Listen-While-Talking: Toward dApp-based Real-Time Spectrum Sharing in O-RAN

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***Abstract*—This demo paper presents a dApp-based real-time spectrum sharing scenario where a 5th generation (5G) base station implementing the NR stack adapts its transmission and reception strategies based on the incumbent priority users in the Citizen Broadband Radio Service (CBRS) band. The dApp is responsible for obtaining relevant measurements from the Next Generation Node Base (gNB), running the spectrum sensing inference, and configuring the gNB with a control action upon detecting the primary incumbent user transmissions. This approach is built on dApps, which extend the O-RAN framework to the real-time and user plane domains. Thus, it avoids the need of dedicated Spectrum Access Systems (SASs) in the CBRS band. The demonstration setup is based on the open-source 5G OpenAirInterface (OAI) framework, where we have implemented a dApp interfaced with a gNB and communicating with a Commercial Off-the-Shelf (COTS) User Equipment (UE) in an over-the-air wireless environment. When an incumbent user has active transmission, the dApp will detect and inform the primary user presence to the gNB. The dApps will also enforce a control policy that adapts the scheduling and transmission policy of the Radio Access Network (RAN). This demo provides valuable insights into the potential of using dApp-based spectrum sensing with O-RAN architecture in next generation cellular networks.**

I. INTRODUCTION

The radio spectrum is a valuable and finite resource. The proliferation of systems and wireless technologies supporting various users, devices, and machines in this era of connected intelligence has led to spectrum congestion, especially in the frequency bands below 6 GHz. The traditional approach of dividing the spectrum into licensed and unlicensed bands has resulted in under-utilization as it is unable to exploit the spatial and temporal variations in the spectrum demands. To this end, dynamic spectrum sharing has emerged as a key technology and it is expected to become a fundamental part of next-generation wireless system design.

In a spectrum sharing scenario, multiple categories of users, likely leveraging different wireless access technologies, dynamically select the unused portion of the spectrum while satisfying the sharing constraints such as access priorities and interference limits. A popular spectrum sharing example in the U.S is the Citizen Broadband Radio Service (CBRS), in the 3.55-3.7 GHz frequency range. Mobile network operators (also known as Priority Access License (PAL) users) and unlicensed users, or General Authorized Access (GAA) users, may coexist with high priority incumbent federal radar and satellite systems users. When considering 5G NR systems, the CBRS band is a subset of the bands n77 and n78.

Spectrum sharing in CBRS is managed by a centralized Spectrum Access System (SAS), with the aid of dedicated Environmental Sensing Capability (ESC) sensor networks [1]. The SAS requires PAL and GAA users to register to a database and coordinate the spectrum access based on the priority rules. The ESC network is used for spectrum sensing, to detect the primary user presence in case this is not advertised beforehand. The drawback of this method is the need of a dedicated sensing infrastructure and coordination of various entities belonging to different wireless access technologies by a central station. In addition, CBRS systems operate in a timescale of minutes, not allowing for the subframe-level sharing that would improve spectrum utilization.

On the other hand, the Open Radio Access Network (RAN) paradigm, implemented through the specifications of the O-RAN ALLIANCE, has introduced the possibility of performing closed-loop control and adaption of the RAN, as well as open, virtualized, disaggregated wireless networks. The intelligent control loops have been shown as enablers of several dynamic optimization use cases, toward a data-driven RAN with bespoke configurations and optimized performance [2], [3]. The current O-RAN architecture, however, does not extend to the user plane, wherein lies key information that can be used for spectrum sensing, and to real-time control, necessary to implement strategies that promptly adapt the Next Generation Node Base (gNB) stack to avoid interference.

In this work, we build on the concept of dApps, a real-time and user-plane extension of the O-RAN architecture we proposed in [4], to introduce the "listen-while-talking" approach for real-time RAN-driven spectrum sharing. With this, gNBs can communicate while simultaneously performing the spectrum sensing task in the CBRS band, effectively configuring the whole RAN as a spectrum sensor. dApps, which are currently studied as components for the next generation of O-RAN systems, interface with the gNB stack to (i) extract I/Q samples from dedicated symbols reserved for spectrum sensing at the gNB; (ii) perform data-driven inference on whether the spectrum is available, or, in case an incumbent is detected, to determine which portion of the spectrum needs to

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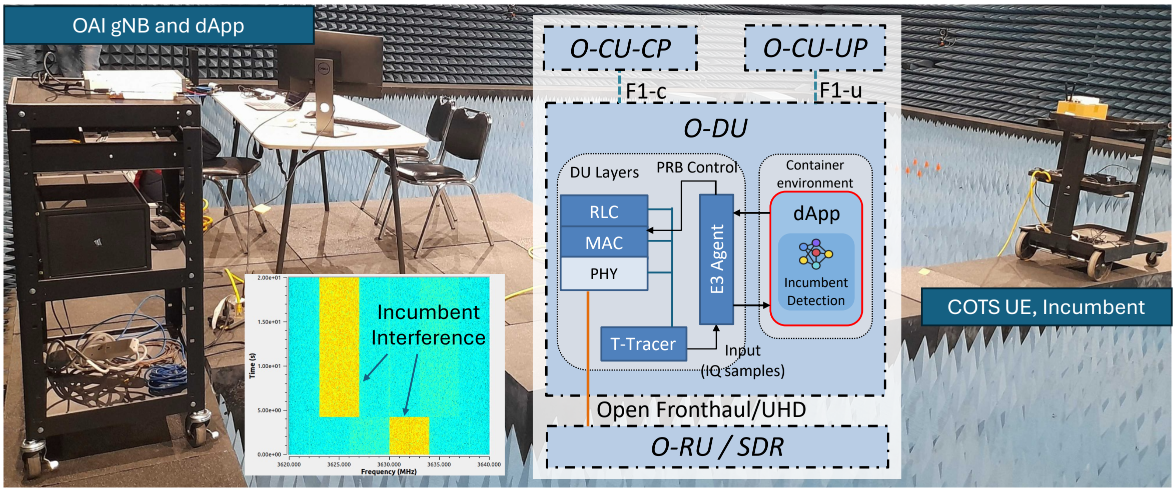

Figure 1: dApp-based spectrum sharing architecture and Over-the-Air (OTA) demo.

be vacated; and (iii) to inform the gNB about possible control actions that need to be adopted to avoid the incumbent. Here, we consider barring the scheduling over the Physical Resource Blocks (PRBs) where an incumbent user is detected. This allows for the minimum disruption of cellular services while vacating the spectrum for the incumbent user. To the best of our knowledge, an O-RAN-based real-time spectrum sharing system with a 5G gNB operating in the CBRS band has not been demonstrated before.

II. System Architecture

The proposed spectrum sharing framework is illustrated in Figure 1. It leverages the following components.

Programmable 5G RAN. The 5G network comprises of a core network and gNB running in the standalone mode, using the open-source OpenAirInterface (OAI) stack. The gNB uses the Time Division Duplexing (TDD) mode and is configured with *sensing symbols* in some of the Uplink (UL) slots. These are dedicated for spectrum sensing, and the gNB does not schedule any User Equipments (UEs) in these symbols, for any of its uplink channels. In this demo, we configure one Orthogonal Frequency Division Multiplexing (OFDM) symbol per frame to be used for sensing. This leads to periodic spectrum sensing over the entire gNB bandwidth every 10 ms, i.e., an overhead of 0.35%, or 1 symbol every 280 with NR numerology 1. Note that this configuration is programmable. Once the I/Q samples in the *sensing symbols* are available, they are shared with a dApp, where the inference is performed. To this purpose, we implemented an *E3 agent* in the OAI stack. The E3 is an O-RAN E2-like interface created to extract parameters from the gNB that are not exposed to the xApps, e.g., user plane elements. The E3 agent running inside the OAI gNB leverages the `T_tracer` tool to extract the data [5]. The E3 agent follows a publish/subscribe message mechanism so that several dApps can interact with the gNB while reducing the inter-dependency. In this demo, we use the E3 agent along with the dApp to extract the IQ samples.

dApp. These programmable elements complement existing xApps/rApps to extract real-time data and perform inference on lower-layer functionalities. In our implementation, the spectrum sensing dApp connects with the gNB using the E3 interface and extracts the I/Q samples from the configured *sensing symbols*. An inference algorithm takes this data as input and outputs the list of PRBs where the incumbent user presence is detected, which are then sent as barred PRBs to the gNB scheduler. For this demo, we leverage an energy threshold method, with more advanced solutions employing machine learning as future work.

III. Demonstration

This demonstration consists of an OAI gNB, a Commercial Off-the-Shelf (COTS) UE and an incumbent user. A computer running Ubuntu 22 OS attached with USRP SDR hosts the core, gNB (with E3 agent), and dApp application. The COTS UE is connected to the gNB over-the-air and runs an `iperf` session all the time. The incumbent user is modeled using a GNU-radio script hosted on a mini computer attached to a USRP. In the live experiment, we will show a) the incumbent user spectrum with dynamic changes over time; b) spectrum sensing through the dApp; and c) changes in the UE throughput due to the barred PRBs that are occupied by the incumbent user. This demo can be run without the need of specific experimental spectrum licenses by placing the COTS UE and the antennas in a shielded RF box.

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