Demonstration of 5G non-terrestrial network regenerative L1 processing

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***Abstract*—The regenerative architecture for 5G Non-Terrestrial Networks (NTNs) offers several advantages over the transparent architecture, including reduced latency, improved quality of service, lower feeder link bandwidth, support for inter-satellite links and the provision of edge compute services. However, it has the challenge of requiring computationally intensive 5G base stations to be placed into the Low-Earth Orbit (LEO) satellites, rather than into ground stations as is done in the transparent architecture. Based on AccelerComm's portfolio of flexible O-RAN L1 solutions, this paper describes a demonstration of a low-power radiation-tolerant 5G base station L1 implementation which addresses this challenge, making it suitable for LEO satellite deployment.**

Keywords—5G mobile communication, physical layer, system-on-chip, satellite communication

I. Introduction

Non-Terrestrial Networks (NTNs) based on 3GPP 5G New Radio (NR) offer the promise of global connectivity for a wide variety of mobile User Equipment (UE) [1]. Two architectures have been proposed for the deployment of 5G NR NTN infrastructure: (i) Transparent architecture (also known as "bent-pipe"), where Low-Earth Orbit (LEO) satellites relay 5G NR transmissions between UEs and 5G NR base stations (gNodeBs) located on the ground; (ii) Regenerative architecture, where the gNodeBs are located on the satellites themselves and a different waveform may be used for backhaul (feeder link) between the satellites and the ground-stations, as shown in Fig. 1

There are several advantages to regenerative architecture [2]. Firstly, since the service link between UEs and the satellite typically has a low Signal to Noise Ratio (SNR), several retransmissions may be required to successfully transmit data. By integrating the gNodeB onboard the satellite, the regenerative architecture can handle these retransmissions with significantly lower latency compared to the transparent architecture, which also suffers from the long propagation delays of the feeder link between the ground station and the satellite. This lower latency also enables the gNodeB to make scheduling, adaptive modulation and power control decisions based on more up-to-date information, leading to superior quality of service and improved bandwidth utilization.

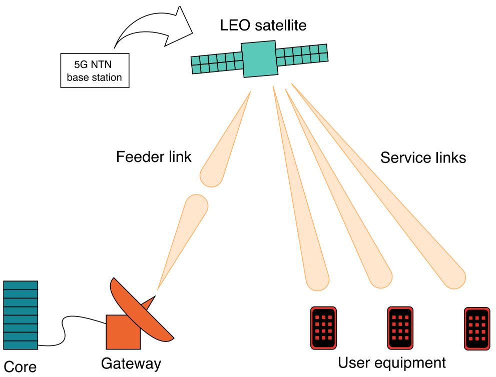

Fig. 1. Regenerative NTN system architecture.

Additionally, the regenerative architecture supports inter-satellite links, allowing multi-hop connectivity for UEs located in remote regions and enabling load-sharing between ground-stations that are overloaded or that are affected by poor weather. Furthermore, a significantly lower bandwidth is required for the feeder link of the regenerative architecture, since it supports the use of a higher spectral-efficiency waveform. Finally, having compute capability onboard the satellites enables cloud edge services, direct low-latency UE-satellite-UE connectivity and hold-and-forward capabilities for more efficient opportunistic use of spectrum.

However, the regenerative architecture faces the challenge of requiring computationally-intensive 5G NR physical layer (L1) signal processing to be performed onboard the satellite. Furthermore, this processing must be performed on low-power radiation-tolerant processor devices, which restricts choice. To demonstrate that these challenges can be overcome and that the benefits of the transparent architecture can be realized, Section II of this paper presents a real-time demonstration of the 5G NR L1 suitable for deployment on a LEO satellite. More specifically, unlike previous

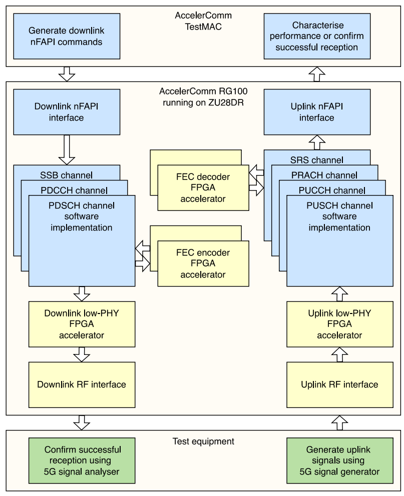

Fig. 2. Block diagram of AccelerComm RG100 regenerative 5G NTN L1 demonstration.

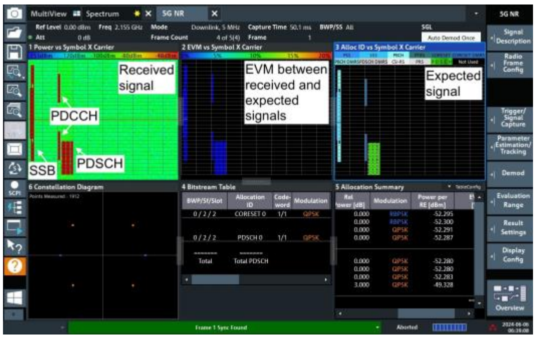

Fig. 3. Screen-shot of signal analyser when receiving a 5G NR downlink signal generated by the AccelerComm RG100 regenerative 5G NTN L1.

demonstrations of 5G NR L1 solutions for NTN [3][4], our demonstration runs on a low-power radiation-tolerant processor. We offer our conclusions in Section III.

II. Regenerative 5G NTN L1 demonstration

A block diagram of the 5G NR L1 demonstration is provided in Fig. 2. This demonstration features the AccelerComm RG100 5G NR L1 Intellectual Property (IP), running on a low-power radiation-tolerant ZU28DR RFSoC device on a ZCU111 development board. The RG100 L1 IP implements all functionality of the 5G NR L1, including the Forward Error Correction (FEC) encoding and QAM modulation of the SSB, PDCCH and PDSCH downlink high-PHY channels, the detection, channel estimation, equalization, QAM demodulation and FEC decoding of the PRACH, SRS, PUCCH and PUSCH uplink high-PHY channels, as well as the OFDM modulation and demodulation of the low-PHY. The low-PHY and FEC components are accelerated in the ZU28DR's FPGA, while the rest of the L1 functionality is implemented in software running on the ZU28DR's quad-core A53 processor. The RG100 L1 IP is capable of interfacing with an external L2 via nFAPI protocol over Ethernet, as well as with an external RF front end via SMA connectors operating at S-band carrier frequencies.

The 5G NR L1 demonstration combines the above-described RG100 L1 IP running on a ZCU111 development board with test equipment comprising a 5G NR signal analyser and a 5G NR signal generator. The RG100 L1 IP and the test equipment are controlled by the AccelerComm TestMAC application, which runs on a laptop. This issues nFAPI commands to the RG100 L1 IP via Ethernet and accepts nFAPI responses in return. Furthermore, TestMAC interacts with the test equipment by issuing SCPI commands and accepting SCPI responses in return. TestMAC automates a downlink test by issuing nFAPI commands to instruct the RG100 L1 IP to generate a particular combination and configuration of downlink channel signals, as well as by issuing SCPI commands to inform the signal analyser of what it should expect to receive. As exemplified in Fig. 3, the signal analyser visualises the received signal and if it determines that this signal matches the expectation, then it informs TestMAC using a SCPI response. Similarly, TestMAC automates an uplink test by issuing SCPI commands to instruct the signal generator to generate a particular combination and configuration of uplink channel signals, as well as by issuing nFAPI commands to inform the RG100 L1 IP of what it should expect to receive. Furthermore, TestMAC may inform the signal generator to emulate the transmission of the uplink signal over a noisy fading channel having a particular SNR. Upon reception of the corrupted signal, the RG100 L1 IP attempts to recover the uplink channels and reports its success or failure status to TestMAC via nFAPI responses. In this way, TestMAC can automate a sequence of tests and can collect statistics to plot Block Error Ratio (BLER) against SNR, for example. This is exemplified in Fig. 4 for the case of up to four transmissions in a PUSCH HARQ process using 1 resource block, a coding rate of 340/1024 and 16QAM.

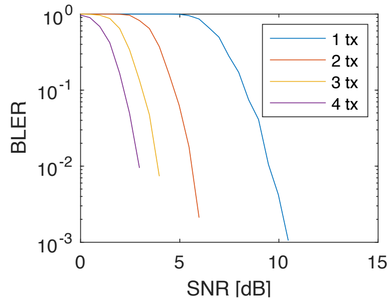

Fig. 4. BLER plot obtained using the AccelerComm RG100 regenerative 5G NTN L1 demonstration for the case of up to four transmissions in a PUSCH HARQ process using 1 resource block, a coding rate of 340/1024 and 16QAM.

III. Conclusions

This paper has thoroughly described the benefits and challenges of the regenerative 5G NTN architecture. We have presented a groundbreaking demonstration of a low-power, radiation-tolerant 5G base station implementation that realizes these benefits and addresses these challenges, making it well suited for LEO satellite deployment. Lockheed Martin (LM) has integrated the AccelerComm RG100 L1 IP with L2, L3 and 5G core IP on a space-qualified processor, which will be launched into low-Earth orbit later in 2024. LM's lab-based demonstration of this capability showcases streaming video between two UE's via LM's regenerative 5G NTN NR gNB running on flight hardware with a satellite channel emulator. Please refer to [5] for further discussion on the demonstration of this 3GPP compliant system.

References

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