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Bridging ns-3 and O-RAN: a tutorial on ns-O-RAN

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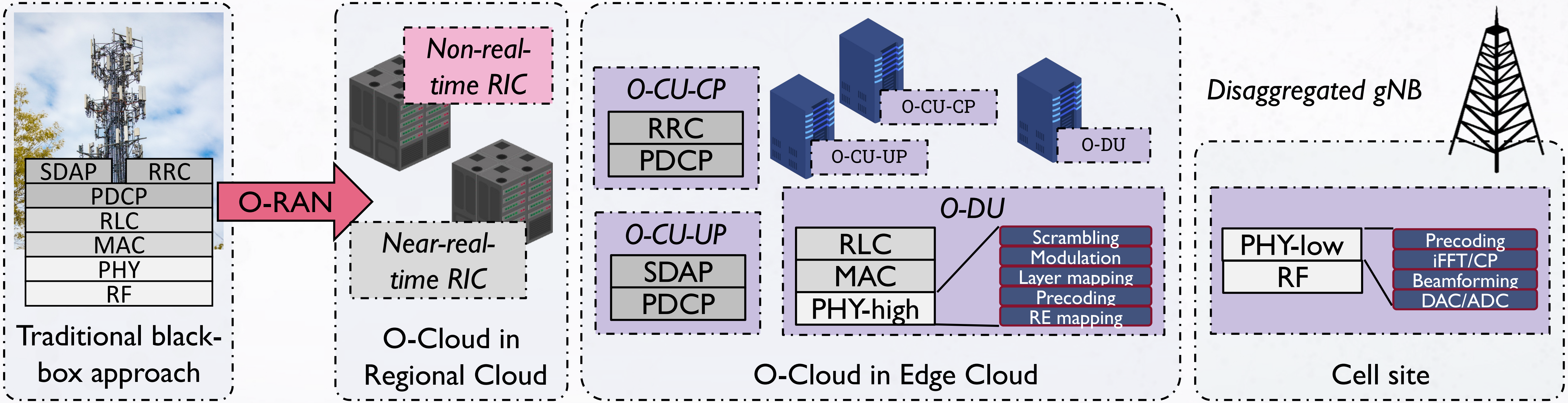
Agenda

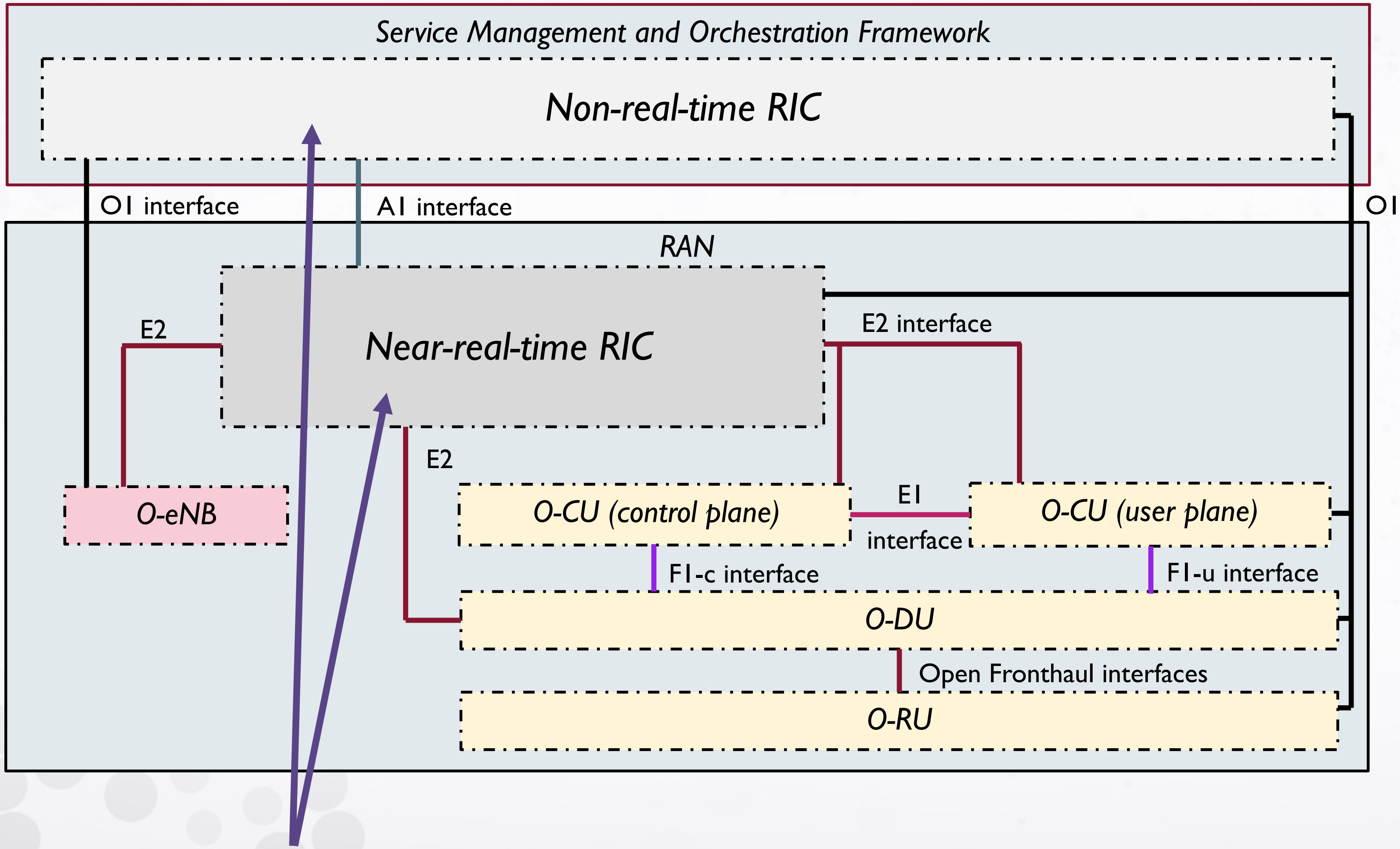
1. O-RAN – a primer
2. RIC Setup
3. ns-O-RAN setup
4. KPI monitor Setup
5. RC Control xApp
6. Scenario Zero

Open RAN



SDAP
RRC
PDCP
RLC
MAC
PHY
RF
Traditional black-box approach
O-RAN
Non-real-time RIC
Near-real-time RIC
O-Cloud in Regional Cloud
O-CU-CP
RRC
PDCP
O-CU-UP
SDAP
PDCP
O-CU-CP
O-CU-UP
O-DU
O-DU
RLC
MAC
PHY-high
Scrambling
Modulation
Layer mapping
Precoding
RE mapping
O-Cloud in Edge Cloud
Disaggregated gNB
PHY-low
RF
Precoding
iFFT/CP
Beamforming
DAC/ADC
Cell site

O-RAN ALLIANCE - a reference architecture for programmable NextG



1. Open, standardized interfaces
2. Disaggregated RAN
3. Softwarization

4. RAN Intelligent Controllers

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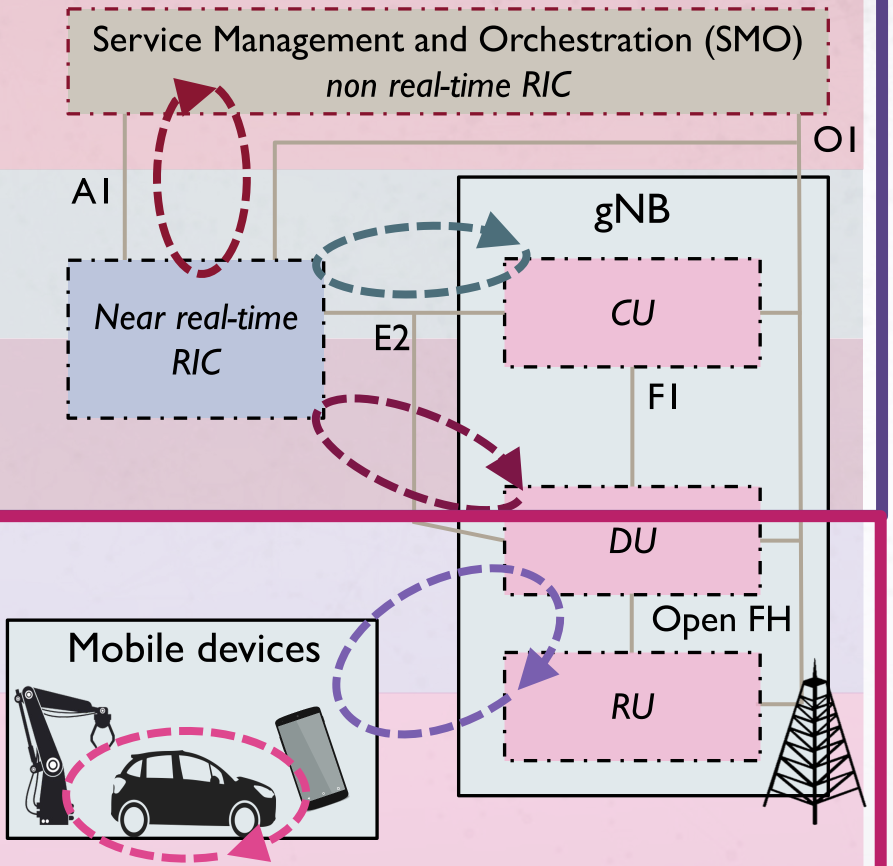
Intelligent Control Loops

Currently supported by O-RAN

Control and learning objective	Scale	Input data	Timescale	Architecture
Policies, models, slicing	> 1000 devices	Infrastructure-level KPIs	Non real-time > 1 s	
User Session Management e.g., load balancing, handover	> 100 devices	CU-level KPIs e.g., number of sessions, PDCP traffic	Near real-time 10-1000 ms	
Medium Access Management e.g., scheduling policy, RAN slicing	> 100 devices	MAC-level KPIs e.g., PRB utilization, buffering	Near real-time 10-1000 ms	
Radio Management e.g., resource scheduling, beamforming	~10 devices	MAC/PHY-level KPIs e.g., PRB utilization, channel estimation	Real-time < 10 ms	
Device DL/UL Management e.g., modulation, interference, blockage detection	1 device	I/Q samples	Real-time < 1 ms	



For further study or not supported

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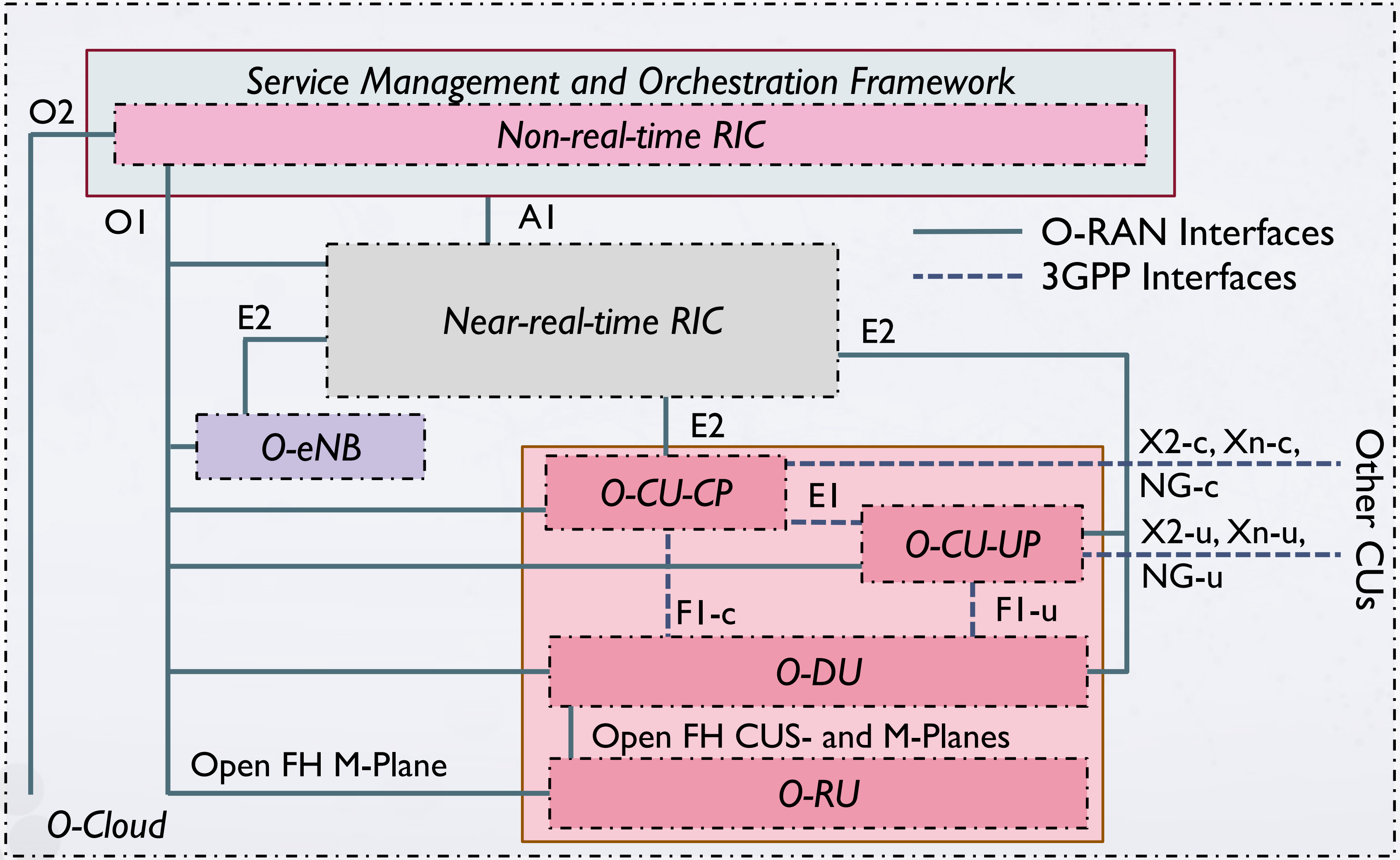
Logical architecture overview



O-RAN Virtualization

O-Cloud:

- Set of computing resources and virtualization infrastructure
  - Pooled together in one or multiple physical datacenters
- Virtualization paradigm for O-RAN
  - Decoupling between hardware and software components
  - Standardization of the hardware capabilities for the O-RAN infrastructure
  - Sharing of the hardware among different tenants
  - Automated deployment and instantiation of RAN functionalities

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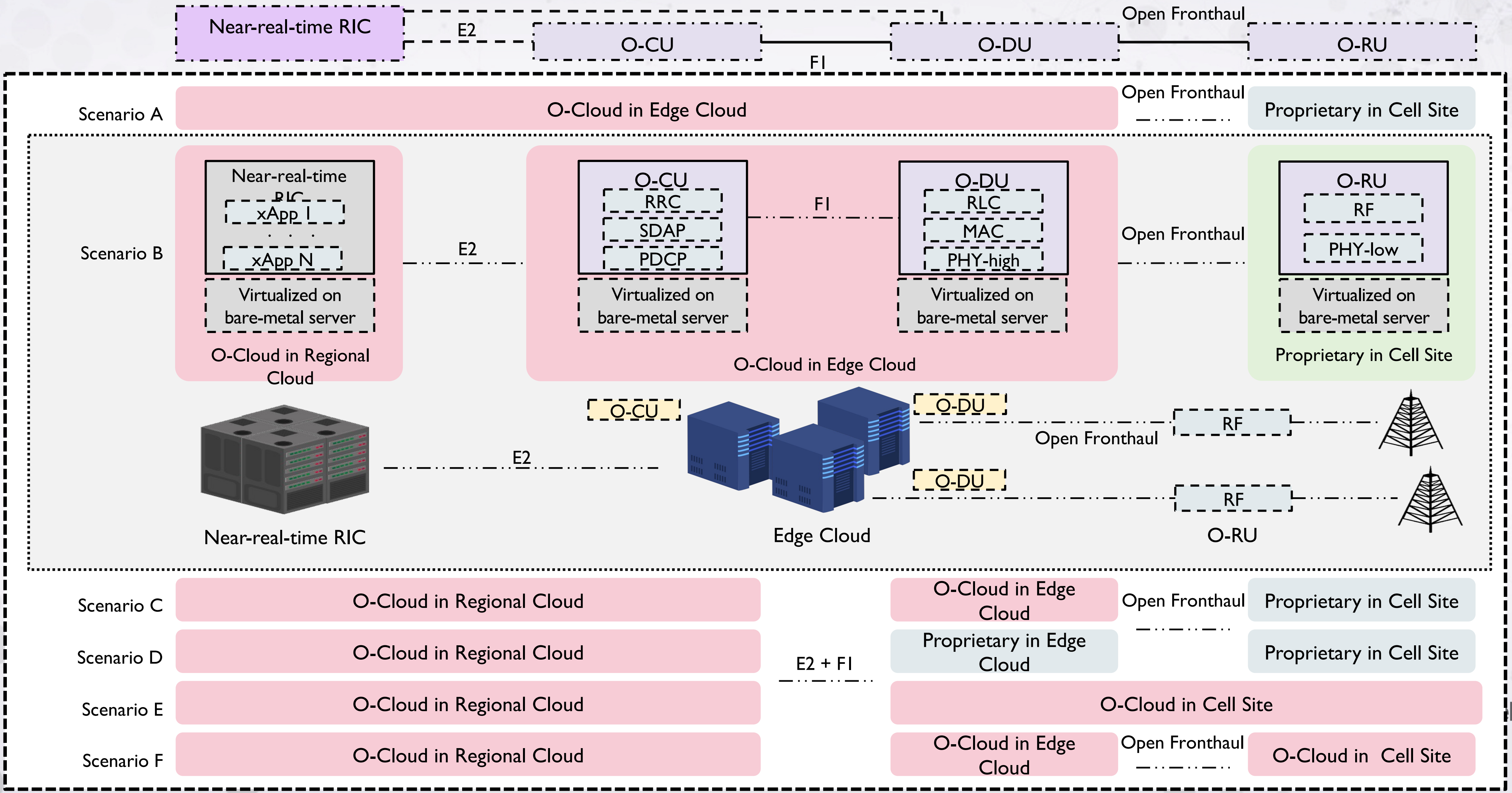
O-RAN Virtualization

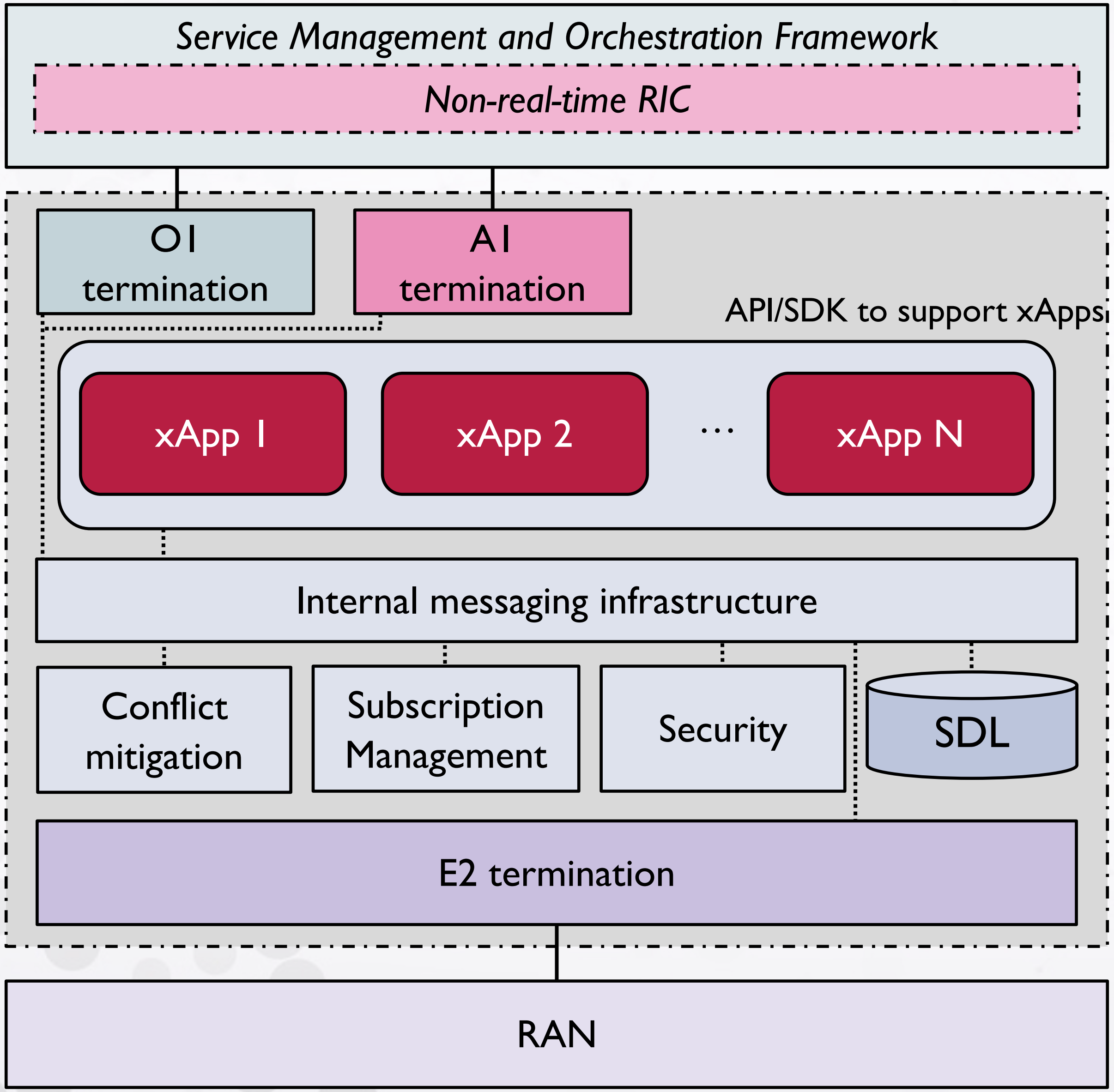
Acceleration Abstraction Layers (AALs):

- APIs between dedicated hardware-based logical processors and the O-RAN softwarized infrastructure
  - e.g., for channel coding/FEC
- Open new opportunities for compute in the RAN
  - e.g., integrate open, programmable GPUs and FPGAs

O-RAN deployment options



Near-real-time RIC



- Standardized blocks and functionality
- Different implementations

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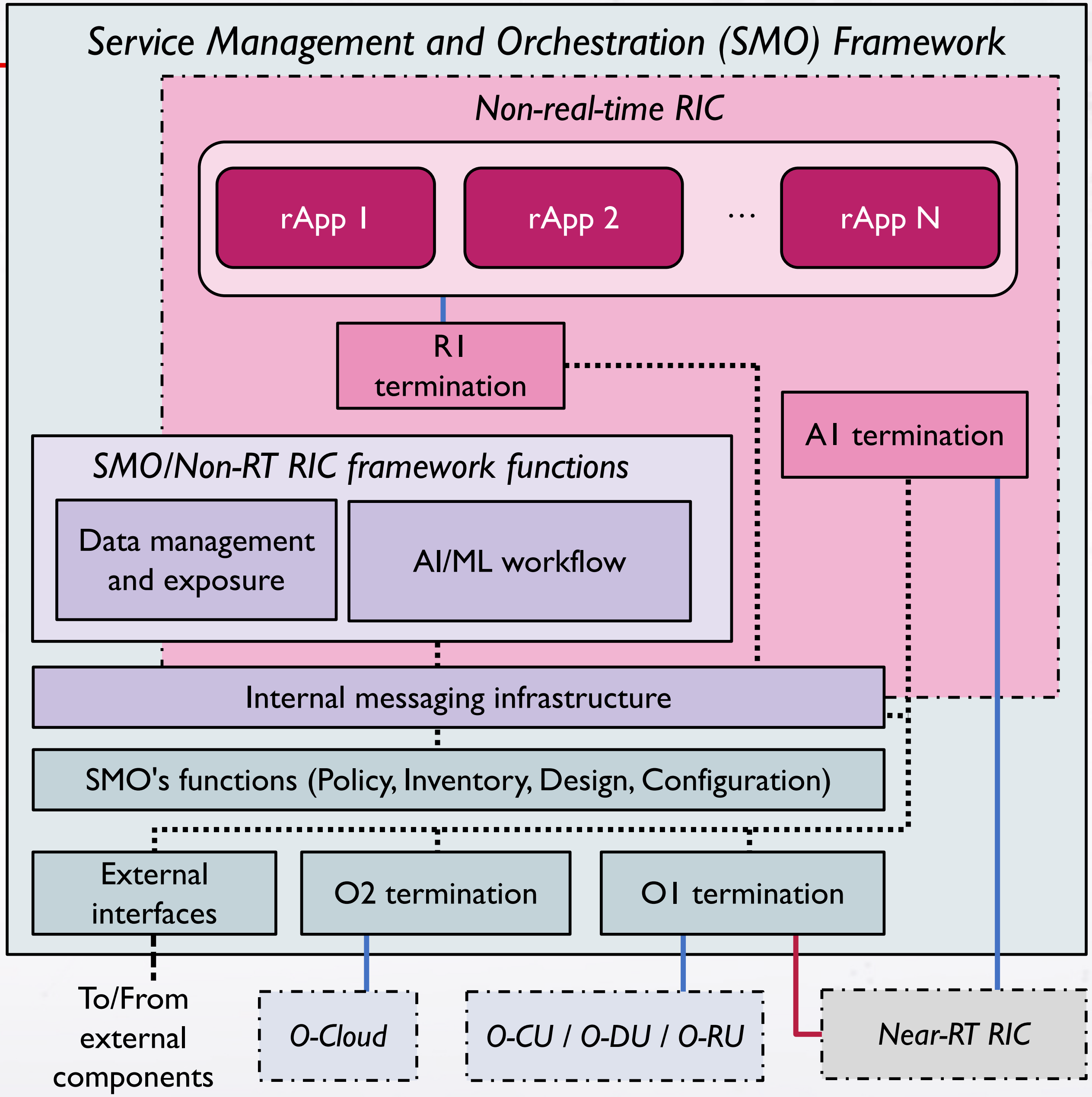
Non-real-time RIC and SMO

SMO functionalities

Non-RT RIC functionalities

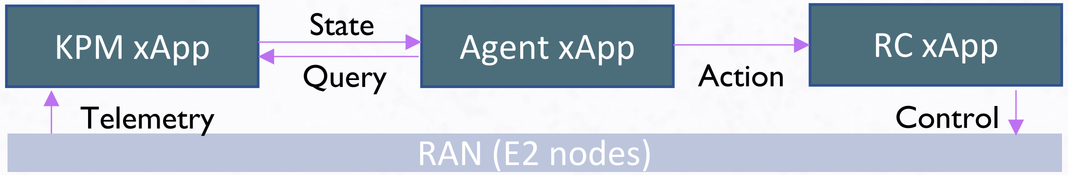
Shared functionalities



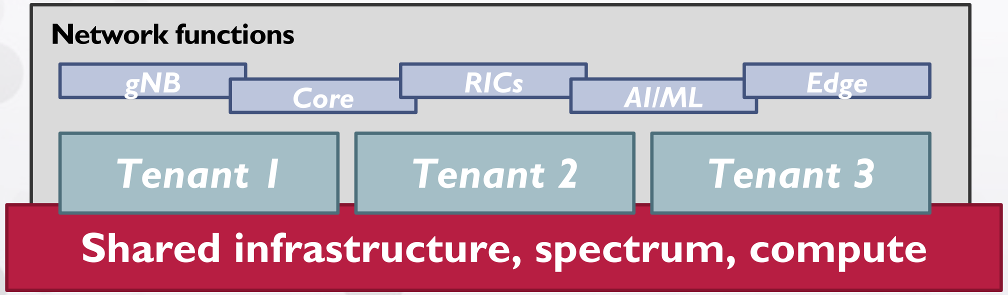
Intelligent Use Cases

Network slicing and scheduling

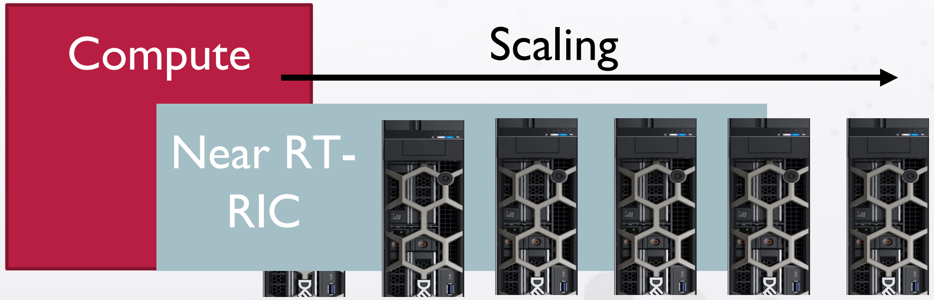
Traffic steering



Spectrum sharing



Energy efficiency

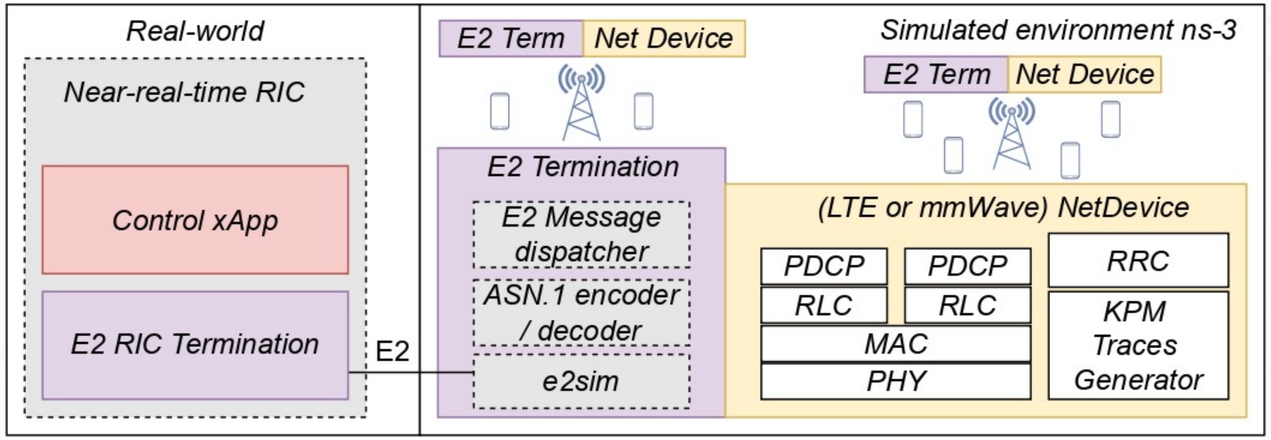


Open Challenges toward Intelligent Open RAN

- Datasets, platforms, development and testing
- AI/ML that generalizes to different deployments and scenarios
- Agile spectrum, infrastructure, and AI management

ns-O-RAN: Simulating O-RAN 5G Systems in ns-3

- Integration of a real-world RIC with a simulated RAN in ns-3
  - Enabling large scale simulations for O-RAN
  - KPI and Control messages exchange supported
  - Realistic dataset generation
- No infrastructure expenses
  - Highly customizable
  - Implement custom use cases
- O-RAN compliant
  - Create the xApp on ns-3 and use it on a real RAN with no software changes



More on the implementation and architecture tomorrow!

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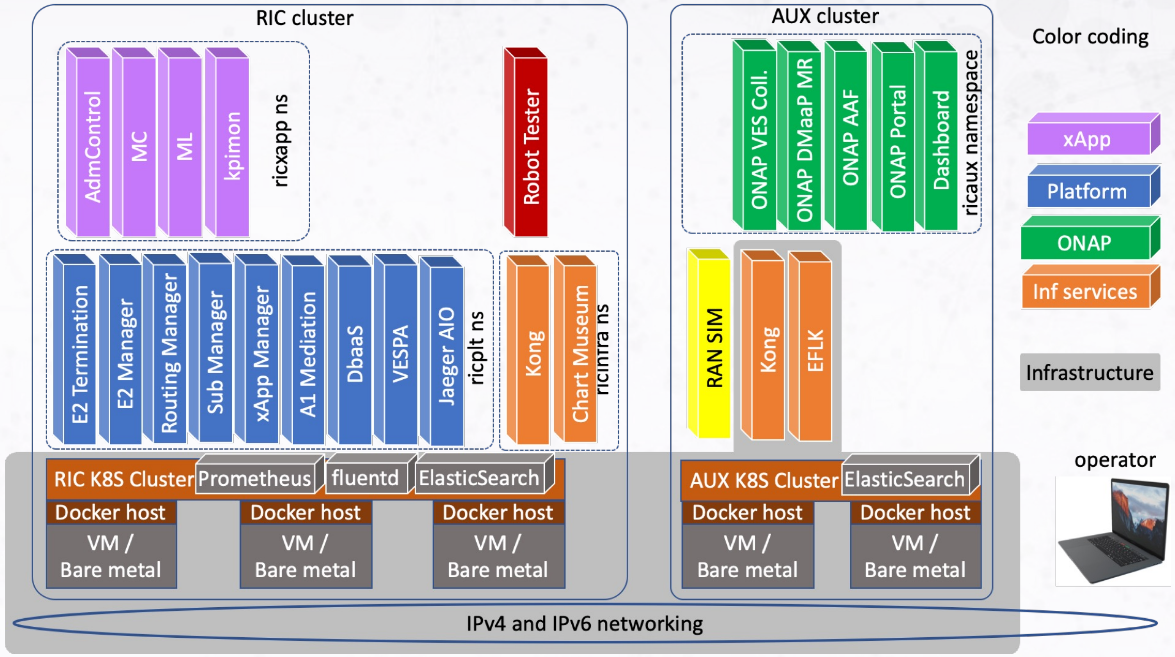
ns-3 simulations with an O-RAN RIC – tutorial

RAN Intelligent Controller (RIC) – OSC Implementation

- Cluster of network functions at the RAN edge or in the cloud
  - Open Specifications
  - Different implementations available
    - OSC - Kubernetes
    - ColoRAN [1]
    - FlexRIC
- Functionalities implemented as microservices (*pods*)
- *Namespaces* isolate services according to their role
  - ricxapp: xApps
  - ricinfra: functional pods for Kubernetes and the RIC
  - ricplt: RIC components connecting to the RAN



[1] M. Polese, L. Bonati, S. D'Oro, S. Basagni, and T. Melodia, "ColO-RAN: Developing Machine Learning-based xApps for Open RAN Closed-loop Control on Programmable Experimental Platforms," IEEE Transactions on Mobile Computing, July 2022.

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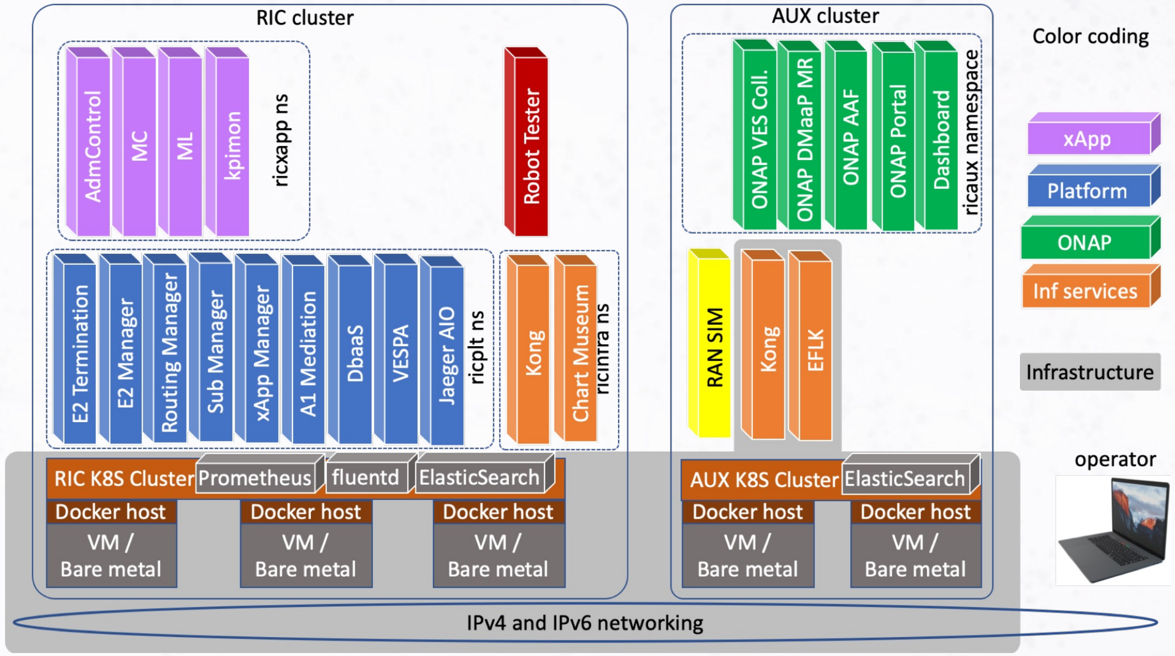
RIC Major Components

- E2 Termination
  - Connection with the RAN
- E2 Manager
  - RAN Subscription Manager
- Routing Manager
  - Intra xApps and RAN
- xApp Manager
  - Handles the onboarding of the xApps
- xApps
  - Network operator applications
  - Custom control logic



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RIC Setup

- We install the G - Release
  - https://docs.o-ran-sc.org/projects/o-ran-sc-it-dep/en/latest/installation-guides.html#ric-platform
- Prerequisites:
  - Kubernetes
  - Docker

```
git clone https://gerrit.o-ran-sc.org/r/ric-plt/ric-dep -b g-release
cd ric-dep/
git submodule update --init --recursive --remote
./uninstall # uninstalling any old version
./install -f ../RECIPE_EXAMPLE/example_recipe_oran_g_release.yaml
```

```
root@wines-PowerEdge-R340:/home/wines/ric-dep# kubectl get pods -n ricplt
NAME                                                      READY   STATUS    RESTARTS   AGE
deployment-ricplt-a1mediator-6ccd8896d7-ddqj4             1/1     Running   0          51d
deployment-ricplt-alarmmanager-56d79dc55-5xvqr            1/1     Running   0          51d
deployment-ricplt-appmgr-8f7467877-8k2dc                  1/1     Running   0          51d
deployment-ricplt-e2mgr-66cdc4d6b6-l2hvr                  1/1     Running   2          51d
deployment-ricplt-e2term-alpha-84d4db76d6-kq2zp           1/1     Running   0          38d
deployment-ricplt-o1mediator-677ff764d7-492g8             1/1     Running   0          51d
deployment-ricplt-rtmgr-578c64f5cf-mqdwg                  1/1     Running   1          51d
deployment-ricplt-submgr-7f64499555d-4zp24                1/1     Running   0          51d
deployment-ricplt-vespamgr-84f7d87dfb-5zlzr               1/1     Running   0          51d
r4-infrastructure-kong-7995f4679b-v5pg9                   2/2     Running   1          51d
r4-infrastructure-prometheus-alertmanager-5798b78f48-46hgt 2/2    Running   0          51d
r4-infrastructure-prometheus-server-c8ddcfdf5-4mhxj       1/1     Running   0          51d
statefulset-ricplt-dbaas-server-0                         1/1     Running   0          51d
root@wines-PowerEdge-R340:/home/wines/ric-dep#
```

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ns-O-RAN Setup

- ns-3 will run in a Docker pod in the Kubernetes cluster
- Installation toolchain
  - https://openrangym.com/tutorials/ns-o-ran
- Dockerfile:
  - https://github.com/wineslab/colosseum-near-rt-ric/blob/ns-o-ran/Dockerfile
- 3 main components will be installed
  - E2sim software
  - ns-O-RAN external module
  - ns-3 MmWave module

```
docker build -t ns3 -f Dockerfile --build-arg log_level_e2sim=2 . --no-cache
```

Log Level e2Sim	Value	Description
LOG_LEVEL_UNCOND	0	Show only the uncoditional logs.
LOG_LEVEL_ERROR	1	Show all the previous logs plus failures on the e2Sim side (such as errors on encoding)
LOG_LEVEL_INFO	2 (default)	Show all the previous logs plus the some info about the size of the messages
LOG_LEVEL_DEBUG	3	Show all the possible logs including the xer_printing of the ASN1.C messages

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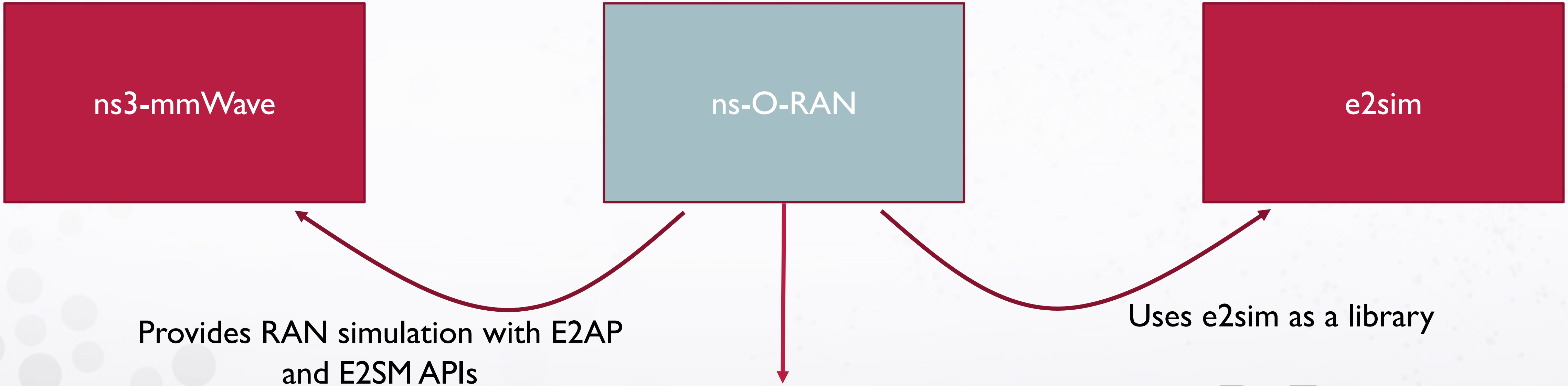
ns-O-RAN Codebase structure

- 3 different repositories

RAN functional simulator, fork of https://github.com/nyuwireless-unipd/ns3-mmwave (aligned to latest updates)

Fork of https://github.com/o-ran-sc/sim-e2-interface in Dec. 2020 – commit a8f2a



Provides RAN simulation with E2AP and E2SM APIs

Uses e2sim as a library

Contributed to OSC (Oct 2022) https://github.com/o-ran-sc/sim-ns3-o-ran-e2

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ns-O-RAN Dockerfile

```
FROM wineslab/o-ran-sc-bldr-ubuntu18-c-go:9-u18.04 as buildenv
ARG log_level_e2sim=2

# Install E2sim
RUN mkdir -p /workspace
RUN apt-get update && apt-get install -y build-essential git cmake libsctp-dev autoconf automake libtool bison flex libboost-all-dev

WORKDIR /workspace

RUN git clone -b develop https://github.com/wineslab/ns-o-ran-e2-sim /workspace/e2sim

RUN mkdir /workspace/e2sim/e2sim/build
WORKDIR /workspace/e2sim/e2sim/build
RUN cmake .. -DDEV_PKG=1 -DLOG_LEVEL=${log_level_e2sim}

RUN make package
RUN echo "Going to install e2sim-dev"
RUN dpkg --install ./e2sim-dev_1.0.0_amd64.deb
RUN ldconfig

WORKDIR /workspace

# Install ns-3
RUN apt-get install -y g++ python3

RUN git clone -b release https://github.com/wineslab/ns-o-ran-ns3-mmwave /workspace/ns3-mmwave-oran
RUN git clone -b master https://github.com/o-ran-sc/sim-ns3-o-ran-e2 /workspace/ns3-mmwave-oran/contrib/oran-interface

WORKDIR /workspace/ns3-mmwave-oran

RUN ./waf configure --enable-tests --enable-examples
RUN ./waf build

WORKDIR /workspace

CMD [ "/bin/sh" ]
```

ns-O-RAN onboarding

- Add the Docker container in the RIC
  - i.e., we create a new pod in the cluster
- We use a k8s file to ease the job
  - Yaml format to dynamically create the pod

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: ns-3-pod
  namespace: ricplt
spec:
  containers:
  - name: ns-3-pod
    image: ns3
    imagePullPolicy: Never
    command: ["sleep", "infinity"]
```

```
kubectl apply -f ns-o-ran-pod.yaml
```

```
wines@wines-PowerEdge-R340:~$ sudo kubectl get pods
NAME        READY   STATUS    RESTARTS   AGE
ns-3-pod    1/1     Running   0          79d
```

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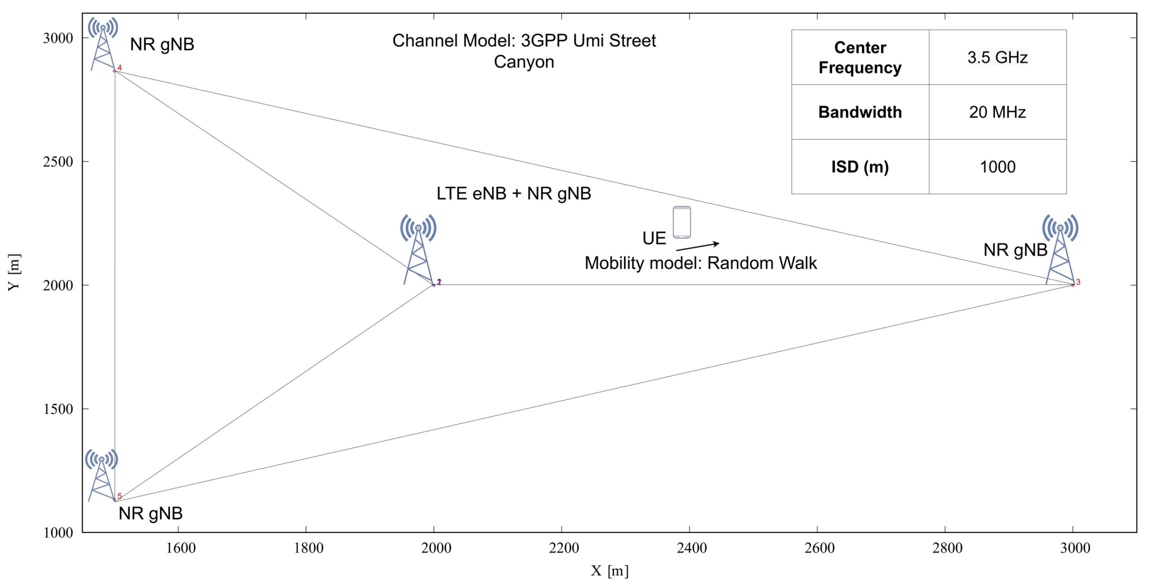
Test ns-O-RAN in stand-alone mode

```
./ns3 run "scratch/scenario-zero.cc --simTime=10 --enableE2FileLogging=1"
```

- ns-3 without RIC
  - Save logs and RAN telemetry
- Scenario Zero
  - 1 eNB, 4 gNB
  - 12 UEs
  - simTime: seconds of the simulation
  - enableE2FileLogging: if true, ns-O-RAN is in stand alone mode
  - e2TermIp: IP address of the RIC E2 Termination



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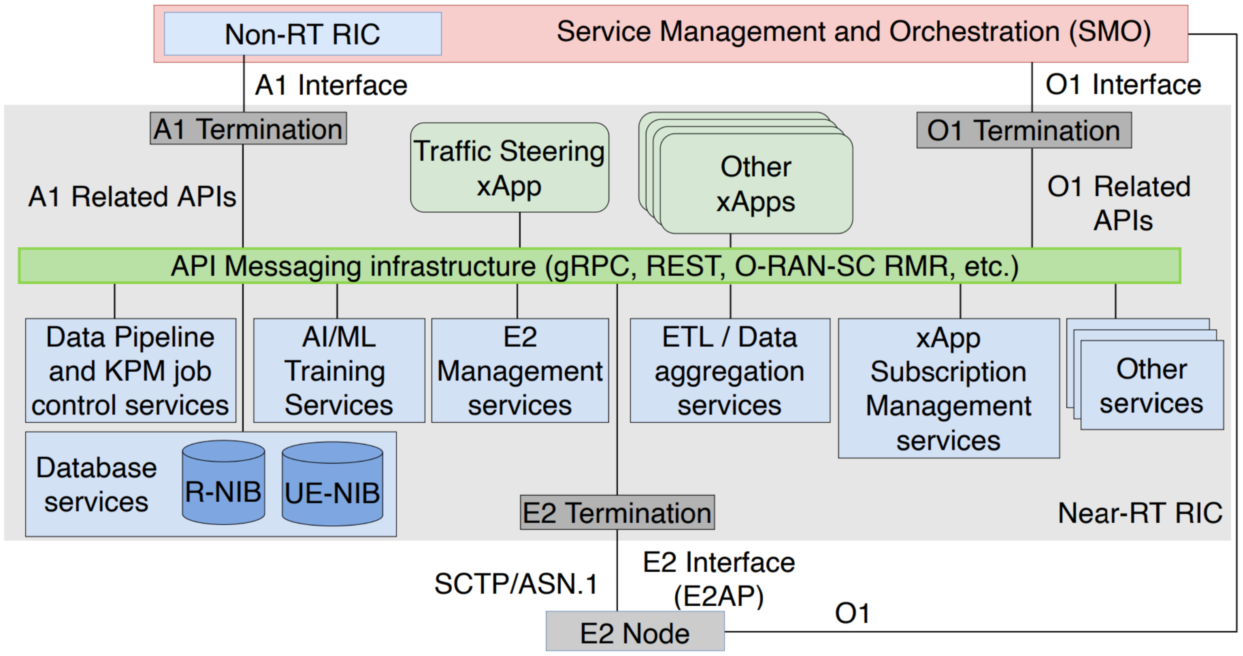
Connecting the xApps

- Working with xApps is hard:
  - Compatibility among versions
  - Handling of Subscription IDs
  - Internal routing of the E2 Messages
- The flexibility of ns-O-RAN can help



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Onboarding a complete xApp

- xApps are designed to be plug and play
- Once you have configurations details they can be deployed with a zero-touch approach
- Two major files are needed to load the xApp in the RIC:
  - config-file.json
  - schema.json

```
# Start chartmuseum
docker run --rm -u 0 -it -d -p 8090:8080 -e DEBUG=1 -e STORAGE=local -e
STORAGE_LOCAL_ROOTDIR=/charts -v $(pwd)/charts:/charts chartmuseum/chartmuseum:latest

# setting environment variable
export CHART_REPO_URL=http://0.0.0.0:8090
# onboard xApp
dms_cli onboard config-file.json schema.json

# install xApp
dms_cli install {name_xapp} {version_xapp} ricxapp
# uninstall xApp
dms_cli uninstall {name_xapp} ricxapp[])
```

- The result is the xApp live and a docker container

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Customizing the xApp

- Changing the code requires recreating the container:
  - Entrypoint
  - Source code
- After building the image, it should be pushed to a registry because dms cli
- Modify then the config-file.json to point the correct registry and image
- To manually work in the container the Dockerfile shall have as ENTRYPOINT the command: ['sleep', 'infinity']

```
# start registry on localhost
docker run -d -p 5000:5000 -- name registry registry:2

# build the docker image always tagging it with -t as 127.0.0.1:5000/${name_xapp}:${version}

# push the image to the registry
docker push 127.0.0.1:5000/${name_xapp}:${version}
```

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Before moving on – ASN.1 Definitions

- Encoding technique used by cellular networks
  - Hard to customize
  - Follows standard definitions
  - Very efficient
  - Must be consistent
- For this tutorial we use:
  - E2AP ASN from OSC G release
  - Custom ns-O-RAN E2SM KPI
  - E2SM RC from G release
- All of them can be found at:
  - https://github.com/wineslab/libe2proto/tree/ns-o-ran

```
RANfunction-Name ::= SEQUENCE{
        ranFunction-ShortName    PrintableString (SIZE(1..150,...)),
        ranFunction-E2SM-OID     PrintableString (SIZE(1..150,...)),
        ranFunction-Description PrintableString (SIZE(1..150,...)),
        ranFunction-Instance     INTEGER OPTIONAL,
        ...
}

RIC-EventTriggerStyle-Item ::= SEQUENCE{
        ric-EventTriggerStyle-Type       RIC-Style-Type,
        ric-EventTriggerStyle-Name       RIC-Style-Name,
        ric-EventTriggerFormat-Type      RIC-Format-Type,
        ...
}
```

All the xApps are taken from the OSC repositories

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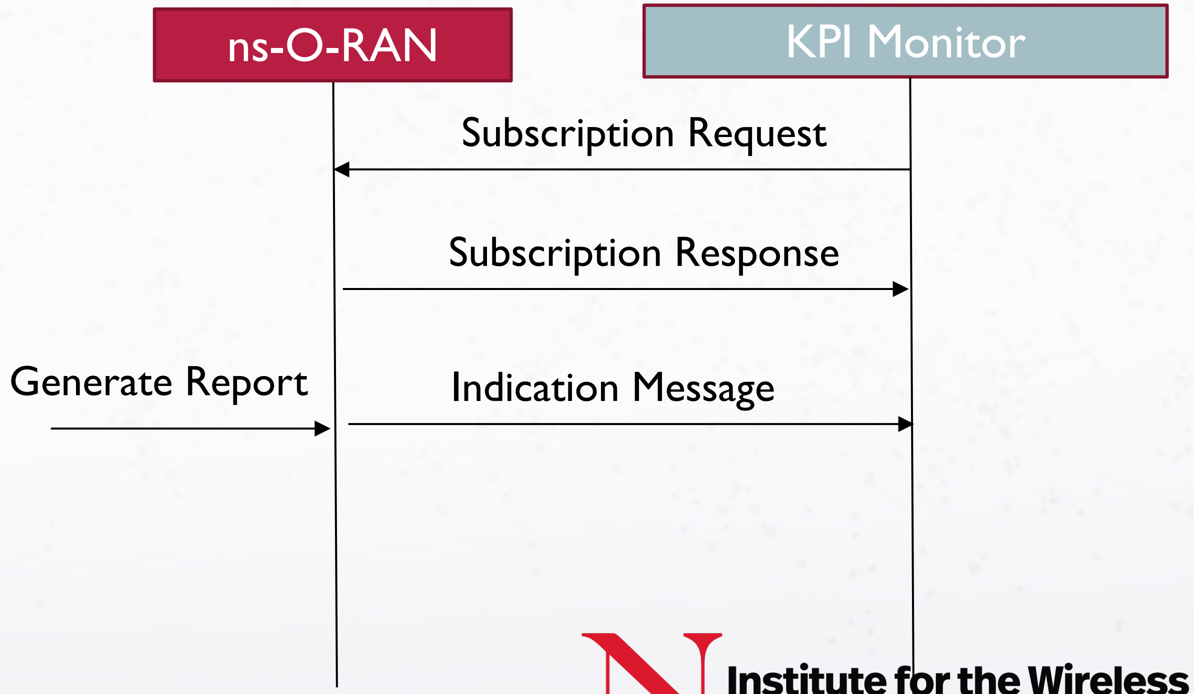
xApp KPI monitor

- Monitoring xApp
  - Send the E2 Subscription Request
  - Receives the Indication Messages from the RAN
  - Decode the parameters
  - Store the values in the real time database (not in this demo)
- Available here:
  - https://github.com/wineslab/ns-o-ran-scp-ric-app-kpimon

```
git clone https://github.com/wineslab/ns-o-ran-scp-ric-app-kpimon kpimon -b libe2proto
cd kpimon
./launch_app.sh
# a shell should spawn inside the kpimon pod
# Actually launch the routine of the xApp
/kpimon -f /opt/ric/config/config-file.json
```



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xApp KPI monitor – launch script

- Creates an env. variable to specify the k8s backend.
- Uninstall old versions
- Building the xApp from source
- Push the image to the registry
- Onboards the xApp, using the descriptor and validation schema.
- Installing the xApp in the RIC
- After 10s, the script returns the name of the pod in the *ricxapp* namespace and the command to shell inside it

```
#!/bin/bash
#set -x

export CHART_REPO_URL=http://0.0.0.0:8090

dms_cli uninstall xappkpimon ricxapp

docker build . -f Dockerfile -t 127.0.0.1:5000/kpimon_master:1.0.0 # --no-cache

docker push 127.0.0.1:5000/kpimon_master:1.0.0

# dms_cli onboard config.json schema.json

dms_cli install xappkpimon 1.0.0 ricxapp

echo "Wait for 10 seconds"
sleep 10

unset $pod_name

pod_name=$(kubectl get pods -n ricxapp --no-headers -o custom-columns=":metadata.name")

echo kubectl exec -ti -n ricxapp $pod_name bash

# To run the kpimon
# ./kpimon -f /opt/ric/config/config-file.json
```

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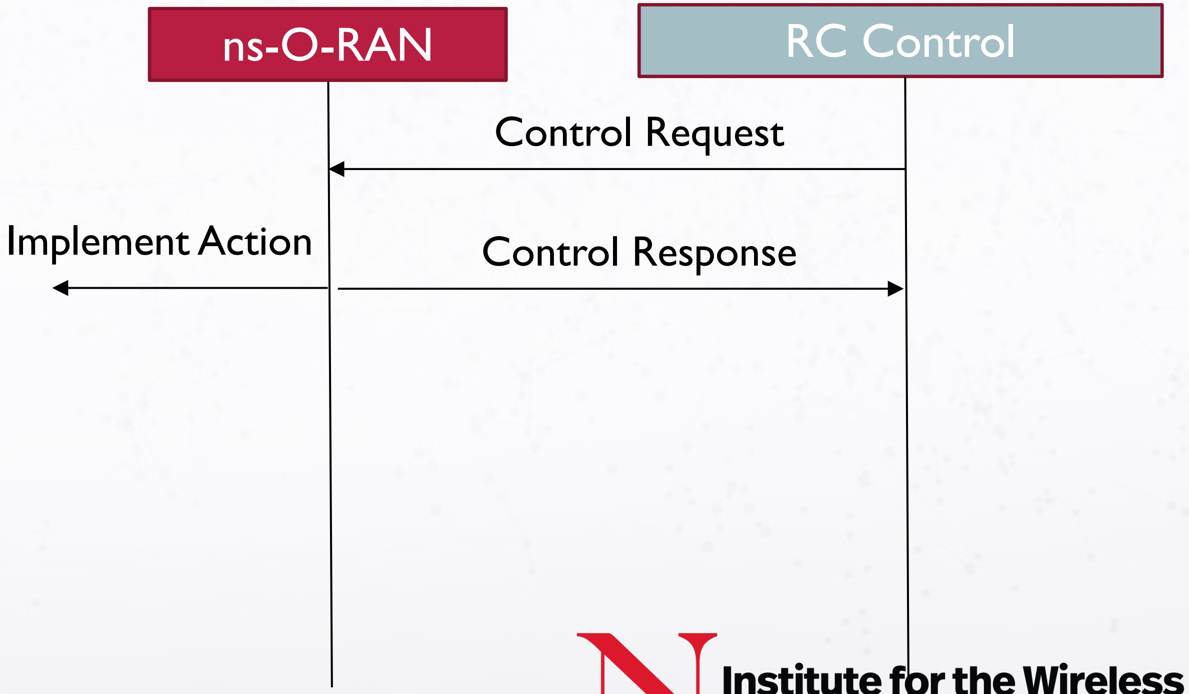
RC Control xApp

- Implements the TS use case
  - Send the E2 RC Control Action to the RAN
    - For example, an handover command
  - Can be used as a network function by other xApps
  - Server GRPC that create the controls on demand

- Available here:
  - https://github.com/wineslab/ns-o-ran-xapp-rc

```
git clone https://github.com/wineslab/ns-o-ran-xapp-rc xapp-rc
cd xapp-rc
./launch_app.sh
```



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RC Control Command

- GRPC commands can be executed:
  - by xApps
  - manually with grpcurl:
    - https://github.com/fullstorydev/grpcurl

```
RC_XAPP_IP=10.104.101.157

grpcurl -plaintext -d "{ \"e2NodeID\": \"36000000\", \"plmnID\": \"313131\", \"ranName\": \"gnb_131_133_31000000\",
\"RICE2APHeaderData\": { \"RanFuncId\": 300, \"RICRequestorID\": 2 }, \"RICControlHeaderData\": { \"ControlStyle\": 3,
\"ControlActionId\": 1, \"UEID\": \"00003\" }, \"RICControlMessageData\": { \"RICControlCellTypeVal\": 4, \"TargetCellID\": \"11103\"
}, \"RICControlAckReqVal\": 0 }"  ${RC_XAPP_IP}:7777 rc.MsgComm.SendRICControlReqServiceGrp
```

Putting things together

- We get the IP of the e2 termination
- We launch the simulation
- Launch and observe the monitoring of the kpimon
- Send control action to ns-O-RAN with GRPC

```
kubectl get pods -n ricplt -o wide
```

```
NS_LOG="RicControlMessage" ./ns3 run "scratch/scenario-zero.cc --simTime=15 --e2TermIp=10.244.0.161"
```

Useful commands for working in the RIC

```
# check IP of RIC components (especially) E2 Termination
kubectl get pods -A -o wide -n ricplt

# check IP of the services in the xApp namespace
kubectl get svc -o wide -n ricxapp
```

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Useful commands for working in the RIC

- APP manager:
  - View all the deployed xApps

```
curl -X GET -H "Content-Type:application/json" http://$APPMGR:8080/ric/v1/xapps | jq .
```

  - Manually remove an xApp

```
curl -X POST -H "Content-Type: application/json" \
        http://$APPMGR:8080/ric/v1/deregister -d \
        '{"appInstanceName": "cnn-31", "appName": "cnn-31"}'
```

- Subscription Manager:
  - View subscription IDs

```
curl -X GET "http://${SUBMGR}:8088/ric/v1/subscriptions"
```

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Useful commands for working in the RIC

- Routing Manager:
  - View routes

```
curl -X GET -H "accept: application/json" \ "http://${RTMGR}:3800/ric/v1/getdebuginfo" | jq .
```

  - Manually add a route

```
curl -X 'POST' \
      "http://${RTMGR}:3800/ric/v1/handles/addrmrroute" \
      -H 'accept: application/json' \
      -H 'Content-Type: application/json' \
      -d '[
      {
        "TargetEndPoint": "service-ricxapp-cnn-1-rmr.ricxapp:4560",
        "MessageType": 12050,
        "SenderEndPoint": "",
        "SubscriptionID": 1
      }
    ]'
```

  - Manually delete a route

```
curl -X 'DELETE' \
      "http://${RTMGR}:3800/ric/v1/handles/delrmrroute" \
      -H 'accept: application/json' \
      -H 'Content-Type: application/json' \
      -d '[
      {
        "TargetEndPoint": "service-ricxapp-cnn-1-rmr.ricxapp:4560",
        "MessageType": 12050,
        "SenderEndPoint": "",
        "SubscriptionID": 1
      }
]'
```

Thanks for the attention!
Questions?

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