Institute for the Wireless Internet of Things at Northeastern University

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

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From monolithic to Open RAN

Traditional "black-box"

Open, programmable and virtualized



2





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;
 - Al 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.



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





Codebase structure

• 3 different repositories



oran-e2sim

- Fork of OSC E2sim
 - <u>https://github.com/o-ran-sc/sim-e2-interface</u>
- 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



oran-e2sim

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



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





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. Ic definitions
- It will be upstreamed to the original project





0 [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



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;









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).

overhead H_u

Mobility

0.5

42

63

(d) UE mobility overhead H_u .

84

Number of users

105

126

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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:
 - <u>https://openrangym.com/tutorials/ns-o-ran</u>







Scenario Zero Results



RIC E2	Termination	

хАрр

thecave3@ubuntu: ~/mmwave-workspace/ns3-mmwave-oran 🛛 🔍 😑 💷 🗙	scenario-zero.pcapng – 🗆 😣
	<u>File E</u> dit <u>V</u> iew <u>G</u> o <u>C</u> apture <u>A</u> nalyze <u>S</u> tatistics Telephon <u>y</u> <u>W</u> ireless <u>T</u> ools <u>H</u> elp
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<criticality><reject></reject></criticality>	No. Time Source Destination Protocol Length Info
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	10037 383 728307193 10 0 2 1 10 0 2 10 E2AP 252 RTC indication [INKINWN PEP: Unknown ex
	10317 393 861812214 10 0.2.1 10 0.2.10 E24P 192 BTCindication[Ma]formed Packet]
	10325 394.064287829 10.0.2.1 10.0.2.10 E2AP 900 RICindication[UNKNOWN PER: too many e
6F 69 74 69 61 6C 2F 51 70 73 6R 00 02 432 01	10669 406,569118458 10.0.2.1 10.0.2.10 E2AP 256 RICindication[Malformed Packet]
70 54 42 25 54 65 74 45 62 72 44 66 49 65 69 74	10677 406.772254687 10.0.2.1 10.0.2.10 E2AP 252 RICindication[UNKNOWN PER: unknown ex
69 61 6C 2E 31 36 51 61 6D 00 01 75 01 70 54 42	10885 416.234720308 10.0.2.1 10.0.2.10 E2AP 200 RICindication[Malformed Packet]
2E 54 6F 74 4E 62 72 44 6C 49 6E 69 74 69 61 6C	10893 416.436256222 10.0.2.1 10.0.2.10 E2AP 1020 RICindication[Malformed Packet], RICi
2E 36 34 51 61 6D 00 02 00 CF 00 C0 52 52 55 2E	11313 431.666645770 10.0.2.1 10.0.2.10 E2AP 260 RICindication[Malformed Packet]
50 72 62 55 73 65 64 44 6C 00 01 5C 01 10 44 52	11321 431.868247255 10.0.2.1 10.0.2.10 E2AP 252 RICindication[UNKNOWN PER: unknown ex
42 2E 4D 65 61 6E 41 63 74 69 76 65 55 65 44 6C	11557 441.563121708 10.0.2.1 10.0.2.10 E2AP 208 RICindication[Malformed Packet]
00 01 06 00 05 40 05 30 30 30 30 30 100 F0 44	11565 441.764258623 10.0.2.1 10.0.2.10 E2AP 1140 RICindication[Malformed Packet], RICi
52 42 2E 55 45 54 68 70 44 6C 2E 55 45 49 44 20	
04 80 00 0D 1D 40 05 30 30 30 30 34 01 00 F0 44	Frame 11565: 1140 bytes on wire (9120 bits) 14 0020 03 00 02 03 06 48 30 46 f5 as 44 20 00 40
52 42 2E 55 45 54 68 70 44 6C 2E 55 45 49 44 20	Frame 1505. The bytes of whe (5120 bits), 1 0020 00 02 00 00 40 00 10 10 10 20 00 00 00 00 00 00 00 00 00 00 00 00
04 80 00 07 87 40 05 30 30 31 31 01 00 F0 44	Therefore Protocol Version 4 Src: 10.0.2.1 D 0040 00.05 40.82 6b 00.00 08 00 1d 00.05 00.00
52 42 2E 55 45 54 68 70 44 6C 2E 55 45 49 44 20	Stream Control Transmission Protocol, Src Port 0050 00 00 05 00 02 00 c8 00 0f 00 01 01 00 1b
05 80 01 00 21 07 40 05 30 30 30 30 36 01 00 F0	E2 Application Protocol 0060 00 01 00 1c 00 01 00 00 19 00 13 12 00 00 0
44 52 42 2E 55 45 54 68 70 44 6C 2E 55 45 49 44	E2AP-PDU: initiatingMessage (0) 0070 86 2c 69 89 5f 00 31 31 31 50 32 00 a3 9c
20 03 80 06 07 40 05 30 30 30 30 35 01 00 F0 44	initiatingMessage 0080 00 82 24 82 22 10 98 00 05 00 00 84 45 52
52 42 2E 55 45 54 68 70 44 6C 2E 55 45 49 44 20	procedureCode: id-RICindication (5) 0090 6c 6c 43 55 00 05 40 05 30 30 30 36 02 0
	criticality: ignore (1)
32 42 22 33 43 34 08 70 44 00 22 33 43 49 44 20 84 08 08 07 53	✓ value
	• RICindication 9000 51 75 61 60 26 53 20 53 49 46 52 26 55
	 protocolIEs: 8 items 00000 44 64 09 00 05 42 71 00 03 42 01 00 04 42
<pre></pre> //Picication-IEs>	✓ Item 0: id-RICrequestID 00f0 30 30 30 30 34 02 01 a0 48 4f 2e 53 72 63
<ricindication-ies></ricindication-ies>	 ProtocolIE-Field 0100 6c 6c 51 75 61 6c 6c 52 53 2d 53 49 4e 52
<1d>20 1d	id: id-RICrequestID (29) 0110 45 49 44 68 00 04 80 00 02 42 c0 06 c0 48
<criticality><reject></reject></criticality>	criticality: reject (0) 0120 54 72 67 74 43 65 6c 6c 51 75 61 6c 2e 52
<value></value>	• Value 0130 53 49 46 52 26 55 45 49 44 64 09 00 05 42 0
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	$= \frac{1}{10} + \frac{1}{10$
	id: id-RefunctionTD (5) 0170 02 42 68 06 c0 48 4f 2e 54 72 67 74 43 65
	criticality: reject (8) 0180 51 75 61 6c 2e 52 53 2d 53 49 4e 52 2e 55
	Frame (1140 bytes) Bitstring tvb (5 bytes)
nitiatingMessage>	

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



- 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



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



Thanks for the attention! Questions?