Institute for the Wireless Internet of Things at Northeastern University

O-RAN Research in Colosseum

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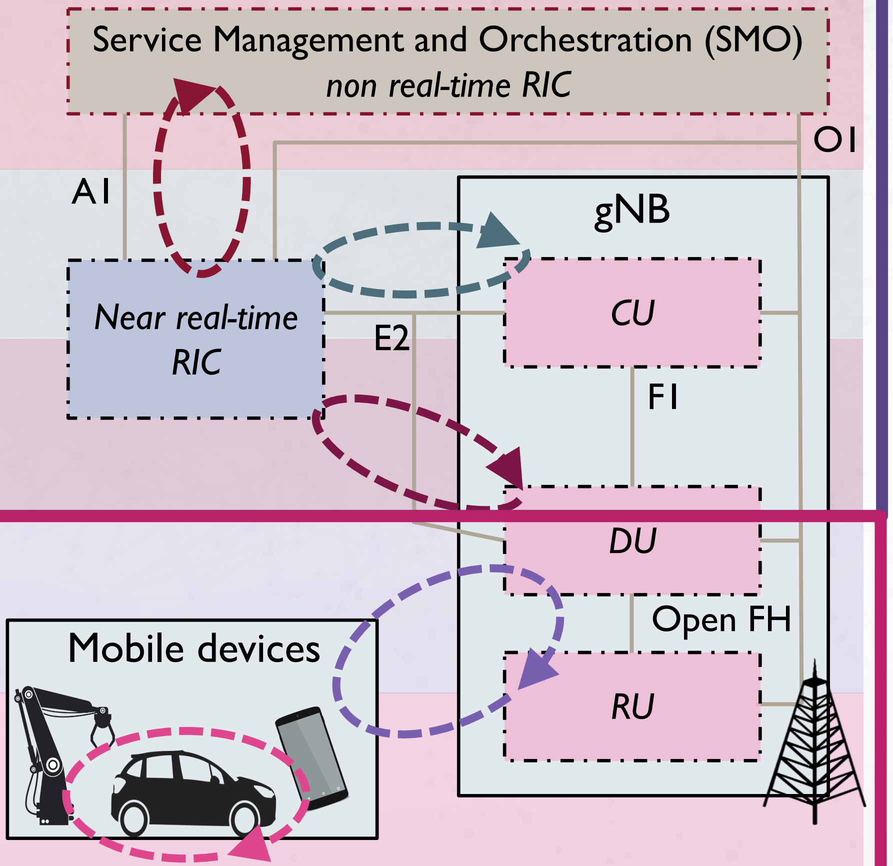
O-RAN opens the RAN to intelligent control

Currently supported by O-RAN

Control and learning objective	Scale	Input data	Timescale
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

Architecture



For further study or not supported

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Open Challenges

- Need large-scale heterogeneous datasets
- Need testing of closed-loop control without compromising network performance
- Need algorithms that generalize to different scenarios and conditions

Experimental platforms for wireless AI

Need large-scale heterogeneous datasets

PAWR platforms and Colosseum can be used to collect ***datasets*** *at scale*

Tools are available for large-scale data collection in cellular networks: SCOPE platform
https://github.com/wineslab/colosseum-scope

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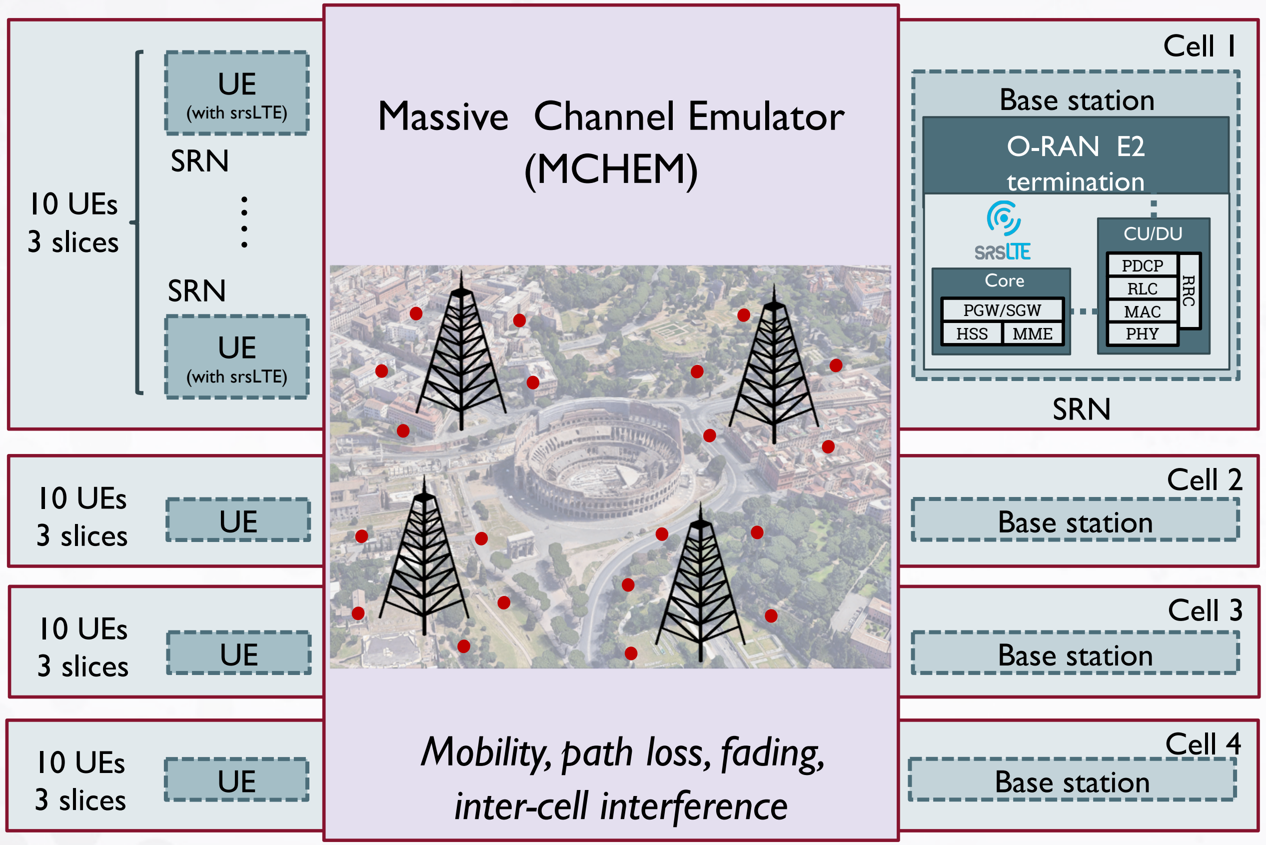
Example of large scale data collection with Colosseum



Large scale cellular scenario with:

- 4 base stations
- 10 UEs in each base station
- *Different configurations and parameters for the RAN*

https://github.com/wineslab/colosseum-oran-commag-dataset

L. Bonati, S. D'Oro, M. Polese, S. Basagni, and T. Melodia, "Intelligence and Learning in O-RAN for Data-driven NextG Cellular Networks", IEEE Communications Magazine (to appear), also on arXiv:2012.01263 [cs.NI]

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Dataset configurations and parameters

- Radio Frequency (RF) scenario setup (Colosseum Rome scenario):
  - Close: UEs uniformly distributed within 20 m of each BS
  - Medium: UEs uniformly distributed within 50 m of each BS
  - Far: UEs uniformly distributed within 100 m of each BS
- UE Mobility:
  - Static: no mobility
  - Slow: 3 m/s
- Traffic classes:
  - eMBB: Constant bitrate traffic (1 Mbps per UE)
  - MTC: Poisson traffic (30 pkt/s of 125 bytes per UE)
  - URLLC: Poisson traffic (10 pkt/s of 125 bytes per UE)

Dataset configurations and parameters

	Slice Scheduling Policy			Slice RBG Allocation		
Training	Slice 0	Slice 1	Slice 2	Slice 0	Slice 1	Slice 2
tr0	PF	RR	PF	1	2	4
tr1	WF	RR	RR	1	4	2
tr2	RR	PF	WF	2	1	4
tr3	WF	WF	PF	2	4	1
tr4	RR	WF	WF	4	2	1
tr5	WF	WF	WF	4	1	2
tr6	PF	PF	WF	2	2	3
tr7	WF	RR	PF	2	3	2
tr8	WF	PF	RR	3	2	2
tr9	PF	WF	RR	3	3	1
tr10	RR	RR	PF	3	1	3
tr11	RR	PF	RR	1	3	3
tr12	RR	RR	RR	1	2	4
tr13	WF	PF	WF	1	4	2
tr14	PF	WF	PF	4	2	1
tr15	RR	WF	PF	3	1	4
tr16	PF	RR	RR	1	2	4
tr17	PF	RR	WF	1	2	4

Slices configured in different ways

- 3 different scheduling policies
  - Policy 0: Round-robin (RR)
  - Policy 1: Waterfilling (WF)
  - Policy 2: Proportionally fair (PF)
- Multiple PRBs allocations

→ 89 hours of experiments automated through the SCOPE framework

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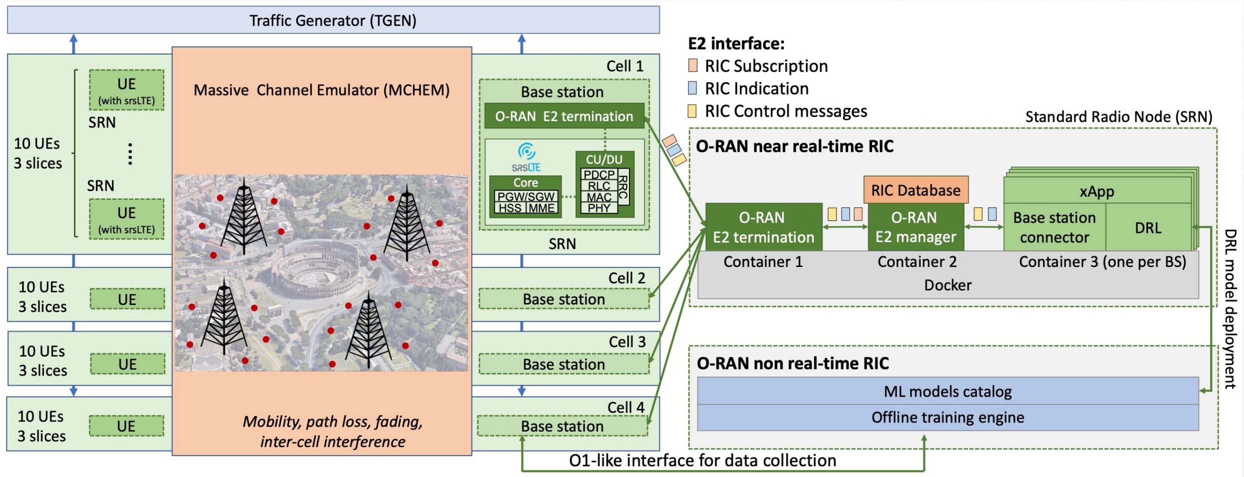
Open Challenges

Need testing of closed-loop control without compromising network performance

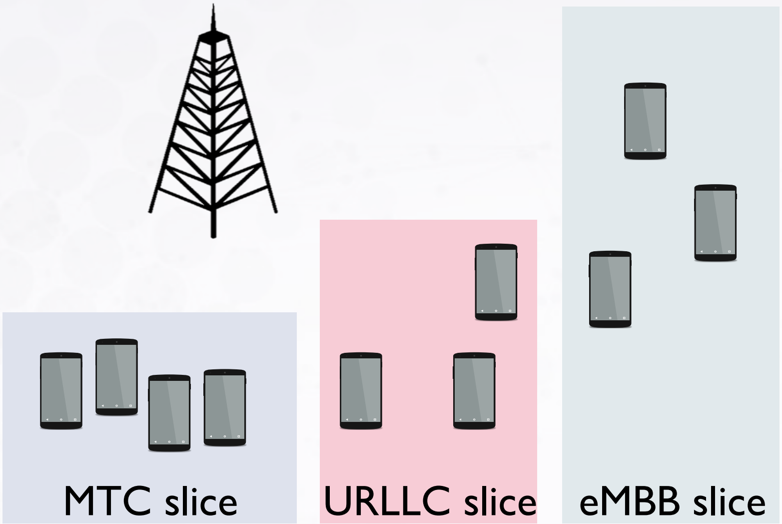
Need algorithms that generalize to different scenarios and conditions

We used Colosseum to deploy & test ***deep reinforcement learning*** *control for O-RAN compliant networks*



More info: L. Bonati, S. D'Oro, M. Polese, S. Basagni, and T. Melodia, "Intelligence and Learning in O-RAN for Data-driven NextG Cellular Networks", IEEE Communications Magazine, 2021

Intelligent scheduling for RAN slicing



Challenging environment:

- Dynamic channel
- Dynamic resource allocations for each slice

Exploit **data-driven** closed-loop control with the **near real-time RIC** to **automatically** tune the RAN parameters for **each slice**

We focus on scheduling policy selection through Deep Reinforcement Learning (DRL)

More info: L. Bonati, S. D'Oro, M. Polese, S. Basagni, and T. Melodia, "Intelligence and Learning in O-RAN for Data-driven NextG Cellular Networks", arXiv:2012.01263 [cs.NI], December 2020

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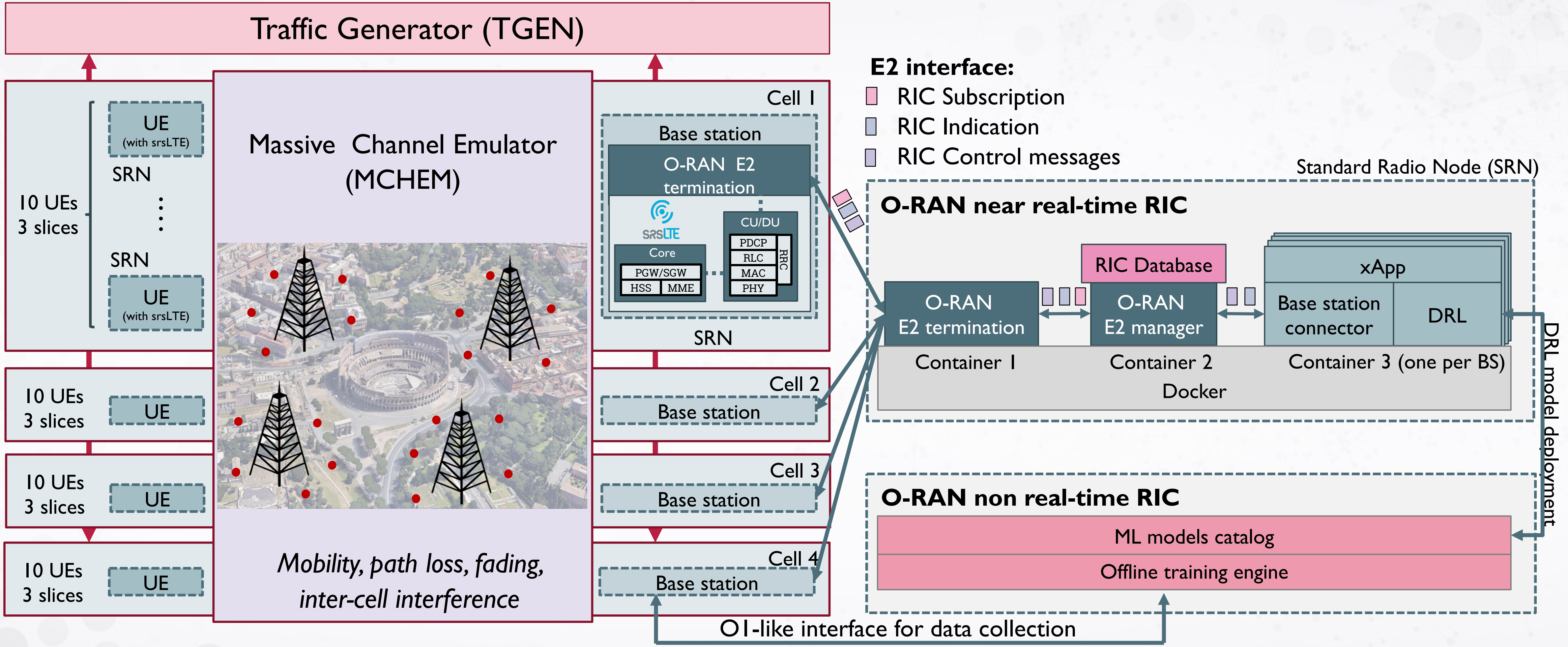
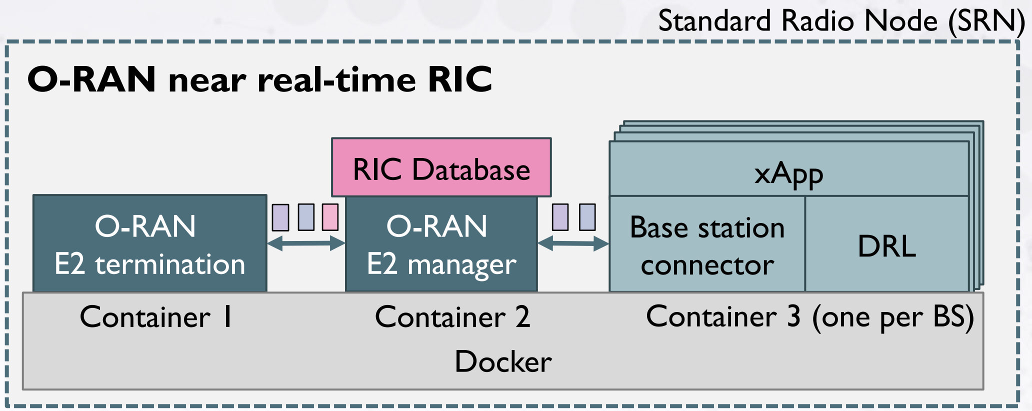
O-RAN Integration in Colosseum



Fully virtualized RAN on white-box hardware

O-RAN open-source infrastructure

Near RT RIC in Colosseum



Near real-time RIC:

- Based on OSC RIC (more on this tomorrow during short talks)
- E2 manager → manages connections within near real-time RIC
- RIC database → keeps a record of connected BSs
- E2 termination → connect to the BSs
- Implemented RIC subscription, indication and control messages → interface and control BSs
- Implemented custom xApps

Soon available as a Colosseum container

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E2 RAN termination

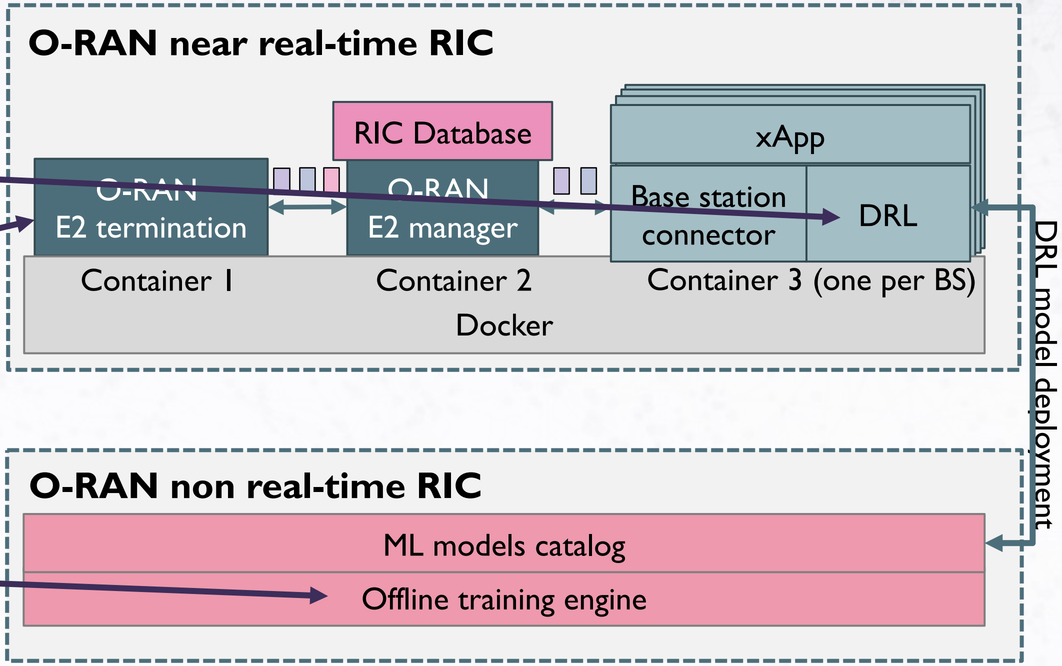
- Use SCOPE APIs to
  - get telemetry from srsRAN base station
  - control slicing and scheduling in srsRAN base station
- Implemented E2 termination with custom service models
  - Extend OSC components
  - E2 setup, indication, control

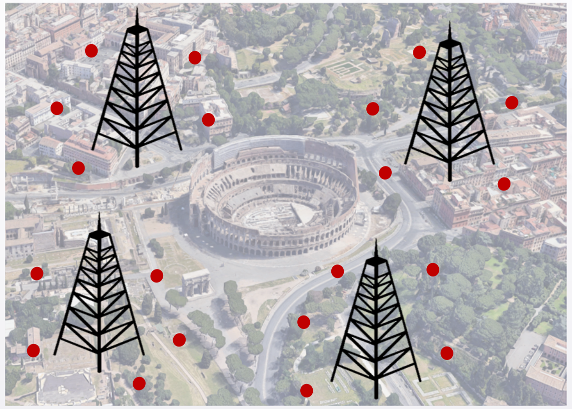
Soon available as a Colosseum container

O-RAN Integration in Colosseum

12 DRL agents running in parallel

- Fully-connected neural network (5 layers & 30 neurons each)
- *Online* inference w/ real-time RAN performance data
- Trained *offline* on 7 GB of data & 89 hours of experiments
- Decisions on scheduling policies of each BS slice
    - Round-robin (RR)
    - Waterfilling (WF)
    - Proportional fair (PF)

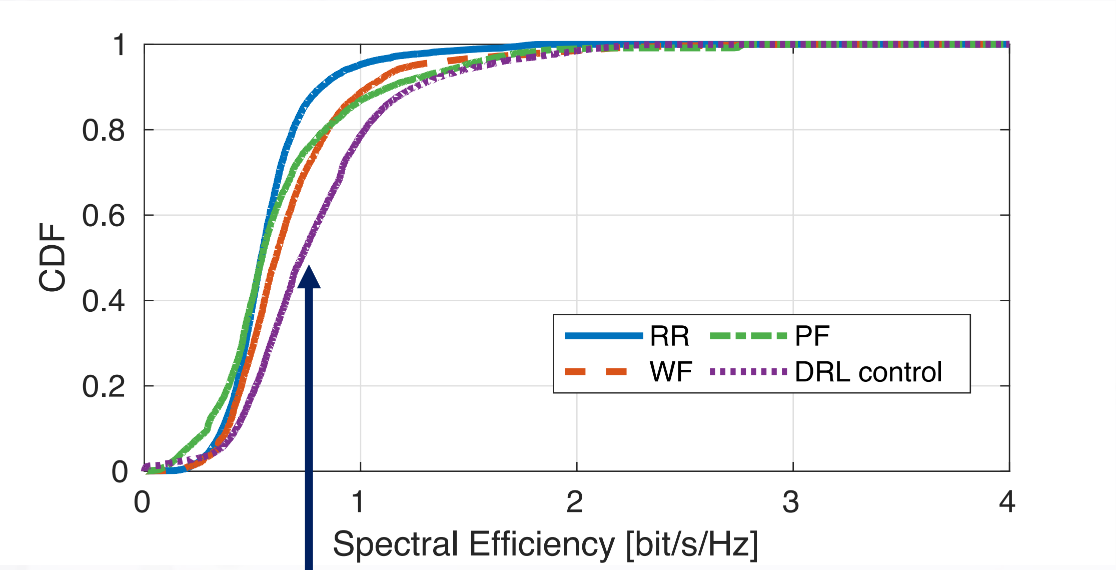




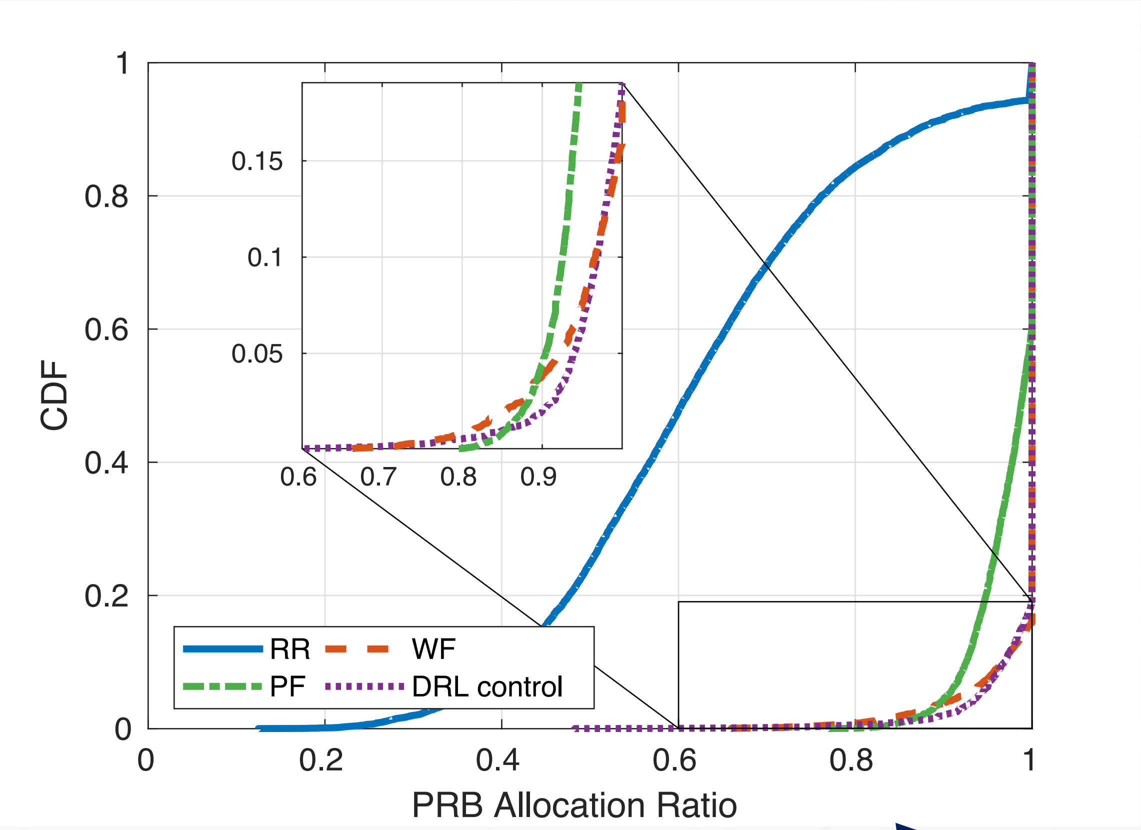
Dense urban scenario, 4 BSs, 40 UEs w/ pedestrian mobility

Experimental results

eMBB slice



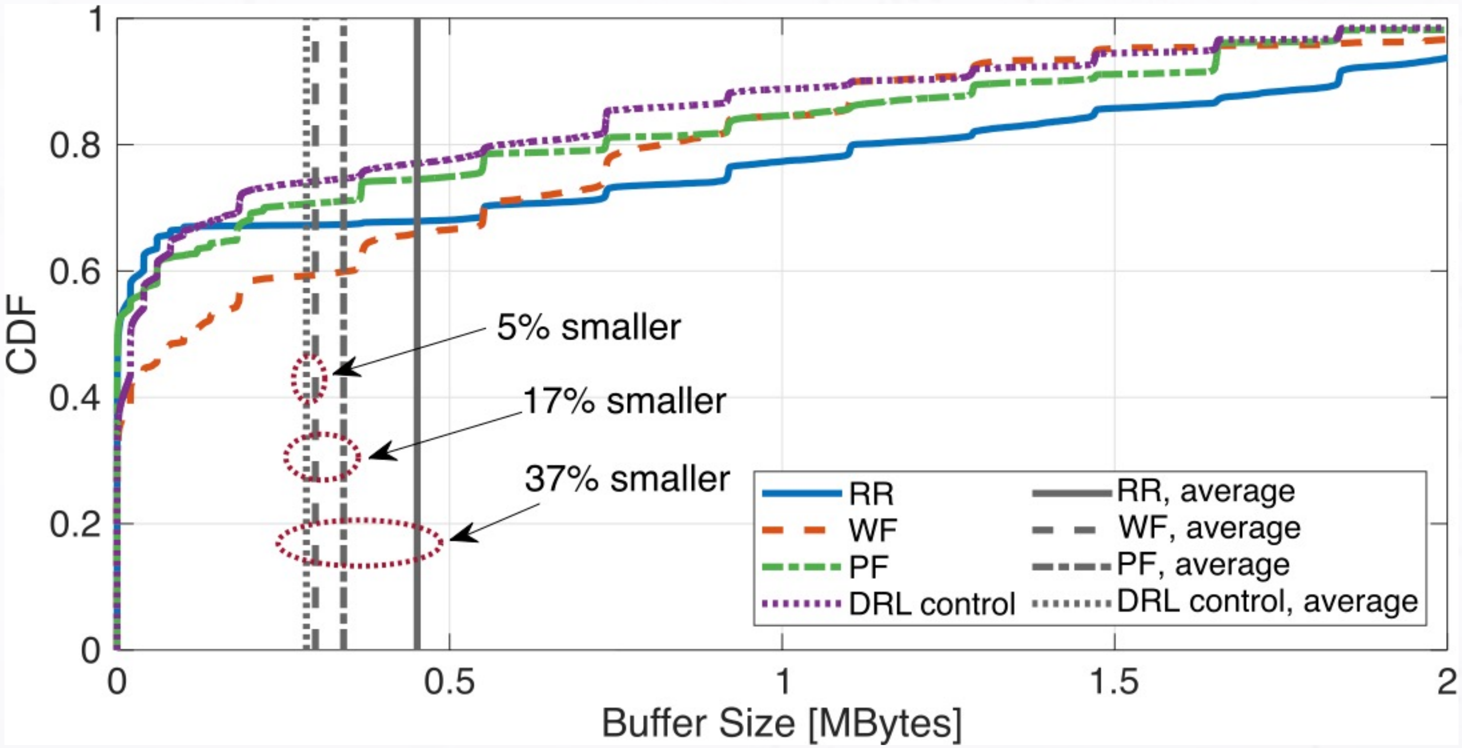
URLLC slice



- Improve spectral efficiency for eMBB users
- Satisfy URLLC users requests
- Reduce RLC buffer occupancy by 20%

Experimental results

URLLC slice buffer occupancy



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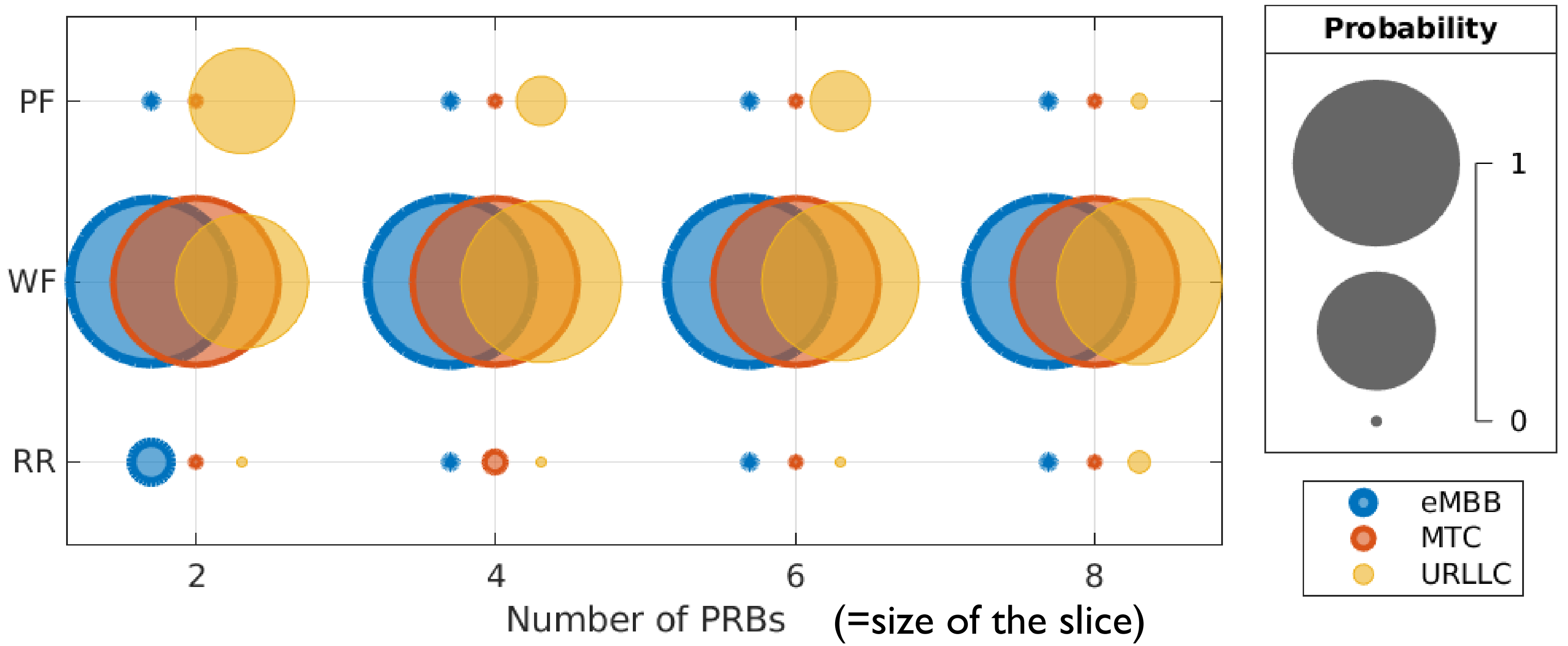
Experimental results – policy selection

Probability that the DRL agent selects a certain policy



(=size of the slice)

- Different behaviors for the 3 slices
- Different behaviors for different slice sizes

Need data-driven, adaptable approach

Conclusions

Future cellular networks will be

Open	Programmable	Virtualized

truly enabling the vision of data- and AI-driven networks

Road ahead:

- Testbeds and platforms for intelligent RAN development
- Dataset availability
- More involvement toward open-source protocol stacks

Resources

- Open source 5G software website: https://open5g.info
- Colosseum website: https://colosseum.net
- PAWR platforms: https://advancedwireless.org

- Institute for the Wireless Internet of Things: https://www.northeastern.edu/wiot/

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