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N Institute for the Wireless
Internet of Things
at Northeastern University



OpenRAN Gym

AI/ML in O-RAN with OpenRAN Gym

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Why OpenRAN Gym?

- Lack of experimental platforms (RAN, Core, SMO, RICs)
- Lack of (public) datasets for designing/testing AI
- Need for large-scale experimentation (not simply bench setups)
- Get academia familiar with efforts from the O-RAN Alliance

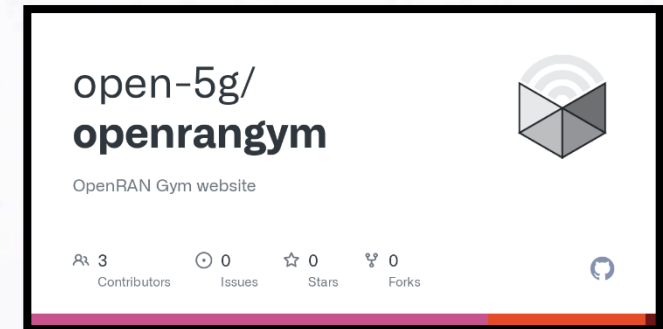
OpenRAN Gym

First publicly-available research platform for data-driven O-RAN experimentation at scale

- **Open-source**
- End-to-end Open RAN network
- Near-RT RIC
- E2 Interface
- xApp dev kit
- Data collection
- Network Slicing
- Integration with Colosseum



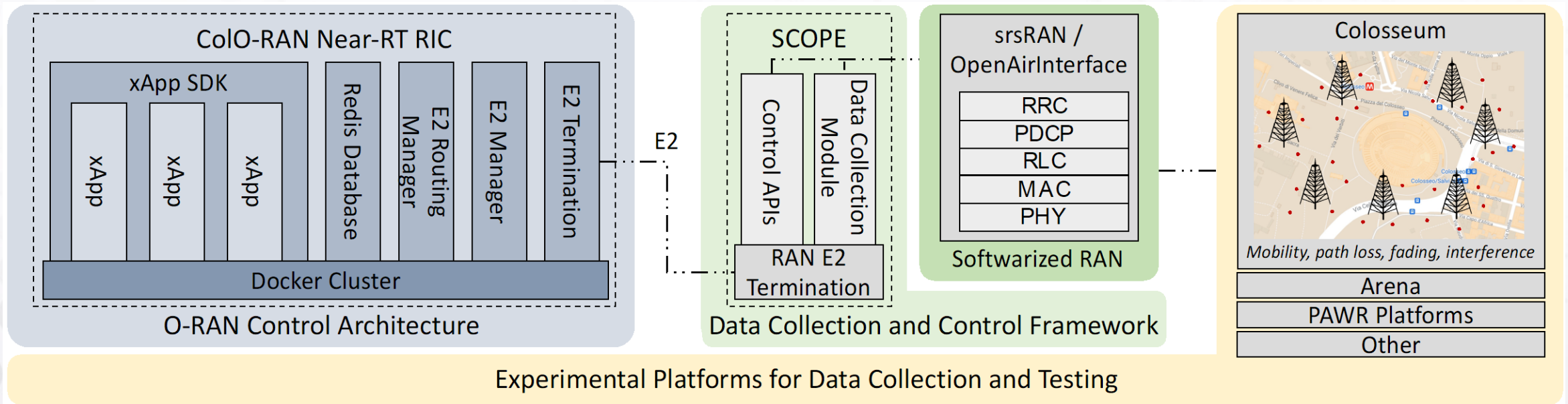
OpenRAN Gym



Website: openrangym.com

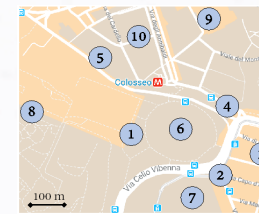
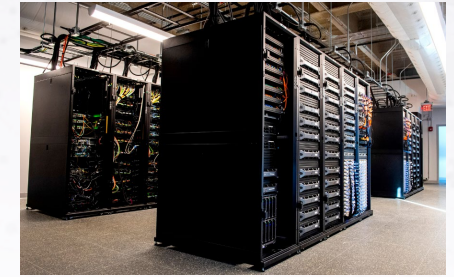
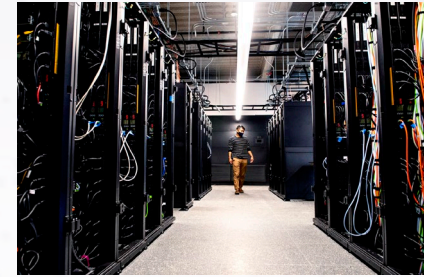
Architecture

- O-RAN-compliant **near-real-time RIC** running on Colosseum (CoIO-RAN)
- RAN framework for **data-collection and control** of the base stations (SCOPE)
- **Programmable** protocol stacks
- Publicly-accessible **experimental platforms** (e.g., Colosseum, Arena, PAWR platforms)

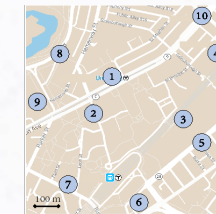


Colosseum – the world’s largest RF emulator

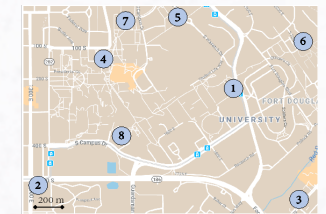
- Container-based
- White-box infrastructure
- 256 Software-Defined Radios
- Realistic channel / traffic emulation
- 65,536 80 MHz emulated RF channels
- Real-time emulation with actual radios



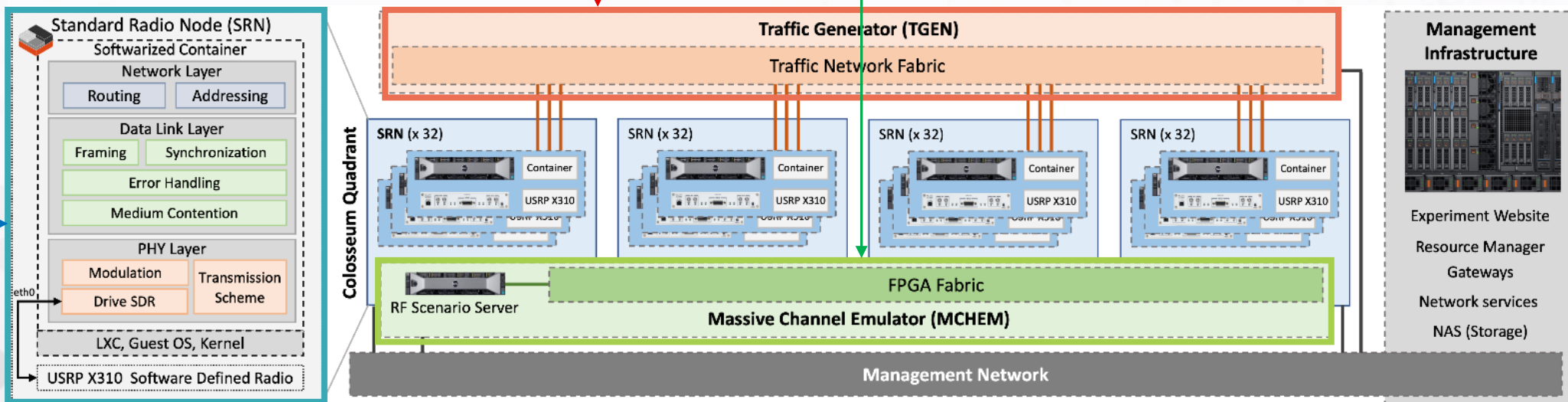
Rome, Italy



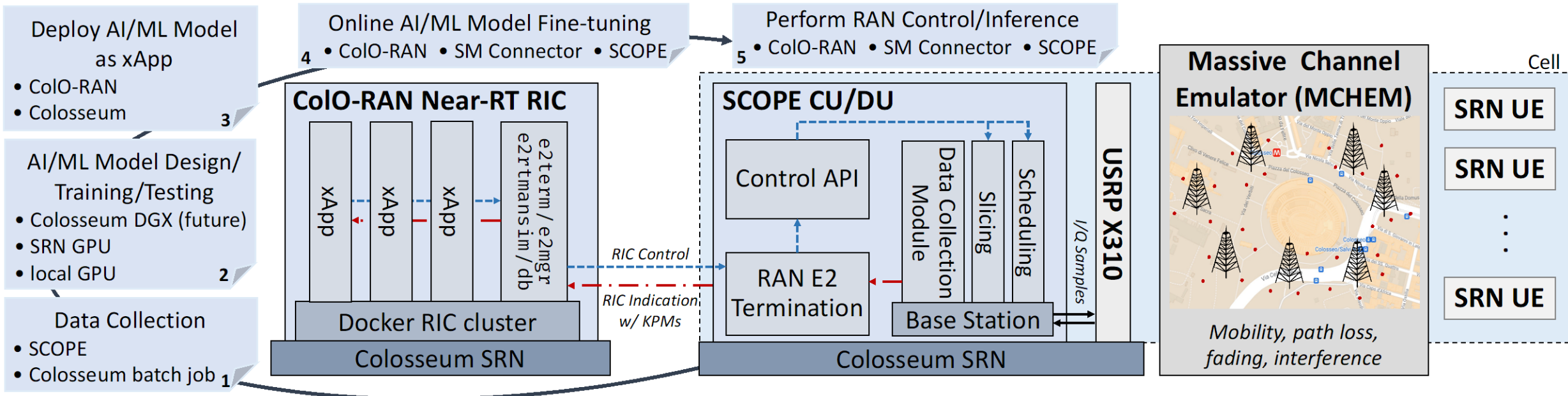
Boston, MA



Salt Lake City, UT (POWDER)



xApp Development Workflow



```
./setup-scripts/setup-ric.sh <eth-interface>
```

→ Start near-RT RIC

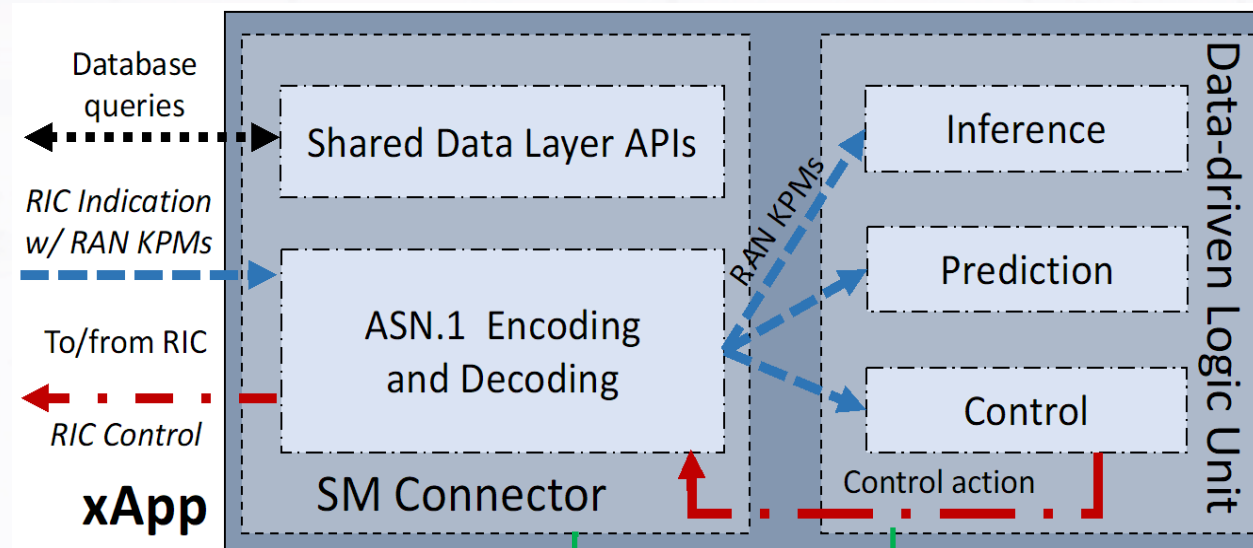
```
python3 ./radio_api/scope_start.py --config-file radio.conf
./radio_code/colosseum-scope-e2/run_odu.sh
```

→ Start gNB and subscribe to RIC

```
./setup-scripts/setup-sample-xapp.sh <basestation-id>
```

→ Start xApp

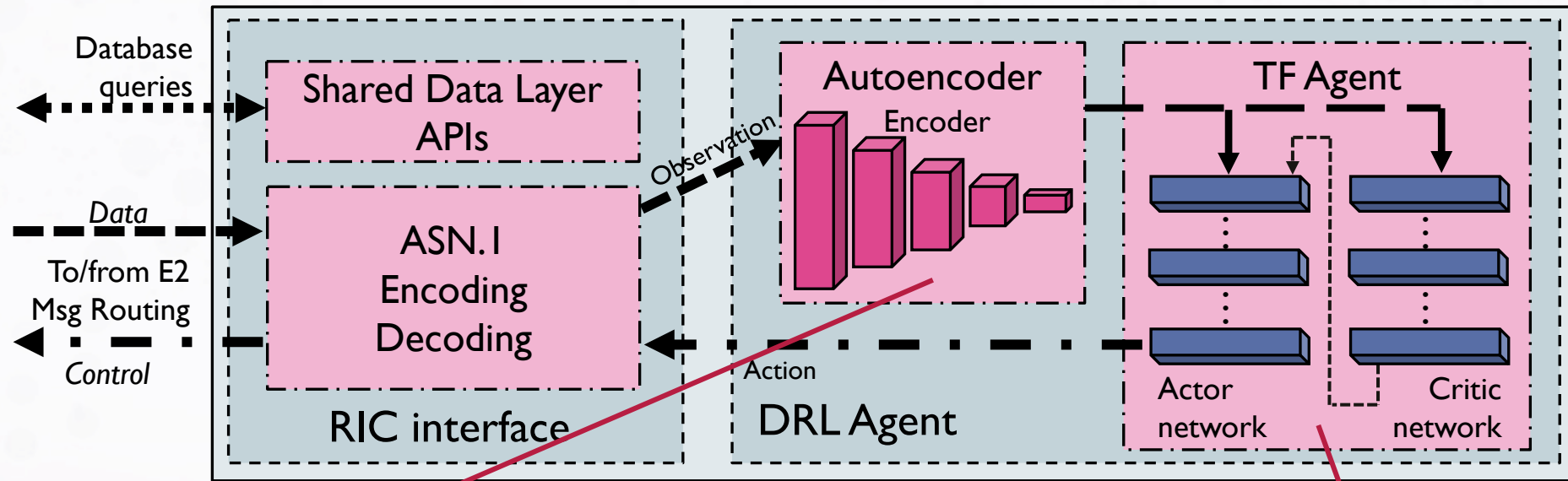
xApp Structure



- Interface with Near-RT RIC (E2)
- Receive KPIs
- Send decisions

- Process KPIs
- Take decisions (e.g., traffic steering, RAN slicing)

DRL structure



Generate a compressed representation of the RAN

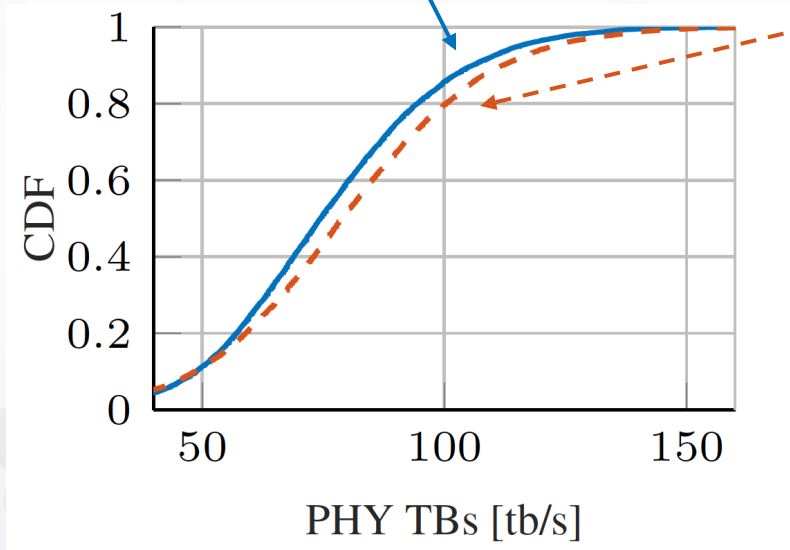
Exploit it to generate control actions in the network

What type of research can you do with OpenRAN Gym?

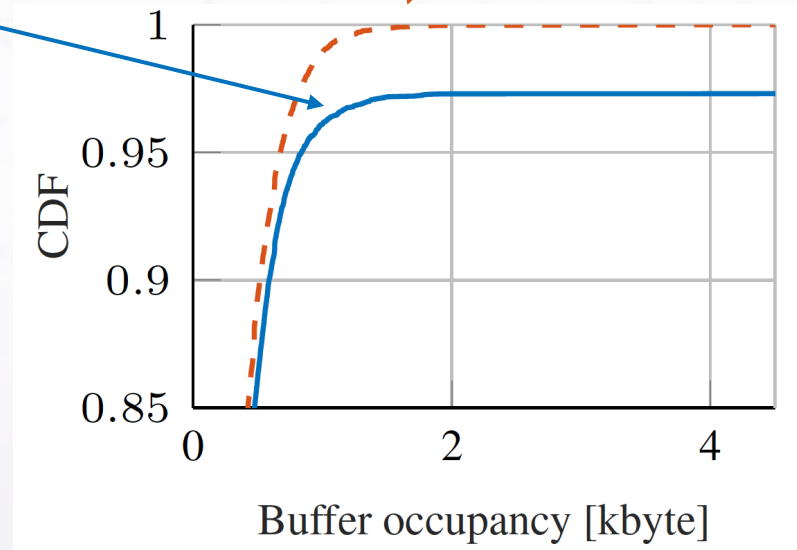
- AI-based control
 - Network slicing
 - Scheduling
 - Traffic steering
 - Energy / mobility management
- Dataset generation for Open RAN
- Forecasting / Classification
- AI orchestration
- Spectrum coexistence / sharing
- Reliable AI
- Online Training
- Adversarial AI for Open RAN
- Security
- AI design

Action space design and DRL-based control

- 7 SDR base stations w/ 42 User Equipments (UEs) on Colosseum
- 3 network slices: eMBB, URLLC, MTC
- Two DRL-based xApps running in the near-real-time RIC:
 - **xApp 1**: control scheduling
 - **xApp 2**: control scheduling & slicing



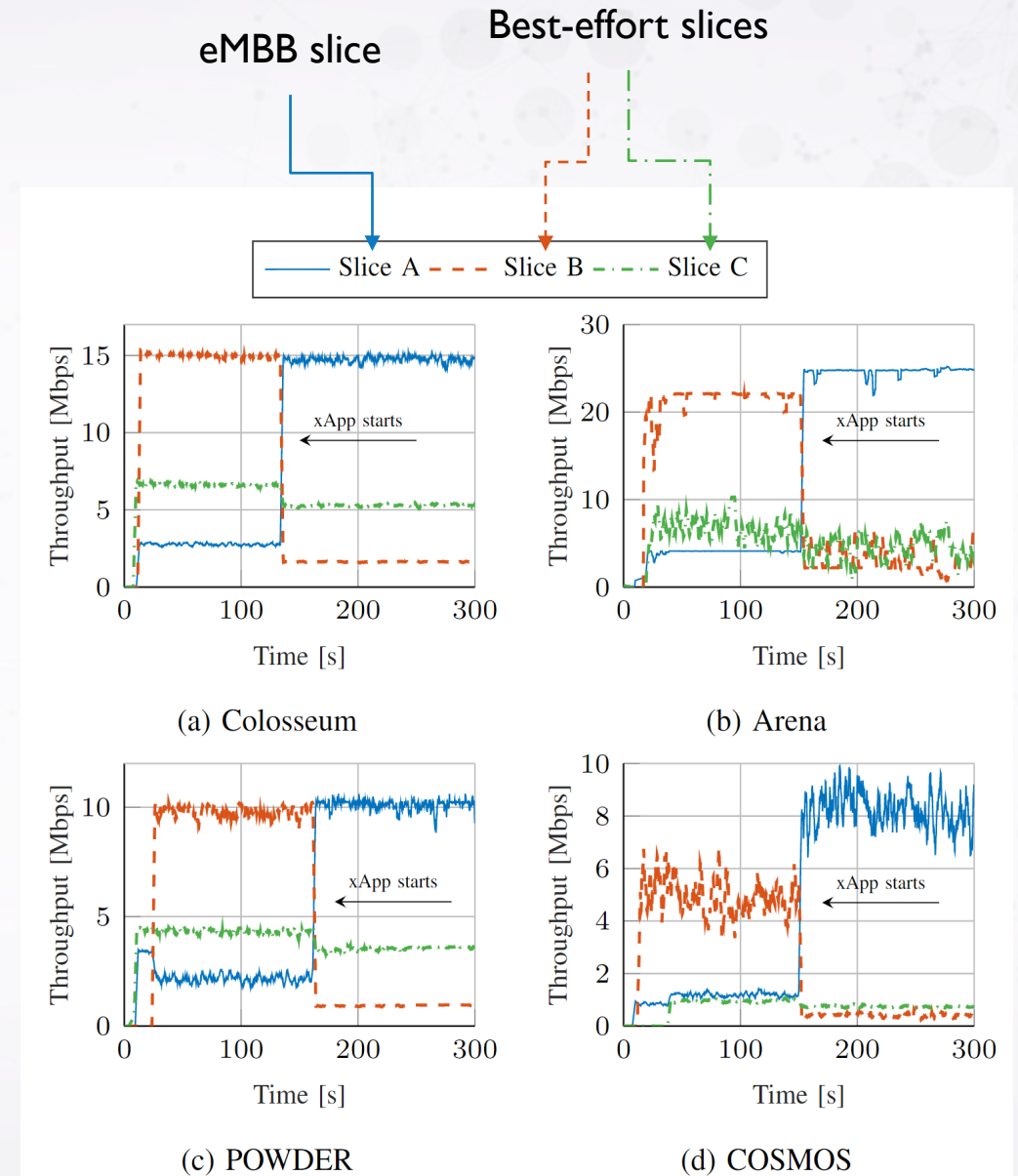
MTC transmitted packets



URLLC buffer occupancy

Portable and General AI

- 3 slices:
 - 1 eMBB slice
 - 2 best-effort slices
- 4 different wireless platforms
 - Colosseum
 - Arena
 - POWDER
 - COSMOS
- Test generalized AI behavior
 - Trained on Colosseum (DRL)
 - Tested on the other platforms



Online training

Action distribution after offline training

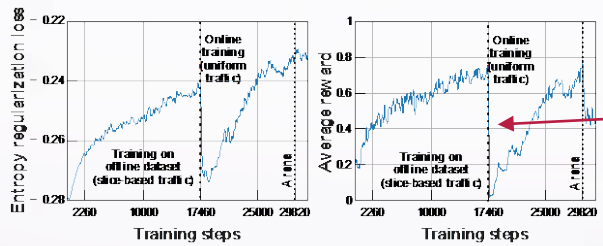


What happens when there is an unforeseen configuration in the network?



Online fine-tuning

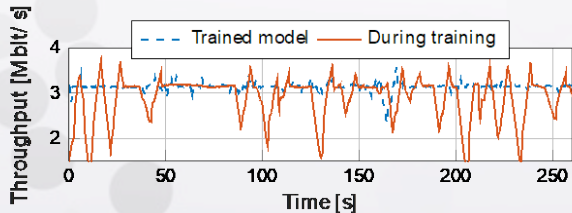
Online reward/loss evolution



Traffic changes (reward loss)

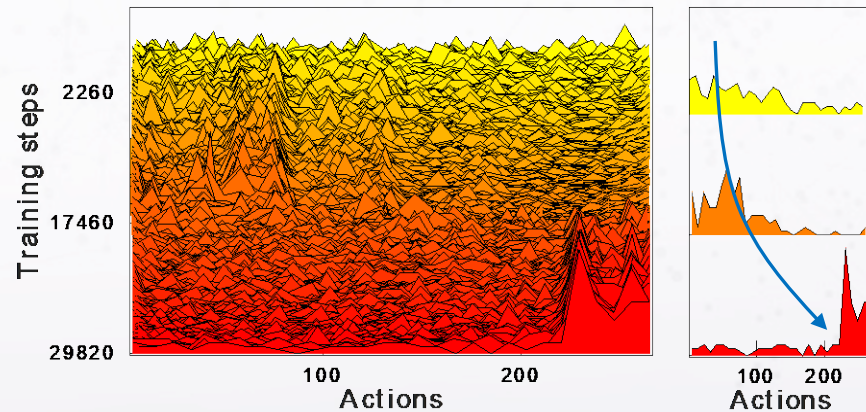


Online training starts

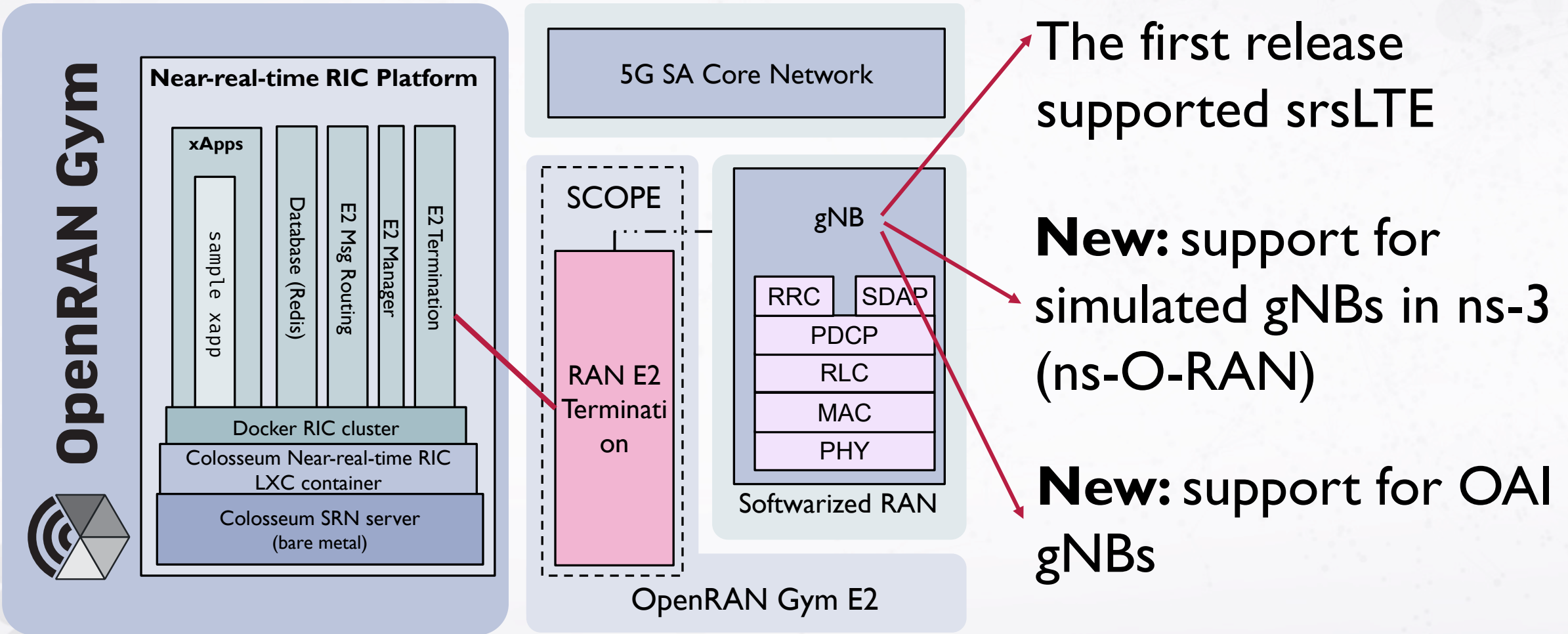


Exploration impacts performance

Action distribution evolution



E2 interfaces for OpenRAN Gym



True interoperability!

```
<E2AP-PDU>
<successfulOutcome>
  <procedureCode>1</procedureCode>
  <criticality><reject/></criticality>
  <value>
    <E2setupResponse>
      <protocolIEs>
        <E2setupResponseIEs>
          <id>4</id>
          <criticality><reject/></criticality>
          <value>
            <GlobalRIC-ID>
              <plmn-identity>13 10 14</plmn-identity>
              <ric-ID>
                10101010110011001110
              </ric-ID>
            </GlobalRIC-ID>
          </value>
        </E2setupResponseIEs>
      </protocolIEs>
    </E2setupResponse>
  </value>
</successfulOutcome>
</E2AP-PDU>

EZAP : Store E2 setup response Params
EZAP : E2 Setup Response received

[INFO ] [SCTP] Connecting to server at 172.30.199.201:36422 ...
[UNCON] Start E2 Agent (E2 Simulator)
[UNCON] Current Log level is 2
[INFO ] [SCTP] Binding client socket with source port 38472
[INFO ] [SCTP] Connecting to server at 172.30.199.201:36422 ...
[UNCON] Start E2 Agent (E2 Simulator)
[UNCON] Current Log level is 2
[INFO ] [SCTP] Binding client socket with source port 38473
[INFO ] [SCTP] Connecting to server at 172.30.199.201:36422 ...
[UNCON] Start E2 Agent (E2 Simulator)
[UNCON] Current Log level is 2
[INFO ] [SCTP] Binding client socket with source port 38474
[INFO ] [SCTP] Connecting to server at 172.30.199.201:36422 ...
[UNCON] Start E2 Agent (E2 Simulator)
[UNCON] Current Log level is 2
[INFO ] [SCTP] Binding client socket with source port 38475
[INFO ] [SCTP] Connecting to server at 172.30.199.201:36422 ...
[INFO ] [SCTP] Connection established
[INFO ] [SCTP] Connection established
[INFO ] [SCTP] Connection established
[INFO ] [SCTP] Connection established
[INFO ] [SCTP] Connection established
[INFO ] [INFO ] About to register a function[INFO ]
[INFO ] About to register a function
[INFO ] About to register a function
[INFO ] About to register a function
[INFO ] [SCTP] Sent E2-SETUP-REQUEST
[INFO ] [INFO ] [INFO ] [SCTP] Sent E2-SETUP-REQUEST
[INFO ] [SCTP] Sent E2-SETUP-REQUEST
[SCTP] Sent E2-SETUP-REQUEST
[SCTP] Sent E2-SETUP-REQUEST
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS
[INFO ] [EZAP] Received SETUP-RESPONSE-SUCCESS

root@neu-test-team-1-eugenio-ran-dev-srn102:~/ocp-e2sim# ./run_e2sim.sh 172.30.199.201
Starting e2term - oai support version

Encoding RAN Function Description
Registering RAN Function Description callbacks
Init done, running loop..
E2sim loop init...
[SCTP] Binding client socket to source port 36422
[SCTP] Connecting to server at 172.30.199.201:36422 ...
[SCTP] Connection established
Generating e2apv1 setup request
Env variable GNB_ID not set. Using default values to build gNB ID
[SCTP] Sent E2-SETUP-REQUEST
[SCTP] Waiting for SCTP data
[SCTP] Received new data of size 33
decoding...
[EZAP] Unpacked E2AP-PDU: index = 2, procedureCode = 1
[EZAP] Received SETUP-RESPONSE-SUCCESS

[1] 0:~$
```

E2 for srsLTE

E2 for ns-3
(5 gNBs)

E2 for OAI

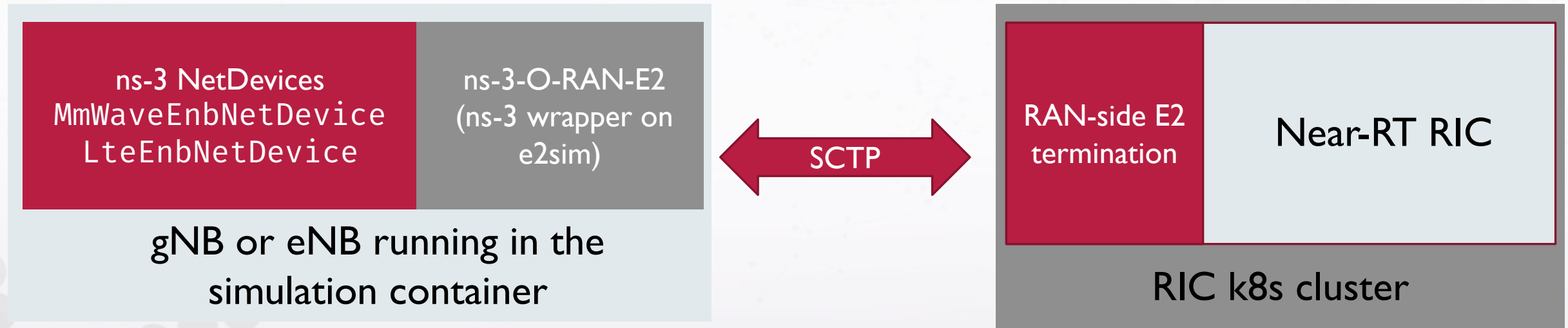
Same OpenRAN Gym RIC

```
7) "{e2Manager}, GNB"
[127.0.0.1:6379> KEYS *
1) "{e2Manager}, GNB: 313131:00110011000000000000000000000000"
2) "{e2Manager}, RAN: gnb_131_133_31000000"
3) "{e2Manager}, E2Addresses"
4) "{e2Manager}, GNB: 313131:00110001000000000000000000000000"
5) "{e2Manager}, GNB: 373437:1011010111000110011101111000"
6) "{e2Manager}, RAN: gnb_131_133_32000000"
7) "{e2Manager}, RAN: gnb_131_133_33000000"
8) "{e2Manager}, GNB: 313131:00110101000000000000000000000000"
9) "{e2Manager}, RAN: gnb_311_048_01090901"
10) "{e2Manager}, RAN: gnb_734_733_b5c67780"
11) "{e2Manager}, E2Instance: 10.0.2.10:38000"
12) "{e2Manager}, GNB: 13F184:00000001000010010000100100000001"
13) "{e2Manager}, RAN: gnb_131_133_35000000"
14) "{e2Manager}, RAN: gnb_131_133_34000000"
15) "{e2Manager}, GNB: 313131:00110100000000000000000000000000"
16) "{e2Manager}, GNB: 313131:00110010000000000000000000000000"
17) "{e2Manager}, GNB"
127.0.0.1:6379> █
```

Based on OSC RIC

OpenRAN Gym and ns-3

- Developed a custom E2 termination for ns-3
- ns-3 provides functional RAN environment and connects to an O-RAN-compliant near-RT RIC
- To be included in the O-RAN SC



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Thanks!

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