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Milli-O-RAN: A Flexible, Reconfigurable O-RAN enabled mmWave Network Testbed

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***Abstract*—This paper introduces the Milli-O-RAN testbed, the first-of-its-kind flexible and adaptable Open Radio Access Network (O-RAN) managing mmWave networks. The implementation of a representative (sub-second) dynamic beam switching feature is demonstrated through a proof-of-concept *beam switching xApp*, a software microservice hosted within the near real-time RAN Intelligent Controller (near-RT RIC) within O-RAN based mmWave networks. This highlights the potential of xApps to intelligently control and manage various RAN functionalities, including, physical and MAC layer, of O-RAN based mmWave networks. Our experiments over Milli-O-RAN testbed validate the effectiveness of beam switching xApp in steering the beams at desired angles within milliseconds, underscoring the transformative impact of O-RAN in enhancing mmWave network performance.**

***Index Terms*—O-RAN, mmWave network, Beam Switching**

I. Introduction

Open Radio Access Networks (O-RAN) revolutionizes the wireless communication landscape, enabling the creation of adaptable networks and fostering the evolution of diverse vendors and new technologies, mainly through its component, called, near-real time RAN Intelligent Controller (near-RT RIC), which enables sub-second (10 ms - 1s) dynamic control of the RAN components via third-party microservices known as xApps. The RIC's potential to control the physical layer is particularly relevant in the domain of Massive Input Massive Output (MIMO) beamforming [1]. Discussions within the O-RAN Alliance have spearheaded the initiative to foster active industry engagement and develop O-RAN-compatible beamforming frameworks [1], [2].

While existing studies diligently analyze challenges and propose solutions for implementing beamforming in O-RAN [3], [4], a persistent research gap exists in the practical implementation of mmWave beamforming within standardized O-RAN management. Recognized mmWave testbeds such as COSMOS [5], POWDER [6], and RENEW [7] have made significant contributions. However, a critical void remains as these testbeds, although excelling in mmWave capabilities, have yet to explore the integration of these capabilities within standardized O-RAN management. Notably, the existing O-RAN testbeds predominantly focus on Sub-6GHz frequencies [8], [9], leaving a substantial gap in exploring the full potential of mmWave within the O-RAN framework.

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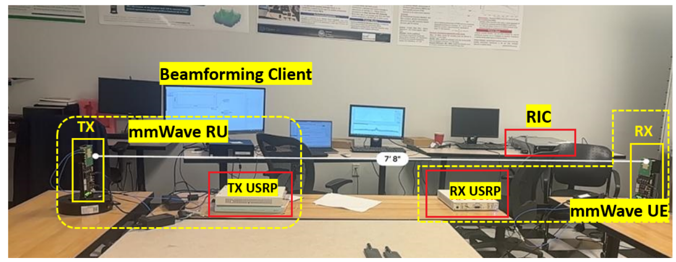

Fig. 1. Overview of the Milli-O-RAN testbed.

Contributions. Motivated by this research gap, our work takes a pioneering step by introducing the Milli-O-RAN testbed. This platform is designed to seamlessly integrate mmWave capabilities with standardized O-RAN management. In contrast to its predecessors, the Milli-O-RAN testbed features mmWave beamforming capabilities and represents a novel initiative within the O-RAN ecosystem. This work positions itself as the first to develop the Milli-O-RAN testbed, subsequently validated through a beam-switching xApp hosted within the near-RT RIC of our Milli-O-RAN testbed.

II. Milli-O-RAN Testbed

Fig. 1 showcases the Milli-O-RAN testbed. Our testbed consists of a computing platform, called the beamforming client, which is connected via USB to a mmWave Radio Unit (RU). The mmWave RU utilizes a Sivers EVK02004, leveraging its integrated BFM02801 4×4 phased array antenna. The EVK provides precise manipulation of output power, gain, beamforming, DC offset, and the Local Oscillator (LO) frequency. Operating the EVK in Intermediate Frequency (IF) mode, we generate a 4 GHz sine wave using a USRP X310 software-defined radio and configure the EVK's LO frequency to 24 GHz to transmit a mmWave signal.

For the mmWave UE, we use the same components as the RU, but configure them to receive mmWave signals. In this way, we establish a mmWave link between the transmitter and receiver. The beamforming client is connected via Ethernet to a near-RT RIC, which is strategically deployed on a virtual machine hosted within a rack server. This connection allows xApps in the RIC to seamlessly control the mmWave RU in near-real-time. Our mmWave testbed, anchored by Sivers EVK02004s and configured for real-world experimentation,

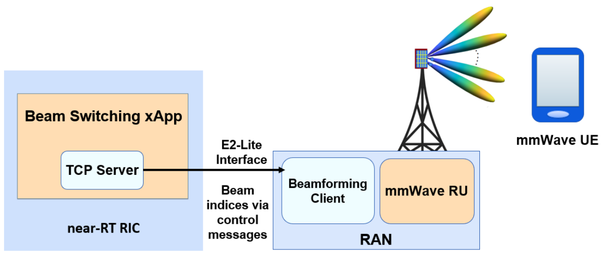

Fig. 2. High-level overview of beam switching xApp workflow.

enables dynamic manipulation of mmWave signals, validating the efficacy of our proposed beam switching approach.

III. Example usecase: Beam Switching xApp design and implementation

Here, we discuss how the example beam switching xApp is implemented using Milli-O-RAN testbed. Fig 2 provides a high-level overview of end-to-end workflow of beam switching xApp, and the involved key O-RAN components.

The mmWave RU, a critical part of our architecture, is managed by the beamforming client. This client interacts with the mmWave beam switching xApp through an *E2-Lite*[1] interface. To ensure compatibility with our Windows-based beamforming client, we employ a TCP server for the E2-Lite interface in our demonstration.

The procedure of the beam switching xApp is as follows:

1) The beamforming client establishes an E2-Lite connection with the xApp in the near-RT RIC.
2) The mmWave beam switching xApp operates by periodically dispatching E2-Lite control messages to the client. These messages contain the beam index to be utilized for beamforming.
3) Upon receiving the beam index, the client issues a command via USB to the mmWave RU. Internally, the transmitter references the beam index within its codebook memory.
4) The mmWave RU configures the phased array antenna with corresponding beamforming weights, facilitating seamless beam switching.

This orchestrated interaction of components ensures rapid, reliable, and precise mmWave beam switching.

Preliminary results. Fig. 3 illustrates the adaptability of the beam switching xApp over Milli-O-RAN testbed. Clear beam transitions are observed at specific beam pointing angles, azimuthal angle $\phi_0 = -15, 0$ and 3 degrees. (elevation angle, $\theta_0 = 0$ in all cases). This visual representation showcases the accuracy and efficiency of the designed mmWave beam switching feature within the O-RAN framework. The time required to switch the beam is close to 10 ms, which hints at the possibility of sub-millisecond performance using a real-time RIC, such as EdgeRIC [10].

[1]E2-Lite is a lightweight E2 implementation, providing functionalities akin to the O-RAN compliant E2 interface while streamlining the subscription process, as well as message encoding and structure for enhanced simplicity.

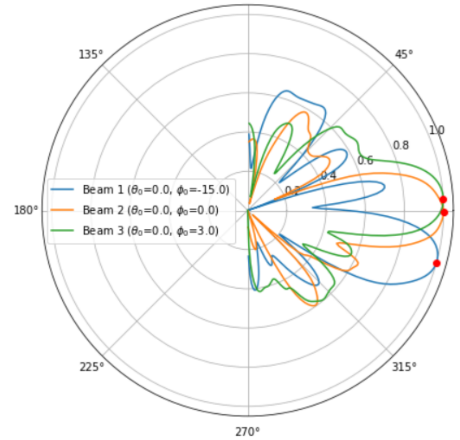

Fig. 3. mmWave beam switching at beam pointing angles: $\theta_0 = 0°$ and $\phi_0 = -15°, 0°, 3°$.

IV. Conclusion and Future Research

Our Milli-O-RAN testbed advances mmWave networks within the O-RAN ecosystem, and is validated by the beam switching xApp. The testbed enhances network efficiency and user experiences, enabling a diverse range of advanced mmWave features and contributing to ongoing innovation in O-RAN. For future research, our focus remains on refining the testbed's capabilty and performance. This includes minimizing beam switching times, integrating UE feedback for dynamic adaptation, and making it cellular protocol stack compliant.

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