Performance Analysis of Transport Protocols and RLC modes in 5G Open RAN Networks

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***Abstract*—Open Radio Access Network (O-RAN) is crucial to the development of the 6th Generation (6G) as it enables an open and disaggregated architecture, fostering innovation, interoperability, and cost reduction—key elements for the efficient development and deployment of next-generation networks. This paper investigates the impact of Acknowledged Mode (AM) and Unacknowledged Mode (UM) Radio Link Control (RLC) modes on the performance of Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) transport protocols in wireless communication networks using the O-RAN architecture. Through tests conducted on a testbed composed of commercial equipment, it is observed that the UM mode achieves the highest throughput levels for the considered transport protocols, with gains of up to 20%. Furthermore, tests using TCP transport protocol show a direct relation between the achieved throughput and the Congestion Window (CWND) size. Thus, it is observed that the RLC UM mode outperforms the RLC AM for the considered Reference Signal Received Power (RSRP) conditions, with gains of up to 18%.**

***Index Terms*—Transport Protocols, RLC, Open RAN.**

I. Introduction

Open Radio Access Network (O-RAN) is a communication network architecture paradigm based on disaggregated, virtualized, and software-based components, connected through open and interoperable interfaces between different vendors [1]. The principles of disaggregation and virtualization allow for flexible network deployments based on cloud-native principles. In this context, O-RAN networks are characterized by increased resilience and reconfigurability of the Radio Access Network (RAN) [1]. As a result, O-RAN has attracted considerable interest from standardization organizations, telecommunication companies, and academic researchers [2].

The disaggregation of the RAN splits the functionalities of the Next Generation Node Base (gNB) into different units called Centralized Unit (O-CU), Distributed Unit (O-DU), and Radio Unit (O-RU). This logical division allows for the deployment of various functionalities across different locations within the network, as well as on different hardware platforms. These units are responsible for delivering various functions of the radio protocol stack associated with Radio Resource Control (RRC), Service Data Adaption Protocol (SDAP), Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), Medium Acess Control (MAC), and the PHY layer.

In the split configuration considered in the test setup of this paper, namely Option 2 for the midhaul and Option 7.2x for the fronthaul, the O-DU is responsible for the higher-level processing functions in the PHY layer, the MAC layer, and the RLC layer. The upper layers of the radio protocol—namely RRC, PDCP, and SDAP—are under the responsibility of the O-CU [2]. The O-DU manages radio link control functions such as error detection and correction, lost packet retransmission, and packet sequencing. It handles the RLC protocol, being responsible for the segmentation of Service Data Units (SDUs) from the PDCP layer into appropriately sized Protocol Data Units (PDUs). It also deals with the retransmission of erroneously received PDUs and the removal of duplicate PDUs [3], [4].

Depending on the type of service, the RLC can be configured in one of three modes: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC is completely transparent in TM mode, meaning it is essentially bypassed, as there are no retransmissions, no duplicate detection, and no segmentation. This configuration is used for control plane broadcast channels such as Broadcast Control Channel (BCCH), Common Control Channel (CCCH), and Paging Control Channel (PCCH) [3]. The size of these messages is selected to ensure that all intended devices are reached with high probability, so there is no need for segmentation to handle varying channel conditions or retransmissions to provide error-free data transmission. UM mode supports segmentation and duplicate detection. This mode is used when error-free delivery is not required, such as in Voice over IP (VoIP) services. AM mode, on the other hand, supports segmentation, duplicate removal, and retransmissions of erroneous data, being the primary mode of operation for Downlink Shared Channel (DL-SCH) and Uplink Shared Channel (UL-SCH) channels [3].

Some types of services, such as file transfers and web browsing, require reliable links and cannot afford to lose PDUs. Other types of services, like voice calls and video calls, can tolerate some degree of PDU loss without degrading the end-user experience. Thus, retransmission techniques are necessary to recover lost PDUs. Retransmission is performed at various layers of the protocol stack. At the MAC layer, it is handled by Hybrid Automatic Repeat Request (HARQ). In the RLC layer, this control is managed by Automatic

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Repeat Request (ARQ) and the RLC protocol, with its different modes. Additionally, transport protocols such as Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) also perform retransmissions if PDU loss is detected. TCP ensures reliable data transmission by introducing mechanisms such as handshakes, error checking, retransmission requests, and congestion control. On the other hand, UDP eliminates transmission overhead but offers no guarantee of delivery. The performance of transport protocols is influenced by numerous factors, such as the congestion control function's reaction to the unpredictability of the radio link, the overhead of protocol mechanisms at other layers, and the extent to which the retransmission scheme recovers the packets.

The literature presents several studies about performance evaluation of transport protocols and RLC modes. In [5], the problem of optimizing the TCP transport protocol over different RLC modes for Universal Mobile Telecommunications System (UMTS) is studied. In [6], a performance evaluation of UDP and TCP transmission protocols operating under the RLC AM and UM modes in a Long Term Evolution (LTE) network is presented. The study aims to highlight the benefits of each mode and each transmission protocol by conducting simulations using the NS-3 simulator, providing insights into their respective performance characteristics. In [7], the impact of adjusting RLC AM and RLC UM parameters on the Quality of Experience (QoE) perceived by the user is studied, focusing on real-time video streaming and file transfer for LTE networks. In [8], the study of [7] is extended by optimizing the RLC layer configurations using Taguchi's method [9]. Therefore, the authors in [8] add a deeper analysis of RLC operation modes and a more comprehensive evaluation of the parameters involved. In [10], system-level simulations based on Third Generation Partnership Project (3GPP)-compliant models for Sixth Generation (6G) are used, studying residual error rates after HARQ in both uplink and downlink control channels. It identifies scenarios where second-level data recovery provides negligible benefit, allowing for its deactivation in latency-sensitive applications. Additionally, it explores how the ARQ mechanism, often used in RLC AM mode, can enhance throughput when strict reliability targets are not satisfied. Although the studies cited have their own merits, the literature presented lacks studies on the performance evaluation of transport protocols and RLC modes in Fifth Generation (5G) networks implemented with the O-RAN architecture using commercial O-RAN stack.

The main paper contribution is to evaluate how RLC mode configurations impact TCP and UDP protocol performance through retransmission mechanisms. Using a commercial O-RAN testbed with real-world hardware and software, we analyze network throughput and latency performance under practical conditions.

The remainder of this paper is organized as follows. Section II describes the 5G O-RAN testbed architecture. Section III presents methodology and performance evaluation. Finally, Section IV highlights the paper's final remarks and research perspectives.

II. Setup of 5G Open RAN Testbed

This paper evaluates the performance of transport protocols in a realistic testbed, which utilizes a Commercial Off-The-Shelf (COTS) version of O-RAN components. The O-DUs and O-CUs use the Radisys commercial O-RAN stack, which offers several advantages for modeling complex ecosystem conditions [11]. It allows researchers to replicate network scenarios with tests that resemble realistic network conditions, including the impact of channel link between the User Equipment (UE) and the network. This focus on commercial components increases the validity and relevance of the tests, providing valuable insights into O-RAN performance and optimization for practical deployments. The 5G Core Network (CN) used in the testbed is the Open5GS [12].

The testbed has three servers interconnected equipped with advanced hardware to support our O-RAN deployments, as shown in Fig. 1. The servers are two Dell PowerEdge R750 with 2x Intel(R) Xeon(R) Gold 6348 CPUs running at 2.60GHz, 256GB of DDR4 3200MHz RAM, and includes an Intel(R) vRAN ACC100 accelerator, an Intel(R) Ethernet 25G 4P E810-XXV OCP network interface, and an Intel® QuickAssist Adapter 8970 for enhanced data processing. Additionally, the O-DU is also connected to the fronthaul switch, which acts as the Precision Time Protocol (PTP) Grandmaster, enabling clock synchronization between the O-DU and O-RU, facilitating the switching between the control plane and user plane of the Open Fronthaul interface. The testbed considers protocol stack splits according to O-RAN Alliance specifications. It is employed Split 2 for the midhaul, where the RRC and PDCP protocols are located in the O-CU, while the RLC, MAC, and High PHY are located in the O-DU; and Split 7.2x for the fronthaul, wich divides the PHY layer blocks, where the low PHY is located in the O-RU [2], as shown in Fig. 2.

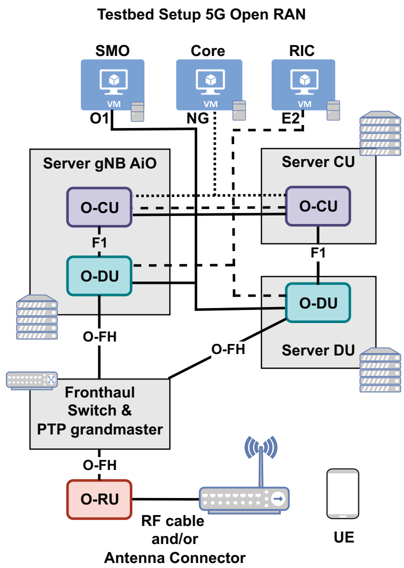

Fig. 1. Topology of 5G Open RAN testbed.

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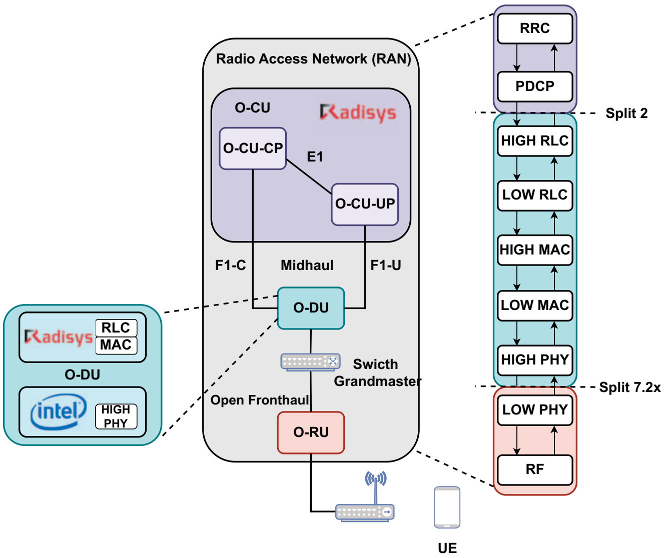

Fig. 2. Protocol stack split among O-RAN components.

III. Results

In this paper, iperf3 is used to measure the downlink data rate and Congestion Window (CWND) between the commercial 5G NR UE and the CN under two distinct Reference Signal Receive Power (RSRP) conditions: a good condition with an average RSRP of -76 dBm and a poor condition with an average RSRP of -115 dBm. The estimated RSRP between the UE and the O-RU was collected through the analysis of dumpstate logs from the UE, obtained via the Logcat tool. For statistical significance, five independent measurements of 40 seconds each were taken at every point, and the mean and variance values were calculated considering a 95% confidence interval. This procedure increases confidence that the results are not due to random variations but reflect true performance differences between the distinct scenarios. Analyzing these protocols and RLC modes in terms of data transmission is important to evaluate whether O-RAN is performing as expected and to understand the impact of these protocols and RLC modes on network performance for O-RAN architectures.

For the tests, only the server All in One (AiO) was used with O-CU and O-DU interconnected through the midhaul interface. A Foxconn RPQN 7801 O-RU operating in Time Division Duplex (TDD) with the n78 band (3.75 GHz) was used. The carrier bandwidth occupies 100 MHz, using 30 kHz subcarrier spacing and a transmission power of 24 dBm in a 4x4 User Multiple Input Multiple Output (MIMO) configuration. Link adaptation dynamically adjusts the Modulation and Coding Scheme (MCS) according to radio link conditions, allocating up to 256 Quadrature Amplitude Modulation (QAM) in Downlink (DL). A high-end 5G NR UE (SM-S918B) operating in a 4×4 MIMO configuration was used to generate the results.

Figs. 3 and 4 show the average throughput for TCP and UDP protocols with RLC AM and UM modes, considering the good and poor conditions of RSRP levels, respectively. As the RSRP levels decrease, both TCP and UDP experience a significant reduction in throughput in both RLC modes. In the poor RSRP scenario, it can be observed that RLC UM outperforms RLC AM for both TCP and UDP transport protocols, achieving gains of up to 20% in terms of throughput. In the good RSRP scenario, both RLC AM and UM achieve similar throughput levels when the same transmission modes are considered. This behavior occurs due to the number of retransmissions required in RLC AM, which is inversely proportional to the RSRP level, thereby degrading the achieved throughput. Comparing TCP and UDP protocols at both RSRP levels, a throughput performance gain can be observed when UDP is used, with gains of up to 20% as noted previously. The largest gain is observed when comparing TCP and UDP in the scenario using RLC AM. This occurs due to the use of two layers of retransmission (RLC AM and TCP), significantly degrading throughput.

Fig. 5 shows the average CWND for TCP protocol with RLC AM and UM modes, considering different RSRP con-

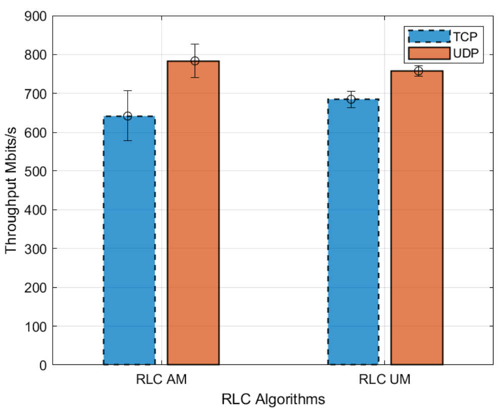

Fig. 3. Average throughput and confidence interval for different RLC configurations for good RSRP condition (-76 dBm).

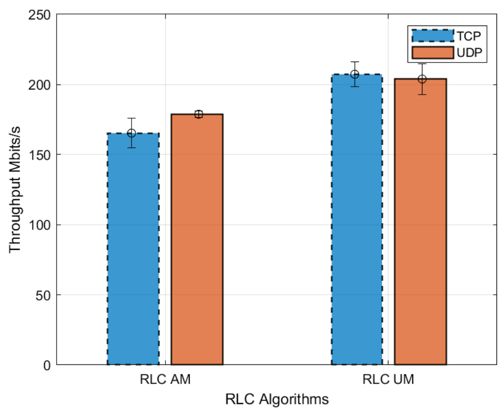

Fig. 4. Average throughput and confidence interval for different RLC configurations poor RSRP condition (-115 dBm).

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ditions. Investigating the CWND is important since its size impacts directly the network performance of TCP transmissions by managing the quantity of data sent without confirmation [13]. Also, the disaggregated architecture of O-RAN introduces more variability in the network setup, with equipment from multiple vendors. Investigating CWND behavior helps identify potential performance issues related to the interaction between different components, such as O-CUs, O-DUs and O-RUs.

Analyzing Fig. 5, it is observed that as the RSRP levels decrease, both RLC AM and UM experience a significant increase in CWND. This behavior occurs due to the CWND size increase as the achieved throughput increases and from Figs. 3 and 4 the highers achieved throughput belongs to the results with better RSRP conditions. Therefore, observing the Figures 3, 4 and 5, we can see a direct relation between the achieved throughput and the CWND size. Also, it is can be observed that RLC UM outperforms RLC AM for both RSRP conditions, achieving gains of up to 18% in terms of CWND. This behavior occurs due to the retransmission mechanism present in the RLC AM mode triggering another layer of retransmissions impacting the CWND size negatively and thus reducing the throughput, as seen in Figs. 3 and 4. In contrast, RLC UM mode does not perform additional retransmissions impacting the CWND size positively and thus increasing the throughput, as seen in Figs. 3 and 4.

Therefore, from this set of results, it can be observed that the choice of RLC modes and transport protocols directly impacts network performance, as they overload the system by adding retransmission levels in different layers, creating a trade-off between reliability and performance. Moreover, the combination that achieved the best throughput performance was RLC UM using UDP, as it obtained the best performance regardless of the RSRP level considered. Transport protocols performance depends of numerous factors, such as congestion control response to the unpredictability of the radio link, protocol overhead from protocol mechanisms, packet recovery level of retransmission schemes.

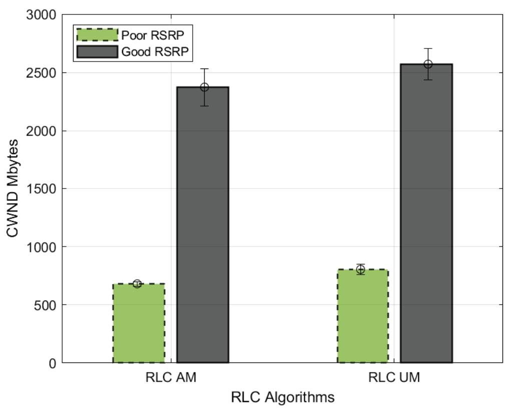

Fig. 5. Average CWND and confidence interval using TCP protocol for different RLC configurations and RSRP conditions.

IV. Conclusion

This paper investigated the impact of RLC modes on the performance of TCP and UDP transport protocols under different RSRP conditions, using a testbed equipped with commercial software and hardware components. The results indicate that RLC UM mode achieves the highest throughput due to the absence of retransmissions. We also observed a direct correlation between throughput and CWND size, with RLC UM showing the largest values. However, the lack of data recovery mechanisms in this mode compromises transmission reliability, which may negatively affect the user experience.

Future research perspectives include evaluation of transport protocols with other services, such as VoIP and video streaming, and more critical applications, such as Ultra-Reliable Low-Latency Communication (URLLC); performance assessment of different RLC modes in different 5G O-RAN implementations, such as SRSRAN and OAI; investigation of transport protocols and RLC modes incorporating long-distance links into the xhaul, which involves fronthaul, midhaul and backhaul. As 5G networks are increasingly adopting disaggregated architectures, the challenges of maintaining low latency and high throughput across geographically distant sites become more important.

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