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at Northeastern University

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

A. Lacava, M. Bordin, M. Polese, R. Sivaraj, T. Zugno,
F. Cuomo and T. Melodia
Institute for the Wireless Internet of Things
Northeastern University, Boston, MA | Sapienza, University of Rome
lacava.a@northestern.edu | andrea.lacava@uniroma1.it

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# From monolithic to Open RAN

## Traditional "black-box"

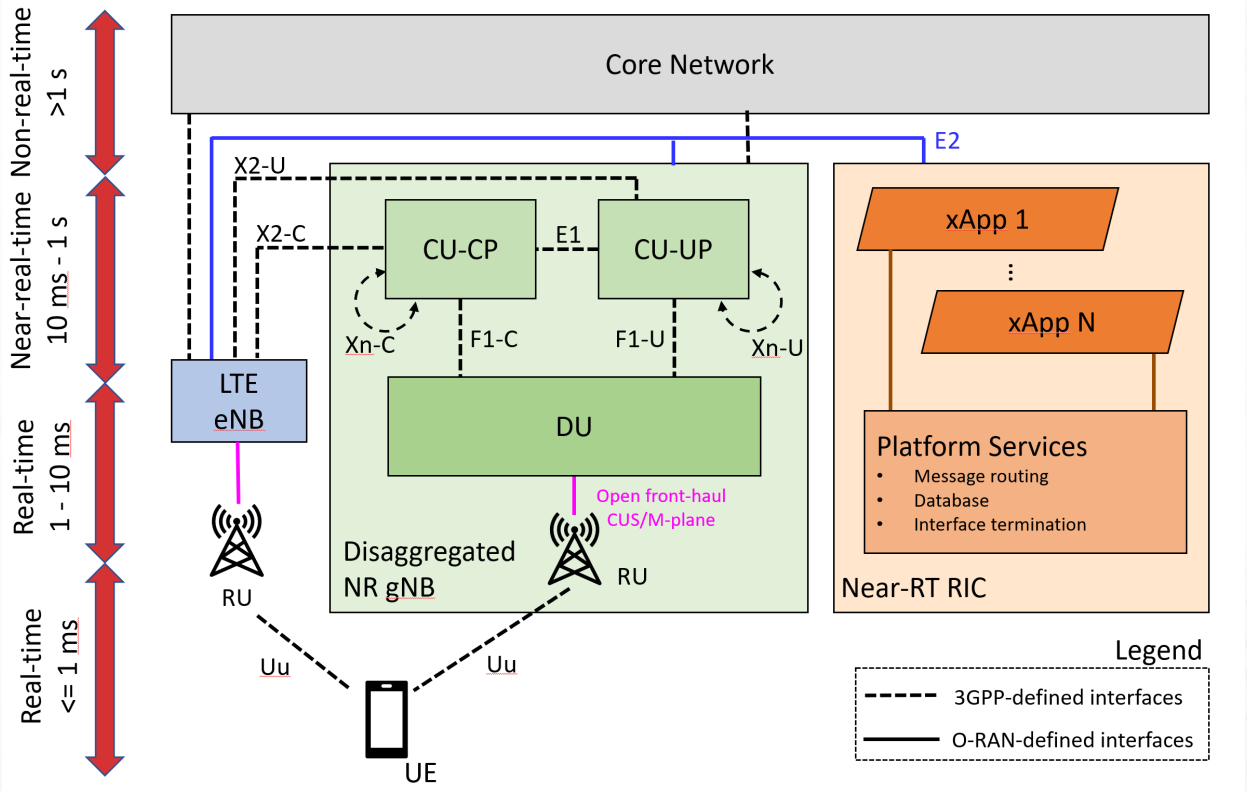
«Black Box» RAN

RRC | SDAP | PDCP

MAC | RLC

PHY | RF

## Open, programmable and virtualized



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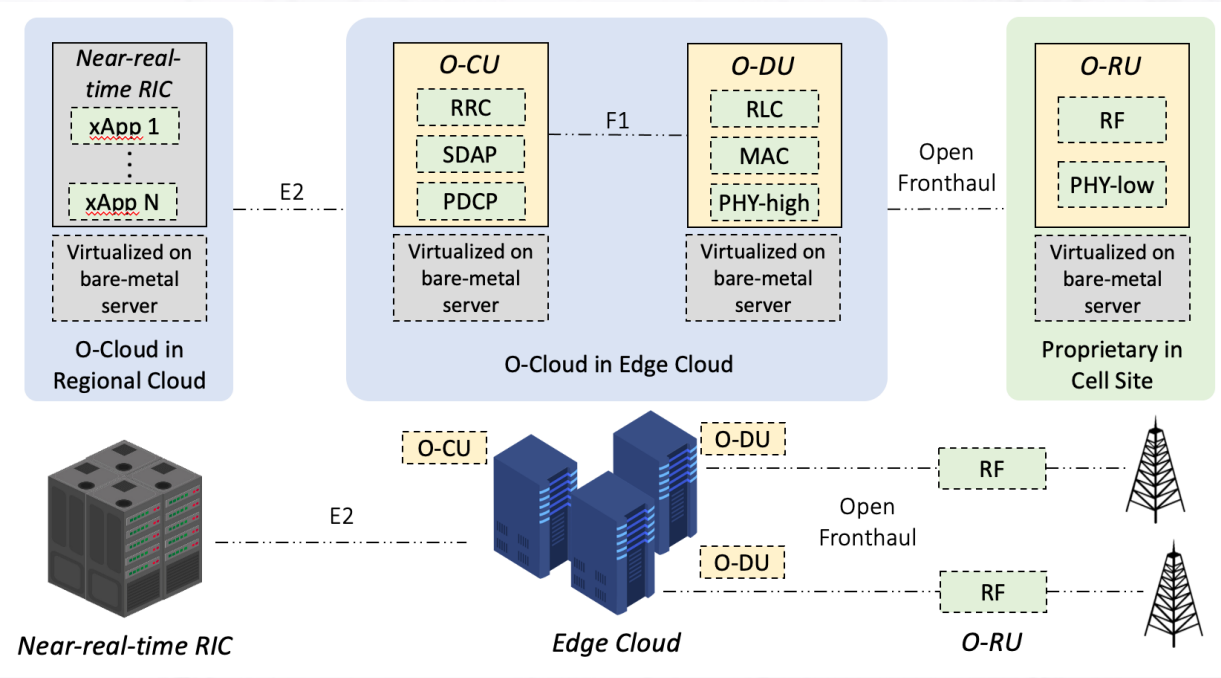
# RIC: Disaggregation and Programmability

- New game changing entity: RAN Intelligent controller (RIC)
  - Centralized abstraction of the network;
  - Open interfaces enabling full control for the operators;
  - AI agents implemented over RAN;
- Base stations functionalities of classical RAN are:
  - Virtualized as network functions (programmability and modularity);
  - Divided across multiple nodes (disaggregation toward scalability);
- Enable interoperability with different wireless networks;




L. Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia, "*Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead,*" Computer Networks, vol. 182, Dec 2020.

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# 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

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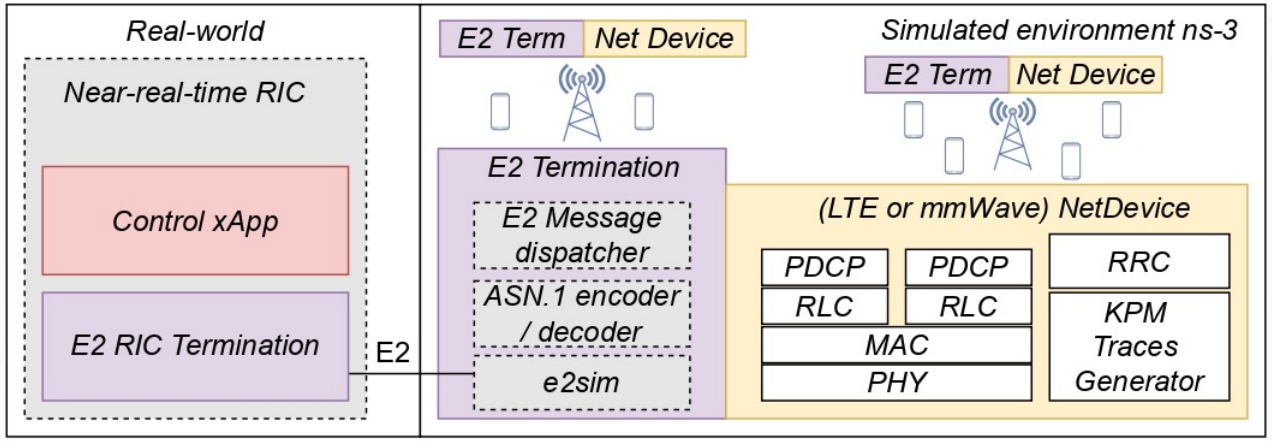
# ns-O-RAN: Simulating O-RAN 5G Systems in ns-3

- 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



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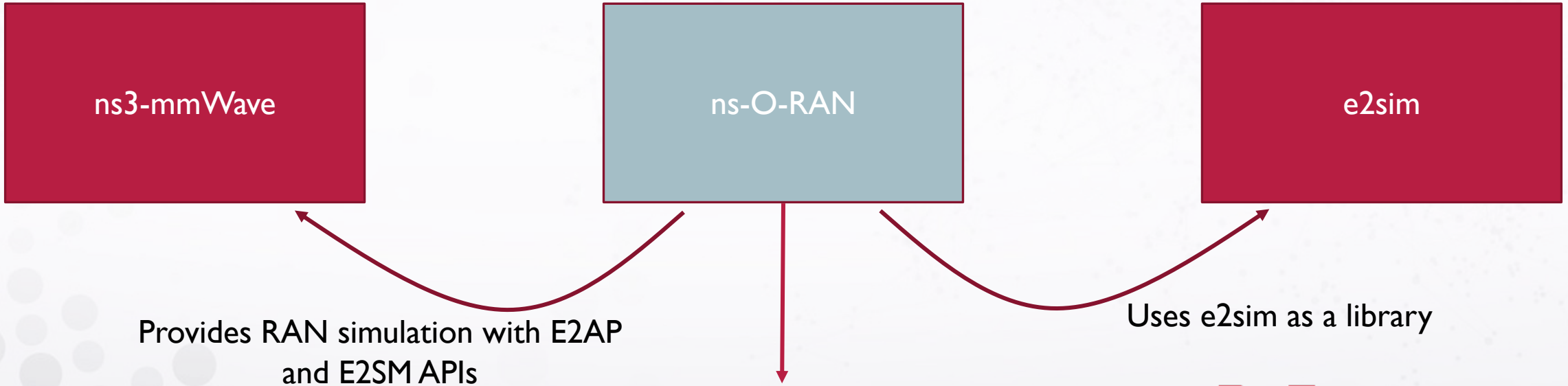
# Codebase structure

- 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

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# oran-e2sim

- Fork of OSC E2sim
  - https://github.com/o-ran-sc/sim-e2-interface
- Originally a framework to develop xApp with no RAN side
  - Connection to the near-RT RIC was the only one supported
  - Only support replay of messages and reading control actions



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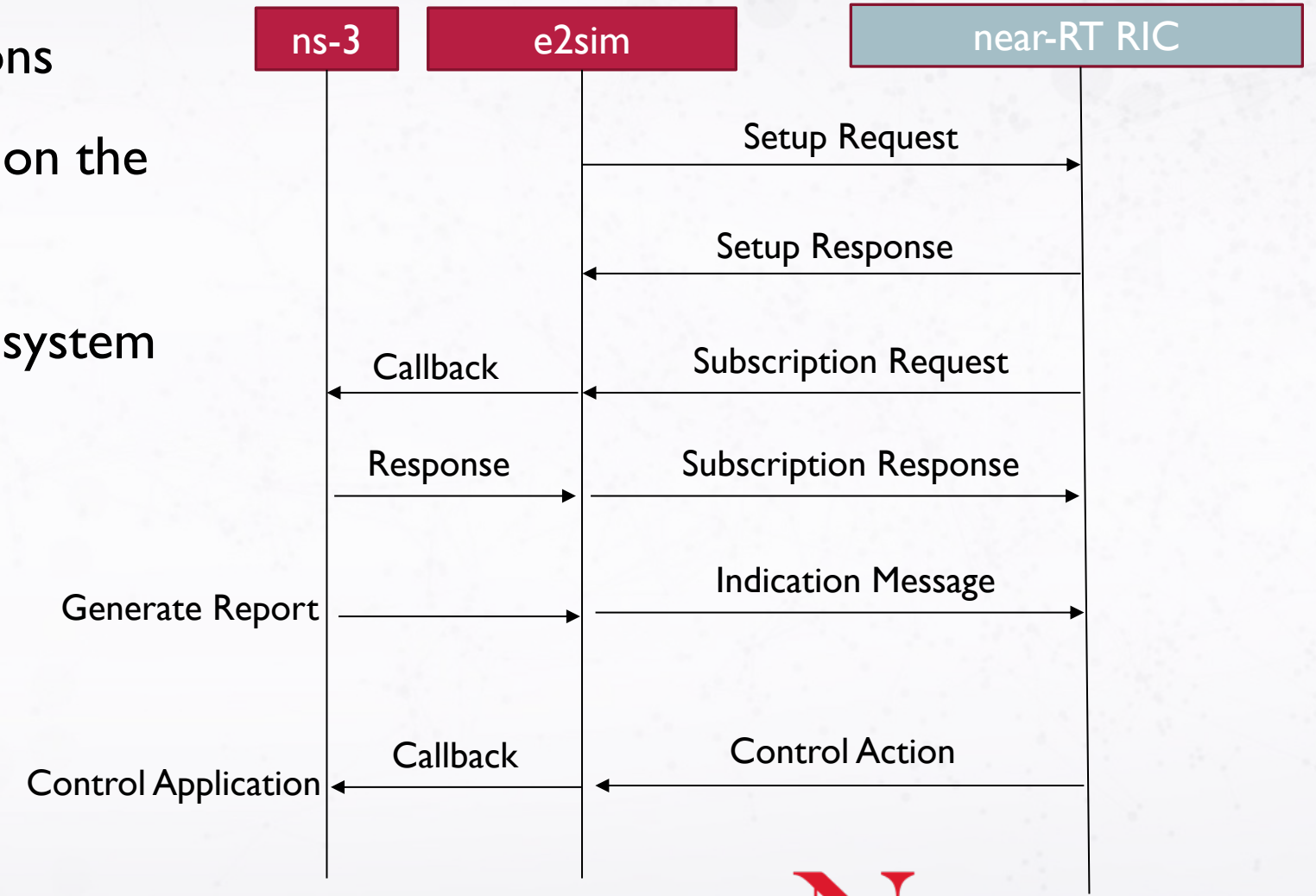
# oran-e2sim

- Update of latest ASN.1c definitions
- Enables multiple E2 connections on the same process
- Implements parsing and callback system for control messages



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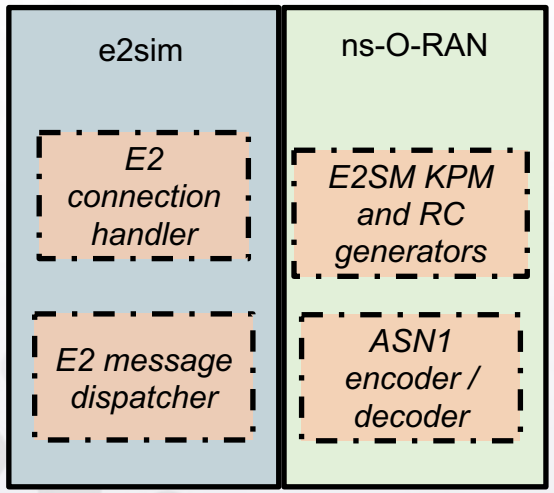
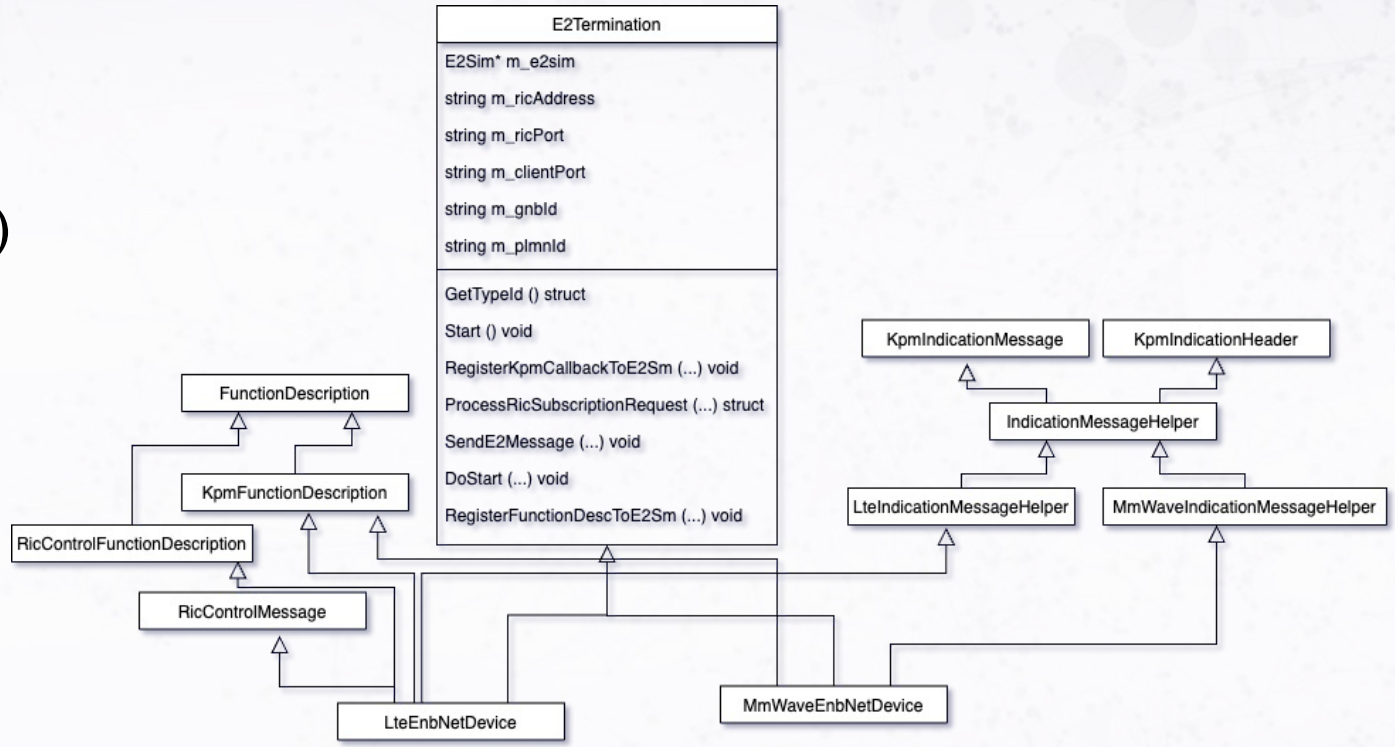
# ns-O-RAN

- Wrapper on e2sim library for ns-3
  - Agnostic from RAN module
  - Uses code from ns-3 (Ptr, Object, Simulator)
- Enables O-RAN E2AP and E2SM:
  - Anybody can implement their own scenario using O-RAN




```
def configure(conf):
    conf.env.append_value('CXXFLAGS', '-I/usr/local/include/e2sim')
    conf.env.append_value("LINKFLAGS", ["-L/usr/local/lib"])
    conf.env.append_value("LIB", ["e2sim"])
```



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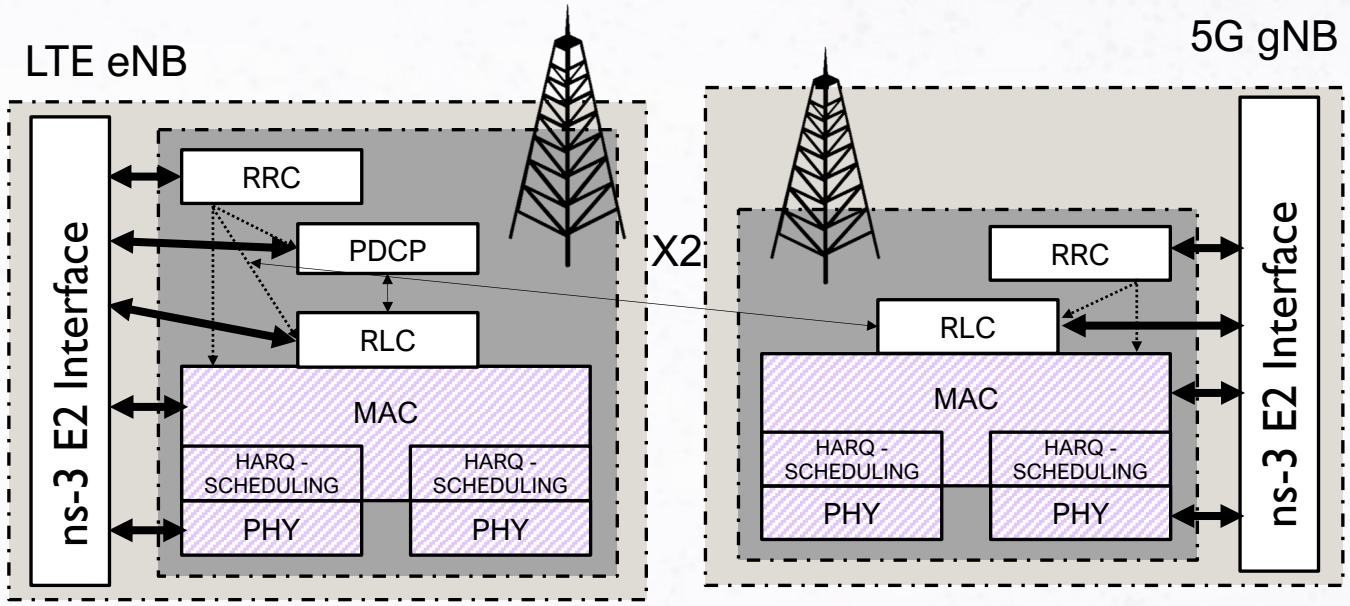
# ns-3 mmWave module for O-RAN

- Customized fork of the ns-3 mmWave module [1]
  - Each NetDevice (eNB or gNB) has its own E2 Interface connected to the RIC;
  - NetDevices can send reports about their status;
  - The RIC can control dynamically the NetDevices;
- Our contribution:
  - Adapted to develop oran-e2sim and use cases
  - Implemented subset of standard KPMs
  - Helper classes that can be extended to support newer ASN.1c definitions
- It will be upstreamed to the original project



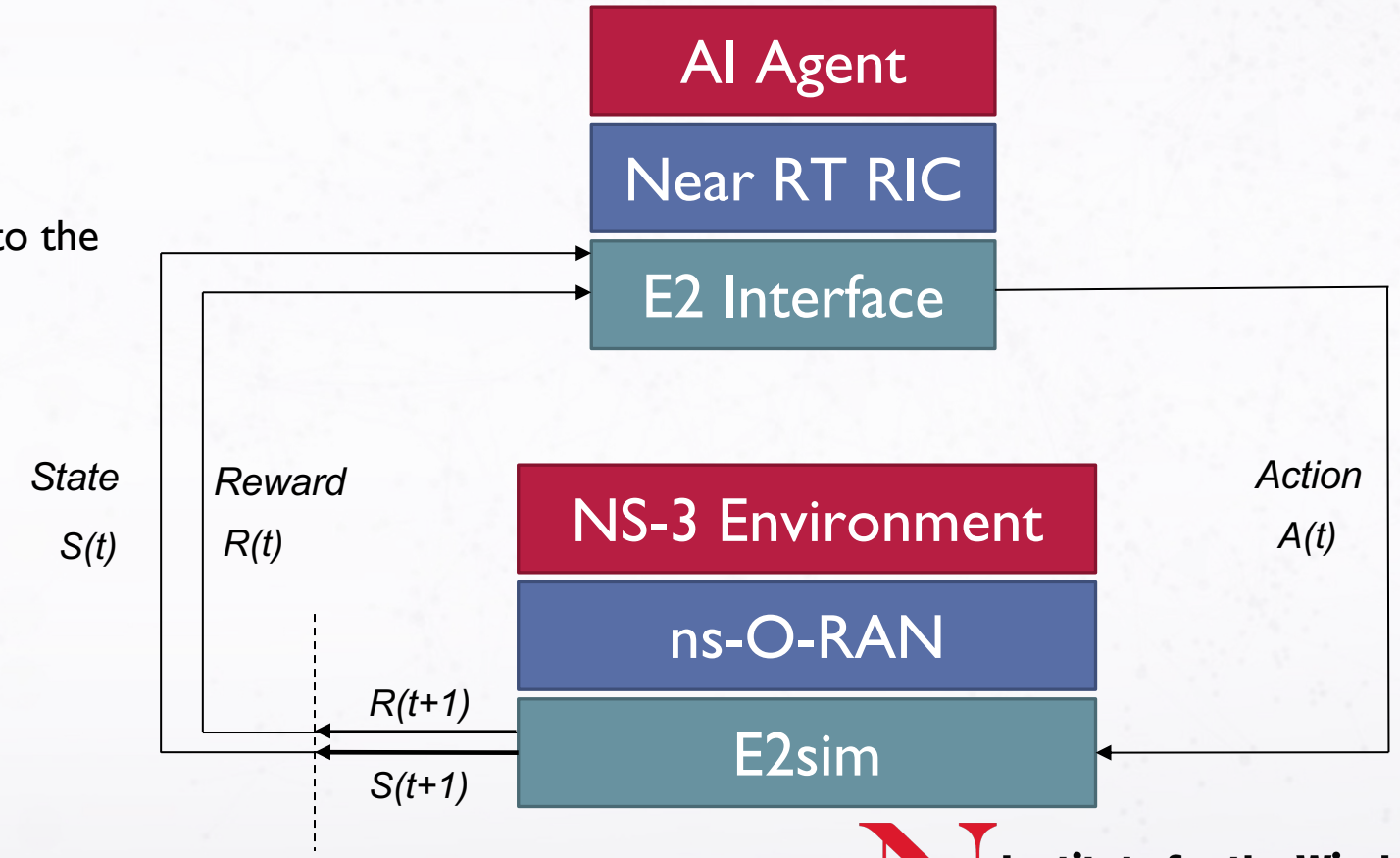



[1] M. Mezzavilla et al., "End-to-End Simulation of 5G mmWave Networks," in IEEE Communications Surveys & Tutorials, vol. 20, no. 3, pp. 2237-2263, thirdquarter 2018

# Building xApps with ns-O-RAN and Simulated Control Loops

Definition of the scenario → Definition of Service Models → Creation of Indication Message → Creation of Control Message → AI design → Training / Testing → Onboarding on a real RAN

- Complete framework for xApps
  - Design of E2SM
  - Study of the TS use case from the scenario to the solution
- Quality of datasets
  - Scalable scenarios
  - 3GPP-based channel conditions
- Enabling AI
  - Offline dataset collection
  - Online simulated inference

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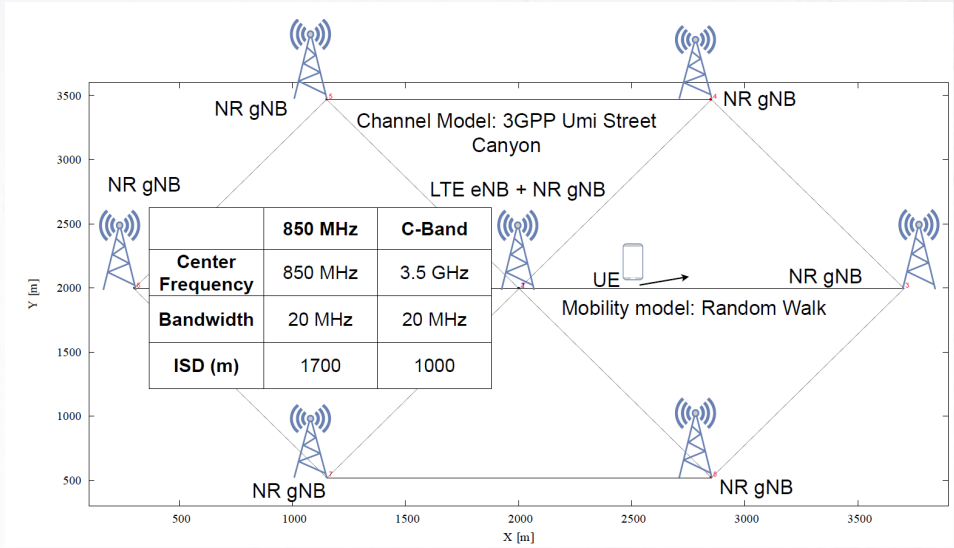
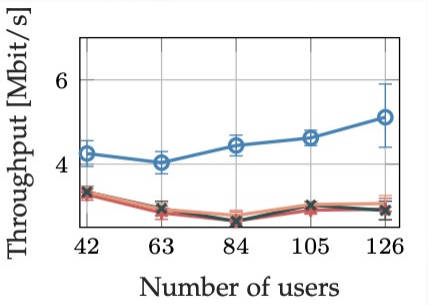
# Programmable and Customized Intelligence for Traffic Steering in 5G Networks Using Open RAN Architectures

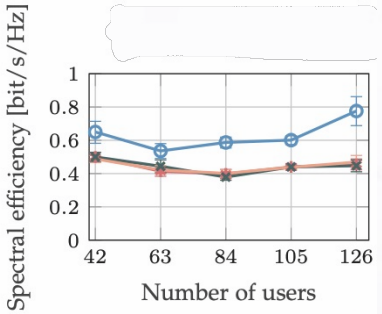
- Optimization of Handover Management using a data-driven approach
- Control over hundreds of UEs and dozens of BSs
- Issues on implementation:
  - Deploy cost
  - No standard framework to support the use case;
  - Need of a LOT of datasets with different policies implemented to train the AI agent;



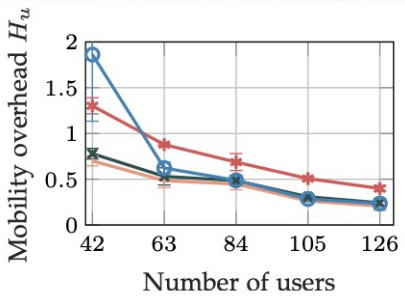

| | 850 MHz | C-Band |
|---|---|---|
| Center Frequency | 850 MHz | 3.5 GHz |
| Bandwidth | 20 MHz | 20 MHz |
| ISD (m) | 1700 | 1000 |




(a) Average UE throughput (LTE+NR).




(b) Average spectral efficiency, per cell.




(d) UE mobility overhead $H_u$.

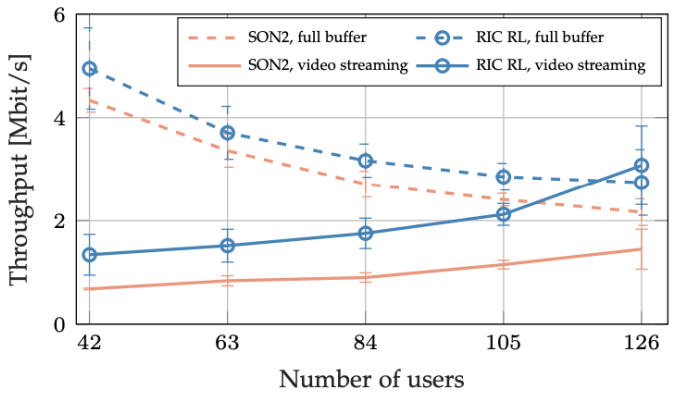




Fig. 9: Comparison between the average UE throughput for RIC RL and SON2 for different kinds of source user traffic (full buffer, video streaming).

[1] Lacava, Andrea, Michele Polese, Rajarajan Sivaraj, Rahul Soundrarajan, Bhawani Shanker Bhati, Tarunjeet Singh, Tommaso Zugno, Francesca Cuomo, and Tommaso Melodia. "Programmable and customized intelligence for traffic steering in 5g networks using open ran architectures." IEEE Transactions on Mobile Computing (2023).



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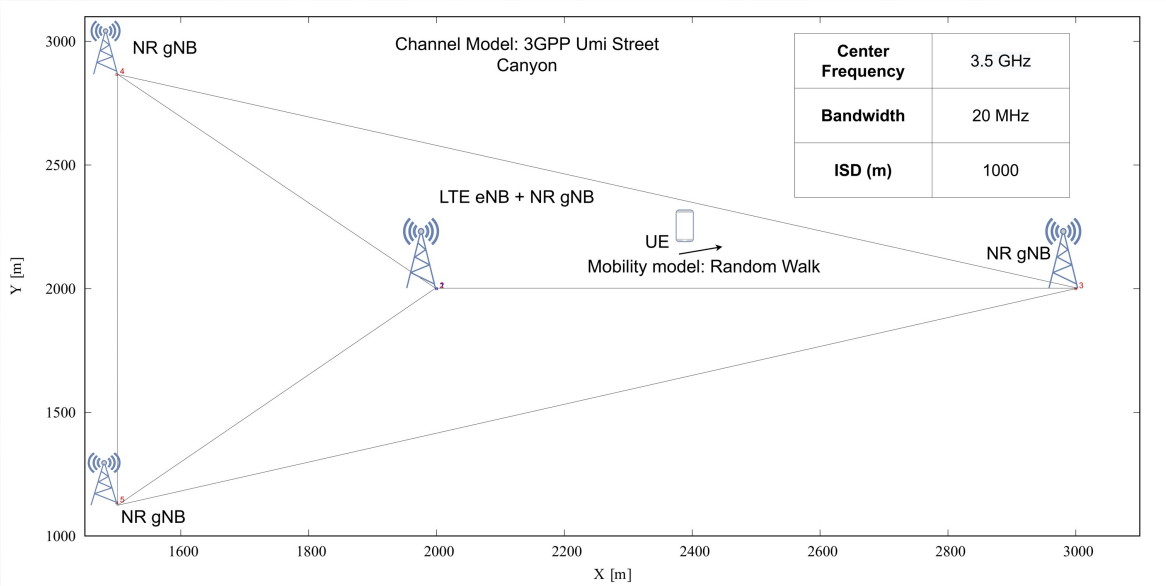
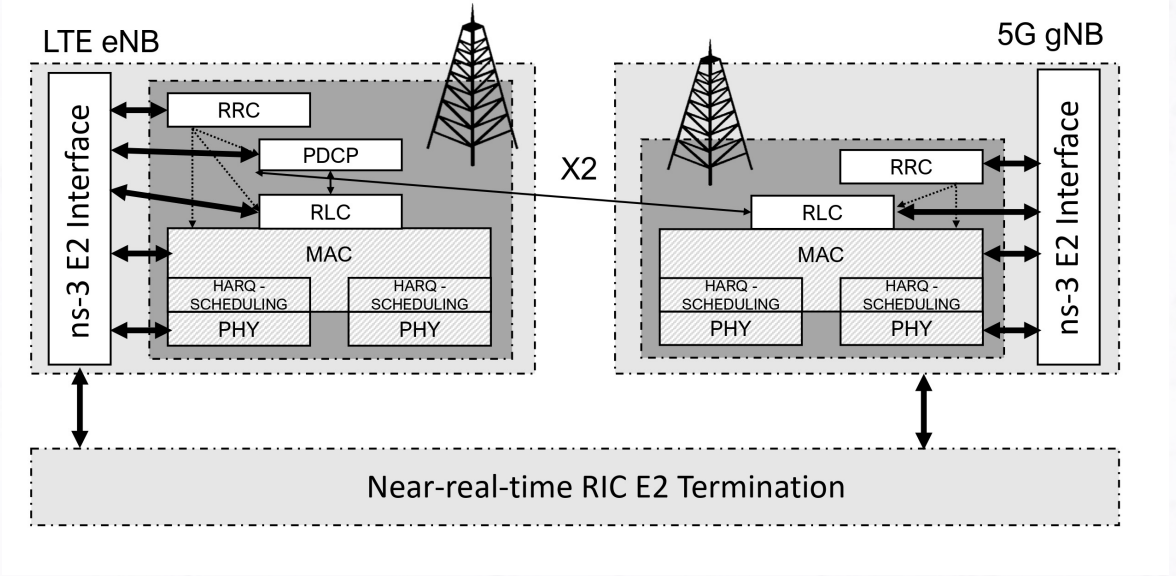
# Hands on ns-O-RAN with Scenario Zero

- Integration of ns-O-RAN with the OpenRAN Gym near-RT RIC
- Tutorial on OpenRAN Gym website:
  - https://openrangym.com/tutorials/ns-o-ran



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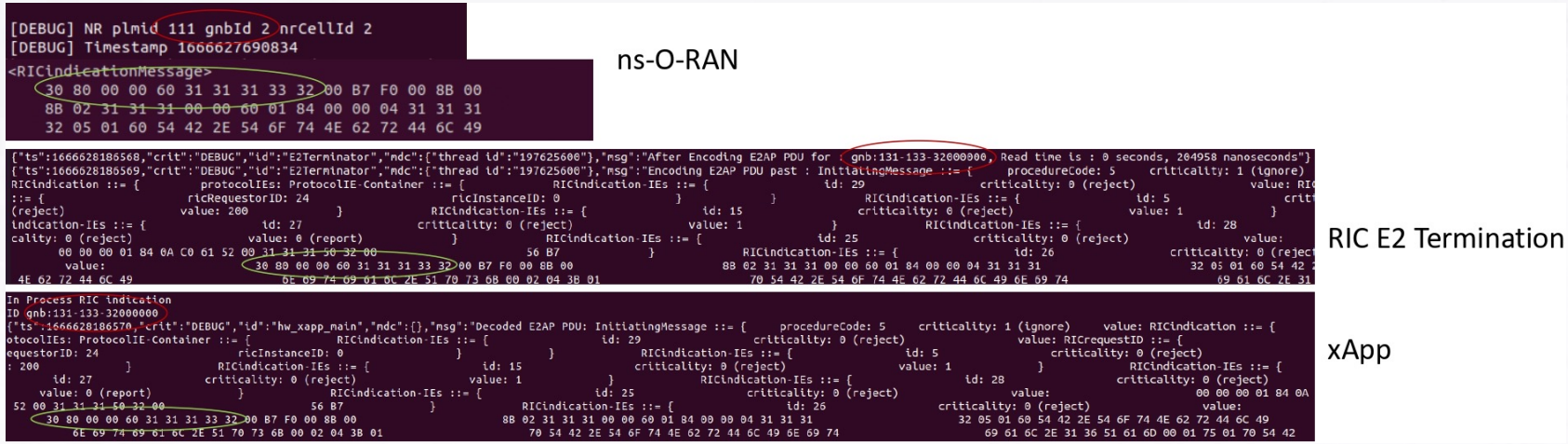
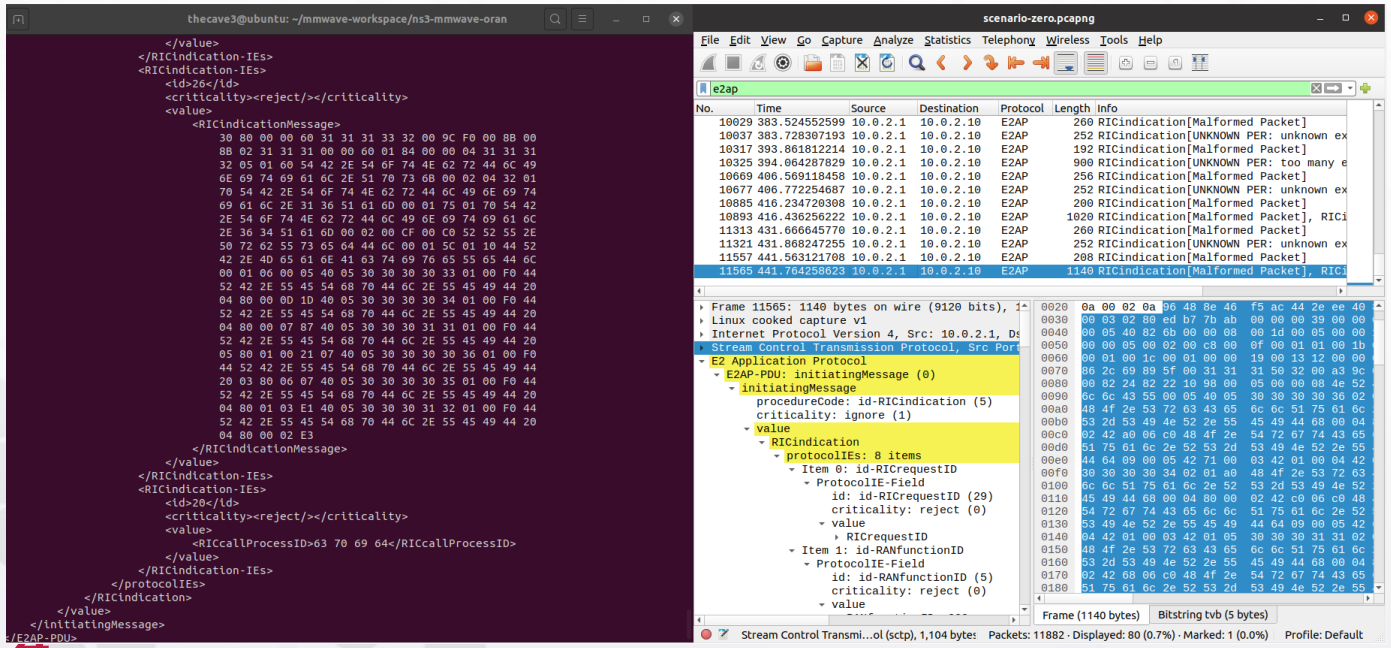
# Scenario Zero Results




| Measurement | All | Single eNB | Single gNB |
|---|---|---|---|
| Wireshark Filter | e2ap | e2ap and sctp.port == 38471 | e2ap and sctp.port == 38472 |
| Number of Packets | 157 | 40 | 40 |
| Time span (s) | 439.220 | 429.324 | 439.211 |
| Average pps | 0.4 | 0.1 | 0.1 |
| Average. size (B) | 396 | 259 | 661 |
| Bytes exchanged | 62148 | 10352 | 26456 |
| Average Data Rate (Bps) | 141 | 24 | 60 |
| Average Data Rate (bps) | 1.131 | 192 | 481 |

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# Next steps

- Upgrade of the ASN definitions for E2AP and E2SM to version 3.0
- Support to new use cases
- Better support for O-RAN and DRL



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# Next release

- Upgrade to ns-3 3.38
  - New building system
  - New channel model
- Release of the custom xApps
- Open Issues for contribution

- September 2023



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# Thanks for the attention!
# Questions?