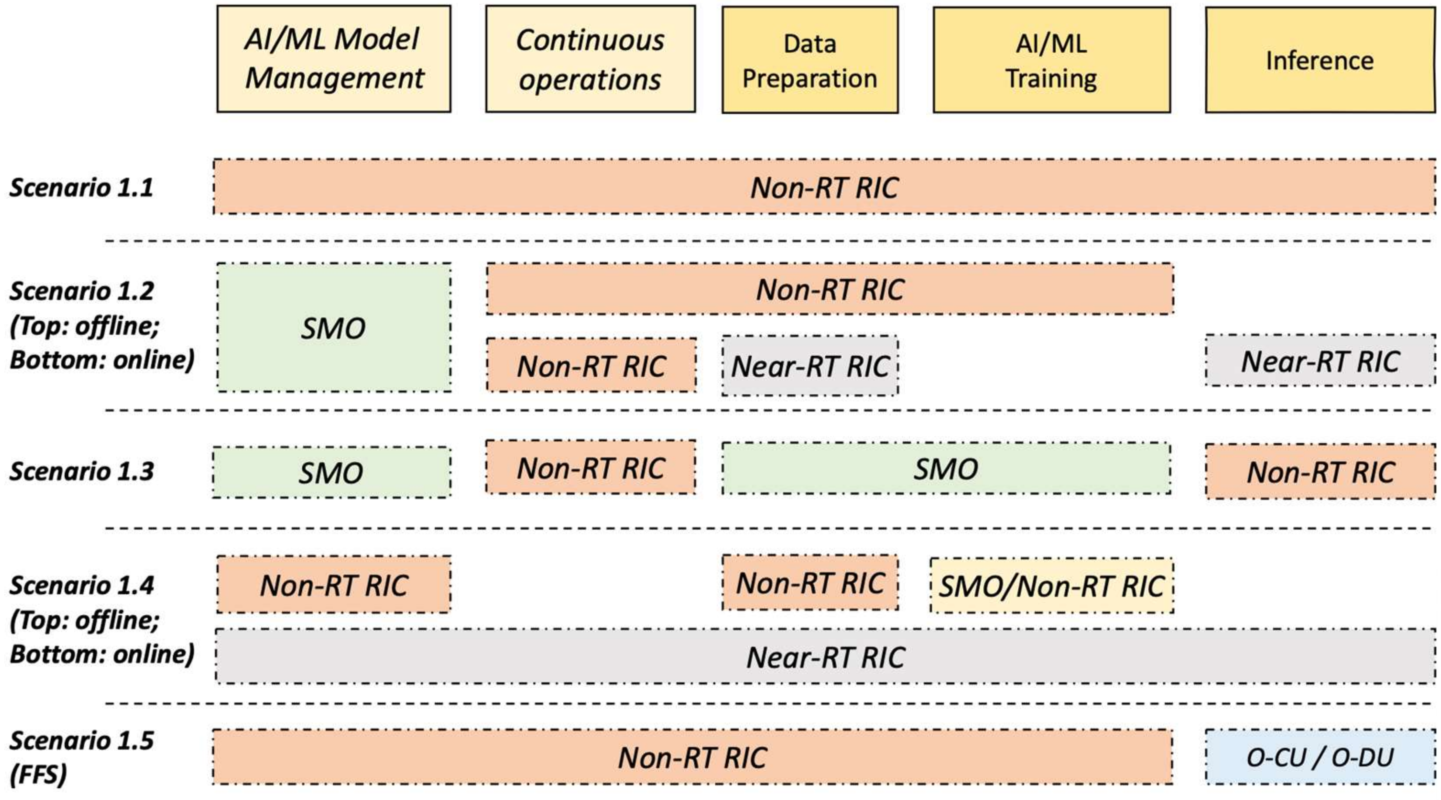
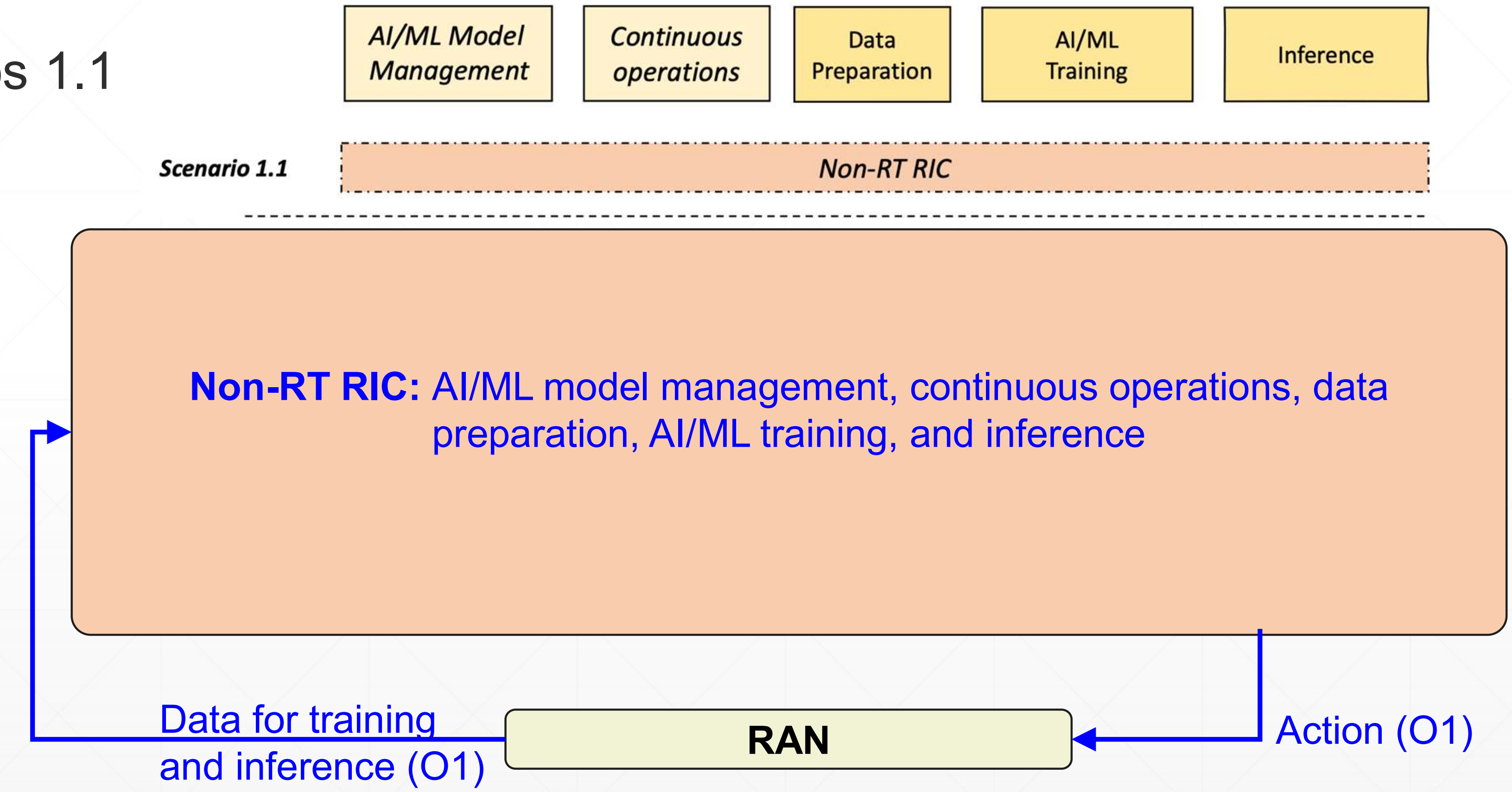


Fig. 14: O-RAN AI/ML deployment scenarios [24].

O-RAN AI/ML Deployment Scenarios

- Scenarios 1.1



O-RAN AI/ML Deployment Scenarios

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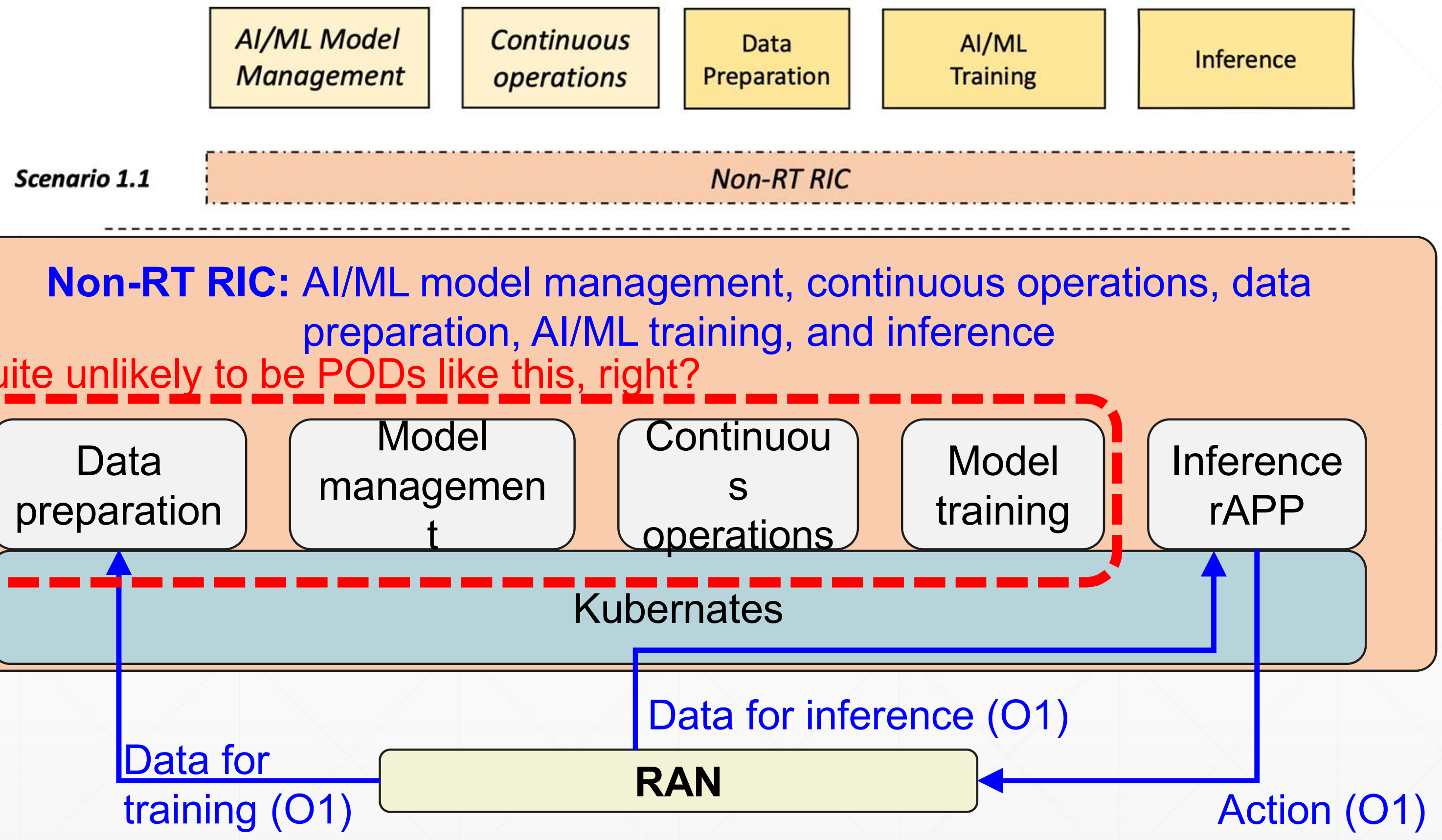

O-RAN AI/ML Deployment

- Scenarios 1.2