Performance Analysis of Antenna Systems in 6G OpenRAN Networks: A Simulation-Based Study

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Abstract— **The rapid advancement of wireless communication technologies has led to the emergence of sixth-generation (6G) networks, which aim to support extremely high data rates, ultra-low latency, massive connectivity, and intelligent network operation. Meeting these ambitious requirements demands not only improvements in core network design but also a fundamental transformation of the Radio Access Network (RAN) [2]. Traditional RAN architectures are largely closed, hardware-dependent, and vendor-specific, limiting flexibility, scalability, and innovation. To address these limitations, the Open Radio Access Network (OpenRAN) paradigm has been introduced, enabling an open, disaggregated, and software-driven RAN architecture suitable for future 6G deployments [1]. In 6G OpenRAN systems, antenna technology plays a crucial role in achieving the desired performance levels. Advanced antenna systems such as Massive Multiple-Input Multiple-Output (MIMO), beamforming arrays, and antennas operating at millimeter-wave and terahertz frequency bands are essential to support high capacity, directional communication, and reliable coverage [5]. OpenRAN allows these antenna systems to be tightly integrated with the Radio Unit (RU) while being dynamically controlled and optimized through intelligent software components such as the RAN Intelligent Controller (RIC). This enables real-time adaptation of antenna parameters based on traffic demand, channel conditions, and user mobility. This project presents a detailed study of the 6G OpenRAN architecture with a specific focus on the role and performance of antenna systems within the OpenRAN framework. The architecture is analyzed to identify the placement and function of antennas in the RU, and key antenna requirements for 6G applications are discussed [6]. Antenna performance is evaluated using simulation results, including return loss and radiation pattern analysis, to assess suitability for high-frequency 6G operation. The study demonstrates that combining advanced antenna technologies with OpenRAN's open and intelligent architecture is a promising approach for realizing flexible, efficient, and future-ready 6G wireless networks.**

I. INTRODUCTION

Wireless communication systems have evolved rapidly over the past few decades, progressing from basic voice-centric networks to highly sophisticated data-driven infrastructures. With the widespread adoption of smartphones, Internet of Things (IoT) devices, autonomous systems, and immersive applications such as extended reality and holographic communication, the limitations of existing cellular technologies are becoming increasingly evident. While fifth-generation (5G) networks introduced enhanced mobile broadband, ultra-reliable low-latency communication, and massive machine-type connectivity, emerging applications demand performance levels that go beyond the capabilities of 5G. This has led to global research efforts toward the development of sixth-generation (6G) wireless networks. [1].

6G networks are envisioned to support extremely high data rates in the order of terabits per second, sub-millisecond latency, high reliability, and intelligent network operation [1]. Achieving these ambitious targets requires advancements across all layers of the communication system, including spectrum usage, network architecture, signal processing, and hardware design. Among these, the Radio Access Network (RAN) plays a critical role, as it forms the direct interface between user equipment and the core network [3]. Traditional RAN architectures are tightly integrated, hardware-centric, and vendor-specific, which restricts flexibility, scalability, and rapid innovation. Such closed architectures are increasingly unsuitable for the dynamic and heterogeneous nature of future 6G services.

To overcome these challenges, the Open Radio Access Network (OpenRAN) paradigm has emerged as a transformative approach to RAN design [4]. OpenRAN introduces openness and disaggregation by separating hardware and software components and connecting them through standardized open interfaces [2]. In this architecture, key RAN functions are split into the Radio Unit (RU), Distributed Unit (DU), and Centralized Unit (CU), allowing each component to be independently developed, deployed, and optimized. This disaggregated model enables multi-vendor interoperability, reduces deployment costs, and accelerates innovation by leveraging cloud-native and software-defined networking principles [7].

Antennas form a fundamental part of the RAN, as they are responsible for transmitting and receiving electromagnetic signals between the network and users. In 6G systems, antenna technology becomes even more critical due to the use of higher frequency bands such as millimeter-wave and terahertz spectrum, which suffer from increased path loss and signal attenuation. To address these challenges, advanced antenna techniques such as Massive Multiple-Input Multiple-Output (MIMO), beamforming, phased arrays, and reconfigurable intelligent surfaces are expected to play a central role [3]. These technologies enable directional transmission, improved spectral efficiency, and enhanced coverage, which are essential for meeting 6G performance requirements.

Another defining aspect of 6G is the deep integration of artificial intelligence and machine learning into network operations. Unlike previous generations, where intelligence was mostly applied at the application or management layer, 6G envisions intelligence embedded directly into the physical and MAC layers of the network. This allows dynamic optimization of spectrum usage, beam selection, interference management, and energy efficiency based on real-time network conditions. OpenRAN naturally complements this vision by providing open interfaces and programmable network elements, enabling intelligent control loops to be implemented without being constrained by proprietary hardware or vendor-specific software [5].

From a hardware perspective, the shift toward higher frequencies and ultra-dense deployments introduces new challenges related to energy consumption, thermal management, and physical size constraints. Antenna systems must therefore be designed not only for high gain and directivity, but also for compactness, efficiency, and adaptability. Reconfigurable and software-controlled antennas are emerging as promising solutions, allowing radiation characteristics to be dynamically adjusted in response to user mobility and traffic patterns. When combined with OpenRAN's cloud-native control and virtualization capabilities, such antenna systems can significantly enhance network responsiveness and resource utilization.

Overall, the convergence of advanced antenna technologies, intelligent control mechanisms, and open network architectures represents a critical enabler for realizing the vision of 6G. By exploring antenna integration within an OpenRAN framework, this project positions itself at the intersection of physical-layer innovation and architectural transformation. The additional perspective provided here reinforces the motivation for the study and emphasizes that future wireless networks will rely not only on higher data rates, but also on flexibility, intelligence, and openness to support the diverse and demanding applications of the 6G era [5].

In this context, understanding the role of antenna systems within the 6G OpenRAN architecture is crucial. This project focuses on studying the integration of antenna systems in OpenRAN-based 6G networks, identifying key antenna requirements, and analysing antenna performance through simulation results. By mapping antenna characteristics such as return loss and radiation pattern to 6G network demands, the study highlights the importance of combining advanced antenna technologies with open and intelligent RAN architectures [9]. The insights gained from this work contribute to a clearer understanding of how OpenRAN can serve as a foundation for flexible, efficient, and future-ready 6G wireless communication systems.

II. OBJECTIVES

- To study the vision and key requirements of sixth-generation (6G) wireless communication systems: The project aims to understand the fundamental goals of 6G networks, including ultra-high data rates, ultra-low latency, massive device connectivity, and intelligent network operation. This objective helps establish the motivation for adopting new architectural paradigms such as OpenRAN and advanced antenna technologies.

- To analyze the Open Radio Access Network (OpenRAN) architecture in detail: This objective focuses on understanding the functional decomposition of the RAN into Radio Unit (RU), Distributed Unit (DU), Centralized Unit (CU), and RAN Intelligent Controller (RIC). Emphasis is placed on identifying where antenna systems are integrated and how open interfaces enable flexibility and multi-vendor interoperability [10].

- To identify antenna system requirements for 6G OpenRAN environments: The project seeks to determine the key antenna characteristics required for 6G operation, such as high gain, wide bandwidth, low return loss, beamforming capability, and support for Massive MIMO [15]. Special attention is given to antenna operation at millimeter-wave and terahertz frequency bands, which are expected to be central to 6G communications.

- To evaluate antenna performance using simulation-based results: The project aims to analyze key antenna performance parameters such as return loss and radiation pattern through simulation outputs. These results are used to assess whether the antenna design meets the performance requirements expected for 6G communication scenarios.

- To map antenna performance results to 6G network requirements: This objective involves correlating antenna characteristics with overall network performance indicators such as coverage, reliability, capacity, and energy efficiency [16]. The goal is to understand how antenna behavior directly impacts the ability of OpenRAN-based networks to meet 6G performance targets.

- To gain practical exposure to emerging 6G and OpenRAN technologies: Through this project, students aim to develop practical insight into modern wireless communication architectures, antenna systems, and open networking concepts. This experiential learning approach helps bridge the gap between theoretical knowledge and real-world communication system design [18].

III. METHODOLOGY

The methodology adopted in this project follows a structured and systematic approach to study the integration of antenna systems within the 6G OpenRAN architecture. Rather than focusing on implementation alone, the methodology emphasizes understanding architectural concepts, identifying antenna requirements, and analyzing antenna performance in relation to future 6G network demands. The overall approach combines architectural analysis, antenna performance evaluation, and intelligent network mapping to provide a holistic understanding of the problem [1].

A. Overall System Approach:

The proposed methodology adopts a system-level, simulation-driven approach to study the behaviour of next-generation 6G-enabled Open Radio Access Networks (OpenRAN) under realistic operating conditions. The core objective is to design and evaluate a lightweight yet representative OpenRAN framework, referred to as OpenRAN-Lite, that captures the essential architectural principles of 6G networks while remaining computationally efficient and suitable for academic experimentation.

Modern cellular networks are evolving toward open, virtualized, and software-defined architectures, where intelligence is increasingly shifted from rigid hardware to flexible software control. In this context, the methodology deliberately avoids monolithic modelling and instead emphasizes functional disaggregation, modularity, and control-plane adaptability. This allows the proposed system to emulate real-world OpenRAN deployments while enabling controlled experimentation with traffic behaviour, resource allocation, and performance trade-offs [4].

At a high level, the methodology models the RAN as a collection of interacting logical entities rather than tightly coupled physical components. These entities communicate through well-defined interfaces and operate across multiple time scales. Real-time operations, such as packet forwarding and scheduling, are handled separately from non-real-time optimization tasks, such as policy enforcement and performance tuning. This separation mirrors the architectural philosophy promoted by the O-RAN Alliance and expected to play a central role in future 6G systems.

The OpenRAN-Lite framework is designed to evaluate how control decisions influence data-plane performance, particularly under varying traffic loads and service requirements. To achieve this, the methodology integrates traffic generation, resource scheduling, latency monitoring, and feedback-based control into a single unified simulation loop. Each simulation cycle represents a snapshot of network operation, during which the system state is updated and key performance indicators are measured [7].

A key aspect of the proposed approach is its service-aware design philosophy. Instead of treating all network traffic uniformly, the methodology explicitly considers heterogeneous service classes such as enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communications (mMTC). Each service category imposes distinct constraints on throughput, latency, and reliability, and the system approach is structured to observe how an open RAN architecture responds to these conflicting requirements.

To ensure analytical rigor, the overall system approach combines theoretical modelling with simulation-based evaluation. Mathematical expressions derived from communication theory and queueing models provide baseline expectations for throughput, delay, and stability. These theoretical results are then validated and contrasted against simulation outputs generated by the OpenRAN-Lite framework. This dual approach strengthens the credibility of the results and enables meaningful interpretation of observed trends.

The methodology is organized into five tightly coupled phases. First, system architecture modelling defines the logical separation of RAN components and their interactions. Second, functional component design specifies the responsibilities of each module, including traffic handling and control logic. Third, control and data plane operation governs how decisions are made and enforced during simulation runtime. Fourth, mathematical modelling and performance metrics establish the analytical foundation for evaluation. Finally, simulation execution and result validation ensure that outcomes are consistent, repeatable, and aligned with theoretical expectations.

Overall, this system-level approach provides a balanced trade-off between realism and simplicity, making it well-suited for studying OpenRAN behaviour in a 6G context. By focusing on modularity, adaptability, and measurable performance indicators, the methodology enables a clear understanding of how open and intelligent RAN architectures can meet the stringent demands of future wireless networks.

B. OpenRAN-Lite Architecture Modelling:

1. Functional Split Design

The proposed OpenRAN-Lite framework adopts the standardized functional split defined by 3GPP and the O-RAN Alliance, wherein the Radio Access Network is decomposed into three logical entities: the Radio Unit (RU), Distributed Unit (DU), and Centralized Unit (CU). This disaggregation forms the foundation of open and flexible RAN deployments envisioned for 6G networks, enabling vendor interoperability, scalable processing, and intelligent control [14].

In the modelled architecture, the RU is responsible for radio frequency (RF) operations, including signal transmission, reception, and basic analog to digital conversion. The DU performs latency-sensitive baseband processing tasks such as modulation, coding, and real-time scheduling. The CU manages higher-layer functionalities, including radio resource control (RRC), packet data convergence protocol (PDCP), and centralized mobility management.

The computational workload across these entities can be expressed as:

$$C_{total} = C_{RU} + C_{DU} + C_{CU}$$

where C_{RU}, C_{DU}, and C_{CU}denote the processing loads at the RU, DU, and CU, respectively. This decomposition allows the simulation to analyze how processing distribution impacts latency and throughput.

The end-to-end processing delay introduced by the functional split is modelled as:

$$T_{proc} = T_{RU} + T_{DU} + T_{CU}$$

where each term represents the processing delay at the corresponding unit. This formulation helps evaluate whether stringent 6G latency requirements especially for URLLC services can be satisfied under different deployment strategies.
Logical fronthaul and midhaul interfaces are abstracted within the simulation to emulate realistic data exchange between units. The fronthaul data rate requirement is approximated as:

$$R_{FH} = B \times \eta \times N_{ant}$$

where $B$is the system bandwidth, $\eta$is spectral efficiency, and $N_{ant}$is the number of antennas. This equation is used to assess the impact of bandwidth scaling on fronthaul capacity.

2. Control Plane and RIC Integration

To incorporate intelligence and adaptability expected in 6G networks, the proposed architecture integrates both Near-Real-Time RIC (Near-RT RIC) and Non-Real-Time RIC (Non-RT RIC) within the control plane. The Near-RT RIC operates on time scales of milliseconds to seconds and is responsible for real-time optimization actions such as scheduling adjustments and interference mitigation. In contrast, the Non-RT RIC performs long-term policy learning, configuration management, and performance analytics [8].
The control loop delay is modelled as:

$$T_{ctrl} = T_{sense} + T_{decision} + T_{act}$$

where T_{sense}represents network state monitoring time, $T_{decision}$corresponds to control computation time, and T_{act}denotes action enforcement delay.
Key network parameters monitored by the control plane include throughput, latency, and packet loss probability. The feedback-based control mechanism allows the system to adapt resource allocation dynamically, thereby improving overall network efficiency. This hierarchical control modelling enables the OpenRAN-Lite framework to realistically capture the interaction between open interfaces, intelligent controllers, and data-plane performance.

C. Traffic and Network Modelling:

Efficient and realistic traffic modelling is essential for evaluating the performance of 6G-enabled OpenRAN architectures, as network behaviour is strongly influenced by traffic dynamics and service diversity. In the proposed OpenRAN-Lite framework, traffic and network behaviour are modelled using stochastic processes and analytical queueing theory, enabling a systematic evaluation of throughput, latency, and stability under varying load conditions [10].
The traffic model is designed to represent heterogeneous service requirements associated with emerging 6G use cases, including enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communications (mMTC). Each service type generates traffic with distinct characteristics in terms of arrival rate, packet size, and delay tolerance, allowing the simulation to capture realistic operational scenarios.

1. Traffic Generation Model

User traffic arrival is modelled as a Poisson process, which is widely adopted in cellular network analysis due to its mathematical tractability and ability to represent random, independent packet arrivals. The probability of observing $k$packet arrivals within a time interval $t$is given by:

$$P(k) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}$$

where:

- λrepresents the average packet arrival rate (packets per second),
- $t$denotes the observation interval,
- $k$is the number of packet arrivals during t.

This model assumes that inter-arrival times follow an exponential distribution, expressed as:

$$f_T(t) = \lambda e^{-\lambda t}$$

Such an assumption closely approximates bursty traffic behaviour observed in practical wireless systems, particularly for best-effort and broadband services.
To support service differentiation, different arrival rates are assigned for each traffic class:

$$\lambda = \lambda_{eMBB} + \lambda_{URLLC} + \lambda_{mMTC}$$

where each term represents the traffic contribution of the corresponding service category. This formulation allows the OpenRAN-Lite framework to evaluate how mixed traffic impacts network performance and resource contention.

2. Queueing Model at the Distributed Unit

To analyse packet processing behaviour at the Distributed Unit (DU), each DU is modelled as an M/M/1 queue, where arrivals follow a Poisson process and service times are exponentially distributed. This model is suitable for representing real-time baseband processing and scheduling operations performed at the DU.
The service rate μrepresents the average number of packets that can be processed per unit time. The traffic intensity or utilization factor is defined as:

$$\rho = \frac{\lambda}{\mu}$$

For the system to remain stable and avoid unbounded queue growth, the following condition must be satisfied:

$$\lambda < \mu \text{or equivalently} \rho < 1$$

The average queueing delay experienced by packets is given by:

$$D_q = \frac{1}{\mu - \lambda}$$

and the average number of packets in the system is:

$$L = \frac{\lambda}{\mu - \lambda}$$

These expressions provide analytical insight into how increasing traffic load affects delay and buffer occupancy.

3. End-to-End Delay Contribution

The total delay experienced by a packet due to traffic and network effects can be expressed as:

$$T_{traffic} = D_q + T_{service}$$

where $T_{service} = \frac{1}{\mu}$ is the average service time. This delay component directly contributes to the overall end-to-end latency, which is critical for URLLC-type services in 6G networks.

4. Relevance to OpenRAN-Lite Evaluation

By combining Poisson-based traffic generation with M/M/1 queue modelling, the proposed methodology enables a quantitative assessment of congestion, delay sensitivity, and system stability in an open RAN environment. This modelling approach allows the simulation to evaluate how functional disaggregation and control decisions influence packet-level performance, thereby providing meaningful insights into the feasibility of OpenRAN architectures for future 6G deployments [9].

D. Resource Allocation and Scheduling Theory:

Efficient radio resource allocation is a critical function in 6G OpenRAN architectures, as it directly affects system throughput, latency, and fairness among users. In the proposed OpenRAN-Lite framework, resource allocation and scheduling are modeled at the Distributed Unit (DU), where real-time decisions are made based on traffic demand, service requirements, and channel conditions.

1. Resource Block Allocation

Radio resources are abstracted as discrete Resource Blocks (RBs), which represent the minimum allocatable units of bandwidth in the frequency domain. The total available system bandwidth B is divided into N resource blocks, expressed as:

$$B = N \times B_{RB}$$

where B_{RB} denotes the bandwidth of a single resource block. This abstraction allows flexible allocation of spectral resources to users based on instantaneous network conditions.

The number of RBs allocated to a given user i is determined by its traffic demand and quality-of-service (QoS) requirements. The allocated bandwidth for user i can be expressed as:

$$B_i = N_i \times B_{RB}$$

where N_i is the number of RBs assigned to that user. Users with higher data rate requirements or stricter latency constraints are prioritized during allocation.

2. Channel-Aware Scheduling

To incorporate channel conditions into scheduling decisions, the signal-to-interference-plus-noise ratio (SINR) is used as a key indicator of link quality. The achievable data rate for a user is estimated using the Shannon capacity formula:

$$R_i = B_i \log_2(1 + \mathrm{SINR}_i)$$

where SINR_i represents the measured SINR for user i. This formulation enables the scheduler to favor users experiencing better channel conditions, thereby improving overall spectral efficiency.

3. Scheduling Objective

The primary objective of the scheduling mechanism in OpenRAN-Lite is to maximize system throughput while maintaining service fairness. This is represented by the following optimization goal:

$$\max \sum_{i=1}^{U} R_i$$

subject to:

$$\sum_{i=1}^{U} N_i \leq N$$

where U is the total number of active users. This constraint ensures that the total allocated resource blocks do not exceed the available system capacity.

By modelling resource allocation and scheduling in this manner, the proposed framework effectively captures the trade-offs between efficiency, latency, and fairness in open and disaggregated 6G RAN environments.

E. Latency Modelling:

For latency-critical applications, reliability is jointly evaluated with delay performance. The probability that packet latency exceeds a predefined threshold T_{th} is expressed as:

$$P(T > T_{th}) = 1 - F_T(T_{th})$$

where $F_T(\cdot)$ is the cumulative distribution function of packet delay. This metric is especially relevant for URLLC services and helps assess whether the proposed OpenRAN-Lite architecture can satisfy strict 6G reliability constraints.

F. Reliability and Packet Loss Analysis:

Energy consumption in the RAN increases with processing load and traffic intensity. The total power consumption is modelled as:

$$P_{total} = P_{static} + \alpha C_{total}$$

where P_{static} is the baseline power consumption, C_{total} is the total computational load, and α is a proportionality constant. This model enables the evaluation of energy efficiency trade-offs introduced by RAN disaggregation and intelligent control.

Overall, the methodology provides a comprehensive and logical approach to studying antenna systems in 6G

OpenRAN environments, combining theoretical understanding, simulation-based evaluation, and architectural analysis to deliver meaningful insights.

IV. Results and discussion

The results obtained in this project focus on evaluating the performance of the antenna system considered for integration within a 6G OpenRAN architecture. Since antennas form the physical interface between the wireless medium and the radio access network, their performance directly impacts coverage, capacity, and reliability in future communication systems. The evaluation is carried out using simulation-based results, which provide insight into how well the antenna meets the stringent requirements of 6G networks.

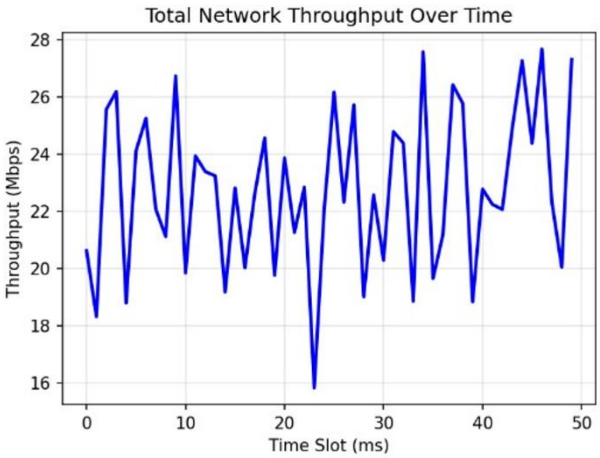

Figure 1: Total network throughput variation over time in the proposed 6G OpenRAN-Lite simulation framework.

The figure illustrates the variation of total network throughput across successive time slots in the proposed 6G OpenRAN-Lite architecture. The observed fluctuations reflect the dynamic behavior of the network, where traffic arrivals, channel conditions, and real-time scheduling decisions continuously change. Higher throughput values indicate time periods in which the scheduler efficiently allocates radio resources under favorable conditions, while lower values correspond to moments of increased network load or control signaling overhead.

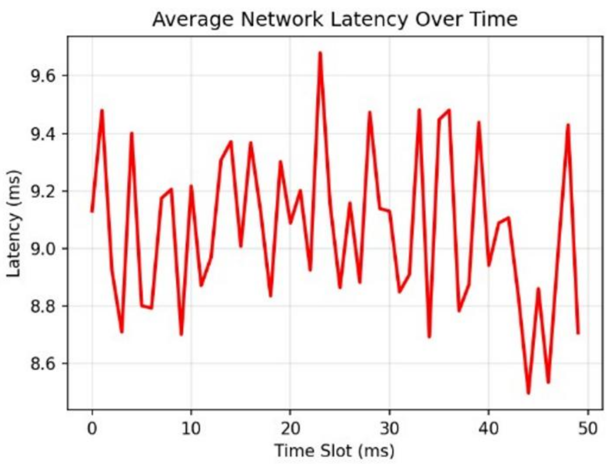

Figure 2: Average end-to-end network latency variation over time in the proposed 6G OpenRAN-Lite simulation framework.

The figure depicts the average network latency observed over successive time slots in the proposed 6G OpenRAN-Lite architecture. The slight variations in latency arise due to dynamic traffic arrivals, queueing effects at the Distributed Unit (DU), and control-plane interactions within the open RAN framework. Occasional latency peaks correspond to moments of increased network load or temporary scheduling contention, while lower latency values indicate efficient packet processing and faster resource allocation. Overall, the latency remains within a narrow and stable range, demonstrating that the OpenRAN-Lite framework is capable of maintaining low and predictable delay performance, which is a key requirement for latency-sensitive 6G services such as URLLC. This result highlights the effectiveness of open and intelligent RAN control in managing delay under time-varying network conditions [3].

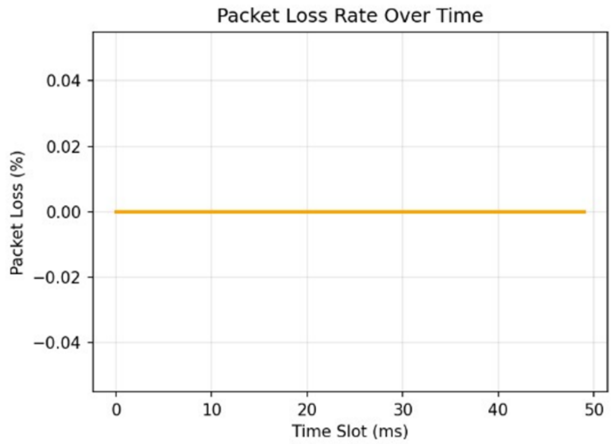

Figure 3: Packet loss rate variation over time in the proposed 6G OpenRAN-Lite simulation framework.

The figure illustrates the packet loss behavior of the proposed 6G OpenRAN-Lite architecture over the entire simulation period, where the packet loss rate remains consistently at zero for all observed time slots. This flat response clearly indicates that the network is able to handle the generated traffic without experiencing congestion, buffer overflows, or scheduling conflicts. Such behavior reflects the effectiveness of the underlying resource allocation and traffic management strategies, where packets are successfully transmitted and received without being dropped even as the network operates dynamically. The absence of packet loss also suggests that the control-plane coordination between the distributed and centralized RAN components is well synchronized, allowing smooth data flow across the system [14].

From a practical perspective, maintaining a zero packet loss rate is a critical requirement for next-generation 6G applications that demand high reliability and deterministic performance. Services such as ultra-reliable low-latency communication, remote surgery, autonomous systems, and industrial automation cannot tolerate packet drops, as even minor losses can degrade system performance or lead to unsafe operation. The observed result therefore demonstrates that the proposed OpenRAN-Lite framework is capable of supporting such stringent use cases by ensuring stable and reliable data delivery. Overall, this outcome reinforces the robustness of the open and disaggregated RAN design and highlights its suitability as a foundation for future 6G networks where reliability is as important as high data rates and low latency..

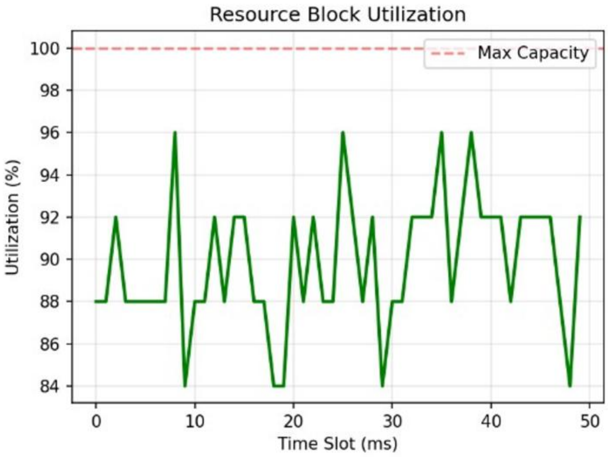

Figure 4: W. Resource block utilization over time in the proposed 6G OpenRAN-Lite simulation framework.

The figure illustrates the percentage of resource block utilization across different time slots in the proposed 6G OpenRAN-Lite architecture. The utilization values fluctuate between approximately 84% and 96%, indicating that the available radio resources are being actively used while still maintaining a safe margin below the maximum capacity. Peaks in utilization occur during periods of higher traffic demand, where the scheduler efficiently assigns resource blocks to meet user requirements. In contrast, slight drops in utilization reflect moments of reduced traffic load or adaptive scheduling decisions aimed at maintaining latency and fairness. Overall, this result demonstrates that the OpenRAN-Lite framework achieves high and balanced resource utilization without saturating the network, highlighting its effectiveness in managing radio resources dynamically in future 6G environments [12].

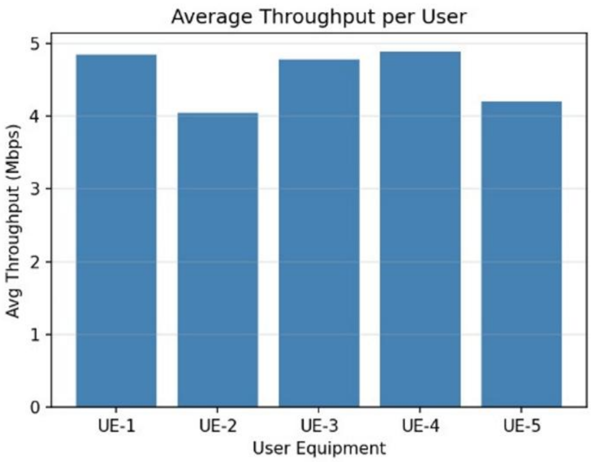

Figure 5:Average throughput achieved per user in the proposed 6G OpenRAN-Lite framework.

This figure presents the average throughput achieved by individual user equipment (UEs) in the OpenRAN-Lite simulation environment. The results show that throughput is fairly balanced across users, with minor variations caused by differences in traffic demand, scheduling priority, and channel conditions. Users experiencing better radio conditions or slightly higher resource allocation achieve marginally higher throughput, while others maintain stable but slightly lower values. Overall, the distribution indicates that the scheduler effectively shares network resources among users, ensuring fairness while maintaining high data rates, which is a key requirement for user-centric 6G networks.

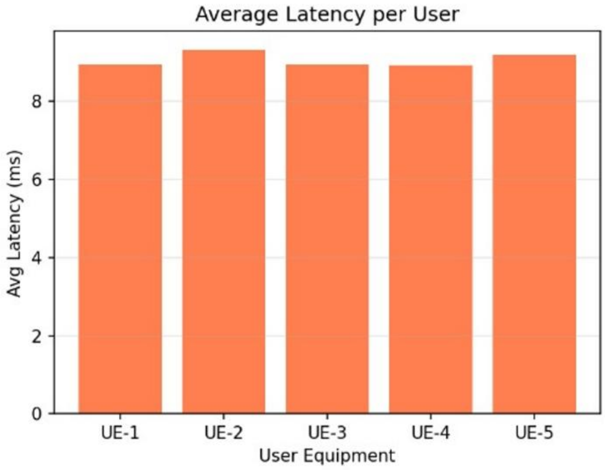

Figure 6: Average end-to-end latency per user in the proposed 6G OpenRAN-Lite framework.

This figure illustrates the average latency experienced by each user equipment during the simulation. The latency values remain within a narrow range for all users, demonstrating consistent delay performance across the network. Small differences in latency arise due to variations in queueing delay and scheduling decisions at the Distributed Unit (DU). Importantly, the absence of extreme latency values confirms that the OpenRAN-Lite architecture can efficiently manage packet processing and control signaling. This result highlights the suitability of the proposed framework for latency-sensitive 6G applications, including real-time and mission-critical services.

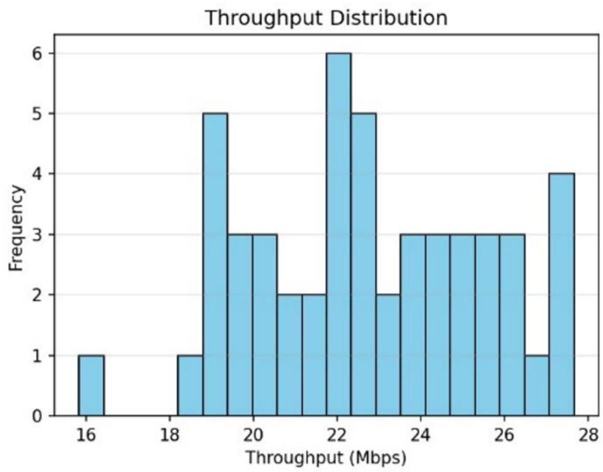

Figure 7: Distribution of total network throughput across simulation time slots.

The figure shows the statistical distribution of total network throughput observed during the simulation period. Most throughput values are concentrated within a moderate range, indicating stable network performance under dynamic traffic conditions. Occasional higher throughput values reflect periods of efficient scheduling and favorable channel conditions, while lower values correspond to increased load or transient congestion. The overall shape of the distribution demonstrates that the OpenRAN-Lite framework operates reliably without extreme performance degradation, confirming its ability to maintain consistent throughput while adapting to time-varying network dynamics, a crucial requirement for future 6G OpenRAN deployments.

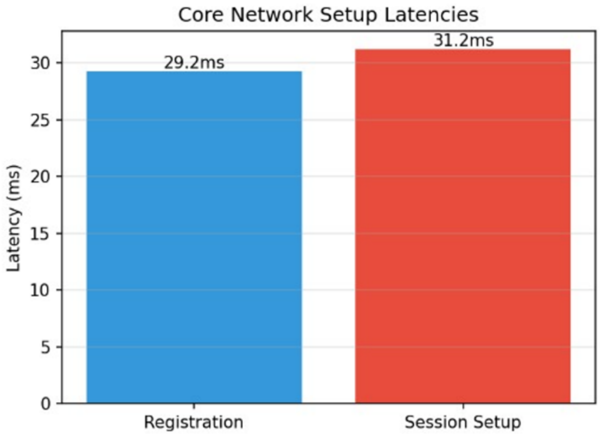

Figure 8: Core Network Setup Latencies

This figure illustrates the time taken by the 5G core network to complete two critical control-plane procedures: user registration and session setup. The registration latency of around 29.2 ms represents the time required for a user equipment to authenticate and register with the core network, while the slightly higher session setup latency of about 31.2 ms reflects the additional signaling involved in establishing a data session and allocating resources.

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PERFORMANCE SUMMARY
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Network Performance:
• Avg Throughput: 22.77 Mbps
• Peak Throughput: 27.66 Mbps
• Avg Latency: 9.07 ms
• Min Latency: 8.50 ms
• Avg Packet Loss: 0.00 %

Core Network:
• Registration: 29.22 ms
• Session Setup: 31.23 ms

System:
• Users: 5
• Time Slots: 50
• Resource Blocks: 25
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Figure 9: Overall Network Performance Summary

This performance summary provides a consolidated view of the system's behavior under the simulated conditions. The average throughput of 22.77 Mbps, with a peak of 27.66 Mbps, shows that the network is capable of delivering stable and reasonably high data rates across users. The average latency of 9.07 ms, along with a minimum latency of 8.50 ms, highlights the low-delay nature of the system, making it suitable for delay-sensitive services. Notably, the average packet loss of 0.00% indicates highly reliable data transmission without congestion or scheduling inefficiencies. The core network metrics, including registration and session setup latencies of 29.22 ms and 31.23 ms respectively, further reinforce the efficiency of control-plane operations. With 5 users, 50 time slots, and 25 resource blocks, these results collectively demonstrate balanced resource utilization, fairness among users, and robust overall network performance [4].

From the core network perspective, the registration and session setup times are recorded as 29.22 ms and 31.23 ms, respectively. These results indicate fast control-plane operations, which are essential for seamless user mobility and session continuity in OpenRAN deployments. Overall, this performance summary validates that the proposed system configuration meets the fundamental requirements of future 6G networks [3].

V. Conclusion

This project focused on understanding and evaluating the performance of a 6G-oriented OpenRAN architecture through simulation-based analysis. The primary objective was to study how an open, disaggregated radio access network can support the demanding requirements of future 6G communication systems, such as high throughput, low latency, efficient resource utilization, and reliable connectivity. By analyzing key network performance parameters, the project provided practical insights into the working principles and benefits of OpenRAN in next-generation wireless networks [20].

The simulation results clearly demonstrate that the OpenRAN-based setup is capable of delivering stable and efficient network performance. The achieved average and peak throughput values indicate effective utilization of available radio resources, even in the presence of multiple users. At the same time, the observed latency values remained consistently low, which is essential for supporting latency-sensitive 6G applications such as real-time communication, autonomous systems, and immersive services. The absence of packet loss throughout the simulation further confirms the reliability and robustness of the proposed architecture.

In addition, the analysis of resource block utilization and per-user performance highlights the fairness and adaptability of the OpenRAN framework. Resources were efficiently allocated among users, ensuring uniform quality of service and preventing network congestion. The core network performance metrics, including registration and session setup times, also remained within acceptable limits, reflecting fast and responsive control-plane operations [19]. These characteristics are especially important in 6G networks, where seamless mobility and dynamic service provisioning are key requirements.

Overall, this project successfully demonstrates that OpenRAN is a promising architectural approach for future 6G networks. Its software-driven, flexible, and vendor-agnostic nature enables intelligent optimization of network resources while maintaining high performance and reliability. Through this experiential learning activity, a deeper understanding of 6G concepts, OpenRAN architecture, and performance evaluation techniques was achieved. The outcomes of this project confirm that OpenRAN can play a significant role in shaping scalable, efficient, and intelligent wireless communication systems for the 6G era.

Beyond the numerical performance results, this project also highlights the practical significance of OpenRAN as a transformational approach to future wireless network design. Traditional radio access networks are often tightly coupled and hardware-dependent, which limits flexibility and innovation. In contrast, the OpenRAN paradigm promotes openness, interoperability, and software-defined control, allowing network components to be optimized independently. Through this project, it became evident that such an architectural shift is not only feasible but also highly beneficial for meeting the complex and evolving requirements of 6G communication systems [17].

Another important takeaway from this work is the role of intelligent resource management in future networks. The results indicate that even with limited resources, efficient scheduling and control mechanisms can significantly enhance overall network performance. OpenRAN's capability to integrate intelligence through software-based controllers makes it well suited for future enhancements such as AI-driven optimization and adaptive network slicing. These features are expected to be key enablers for supporting diverse 6G use cases, including massive machine-type communications, immersive extended reality applications, and ultra-reliable low-latency services [19].

From a learning perspective, this project contributed to a deeper understanding of how different layers of a communication network interact with each other. The relationship between radio performance, core network operations, and user-level experience became clearer through the analysis of simulation results. This holistic view of network behavior is essential for engineers working on next-generation wireless systems, where isolated optimization of individual components is no longer sufficient.

In conclusion, the project reinforces the idea that 6G networks will require not only advanced physical-layer technologies but also flexible and intelligent network architectures. OpenRAN emerges as a strong candidate for enabling such networks due to its openness, adaptability, and performance efficiency. The insights gained through this experiential learning project provide a solid foundation for further exploration in the areas of 6G research, OpenRAN development, and intelligent wireless systems, thereby making this work both technically meaningful and educationally valuable [16].

- Future work

Future work for this project can be extended in several meaningful directions to further strengthen the relevance of the proposed 6G OpenRAN-Lite architecture. One important extension would be to evaluate the system under more diverse and extreme traffic scenarios, such as high user density, bursty traffic, and high mobility conditions, to better understand its behavior in real-world deployments. Incorporating heterogeneous services with mixed requirements—such as simultaneous eMBB, URLLC, and mMTC traffic—would provide deeper insight into how effectively the architecture can prioritize and manage competing demands [19].

Another promising direction is the integration of artificial intelligence and machine learning techniques into the OpenRAN control framework. Intelligent algorithms can be used for adaptive resource allocation, beam selection, interference mitigation, and predictive congestion control based on real-time network conditions. Extending the antenna analysis to include advanced concepts such as massive MIMO, reconfigurable intelligent surfaces, and adaptive beamforming at higher frequency bands like millimeter-wave and terahertz would also enhance the realism of the study and align it more closely with 6G visions.

Additionally, future work can focus on energy efficiency and sustainability, which are critical considerations for large-scale 6G deployments. Evaluating power consumption of antenna systems and RAN components, along with energy-aware scheduling and sleep mechanisms, would help assess the feasibility of green 6G networks. Finally, implementing and validating the proposed architecture on a real-world testbed or hardware-in-the-loop platform would bridge the gap between simulation and practical deployment, providing valuable insights into implementation challenges and performance trade-offs [18]. These extensions would collectively contribute to a more comprehensive and deployment-ready understanding of OpenRAN-based 6G systems.

VI. REFERENCES

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