

# End-to-End Orchestration across MCF Infrastructure: Field Trial of Spatial PON and Metro Convergence with O-RAN for AR/VR Services with Edge Offload

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**Abstract:** First field trial demonstrating energy-aware convergence of spatial PON with 5G O-RAN for AR/VR services. Traffic-driven orchestration dynamically activates/deactivates spatial lanes and radio units, achieving 8% energy reduction while maintaining service quality.

## 1. Introduction

The emergence of 6G-envisioned services like immersive AR/VR applications is driving the evolution toward next-generation networks that must simultaneously deliver ultra-high bandwidth, ultra-low latency, and sustainable operation. These demanding requirements, central to the 6G vision, necessitate a fundamental rethinking of optical access and metro network architectures. Space Division Multiplexing (SDM) represents a key enabling technology to scale optical access networks toward higher capacity and richer node connectivity [1–3]. In parallel, IPoWDM technologies with coherent pluggable transceivers are rapidly leading to effective IP-photonic layer convergence [4].

While access-metro convergence has been addressed in recent works [5,6], previous solutions have not considered the joint optimization of SDM infrastructure with 5G O-RAN deployments. Furthermore, immersive AR/VR applications require ultra-low latency, high bandwidth, and energy-efficient connectivity which current architectures struggle to provide simultaneously.

In this work, as final outcome of the SEASON project, we demonstrate the world's first deployed MCF infrastructure combining spatial Passive Optical Networks (PONs), O-RAN-based Distributed Unit (DU) scaling, and midhaul transport. Our solution dynamically adapts resources to match traffic demands while minimizing power consumption through coordinated spatial lane and radio unit activation/deactivation.

## 2. Integrated System Architecture and Control

Fig. 1(a) illustrates the converged architecture consisting of metro and access domains. The metro domain provides high-speed optical connectivity through IPoWDM packet-optical switches equipped with coherent ZR+ pluggable

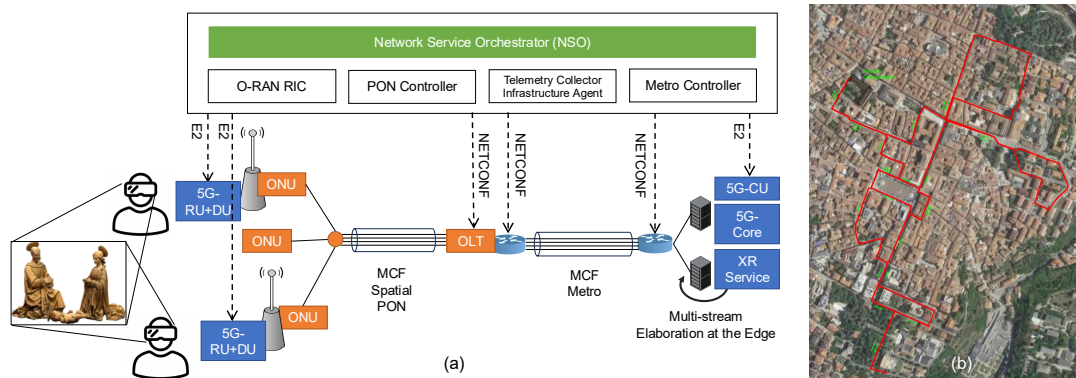


Fig. 1. (a) Reference architecture; (b) Map of the SDM fiber infrastructure deployed in L'Aquila.

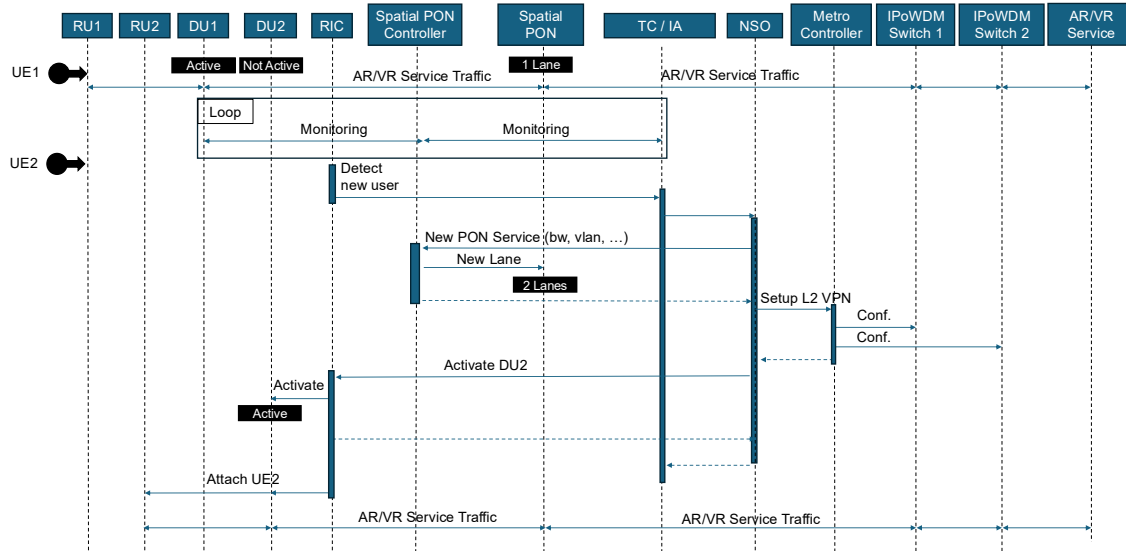


Fig. 2. Control plane workflow for dynamic resource scaling showing TC/IA monitoring, RIC-triggered DU activation, spatial PON lane reconfiguration, and IPoWDM L2VPN provisioning coordinated through NSO.

transceivers. The 5G access domain consists of a commercial PON system where the 5G Core is deployed at the metro end, the Centralized Unit (CU) at the metro-access border, and the Distributed Unit (DU) close to the Radio Unit (RU) at cell sites.

The architecture delivers edge-hosted AR/VR services to users with head-mounted displays. A spatial PON, unlike traditional PON architectures, supports dynamic activation/deactivation of spatial lanes to match bandwidth demand. When an additional DU is activated for small cell overlay, the spatial PON activates a corresponding spatial branch. A RAN Intelligent Controller (RIC) continuously monitors traffic and triggers DU scaling when capacity is needed, coordinating with the PON system to enable spatial lanes for the additional bandwidth required by AR/VR services.

The control solution orchestrates components across domains through a hierarchical architecture. The spatial PON controller exposes RESTful APIs to the Network Service Orchestrator (NSO) and NETCONF-based APIs to the Optical Line Terminal (OLT) and spatial switches, dynamically activating MCF lanes based on traffic demand [7]. The O-RAN RIC monitors traffic via E2 interfaces and triggers DU scaling through a novel xApp that processes performance metrics via Kafka message bus. The Metro Controller, based on TeraFlow SDN, manages IPoWDM switches via NETCONF using OpenConfig models, enabling L2VPN activation between RAN elements and edge resources. The Telemetry Collector/Infrastructure Agent (TC/IA) collects real-time metrics from transport and RAN, triggering NSO reconfiguration when thresholds are crossed.

The workflow in Fig. 2 demonstrates coordinated operation. Initially, UE1 accesses AR/VR through RU1/DU1 via a single spatial PON lane. When UE2 joins, TC/IA detects increased load and triggers NSO scaling: (i) Spatial PON Controller activates a new lane, (ii) Metro Controller activates a new L2VPN client port, (iii) RIC activates DU2/RU2. The automated service re-optimization takes approximately 50s from UE2 attachment, mainly due to commercial hardware configuration times.

### 3. Experimental validation

The field trial was conducted in the city of L'Aquila, Italy, leveraging a real urban deployment SDM infrastructure [8]. The experimental setup comprised a converged metro-access architecture with an XGS-PON system enhanced with a spatial aggregation node integrating a Polatis optical switch and PLC splitters. The 5G O-RAN deployment included two RUs, two DUs, and one CU, interconnected via a 6.3 km in-field deployed four-core fiber ring, as shown in Fig. 1(b). Metro connectivity was provided by IPoWDM EdgeCore switches equipped with 400G ZR+ transceivers running SONiC and the SEASON OpenConfig SDN agent. The control plane orchestration was implemented through the TeraFlow SDN controller, coordinating the PON access controller, the RIC, and the optical metro controller, with integrated telemetry support. At the application layer, the WEST VR service was deployed to validate end-to-end AR/VR delivery.

Fig. 3(a) illustrates the O-RAN behavior after DU scaling, showing the active state of both RUs serving distributed users. The AR/VR application interface captured from the user's Meta Quest headset is displayed in Fig. 3(b), presenting a virtual museum experience with artwork rendered in real-time at the edge, confirming uninterrupted

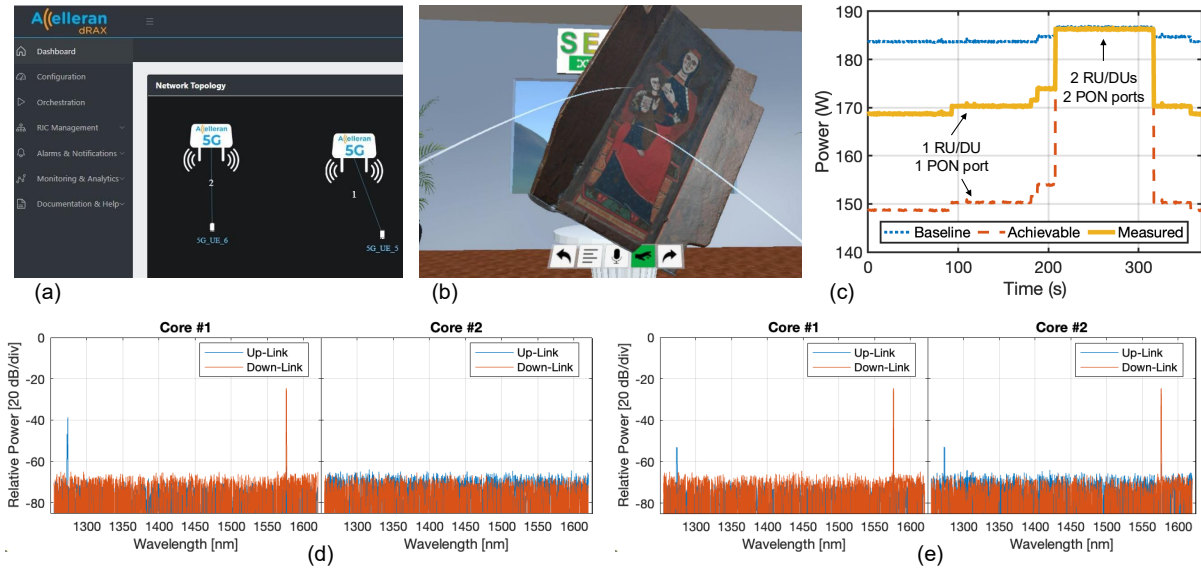


Fig. 3. (a) O-RAN user association with DU Scaling; (b) AR/VR App; (c) Power consumption dynamics during the experiments; (d) Core 1 and 2 spectrum with 1 spatial lanes active; (e) Core 1 and 2 PON spectrum with 2 spatial lanes active

service quality during network reconfiguration. The power consumption dynamics in Fig. 3(c) demonstrate the system's energy-aware operation through three traces: baseline (blue) shows 185W with both RUs and PON ports continuously active; measured (yellow) captures the actual system transitioning from ~170W (single RU/PON) to ~185W (dual operation) and back; achievable (red dashed) indicates the scenario with complete RU shutdown which was not available in the adopted commercial O-RAN. The 15W (8%) measured reduction and 35W (19%) achievable saving validate the effectiveness of traffic-driven orchestration.

The optical spectrum measurements validate the MCF-based spatial multiplexing operation. Fig. 3(d) shows the single lane configuration where only one RU is active: core #1 carries bidirectional XGS-PON traffic with downstream at 1577 nm and upstream at 1270 nm, while core #2 remains idle. Upon scaling to the 2 lanes configuration shown in Fig. 3(e), both cores become active optical distribution networks (ODNs), each supporting independent PON transmissions to serve their respective RUs, demonstrating successful spatial resource allocation without inter-core crosstalk.

#### 4. Conclusions

A field trial demonstrates a converged architecture integrating spatial PON, O-RAN DU scaling, and midhaul connectivity, enabling energy-efficient, scalable edge support for AR/VR. Dynamic resource activation and traffic optimization achieve 8% savings for each small cell under low traffic conditions.

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