Towards Achieving Energy Efficiency and Service Availability in 6G O-RAN via Formal Verification

Roberto Metere[*] Yue Gu[‡] Zhi Zhang[†] Kangfeng Ye[*]
Dalal Alrajeh[†] Michele Sevegnani[‡] Poonam Yadav[*]

[*] University of York [†] Imperial College London [‡] University of Glasgow

CHEDDAR

UKRI Engineering and Physical Sciences Research Council

International Symposium DataMod 2024 – From Data to Models and Baco

4-5 November – Aveiro, Portugal

Outline

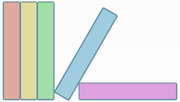
Introduction to O-RAN

Problem Statement

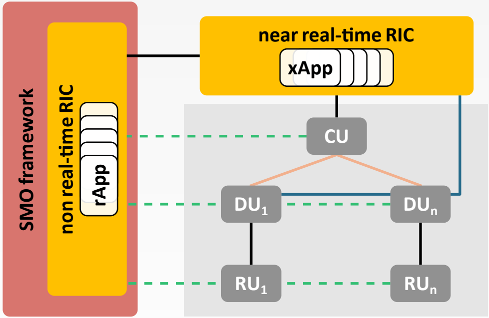
Energy Efficiency and Service Availability Trade-offs

Results

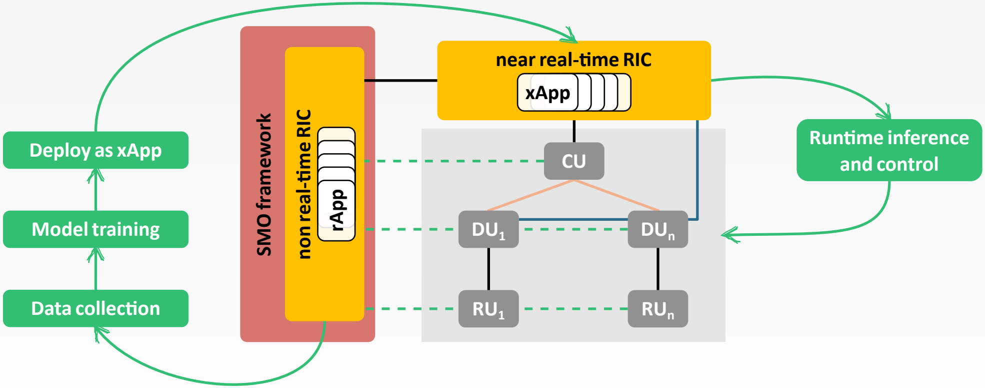
Conclusions



Introduction to O-RAN



Introduction to O-RAN



Introduction to O-RAN

Open Radio Access Network (O-RAN)

- Open, standardized interfaces that enable **interoperability** among components from **different vendors**
- AI-driven applications for real-time network optimization and energy efficiency, making it essential for scalable, adaptable 5G and future 6G networks.
- Aim is to **reduce operational costs**, minimize environmental impact, and ensure **reliable, high-quality connectivity** for **diverse, data-intensive applications**.
- Applications are called **xApps** (near real-time) or **rApps** (non real-time).

Problem Statement

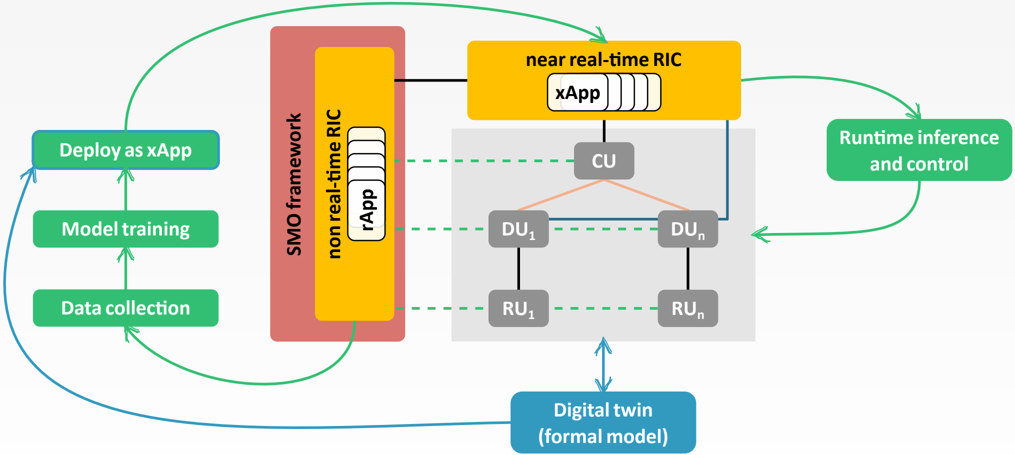
Balancing energy efficiency vs service availability

- **Challenges**: continuous, adaptive management of network resources
- **Highly dynamic**: Minimizing power use without compromising Quality of Service (QoS) under fluctuating demand and user mobility.

What can go wrong

- Wrong adaptation to real-time changes, making them less efficient for managing fluctuating demand and energy use in dynamic environments.
- Risk of misconfigurations

Why Formal Verification?

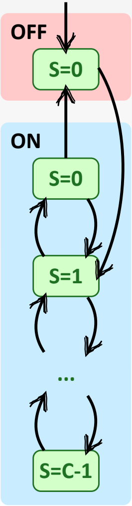


Why Formal Verification?

Formal verification is a powerful tool to analyse and avoid security catastrophic oversights in 6G O-RAN

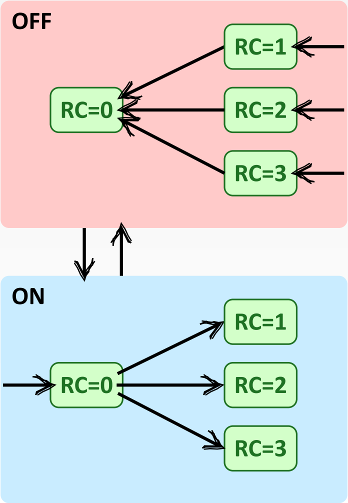
- Manipulate the (control) output from AI-driven applications to ensure network decisions are logically consistent, enhancing reliability and preventing misconfigurations.
  wrong data
- Use of probabilistic model checking to prevent logical inconsistencies in xApp development.
  wrong algorithms

Case study - Radio Controller



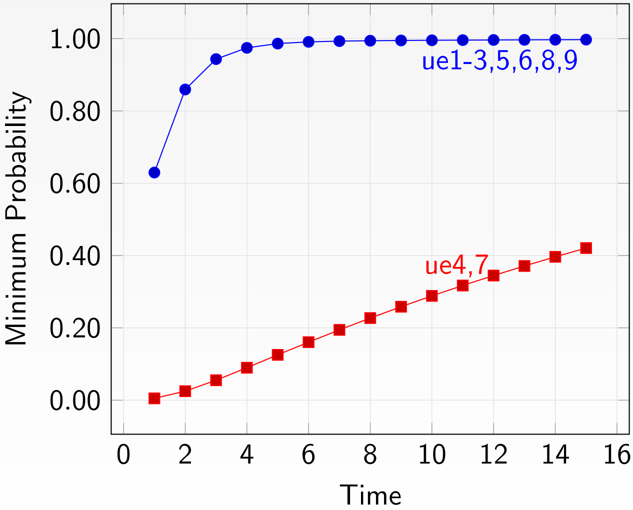
- **Initial State**. The RC is Off with no User Equipment (UE) connected (i.e., $S = 0$).
- **Switch On**. It can be switched On upon demand from a UE, connecting the UE and increasing S to 1.
- **Capacity Management**. Before reaching capacity ($S = C - 1$), the RC allows
  - **UE Disconnection**: UE can disconnect, decreasing S.
  - **New UE Connections**: Additional UEs can connect, increasing S.

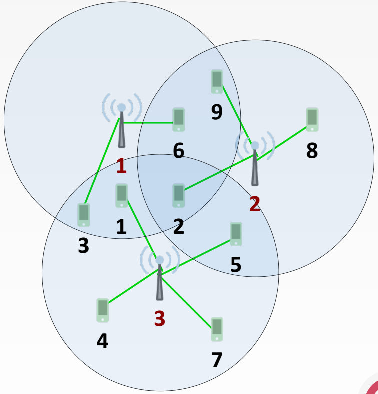
Case study - User Equipment



- **Initial State**. The UE starts Off and switches On according to the exponential distribution.
- **Status Switching**. Switching is not action-triggered but follows an exponential distribution.
- **Substates**. Within both On and Off states, there are four substates to log the connected RC ID or no connection ($RC = 0$).

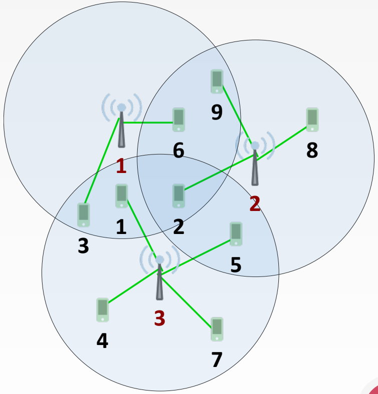
Dynamic UE Management



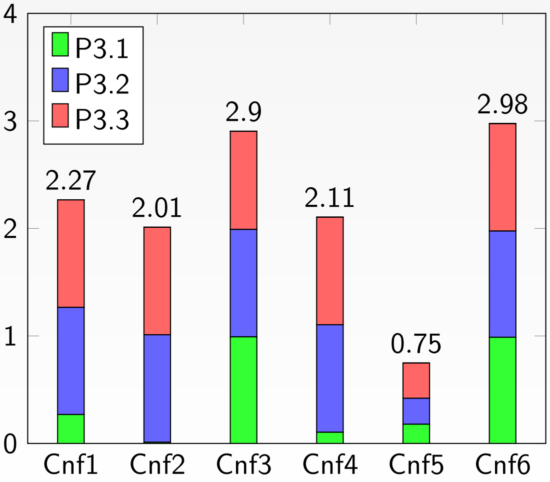


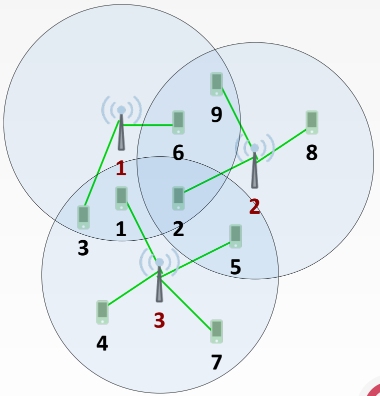
Dynamic UE Management

- Cnf1 **RC status** RCs limit connections to manage power use without compromising connectivity.
- Cnf2 **UE Coverage** Ensures connections are only made within viable ranges.
- Cnf3 **UE On/Off States** Reduce power consumption when UEs are inactive.
- Cnf4 **Connection Policy** Maintains QoS by avoiding overloaded RCs and keeping stable connections.
- Cnf5 **UE Disconnection** When UE turns Off, its RC connection ends, freeing up resources.
- Cnf6 **Timing Rates** Balances service responsiveness and power efficiency; ensures quick reconnect.



Dynamic UE Management





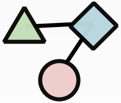
Conclusions

Summary

- Formal methods provide insights on policies that balance **energy efficiency** and **service availability** that can be used in real scenarios

Limitations and future work

- Model may be too simple
- Considering RSRP and mobile UEs
- We abstract AI-based predictions as distributions, can we do better?
- Potential integration into O-RAN simulation testbeds



Formal verification is a powerful tool to analyse and avoid security catastrophic oversights in 6G O-RAN

Roberto **Metere**

University of York

roberto.metere@york.ac.uk

Dalal **Alrajeh**

Imperial College London

dalal.alrajeh04@imperial.ac.uk

Yue **Gu**

University of Glasgow

yue.gu@glasgow.ac.uk

Michele **Sevegnani**

University of Glasgow

michele.sevegnani@glasgow.ac.uk

Poonam **Yadav**

University of York

poonam.yadav@york.ac.uk

Kangfeng **Ye**

University of York

kangfeng.ye@york.ac.uk

Zhi **Zhang**

Imperial College London

zhi.zhang@imperial.ac.uk

CHEDDAR

UKRI Engineering and Physical Sciences Research Council