Enhancing Throughput in 5G-NTN through Early RLC Layer Retransmissions

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Abstract

Lower layer retransmission schemes in 5G Non-Terrestrial Networks (5G-NTN), in particular Hybrid Automatic Repeat Request (HARQ) from the Medium Access Control (MAC) layer, are severely hampered by the large Round Trip Times (RTTs) imposed by satellite components. In this demonstration, we show that enabling Radio Link Control (RLC) layer retransmissions can significantly increase throughput without additional processing complexity. Using the OpenAirInterface (OAI) 5G-NTN suite, we showcase the effectiveness of RLC Acknowledged Mode (AM) retransmissions in facilitating early recovery of lost packets and maintaining reasonable Quality of Service (QoS), even in the absence of HARQ feedback from the MAC layer.

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1 Introduction

Adaptations for 5G-NTN were introduced in 3GPP Release 17 and will be continued in Releases 18 and 19 [2, 8]. There are several benefits as well as complexities in their implementations [9]. The current 5G Terrestrial Networks (5G-TN) protocol stack has been taken as a baseline, but several procedures cannot be realized in 5G-NTN due to the excessive RTT. One of them is HARQ feedback from the MAC layer. It is a critical process to ensure data reliability by recovering the erroneous packets at MAC before the error propagates to the higher layers. HARQ is very effective for 5G-TN due to the small RTT (≈ 10 ms), but the excessive RTT in 5G-NTN prevents such back-and-forth HARQ feedback at MAC.

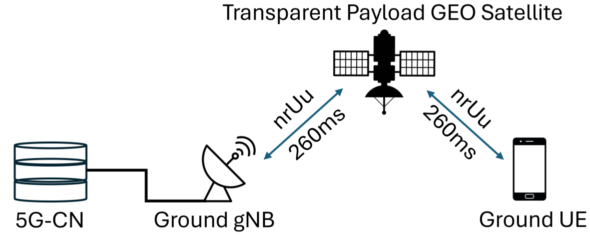

Figure 1: Illustration of a transparent payload GEO-based 5G-NTN. The RTT between the ground gNB and the UE is approximately 520 ms.

For example, in a Transparent payload Geostationary Orbit (GEO)-based 5G-NTN (Figure 1), where RTT could be as high as 520 ms, HARQ feedback becomes impractical [4, 6, 10]. Although other satellite orbits, such as Low Earth Orbit (LEO), have a lower RTT (≈ 30 ms) compared to GEO, it comes at the cost of reduced coverage and frequent handover.

In this work, we focus on Transparent payload GEO satellite-based 5G-NTN, as this configuration allows the use of the existing fleet of GEO satellites, thus facilitating the rapid deployment of 5G-NTN-based services [5]. Nevertheless, our work is equally applicable to Medium Earth Orbit (MEO) and LEO-based 5G-NTN in case the HARQ feedback is disabled due to reasons such as on-board processing complexity and on-board storage constraints.

In the absence of HARQ, the current approach is to delegate the responsibility of recovering lost packets through retransmissions from the application layer [5]. However, this comes at a significant cost of transmitting larger packets, resulting in increased end-to-end latency and reduced throughput. Figure 2 shows different retransmission techniques available from the 5G protocol stack and the IP stack.

Unfortunately, the capabilities of the RLC layer to recover the lost packets have not received much attention for 5G-NTN. The RLC layer is located between the MAC and the application layer (see Figure 2), so the retransmission overhead of the RLC layer is higher than the MAC layer, but

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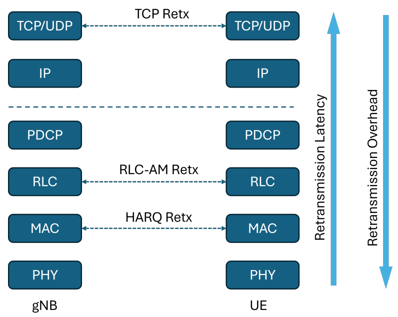

Figure 2: Retransmission options in the 5G New Radio (NR) protocol stack from different layers. As we move higher in the stack, both the retransmission latency and overhead increase. Therefore, it is preferable to recover the lost packets as early as possible.

lower than the application layer [1]. Similarly, retransmission latency is higher than the MAC layer, but significantly lower than the application layer.

In its normal operation, the RLC-AM (a) maintains a count of received packets through sequence numbers, (b) detects any packet loss, and (c) initiates a retransmission from the transmitting entity to recover the packet [1, 7]. The last step is performed a preconfigured number of times, after which the task of recovering the lost packets is delegated to the application layer (if the application uses TCP, otherwise the packet is dropped). In our previous work [7], we exploit this feature of retransmission from the RLC layer in RLC-AM mode, and enforce it for the scenarios where HARQ has been disabled. Preliminary experiments showed promising gains, especially in low Signal-to-Noise Ratio (SNR) scenarios.

2 Contribution

In this demonstration, we extend our previous work [7] (which used synthetic traffic) and use real-time applications: (a) Video-Streaming, (b) Web-Browsing, and (c) File-Transfer, to qualitatively showcase the effectiveness of RLC-AM retransmission in the absence of HARQ. Video-Streaming uses UDP and does not retransmit lost packets. Thus, under low SNR, QoS is degraded. Using RLC-AM, we show that the number of lost packets is significantly reduced, resulting in sustained QoS. In contrast, Web-Browsing and File-Transfer use TCP. Using RLC-AM, we show that the number of retransmissions from the application layer under low SNR is reduced, resulting in better (a) throughput for File-Transfer and (b) user experience during Web-Browsing. Moreover, our previous work evaluated lower Modulation and Coding Scheme (MCS) (up to 9 which is still QPSK); in this demo, we have extended the MCS up to 16 (16 QAM) and show that the gain is more prominent for higher MCS under low SNR.

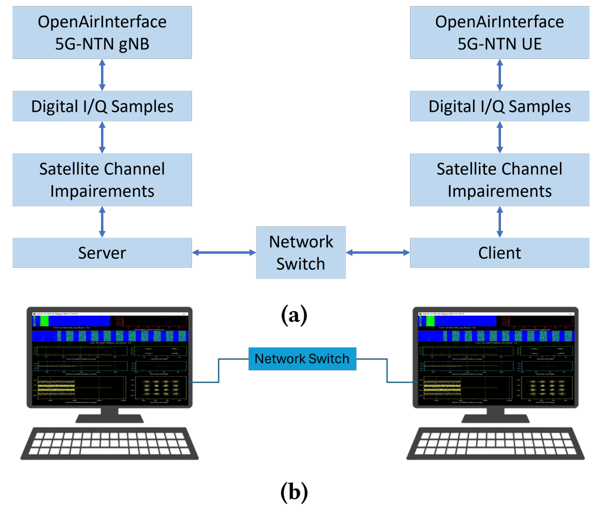

Figure 3: (a) OAI 5G-NTN Radio Frequency (RF)-Simulator mode of operation provides complete replication of satellite channel impairments. In our case, an RTT of 520 ms and variable SNR (b) Demo set-up using two general-purpose CPUs with Intel processors.

However, at higher SNR, the performance of RLC-AM and RLC-Unacknowledged Mode (UM) are similar.

Our initial assessment shows that for a downlink SNR as low as 3 dB, the percentage packet loss with RLC-AM for UDP traffic is four times lower than with RLC-UM. Similarly, for TCP traffic, the throughput of RLC-AM is three times higher compared to RLC-UM. In addition, the number of retransmissions from the higher layer for TCP traffic is 25 % less for RLC-AM compared to RLC-UM. However, at higher SNR, the performance of both the modes is similar.

3 Demonstration Setup

The demo setup, shown in Figure 3, includes two general-purpose CPUs running the 5G-NTN gNB and UE using the OAI 5G-NTN suite [6]. OAI has a 5G-NTN simulation framework, RF-Simulator, that closely mimics the satellite channel impairments [6]. In the RF-Simulator mode (Figure 3a), the digital I/Q samples are exchanged between the gNB and UE using a client-server model, after applying the satellite channel impairments. In our setup, we implement a transparent payload satellite configuration with an RTT of 520 ms and 30 kHz sub-carrier spacing. To have full control over the MCS and SNR, we disable the Adaptive Modulation and Coding and use the PHY-TEST mode of OAI[3]. The gNB machine also acts as a Video/File/Web server.

In the live demo, we initiate downlink traffic first using RLC-UM, followed by RLC-AM. By a qualitative comparison, we show a clearer video stream, faster file transfer, and smoother web browsing response time for RLC-AM compared to RLC-UM, especially at lower SNR and higher MCS.

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