Demo: PVTR, a Physical–Virtual O-RAN Testbed for FRMCS Slicing

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***Abstract*—Evaluating dynamic slice control in Future Railway Mobile Communication System (FRMCS) is challenging: simulations miss the full radio/application loop, while field trials are costly and hard to reproduce. We present PVTR, a hybrid physical–virtual O-RAN testbed running the same 5G core, CU/DU, near-RT RIC, and xApp across two execution modes. Its physical mode closes the control loop over a USRP 5G radio and mobile devices, whereas its virtual mode uses ZeroMQ-connected UEs driven by train-collected channel traces. As a flagship use case, *RSlice* maps per-slice service state and channel quality to E2SM-RC PRB allocations, with a safety mask protecting critical traffic. The demonstration exposes live telemetry, allocation decisions, and SLA indicators under congestion, and illustrates the complementary experimental conditions provided by over-the-air and railway-trace execution.**

***Index Terms*—FRMCS, O-RAN, network slicing, testbed, radio resource allocation, Railway, xApp.**

I. Introduction

The Future Railway Mobile Communication System (FRMCS) is a 5G system designed to support heterogeneous services over bandwidths as narrow as 5–10 MHz [1]. Based on 3GPP TR 22.889 service classes, three railway slices can be considered: a *critical* slice for ultra-reliable, low-latency ETCS, ATO, and emergency voice; a *performance* slice for medium- to high-rate applications such as CCTV and passenger information systems; and a *business* slice for non-critical services such as onboard Wi-Fi.

High-speed mobility causes severe channel fluctuations, complicating PRB allocation when protecting safety-critical traffic [2]. Most FRMCS studies rely on simulation or traces: field trials require heavy logistics and railway datasets remain scarce. While repeatable, trace evaluations miss the full radio, device, control, and application loop. Conversely, laboratory radio trials expose implementation and propagation effects, but cannot reproduce train-speed mobility over a railway route.

This demo presents *PVTR*, a hybrid physical–virtual O-RAN testbed that connects these two experimental regimes. PVTR implements closed-loop slice control from a near-real-time RAN Intelligent Controller (near-RT RIC) to per-slice PRB enforcement in the srsRAN distributed unit (DU) over the standardized E2 interface using E2SM-RC. The same core, CU/DU, RIC, slice configuration, traffic, and xApp operate in two interchangeable execution modes. The physical mode uses a USRP-based radio, two mobile unmanned ground vehicles (UGVs), and a smartphone. The virtual mode replaces the over-the-air path with ZeroMQ (ZMQ)-connected UEs driven by channel quality indicator (CQI) traces collected on an operational train [3].

PVTR's main contribution is an integrated environment evaluating an unchanged O-RAN controller under live and trace-driven railway conditions while preserving the network stack. We demonstrate the platform with *RSlice*, a learning-based xApp trained on railway data, alongside baseline schedulers [4]. RSlice serves as a demanding use case for enforceable, slice-aware control under congestion; the demo does not seek to establish an algorithmic ranking among evaluated policies.

II. Related Work

Open-source 5G stacks enable programmable RAN experiments, but lack reproducible closed-loop slice control. PVTR connects E2SM-RC to the DU scheduler for per-slice PRB enforcement, orchestrating the RIC, RAN, core, traffic, and monitoring seamlessly across physical and trace-driven modes. Unlike prior FRMCS slicing studies [2], or public network proposal [4] evaluated solely in simulation, PVTR executes unchanged controllers on a physical O-RAN stack and replays train-collected CQI traces through the same stack. Its novelty lies in bridging repeatable trace-based evaluation and over-the-air closed-loop validation.

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III. Design and Implementation

As shown in Fig. 1, PVTR is a disaggregated 5G system where a near-RT RIC xApp controls per-slice radio resources in a closed loop. The platform comprises three main blocks:

5G core and disaggregated RAN. The RAN follows the O-RAN functional split into a central unit (CU), a distributed unit (DU), and a radio unit (RU), implemented with the srsRAN Project. An Open5GS core provides access and mobility management, session management, and user-plane functions. Three slices are configured end-to-end from core subscriber profiles down to per-slice radio scheduling, and each UE retains the same slice mapping in both execution modes.

RIC and RSlice xApp. The control application runs on the O-RAN Software Community near-RT RIC. At each interval, it retrieves per-UE CQI and downlink rates via the monitoring interface, aggregates them into per-slice states, and computes allocations. Minimum PRB shares are sent to the DU scheduler through E2SM-RC, closing the observe-decide-enforce loop. RSlice maps slice satisfaction and channel quality to PRB allocations, protected by a safety mask preventing critical-slice starvation. Trained on train traces up to 350 km/h [2], PVTR supports interchangeable DRL agents (RSlice-PPO, RSlice-A2C), a fast value-based agent (RSlice-DQN), a best-CQI baseline, and the KBL method [4].

Hybrid railway environment. The distinguishing feature of PVTR is that the same core, CU/DU, RIC, controller, slice configuration, and traffic run across two execution modes. In *physical mode*, the DU drives a software-defined radio and real UEs communicate over the air. In *virtual mode*, the over-the-air path is replaced by a ZeroMQ (ZMQ) transport and UEs replay train-collected CQI measurements. This mode supports repeatable policy comparisons, controlled traffic and load variations, and the reproduction of channel evolution along railway routes. Switching modes changes radio execution conditions without changing the evaluated control logic.

IV. Demo Setup

The platform is deployed on two Dell Precision workstations, as illustrated in Fig. 2. *Tower 1* hosts the srsRAN CU/DU, a USRP X310 equipped with two UBX-160 daughterboards and connected over 10 GbE, the containerized near-RT RIC, the RSlice xApp, and a metrics logger. *Tower 2* hosts the Open5GS core and the downlink traffic generator, connected to Tower 1 through standard 5G N2 and N3 interfaces.

The radio operates in a 5G New Radio (NR) FDD configuration with 15 kHz subcarrier spacing within the narrow FRMCS spectrum. Three physical UEs attach over the air and are mapped to distinct slices, allowing the scheduler's decisions to be observed simultaneously through radio measurements, application throughput, and service-level indicators. Two mobile UGVs, each equipped with a Jetson Orin Nano and a Quectel RM530N-GL modem, represent critical and performance services. A Google Pixel smartphone carries business-slice traffic. The PVTR configuration and RSlice implementations are publicly available to support reproducibility [5]. The demonstration video is accessible in [6].

V. Demonstration Procedure and Results

The demo reproduces a congested FRMCS cell with competing unequal-priority services: critical (train-control signaling), performance (video surveillance), and business (passenger video). Because aggregate load exceeds capacity, the chosen scheduler determines target satisfaction. Operators select an execution mode and policy per run, repeatable across controllers while keeping service definitions unchanged. The dashboard displays CQI, throughput, PRB allocations, and SLA indicators. Physical mode uses UGV movement for live channel variations, while virtual mode replays railway CQI traces up to 350 km/h. The controller reacts at each interval, making policy effects visible instantly without reconfiguring traffic.

Experiment 1: closed-loop allocation on physical hardware. Fig. 3a reports per-slice SLA satisfaction during a representative overloaded physical-mode run. The RSlice agents maintain critical-slice satisfaction at approximately 0.9–1.0 and assign the residual capacity according to service priority. KBL produces a similar priority-oriented profile. In contrast, best-CQI improves satisfaction for the performance and business UEs but provides weaker protection to the critical slice because it allocates resources according to instantaneous channel quality rather than service criticality. The experiment demonstrates that the selected xApps produce distinct, enforceable PRB decisions on the physical RAN; it is not intended as a statistically significant ranking of the scheduling algorithms.

Experiment 2: complementary physical and virtual regimes. Fig. 3b reports SLA violations when executing the same controller over the physical radio and ZMQ trace-replay paths. The physical run shows stronger critical-slice protection and larger violations for lower-priority traffic, whereas the trace-driven run exposes a distinct service profile under high-speed channel evolution. Because channel trajectories differ, these runs illustrate mode complementarity rather than a direct performance benchmark: physical execution captures real radio, device, and mobility effects, while virtual execution provides repeatable access to high-speed railway traces up to 350 km/h.

VI. Conclusion

We presented PVTR, a hybrid physical–virtual O-RAN testbed executing identical slice control across USRP hardware and trace-replay paths. RSlice enforces slice priorities under congestion via E2SM-RC. The two modes offer complementary benefits: repeatable evaluation under high-speed railway traces vs. live execution with real hardware and mobility. Their distinct outcomes show that trace-driven results do not transfer directly to physical deployments. While currently focused on single-cell downlink slicing, PVTR provides an open substrate for future railway xApps targeting handover, admission control, and energy management.

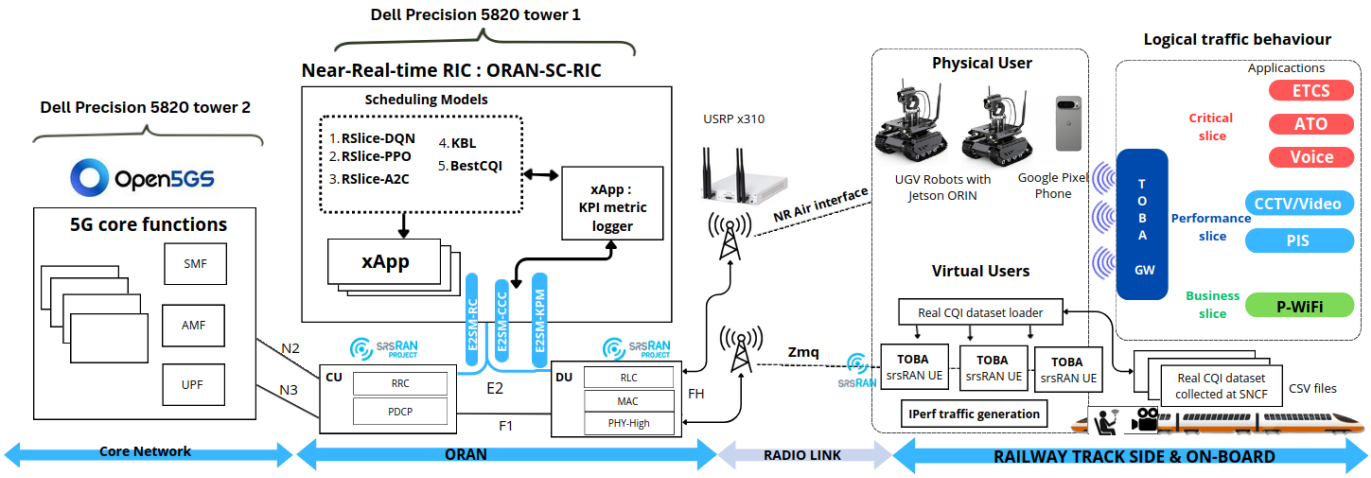


Fig. 1. Architecture of our Physical-Virtual Testbed for Railways FRMCS

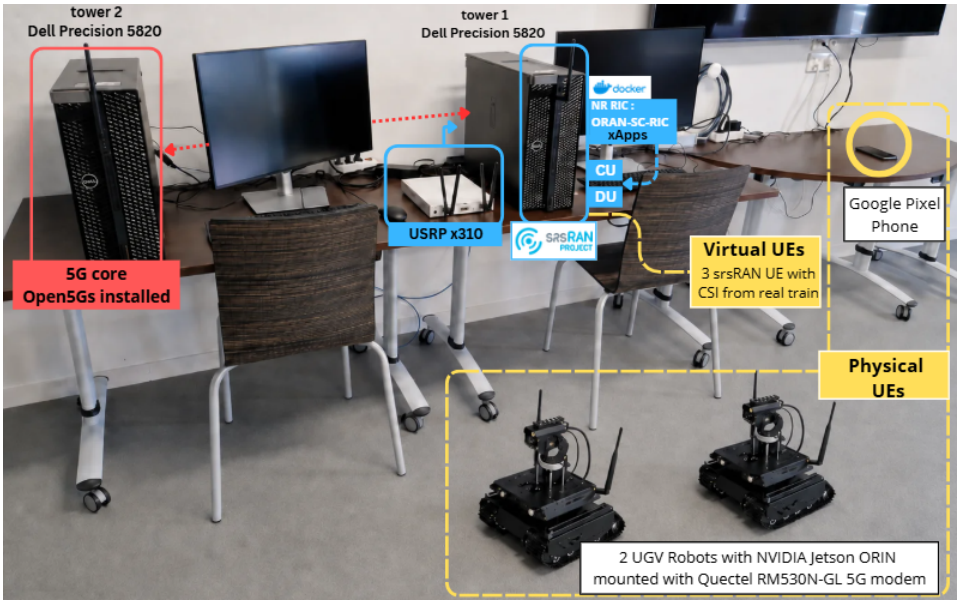
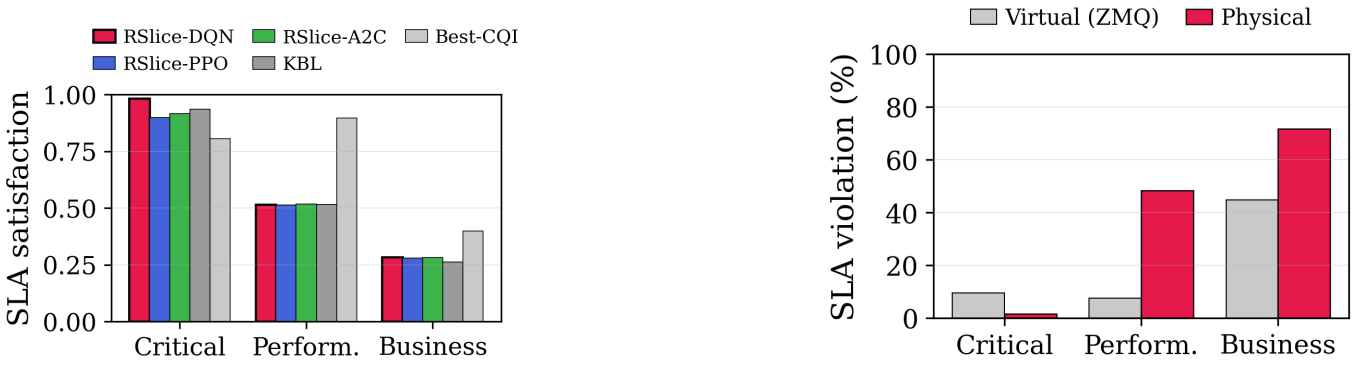


Fig. 2. Our PVTR Testbed for Railways FRMCS



(a) Slice SLA satisfaction in overloaded physical mode.

(b) SLA violations in physical-radio and virtual modes.

Fig. 3. Slice-level performance under physical and trace-driven execution.

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