DT-RAN: Enabling Next-Generation RAN Optimization and Control through Digital Twin-Based O-RAN

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***Abstract*—This paper outlines the background and key components of the Digital Twin Radio Access Network (DT-RAN) in the context of an Open Radio Access Network (O-RAN) environment, demonstrating the potential for real-time optimization and intelligent network control. Furthermore, various use cases are presented, and improvement directions are suggested based on the limitations of existing studies. As DT-RAN is still in the conceptual stage, this work provides guidelines for researchers and developers aiming to initiate DT-RAN research.**

***Index Terms*—DT-RAN, O-RAN, Digital Twin, Optimization, xApp, rApp, Intelligent Control**

I. Introduction

To support interoperability, control policy verification, operational efficiency, AI/ML model training and validation, and performance prediction based on large-scale scenarios in real time, the wireless access network (RAN) is transitioning away from vendor-locked architectures through the adoption of Open RAN (O-RAN). However, as network complexity increases, more precise verification and prediction methods are required [1]. Moreover, 5G is rapidly expanding beyond public networks into specialized 5G private networks tailored for specific areas such as smart factories, logistics centers, and campuses, which require ultra-low latency, high reliability, enhanced security, and local control [2].

To meet both the verification and operational needs of O-RAN and the service requirements of private networks, this paper proposes DT-RAN (Digital Twin RAN). DT-RAN replicates the topology, channel conditions, and traffic patterns of physical RANs in a virtual environment, enabling safe and efficient control by supporting policy pre-validation, AI/ML workflow validation, and scenario-based performance prediction. The remainder of this paper discusses the background and necessity of DT-RAN in the O-RAN context, introduces its architecture and use cases, and outlines improvement directions based on the limitations of previous research.

II. DT-RAN: Background and Architecture

A. Background

RAN is a complex system involving real-time interactions between base stations, DUs, CUs, and user equipment (UE). As we move beyond 5G towards 6G, the number and interdependency of control parameters increase exponentially. Although the O-RAN architecture significantly improves flexibility and scalability through open interfaces and multi-vendor compatibility, large-scale field verification remains practically infeasible due to cost, time, and risk. Direct application of new control policies to live networks entails risks such as QoS degradation and service interruption.

DT-RAN addresses these limitations by reproducing the real-time measurement data of physical RANs—such as network topology, channel status, and traffic patterns—into a synchronized virtual environment. It provides workflows for AI/ML-based automatic optimization and safe application of validated scenarios. The ITU-R M.2516-0 report also highlights digital twin technology as a key infrastructure for realizing automation and autonomy in next-generation wireless networks [3], [4].

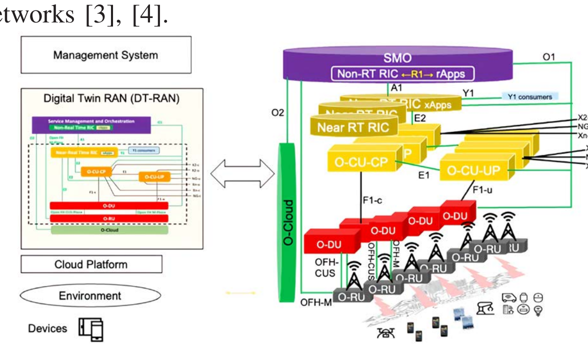

Fig. 1: DT-RAN Architecture proposed by O-RAN nGRG

B. Architecture and Implementation

As shown in Fig. 1, DT-RAN is constructed to mirror the physical RAN and communicate through standard interfaces in the virtual environment. The implementation process includes:

- **O1/O2 Subscription Agents:** Subscription agents are placed at the Non-RT RIC to subscribe to Performance Management (PM), Configuration Management (CM), Fault Management (FM) indicators and long-term traffic and policy data from the physical RAN.
- **E2 Subscription Agents:** xApps are deployed at the Near-RT RIC to receive data such as Physical Resource Block (PRB) utilization and Modulation and Coding Scheme (MCS) metrics at intervals of 10 to 100 ms.
- **3D Environment and Channel Model:** 3D meshes are generated using drive test data, LiDAR, or satellite imagery. Since DT-RAN does not require ultra-precise 3D modeling, the meshes are lightweight. Stochastic channel models are then applied to simulate distance and fading characteristics, and the parameters are repeatedly adjusted against measurements to maintain channel accuracy [3].

As research on DT-RAN is still in its early stages and no standards exist, the above structure follows the DT-RAN proposal from the O-RAN Alliance's next Generation Research Group (nGRG). Other approaches include using platforms like Azure or starting with module-level twins that can later be extended to full-scale replicas [5], [6], [8].

III. Use Cases of DT-RAN

DT-RAN can be applied to a variety of RAN operation and validation scenarios based on data collection, modeling, simulation, and interface technologies.

A. Network Planning

In a digital twin environment, various cell placements and beam configurations can be tested through simulation. By combining these simulations with AI/ML, optimal cell placement or beamforming configurations can be identified.

B. Network Performance Predictions

Since all actual interfaces such as A1 and E2 are replicated in DT-RAN, KPI predictions can be performed under various simulated scenarios.

C. Network Energy Saving

AI/ML-based simulations can be conducted to evaluate cell switching, On/Off operations, or antenna count adjustments. The goal is to find a configuration that achieves maximum performance with minimum energy consumption.

D. xApp/rApp Testing

Network volatility is expected to increase further [4], which increases the risk of applying new xApp or rApp policies directly to the physical RAN. However, DT-RAN allows for safe testing and validation of such policies. Through repeated execution and optimization, these policies can be safely deployed to the physical network [3], [7].

IV. Limitations and Improvements

System Type	GPU Qnty	GPU vRAM	GPU Requirement	GPU Notes
Frontend alone	1	12GB+	GTX/RTX	e.g. RTX 6000 Ada, A10, L40
Backend alone	1	48GB+		e.g. RTX 6000 Ada, A100, H100, L40
Frontend and backend replay	1	48GB+		e.g. RTX 6000 Ada, L40
Frontend and backend colocated	2	see note	see note	1x frontend-capable GPU, 1x backend GPU

TABLE I: GPU Requirements for Aerial Omniverse Digital Twin

To date, DT-RAN remains at the conceptual stage, and discussions regarding the required system resources and operational constraints have not been sufficiently addressed. For example, as shown in Table I, NVIDIA's AODT (Aerial Omniverse Digital Twin) demands high-end GPUs with at least 12GB VRAM, and in some cases, 48GB or more. Yet, DT-RAN goes even further—requiring real-time modeling of channels, traffic, and 3D environments, 24/7 operation, dynamic modeling of thousands of base stations and UEs, and AI-driven optimization. Consequently, DT-RAN poses even more stringent requirements in terms of computational power, energy efficiency, cost, system design, and low-latency synchronization [6].

Regarding power consumption, continuous research is needed to evaluate whether the optimization benefits from DT-RAN outweigh its added energy cost. In terms of latency, event-based data collection—where data is transmitted only when a threshold is exceeded—may be more efficient than continuous transmission. Furthermore, architectures that do not replicate the RIC but only receive its data are being explored [6], [8]. However, such designs may introduce delays in xApp/rApp testing and make internal AI/ML simulations infeasible.

V. Conclusion

This paper presented the concept, architecture, implementation procedures, and potential applications of DT-RAN. Based on the openness and intelligent control capabilities of O-RAN, DT-RAN offers a virtual environment that replicates real RANs, enabling pre-validation and optimization of control policies and AI/ML models. This helps reduce uncertainty and risk in network operations, and enables efficient planning and automation.

Although DT-RAN shows promise in network prediction, energy efficiency, and app testing, it remains conceptual and must overcome challenges such as high resource demands, energy consumption, and real-time synchronization. Future research should focus on practical solutions including lightweight simulation, event-driven data collection, and modular twin architecture.

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