

dApps: Enabling Real-Time AI-based Open RAN Control

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Road toward 6G on O-RAN: What is missing?

Context

6G Use Cases

- Spectrum management
- ISAC
- Energy efficiency
- AI-native

Analysis

O-RAN Architectural Gaps

Limitations and missing capabilities in the O-RAN architecture

Our proposal

6G-ready O-RAN

An evolution of the architecture with *real-time observability and programmability* as foundational elements

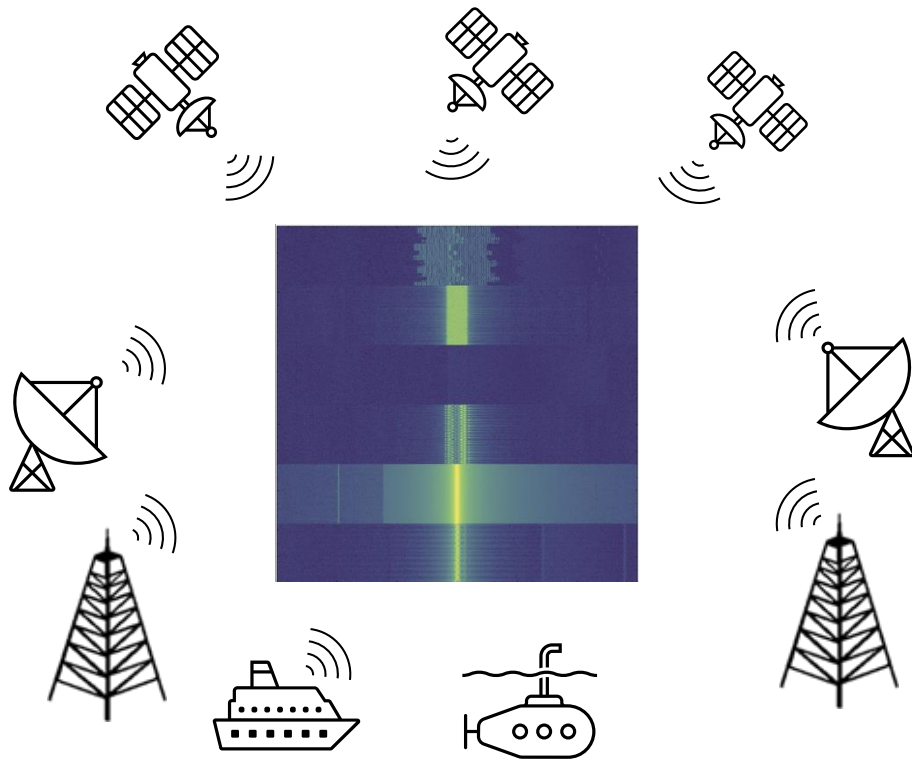
Gap 1: Real-time Spectrum Management

Significant interest on shared spectrum approaches for 6G:

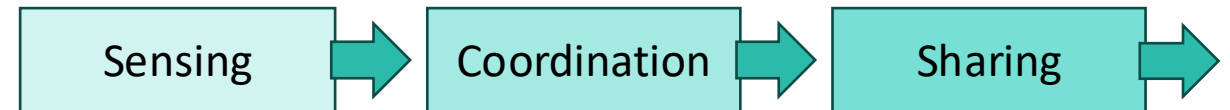
- FR-3 band (6-24 GHz) with several incumbents
- Lower 3 GHz band



Coexistence facilitates allocating additional spectrum to commercial cellular services



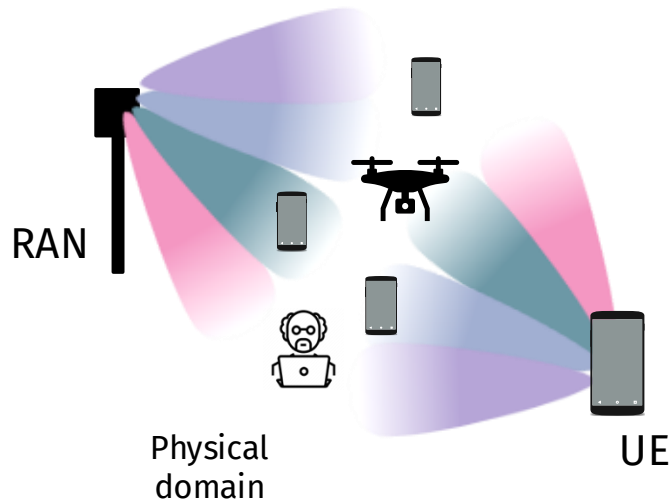
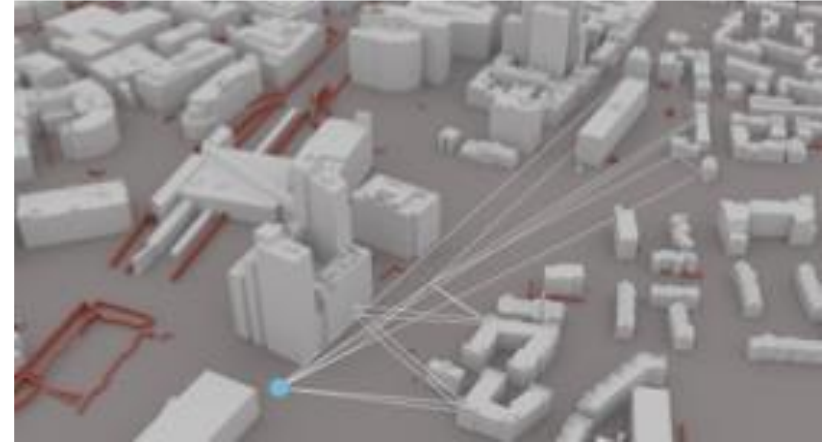
- CBRS is deployed (420000 CBSDs) but is slow and conservative
 - Leave spectrum on the table
 - Need external sensor network
- Pervasive cellular infrastructure can enable real-time



- **Gap:** Limited support in O-RAN
 - Lack of **real time** observability and programmability
 - Advanced sensing requires interactions with **user plane**
 - Lack of real-time failsafe mechanisms in the architecture

Gap 2: Integrated Sensing and Communications

- Integrated sensing and communications (ISAC) is being considered as a key capability for 6G
- Networks become distributed sensors exposing physical domain into the digital environment
- Commercial and defense applications
- Sensors market estimated at 300B by 2030



- What is the ISAC control plane?
- What is the life-cycle management for ISAC algorithms?
- How can vendor and operators collaborate to advance ISAC operations?
- **Gap:** How can the O-RAN architecture support ISAC?

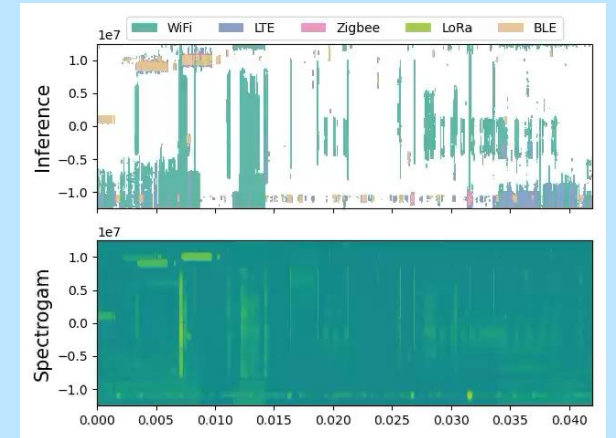
O-RAN Architecture Limitations

No interactions with the user plane

- IQ, bits, bytes, packets
- Cannot be used by the RICs because of data rate, security, privacy constraints



Inference on user plane data enables advanced spectrum and RF sensing, analytics



No real-time control plane

- O-RAN interactions with the control plane only extend to near-real time and above



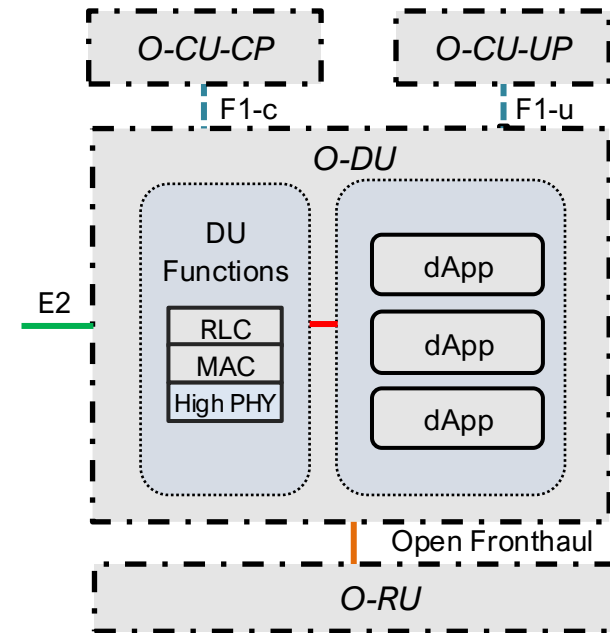
Limit sensing, dynamic optimization, coordination at multiple time scales, observability

Key to introduce new services to be monetized

dApps - Key to AI-RAN Development and Testing Methodology

- Programmable logic unit embedded in RAN components
- Low-latency control/inference
- Access to user/data plane
- Enable swappable logic for AI-for-RAN and some AI-on-RAN use cases
 - Scheduling
 - Spectrum sensing
 - ISAC
 - CSI prediction
 - Beam management
 - ... and more

Northeastern University, NVIDIA, Mavenir, MITRE, and Qualcomm, "dApps for Real-Time RAN Control: Use Cases and Requirement," O-RAN next Generation Research Group (nGRG), Research Report, 10 2024, report ID: RR-2024-10. [Online].



S. D'Oro, M. Polese, L. Bonati, H. Cheng, and T. Melodia, "dApps: Distributed applications for real-time inference and control in O-RAN", IEEE Communications Magazine 60.11 (2022): 52-58

A. Lacava, L. Bonati, N. Mohamadi, R. Gangula, F. Kaltenberger, P. Johari, S. D'Oro, F. Cuomo, M. Polese, and T. Melodia. "dApps: Enabling Real-Time AI-Based Open RAN Control", Computer Networks (2025), [DOI:10.48550/arXiv.2501.16502](https://doi.org/10.48550/arXiv.2501.16502)

dApp Open-Source Framework

- Enable research on real-time RAN control <https://openrangym.com/tutorials/dapps-oai>

- Extended dApp Client for d

libe3 - Vendor-Neutral E3AP C++ Library

License [Apache 2.0](#) C++ [17](#) version [0.0.4](#) docs [GitHub Pages](#)

libe3 is a standalone, vendor-neutral C++ library for implementing the E3AP (E3 Application Protocol) on **both sides of the protocol** — RAN functions (DU, CU-CP, CU-UP) and dApp clients. It provides a clean object-oriented API for both roles while hiding transport, encoding, and protocol complexity.

Features

- **Vendor-Neutral API:** Clean E3Agent facade that hides implementation details
- **Both Roles:** Single `E3Agent` class acts as either **RAN** (server, binds sockets) or **dApp** (client, connects to a remote RAN), switched by `E3Config.role`
- **Multi-Peer dApps:** One dApp process can hold N `E3Agent` instances connecting to N different RAN agents (e.g. a DU-HIGH and a DU-LOW)
- **Multiple Transports:** Support for ZeroMQ and POSIX sockets (TCP, SCTP, Unix Domain)
- **Multiple Encodings:** ASN.1 APER (primary), JSON, and Protocol Buffers encoders
- **Service Model Extensions:** Easy-to-implement SM interface for custom functionality
- **Python Bindings:** Optional SWIG bindings (`LIBE3_ENABLE_SWIG=ON`) so the same C++ library can back Python dApp clients
- **Thread-Safe:** Proper synchronization for concurrent dApp operations
- **Modern C++17:** Uses `std::variant`, `std::optional`, RAI patterns
- **Lightweight:** Minimal external dependencies

deploy a dApp can be found on the [OpenRAN Gym website](#). Please refer to that guide to

soon to be updated and hopefully merged with the original branch)
on of what are the dApps, please refer to [our recent architecture paper](#) and [this](#)

dApp Framework Organization

Four Separate Repositories

dApp side

- Public **Python library**
- One abstract class dApp wrapping E3AP
- External GUI and APIs for data visualization
- Custom Service Models:
 - Create your own data reports
 - Create your own data control

RAN side

- E3 Agent implemented on **OAI**
- Exposes RAN measurements
- Exposes access to the E2 interface
- **LibE3** vendor-neutral library, integrated in OAI

RIC side

- E2SM-DAPP implemented on **FlexRIC** and **OSC RIC with xDevSM**
- Exposes dApp data to xApp
- Enable multiple dApp sync
- dApp-xApp synchronization
 - The E3 module can be transitioned to any other OSS RAN stack

Communication enabled through the new E3 logical interface and E2SM-DAPP

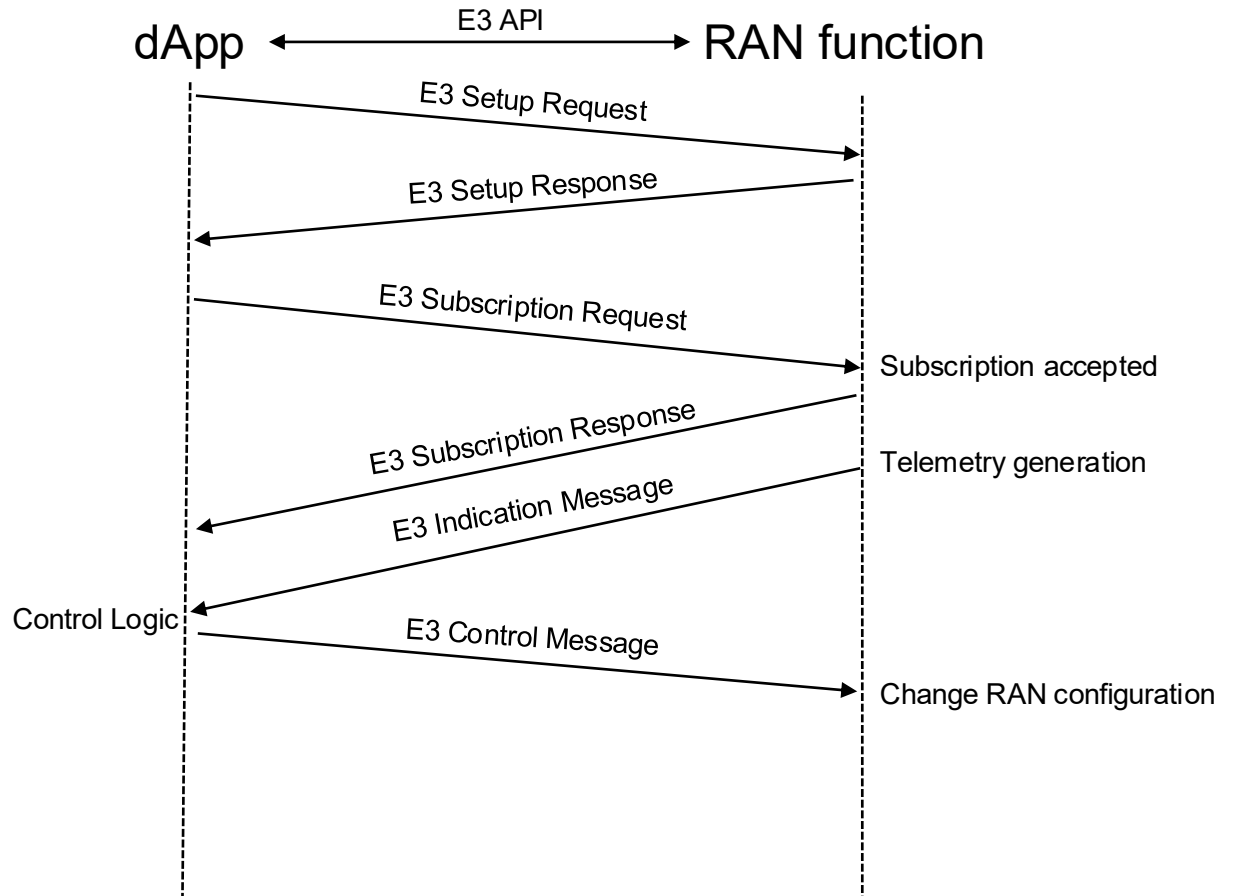
Landing repo: <https://github.com/wineslab/dApp-framework>

LibE3 Repo: <https://github.com/wineslab/libe3> and <https://pypi.org/project/libe3py/>

Python library: <https://github.com/wineslab/dApp-library> and <https://pypi.org/project/dapps>

E3 Service-Based Interface

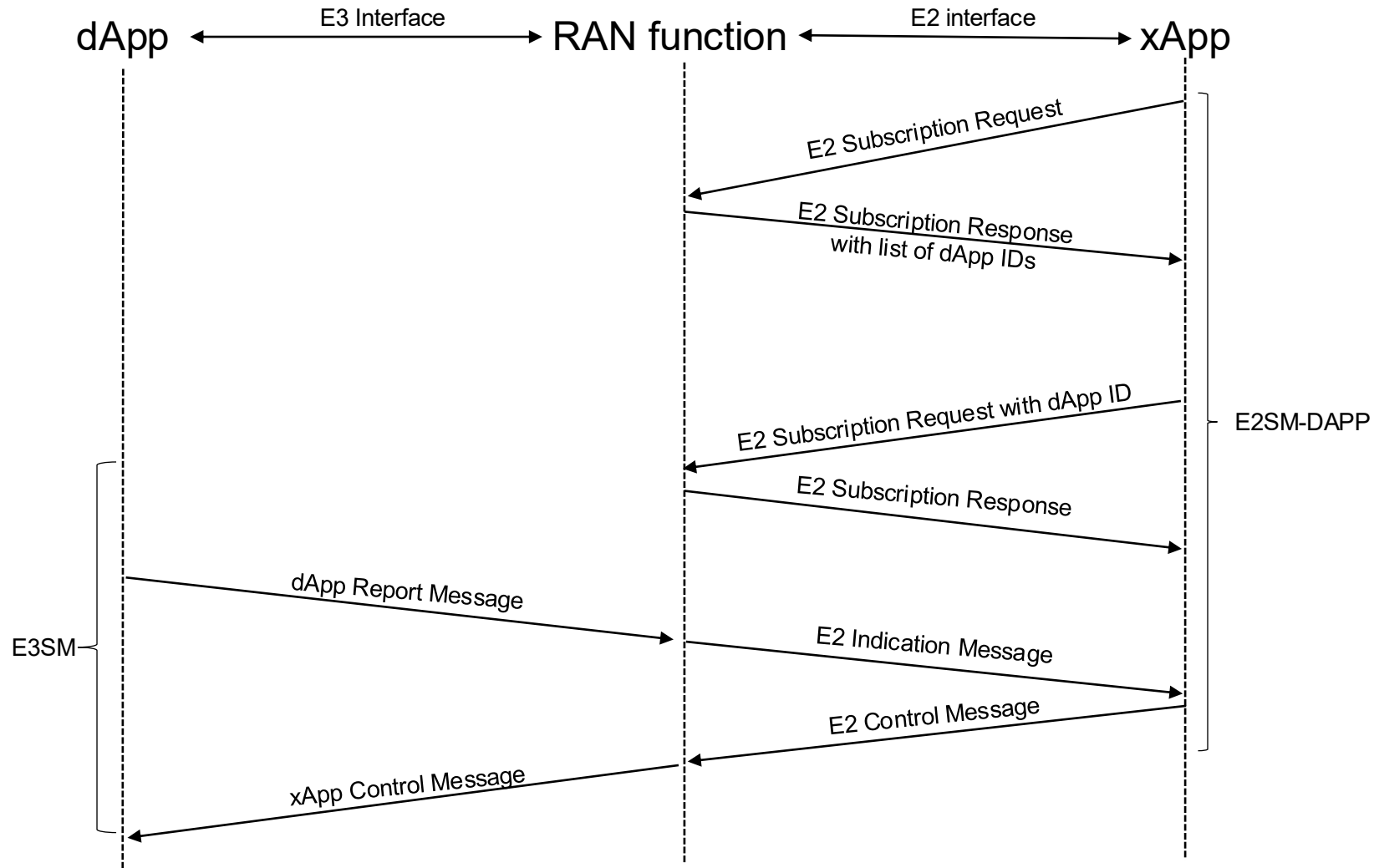
- E3 interface inspired by the O-RAN E2
- E3 APIs composed of Application Protocol (AP) and Service Model (SM) APIs
- Custom and extensible SMs for Control, Report and Indication messages
- Open Source Stacks supporting E3:
 - OpenAirInterface using **LibE3** E3AP [1]
 - OCUDU by NEU using **LibE3** E3AP [2]
 - OCUDU by DeepSig using a "dialect" of **LibE3 E3AP**
 - NVIDIA Aerial using another "dialect" of **LibE3 E3AP, but compatible**
- Closed Source Stacks known to support E3:
 - NOKIA, DeepSig, Andro, SMAR-TY, zTouch, and more...



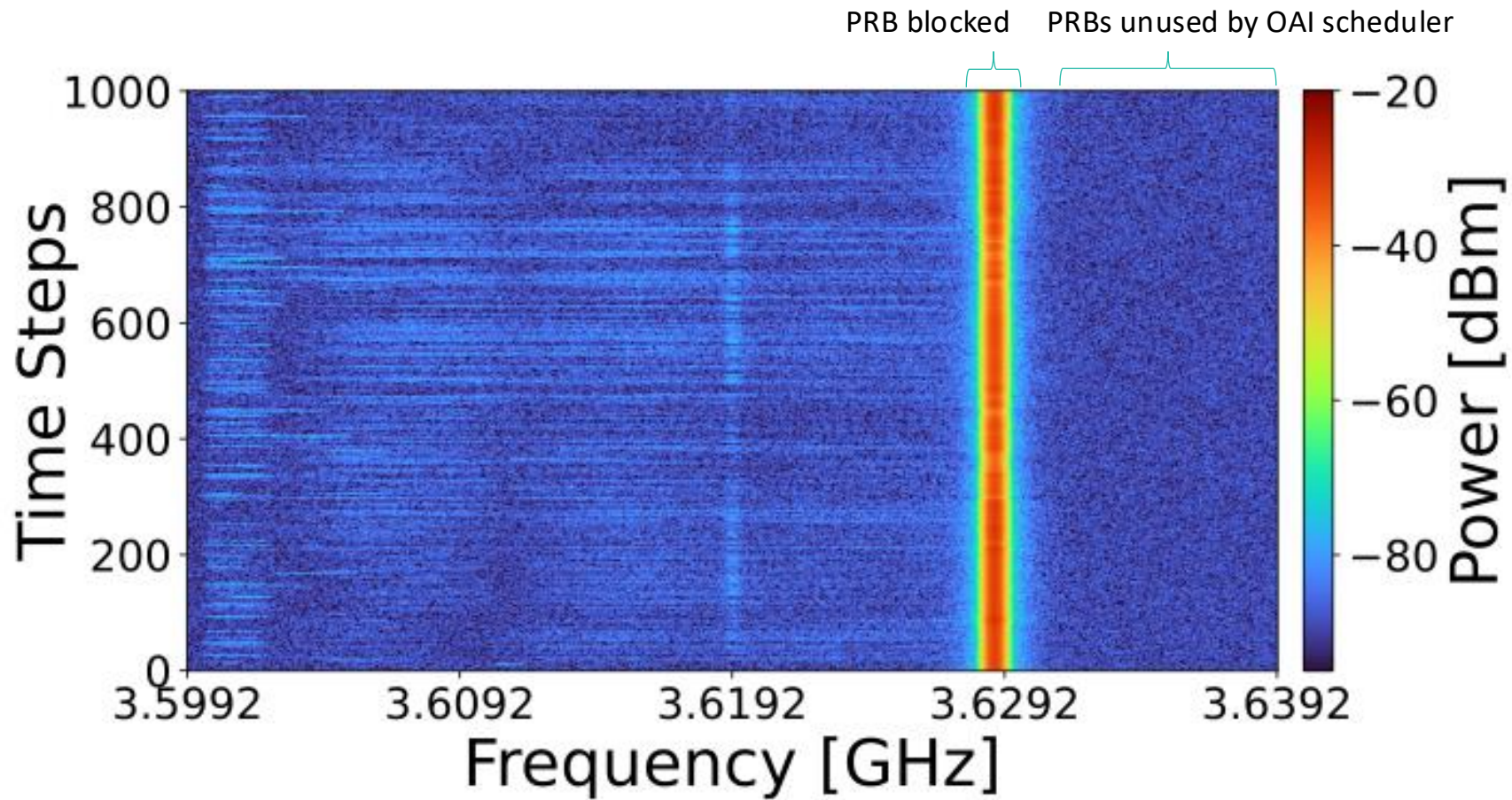
[1] A. Lacava, L. Bonati, N. Mohamadi, R. Gangula, F. Kaltenberger, P. Johari, S. D'Oro, F. Cuomo, M. Polese, and T. Melodia. "dApps: Enabling Real-Time AI-Based Open RAN Control", Computer Networks (2025), DOI:10.48550/arXiv.2501.16502

[2] A. Feraudo, R. Shirkhani, S. Maxenti, A. Lacava, M. Polese, and T. Melodia. "Bringing dApps to OCUDU: An E3 Controller for Real-Time Open RAN Intelligence." Proceedings of the 20th ACM Workshop on Wireless Network Testbeds, Experimental Evaluation & Characterization (2026)

E2SM DAPP for xApps and dApps synchronization



Use case: dApp for Spectrum Sharing

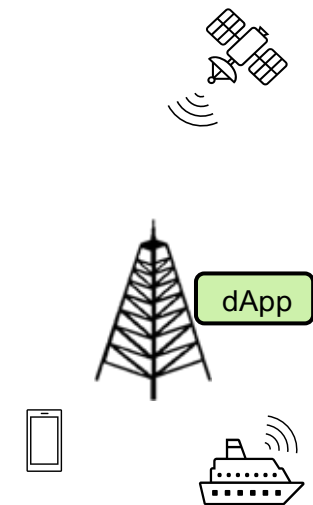


No incumbent

Incumbent in area (No dApp)

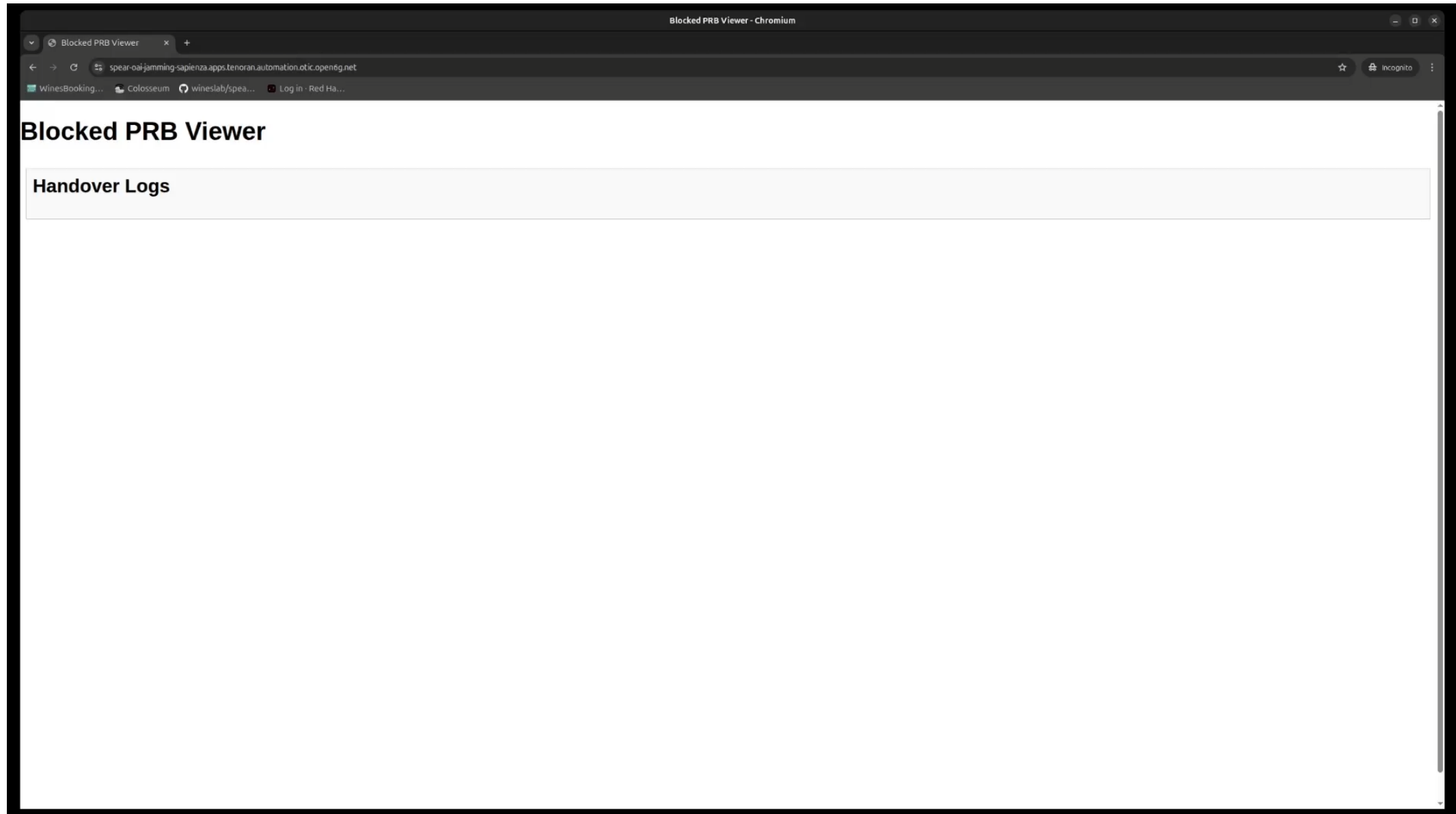
Incumbent in area (dApp on)

~~No co-existence~~
Shared Spectrum



The dApp **detects** the incumbent and **blocks** the scheduling of PRBs associated *in Real Time*

RF-Aware handover through E2SM-DAPP



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