Analysis of Open RAN Performance Indicators Related to Holographic Telepresence Communications

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Abstract—This paper presents experimental work related to the performance measurement of throughput, delay, and delay jitter as key performance indicators (KPIs) for the realization of high-quality holographic telepresence applications. The communication scenario assumes a wireless Radio Access Network (RAN) based on an Open-RAN architecture. For the experiments an LTE testbed based on an open-source platform is used integrating the open RAN architecture with two types of functional splits and an Evolved Packet Core (EPC) deployed on the top of standard Linux based machines. The KPIs are evaluated both in the downlink and uplink in the cases of the different split scenarios.

Keywords—delay, delay jitter, holographic communications, telepresence, Key Performance Indicators, Open-RAN

I. INTRODUCTION

Next-generation networks (NGN) are envisioned to implement time-sensitive engineered applications such as real-time holograms, full sensory digital reality; tactile applications, Internet of Everything [1]. These drive the demands of the performance requirements essential for delivering Quality of Service (QoS) and Quality of Experience (QoE). As an example, for the provision of an immersive 3D user experience in the case of high-fidelity holographic communications, very stringent network requirements related to high bandwidth, ultra-low latency and reliability will have to be met to ensure the required QoS and QoE. In addition to the above-mentioned key performance indicators (KPIs), network resilience is of paramount importance because it is related to the minimization of the packet loss, delay jitter, and latency, in addition to achieving high availability and reliability [2, 3].

Another driving force for the development of advanced wireless technologies is network virtualization and open source because of their essential role to enable interoperability. From the realization of vendor independent interoperable solutions, as a means to spur innovation and competition, reduce costs, increase business efficiency, etc., open-source solutions will present exciting opportunities for the entire communications. Network function virtualization with open source solutions has gained current research interest in relation to the Radio Access Network (RAN) [4]. Opening the RAN will allow for the efficient implementation of intelligence in the network, novel access solutions, and will open up new doors for disrupting innovations and businesses [5, 6, 7]. The concept of Open RAN introduces new technical challenges, very much application dependent, one of which is the computational complexity. For example, high-fidelity holographic communications require the generation, transmission and correct receiving of large amounts of near to real-time data. The application of intelligent algorithms for compression and/or prediction can reduce the required high data rates and incurred latency, on the other hand, this will induce higher computational complexity in the data processing introducing additional delay and communication latency [8].

In this paper we present experimental results from the measurement of some of the KPIs we consider important in the case of holographic communications using an open RAN testbed. The paper is organized as follows. Section II describes the architecture and functionalities of the O-RAN testbed. Section III describes the measured KPIs and the results. Section IV concludes the paper.

II. THE OPEN RAN TESTBED

The Open-RAN concept allows to separate the digital and radio components of the RAN infrastructure. The typical scenarios evolving from 5G, such as further-enhanced mobile broadband (FeMBB), ultra-massive machine-type communications (umMTC), extremely ultra-reliable and low-latency communications (eURLLC), and extremely low power communications (ELPC), are demanding peak data rates >1 Tbps, latency of 10-100μs, user experienced data rate> 1 Gbps; such performance requirements are quite beyond current 5G capabilities. Satisfying these requirements, however, is essential for delivering the 6G applications that more and more will be based on VR or AR content. The currently proposed Radio Intelligent Controller (RIC) as a main functionality for the Open RAN, has been proposed as an open-source cloud-based component that collects together the existing resource management, control and other functions within the RAN by enabling it with AI/ML [5, 9, 10]. This approach allow for taking measurements from various parts of the RAN and sending them along a standardized interface – called the E2 – from the Open Centralized Unit (O-CU) and the Open Distributed Unit (O-DU) to the RIC to make intelligent decisions about the performance optimization that opens up a new level of flexibility in the network and its services (see Figure 1).

The O-RAN architecture is explained in details in the O-RAN alliance white papers [9, 10]. In short, O-RAN includes RRH, DU, Multi Radio Access Technology CU (Multi-RAT CU) and two RAN Intelligent Controllers (near-RT RIC and non-RT RIC). The various modules of the O-RAN are shown in Figure 1. The O-RAN alliance, except for the E2 interface, also defines various open interfaces, such as the A1 and O1 (between the RAN and control system), the F1 Ethernet interface (between the DU-CU), the E1 (between CU-CP and CU-UP), W1 (between 4G CU and DU), X2 (between eNB and gNB), Xn (between gNB and gNB). These interfaces
aim to provide openness at different anchor points in the mobile network, as well as to provide different levels of advantages and complexity in the implementation of the network.

For our experiments we use a small-scale LTE testbed based on the open-source platform “OpenAirInterface” [11]. The testbed integrates an open RAN architecture, with two types of functional splits and an EPC deployed on the top of standard Linux based machines. The testbed represents a fully functional LTE with three types of RAN architectures: legacy eNB (standard RRH-BBU split), PDCP/RLC split (Option 2) and High PHY/ Low PHY split (Option 7.2). The wireless transmission setup is set in FDD mode with 100 Physical Resource Blocks, providing 20MHz bandwidth in band 7. Both RAN and EPC are deployed on three Dell OptiPlex-9030 with Intel Core i5-4590S processors, 8GB of memory, 1Gbit/s integrated Intel Network Interface Card (NIC) I217-LM and Ubuntu 18.04 with low-latency kernel as a host OS. Other main features and components of the network are shown in Figure 2 and Figure 3 and are described below:

- **RRH**: In all three RAN scenarios RRHs are deployed via ETTUS Universal Software Radio Peripheral (USRP) B210 in SISO antenna array configuration. The USRP is connected directly to the vBBU/DU via USB 3.0.

- **DU**: This component is deployed only in the case of functional split different than standard RRH- BBU split. In the case of Option 2 (PDCP/RLC split), all functions under the PDCP layer are performed in the DU. For Option 7.2 (High PHY/ Low PHY split) only the low PHY (RF mapping and lower functions) layer functions are performed in the DU. DU connects to the CU via Ethernet-based Fronthaul, with F1 Application Protocol (F1AP) interface specifications (for Option 2) and NGFI-F4p5 interface specifications (for Option 7.2).

- **CU**: This component is deployed only in the case of functional split different than standard RRH- BBU split. For Option 2 it performs only RRC and PDCP functions, while for Option 7.2 it performs all functions above the RF mapping.

- **vBBU**: This component is deployed only in the case of standard RRH-BBU split. The RRH is connected directly to the vBBU computer via USB 3.0 cable.

- **vEPC**: OpenAirInterface’s Evolved Packet Core is consisted of three elements: HSS, MME and SPGW (combined service and packet gateways). MME and HSS are deployed on a same computer, while SPGW is decoupled from the vEPC and deployed on the vBBU/CU’s PC.

- **UE**: As an User Equipment (UE) is used Samsung Galaxy Note 9 with programmable USIM card set with our network’s characteristics (MNC, MCC, Ki, OP and APN).

III. KPIs AND EXPERIMENTAL RESULTS

We evaluate the following open RAN KPIs both in the downlink and uplink as we consider them of primary importance in the case of holographic and telepresence communications:

- **Hardware load**: The hardware load indicates what amount of CPU and RAM resources are utilized by the system. In the case of functional splits, this KPI is also important because it can give us a rough estimate of how many DUs can connect to the CU, and how many RRHs to the DUs.

- **Round Trip Time (RTT)**: For the evaluation of RTT, ICMP packets are sent from the user device to an internet server and from the UE to the CU / BBU via the Termux terminal application. The received RTT statistic can be used to compare the end-to-end network latency obtained by each functional split.

- **Measuring the RAN throughput and jitter**: By using iperf tool we benchmark the data transmission between the UE and CU/BBU in terms of throughput (for TCP streams), jitter and packet loss (for UDP streams).
• E2E Speed test: Via the free speed test android application provided by Ookla, we measure the end-to-end speed of our network in both UL and DL.

The measurements are made with three types of RAN architectures: legacy eNB (traditional architecture without split), PDCP / RLC split (Option 2), and High PHY/ Low PHY (Option 7.2). The main parameters of the open RAN network are presented in the table below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>20 MHz (100 PRB)</td>
</tr>
<tr>
<td>Downlink frequency</td>
<td>2.68 GHz</td>
</tr>
<tr>
<td>Uplink frequency</td>
<td>2.56 GHz</td>
</tr>
<tr>
<td>Spectrum usage technique</td>
<td>FDD</td>
</tr>
<tr>
<td>Downlink modulation</td>
<td>64QAM</td>
</tr>
<tr>
<td>Uplink modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Transmission mode</td>
<td>1 (SISO)</td>
</tr>
<tr>
<td>TX gain</td>
<td>0</td>
</tr>
<tr>
<td>RX gain</td>
<td>0</td>
</tr>
<tr>
<td>Number of connected UEs</td>
<td>1</td>
</tr>
</tbody>
</table>

A. Hardware load

All network components are deployed on 4-core machines with Intel Core i5-4590S processors with Hasswell architecture and 3.00 GHz base frequency. The measurements are made with one connected to the network user, that is generating traffic (watching video on youtube) and results are taken via Linux’s “top” command. The obtained results are summarized in the table below. We can observe that the sum of CPU and RAM resources required for the implementation of legacy eNB and PDCP/RLC split are almost the same, but those required for the lower layer split are much higher. Another thing we observe is that the split with fewer functions in the DU (Option 7.2 split) requires a bit more CPU resources for the DU, but at the same time uses around 10% less RAM.

<table>
<thead>
<tr>
<th>Split Option</th>
<th>CPU Usage(%)</th>
<th>Memory Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy eNB</td>
<td>65,40</td>
<td>16,00</td>
</tr>
<tr>
<td>High PHY/ Low PHY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU</td>
<td>20,70</td>
<td>34,50</td>
</tr>
<tr>
<td>DU</td>
<td>71,00</td>
<td>5,60</td>
</tr>
<tr>
<td>PDCP/RLC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU</td>
<td>0,30</td>
<td>0,60</td>
</tr>
<tr>
<td>DU</td>
<td>64,50</td>
<td>16,20</td>
</tr>
</tbody>
</table>

B. Round Trip Time

For the RTT evaluation, 1000 ICMP packets were sent from the UE to an internet server (for e2e RTT) and from the UE to vBBU/CU (for RAN RTT). The obtained results for each type of functional split, are summarized in Figure 4. In both graphics, the legacy eNB has a higher levels of latency compared to the other two architectures. We also can see that the results for PDCP / RLC and High PHY/Low PHY are very close, with a difference of 1-2 ms. However, in both links a significant number of outliers are observed in the case of option 7.2. The outlier packets as a percentage of the total number of sent packets is 1.8% and 5.4% for e2e RTT and RAN RTT respectively.

C. Throughput

In order to measure the maximum throughput between the UE and vBBU/CU, using iperf, TCP connections with duration of 60s were established. The summarized results for both UL and DL are shown in Figure 5. We can observe that the legacy eNB and PDCP/RLC have the highest throughput for DL and UL, respectively. However, the results are not very consistent and there is a high variability in the throughput values. For example, in the DL of the legacy eNB, we observed multiple variations in the throughput in the range between 6 Mbps to 22 Mbps. It should be noted that such variations for the legacy eNB are observed only for the DL, while in the case of PDCP/RLC, split variations appear for both, the DL and the UL.
D. Delay jitter

Apart from the delay of the packets, delay jitter is another important factor for network resilience and sensitive applications, such as the ones delivered by holographic telepresence systems. By using iperf 60s long, UDP connections between the UE and CU/vBBU were established. The summarized jitter results for each eNB architecture are shown in Figure 6 in the form of boxplots. The UL and DL delay jitter values are noticeably different but both, the DL and the UL, Option 7.2 exhibits lower jitter values, and for the DL it is even below 1 ms. A dependence that is observed is that the fewer functions are localized in the DU, the lower the jitter range is.

E. Speedtest

In order to verify these dependencies for a longer period (e.g., 60 minutes), the UDP connections between the UE and CU/vBBU were established. The summarized results are shown in Figure 7. We can see that for the DL, the 7.2 split has a slightly better performance than the other two architectures. However, the difference of the delay jitter between the all three architectures is insignificant.

The difference in the median results for the speed in DL for the three types of architectures is not drastic (about 4 Mbps), but in the opposite direction we see improvement in the speed of more than 4 times in the case of functional split. Another thing that can be noticed is that with split we also have lower jitter compared to the legacy eNB architecture.

CONCLUSION

In this paper, experimental results from the measurement of some of the KPIs that are considered of primary importance
for the realization of high-quality holographic telepresence communications have been presented. A communication scenario, in which the wireless RAN is based on an Open-RAN architecture has been considered. The open-source platform “OpenAirInterface” has been used for the LTE testbed, integrating an open RAN architecture with two types of functional splits and an Evolved Packet Core (EPC). In addition to the measurements and analysis of the hardware load, round trip time, throughput, and jitter, the results of the E2E speed test are shown. Although the variation in the results from the evaluation of these parameters in different RAN architecture scenarios is not drastic, the scenarios with a functional split have one significant advantage over the legacy RAN architecture, in the context of holographic telepresence communications. The opportunity for the operators to “offload” part of the RAN processes to remote Data Centers will facilitate the provision of the computational resources required to implement high fidelity holographic communication, while at the same time, the physical distance between the DU and CU does not result in significant degradation of critical parameters such as latency and delay jitter. However, a further study on the different functional split options is needed to find an optimal solution in the case of near-real-time holographic telepresence communication systems.

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