Open-Source 5G Digital Twin: Virtualizing Core and RAN for Network Replication

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***Abstract*—This paper presents a proposed methodology for creating digital twins of 5G networks using open-source 5G core and Radio Access Network (RAN) implementations. Our research will demonstrate how virtualized network functions can be deployed to create accurate digital replicas of operational 5G infrastructures. We will evaluate three leading open-source 5G core implementations—Open5GS, free5GC, and OpenAirInterface—assessing their performance characteristics and suitability for digital twin applications. The proposed architecture will specifically replicate a distributed multi-campus research network, featuring multiple gNodeB units at each location connected through IP transport networks to Compact Mobility Units (CMUs) that bundle core network functions. Our implementation will enable bi-directional synchronization between physical networks and their digital counterparts, facilitating testing, optimization, and AI/ML model training without disrupting operational environments. Performance benchmarks and implementation guidelines provided in this paper will contribute to the growing field of network digital twins, offering a cost-effective approach for creating high-fidelity network replicas using open-source tools.**

***Index Terms*—5G, Digital Twins, Virtualization.**

I. Introduction

The complexity of 5G networks has created significant challenges for network operators in testing, optimization, and troubleshooting without disrupting production environments. Digital twin technology offers a promising solution by creating virtual replicas of physical systems that evolve synchronously with their real-world counterparts. In the telecommunications domain, a Mobile Networks Digital Twin (MNDT) accurately models network devices, communication links, operating environments, and applications running on the physical network.

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The emergence of open-source 5G core implementations has created new opportunities for constructing affordable digital twins. These implementations follow 3GPP specifications but differ in feature support and performance characteristics. When combined with simulated Radio Access Network (RAN) components, they can form comprehensive digital replicas of end-to-end 5G networks.

The concept of network digital twins provides several advantages: it will enable network operators to visualize and simulate network behavior before deployment, facilitate proactive maintenance through predictive analytics, enhance decision-making through data-driven insights, and increase resource efficiency by optimizing allocation based on detailed traffic patterns. As noted in recent industry research, simulation alone may be insufficient for managing 5G complexity, emphasizing the need for real network emulation through digital twins.

In this paper, we present the first phase of a three-phase project aimed at developing a comprehensive digital twin for a specific 5G research network. This initial phase will focus on creating a high-fidelity virtual replica of a physical 5G network to be deployed across two university campuses. Subsequent phases will address real-time data synchronization and AI/ML model training for network autonomy. Our approach will leverage OpenStack virtualization to create a flexible deployment environment for open-source 5G components.

II. Background and Related Work

A. Digital Twins for Telecommunication Networks

Digital twins have emerged as a paradigm for designing, deploying, and operating next-generation networks. This technology creates accurate models of physical networks and establishes bi-directional links between physical and digital elements, allowing them to evolve synchronously throughout their lifecycle.

In 5G networks, digital twins typically focus on three main components:

- **Core Network** – emulating the service-based architecture and network functions.
- **Base Stations (gNodeB)** – modeling radio access behavior.
- **Channels** – simulating electromagnetic propagation and interference.

Recent workshops such as DTwin 2025 suggest that:

> ”DTs play a pivotal role in the development and operation of next-generation (NextG) wireless networks by offering a sophisticated simulation and analysis platform that mirrors the real-world behavior of these physical systems.”

Using these tools, researchers can anticipate network loads, identify potential failure points, and assess various configurations before implementation.

B. Open-Source 5G Core Implementations

Several open-source 5G core implementations have emerged as viable alternatives to commercial solutions:

- **Open5GS**: A C-language implementation following 3GPP specifications with support for both 4G and 5G core functions.
- **free5GC**: A Go-based implementation focusing on cloud-native deployment and network slicing capabilities.
- **OpenAirInterface (OAI)**: A comprehensive platform including both core and radio access components with an emphasis on research and education.

Our research will evaluate these implementations to determine their suitability for digital twin applications, focusing on Control plane performance, Data throughput capabilities, and Resource requirements.

III. Proposed Methodology

A. Physical Network Reference Model

The physical network our digital twin aims to replicate consists of a distributed 5G deployment across two university campus locations. This architecture can be seen in Figure 1 and features:

- **Core Network**: A 5G Standalone (SA) network core with two redundant single-server instances, one at each campus, running 3GPP Release 17. Each core implementation utilizes Compact Mobility Units (CMUs) bundling core functions (AUSF, AMF, UDM, SMF, UPF).
- **Radio Access Network (RAN)**: Three 5G radio units in the n40 band (FR1, 2300MHz) and two units in the n258 band (FR2, 24.25-27.50 GHz) at each campus, with one baseband unit (BBU) at each location.
- **Transport Network**: Two campuses connected via optical fiber links with sub-millisecond latency. The optical transport layer is not the focus of this digital twin implementation.

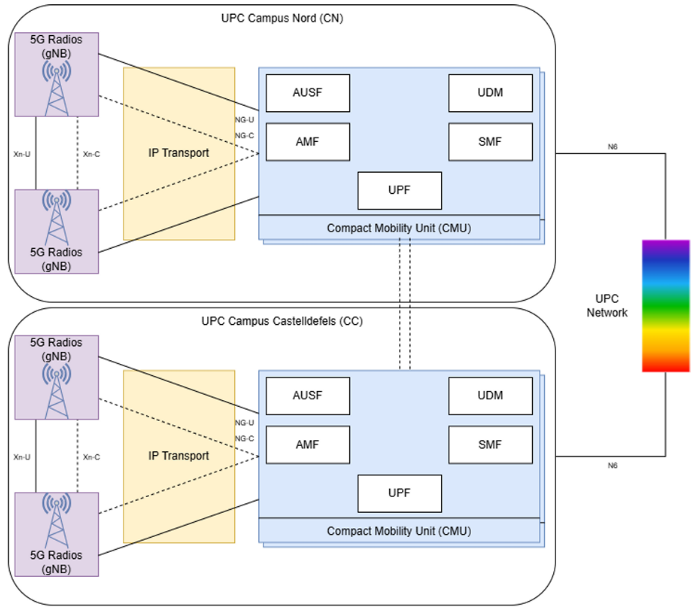

Fig. 1. 5G Network topology.

B. Digital Twin Architecture

Our digital twin implementation, Figure 2, will rely on three primary layers that together create a comprehensive virtual replica of the physical network:

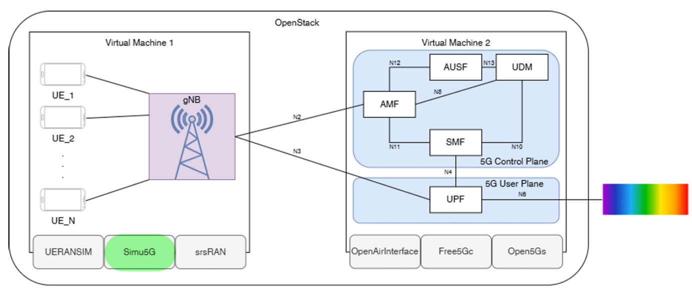

Fig. 2. Virtualization.

1) Core Network Virtualization: For virtualizing the 5G core functions, we will evaluate three leading open-source implementations:

- **Open5GS**: Expected to provide superior control plane performance with low registration times.
- **free5GC**: Anticipated to show the lowest resource consumption for resource-constrained environments.
- **OpenAirInterface (OAI)**: Expected to offer high data plane throughput capabilities.

We will benchmark these implementations to determine the optimal choice for our specific digital twin requirements.

2) RAN Virtualization: For RAN virtualization, we will consider multiple solutions, among them:

- **UERANSIM**: An open-source tool that emulates gNodeB and User Equipment (UE) behavior. We will configure it to replicate the specific characteristics of the physical

network's radio units, including MIMO configurations (4T4R for FR1 band and 2T2R for FR2 band) and transmission parameters.
- **srsRAN**: Will be used as a complementary tool for simulating specific aspects of the FR2 mmWave radio behavior in the n258 band.

3) Channel Emulation: To accurately model radio frequency propagation between network elements, we will implement:

- **RF Channel Models**: Specific to the deployment environments at both campuses, using propagation models appropriate for the 2300MHz and 24.25-27.50 GHz frequency ranges.
- **Campus-Specific Parameters**: Including building layouts, campus topographies, and typical interference patterns.

C. Implementation Plan

The implementation architecture will follow a containerized approach using OpenStack as the virtualization platform:

- **Containerization**: Each network function will operate as a separate container, following microservices architecture principles. This approach provides isolation, portability, and scalability.
- **OpenStack Deployment**: OpenStack will manage the virtualized infrastructure, providing flexible resource allocation and management capabilities.

IV. 5G Core Implementation Plan

A. Release 17 Features Implementation

Our digital twin will implement key 3GPP Release 17 features and try to match the capabilities of the physical network. These features include:

- **Enhanced MIMO Support**: Implementation of advanced MIMO techniques for improved spectral efficiency and performance.
- **Spectrum Sharing Enhancements**: Features for more efficient spectrum utilization across multiple technologies.
- **UE Power Saving and Coverage Enhancements**: Mechanisms to extend battery life and improve coverage reliability.
- **RedCap (Reduced Capability) Devices**: Support for IoT and industrial devices with lower complexity requirements.

B. Core Network Function Virtualization

We will implement the following core network functions in our digital twin:

- **Access and Mobility Management Function (AMF)**: Handles connection and mobility management, configured to support the specified number of simultaneous users.
- **Session Management Function (SMF)**: Manages user sessions and policy enforcement, configured to handle the specified traffic capacities.
- **User Plane Function (UPF)**: Handles user data traffic, properly dimensioned to match the capacity requirements of the physical network.
- **Authentication Server Function (AUSF)**: Provides authentication services for UEs and services.
- **Unified Data Management (UDM)**: Stores subscriber data and profiles.

These functions will be bundled in Compact Mobility Units (CMUs) that mirror the physical network's architecture at each campus location. Each CMU will integrate these core functions to provide a scalable and efficient solution for managing network operations.

V. RAN Implementation Plan

A. FR1 Band Configuration

For the n40 band (2300MHz) radios, our digital twin implementation will include:

- **Radio Configuration**
- **Antenna Parameters**
- **Tilt Configuration**

B. FR2 Band Configuration

For the n258 band (24.25-27.50 GHz) radios:

- **Millimeter Wave Modeling**
- **Radio Configuration**
- **Beamforming Implementation**

C. Multi-Campus Mobility Simulation

A critical aspect of our digital twin will be the accurate modeling of inter-campus mobility:

- **Handover Simulation**: Implementation of handover procedures between radio units within each campus.
- **Latency Modeling**: Accurate simulation.
- **Backhaul Simulation**: Modeling of the IP transport network connecting RAN and core elements at each campus.

VI. Evaluation Methodology

To validate our digital twin implementation, we will conduct comprehensive performance testing.

A. Core Network Performance Evaluation

We will measure key performance metrics for the core network:

- **Control Plane Latency**: Comparison of registration times and session establishment delays between physical and digital environments under varying loads.
- **Data Throughput**: Measurement of maximum achievable throughput in both uplink and downlink directions, validating against the physical network's specifications.
- **Resource Utilization**: Analysis of CPU, memory, and network resource consumption to ensure efficient implementation.

B. RAN Performance Evaluation

Performance evaluation of the virtualized RAN components will include:

- **Radio Link Quality**: Comparison of signal quality metrics between physical and virtual implementations.
- **Mobility Performance**: Assessment of handover success rates and latencies during inter-cell mobility scenarios.

C. Digital Twin Fidelity Assessment

To assess the overall fidelity of our digital twin, we will compare performance patterns between the physical testbed and its digital replica:

- **Procedure Timing Correlation**: We will aim for control plane procedure timing differences of less than 10% between physical and digital environments.
- **Throughput Accuracy**: Measurement of data plane throughput variations, aiming to minimize differences between physical and digital twins.
- **Resource Utilization Patterns**: Analysis of resource utilization pattern correlation between environments.

VII. Implementation Guidelines and Best Practices

Based on our implementation plan, we will develop the following guidelines for similar projects.

A. Core Selection Recommendations

We will determine which open-source 5G core is best suited for different digital twin scenarios. The recommendations are based on the following considerations:

- **Open5GS**:
  - Control plane performance requirements.
  - Feature requirements.
  - Resource availability.
- **free5GC**:
  - Resource constraints.
  - Cloud-native deployment preference.
  - Network slicing requirements.
- **OpenAirInterface (OAI)**:
  - Data plane throughput requirements.
  - Research feature needs.
  - Integration with RAN components.

B. Deployment Best Practices

We will document best practices for deploying 5G digital twins, focusing on the following areas:

- **Resource Allocation**: Guidelines for provisioning adequate resources based on the scale of implementation.
- **Network Configuration**: Recommendations for ensuring low-latency connectivity between components.
- **Monitoring Implementation**: Approaches for comprehensive monitoring of resource utilization and performance metrics.
- **Container Orchestration**: Recommendations for using Kubernetes or similar tools to manage containerized network functions.

C. OpenStack Configuration for 5G Digital Twins

We will develop specific OpenStack configuration recommendations to optimize the deployment of 5G digital twins:

- **Network Optimization**: Configurations for separating control plane, data plane, and management traffic.
- **Resource Management**: Approaches to avoid CPU overcommitment for network functions.
- **Tenant Isolation**: Methods for implementing proper tenant isolation for multiple concurrent experiments.

VIII. Conclusion and Future Work

This paper has presented our proposed methodology for implementing a digital twin of a dual-campus 5G research network using open-source components. This work represents the first phase of a three-phase project, with subsequent phases focused on implementing bi-directional synchronization between physical and digital networks and developing AI/ML models for network optimization and autonomy.

As 5G networks continue to evolve toward 6G, digital twins will play an increasingly important role in managing network complexity and enabling AI-driven automation. Our implementation will demonstrate that open-source tools can provide a cost-effective approach to digital twin development while maintaining high fidelity to physical network behavior.

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