Impact of RAN Virtualization on Fronthaul Latency Budget: An Experimental Evaluation

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Abstract—In 3GPP the architecture of a New Radio Access Network (New RAN) has been defined where the evolved NodeB (eNB) functions can be split between a Distributed Unit (DU) and Central Unit (CU). Furthermore, in the virtual RAN (VRAN) approach, such functions can be virtualized (e.g., in simple terms, deployed in virtual machines). Based on the split type, different performance in terms of capacity and latency are requested to the network (i.e., fronthaul) connecting DU and CU.

This study experimentally evaluates, in the 5G segment of the Advanced Research on NetwOrking (ARNO) testbed (ARNO-5G), the fronthaul latency requirements specified by Standard Developing Organizations (SDO) (3GPP in this specific case). Moreover, it evaluates how much virtualization impacts the fronthaul latency budget for the Option 7-1 functional split.

The obtained results show that, in the considered Option 7-1 functional split, the fronthaul latency requirements are about 250 µs but they depend on the radio channel bandwidth and the number of the connected UEs. Finally, virtualization further decreases the latency budget.

Index Terms—5G, functional split, NGFI, DU, CU, testbed

I. INTRODUCTION

To address the demanding requirements in terms of expected throughput, latency, and scalability, 5G networks are expected to be massively deployed and offer an unprecedented capacity [1], [2]. A new concept of Radio Access Network, called New RAN, has been proposed to increase performance with limited deployment cost. In general, in the New RAN, the evolved NodeB (eNB) functions are split into two new network entities [3]. The base-band processing is centralized in the so-called Central Unit (CU) and the RF processing has been left at the edge of New RAN in the Distributed Unit (DU).

The Common Public Radio Interface (CPRI), so far used to connect BaseBand unit (BBU) (i.e., CU) and Remote Radio Head (RRH) (i.e., DU), has shown some limitations [4]. CPRI is based on carrying time domain baseband IQ samples between RRH and BBU. Thus, CPRI needs a high capacity fronthaul, low latency, low delay variation and fine synchronization. Guaranteeing such requirements, if Ethernet is chosen [5] as fronthaul transport technology, is particularly challenging [6]–[8].

Thus, new upper layer functional splits, proposed by 3GPP in TR 38.801 [3], a Next Generation Fronthaul Interface (NGFI) [9], and the new CPRI specification for 5G called eCPRI [10] are under definition. Different splits, however, demand different requirements in terms of latency and capacity as reported in 3GPP TR 38.801 [3].

Moreover, recent approaches push the CU functions into the “cloud” (where the CU is “virtualized”), thereby paving the way to the so-called virtual RAN (V-RAN) [11]. However, to the best of the authors’ knowledge, no evaluation has been conducted so far of the impact of virtualization on the fronthaul latency budget.

This paper evaluates experimentally the latency and jitter requirements for different radio channel bandwidths and different number of User Equipments (UEs), in both physical and virtual environment. The experimental evaluation is performed in the 5G segment of the Advanced Research on Networking testbed (ARNO-5G) [12]. ARNO-5G allows to emulate the behavior of a 5G network and run performance tests to evaluate several functional split requirements. Another foreseen feature of the ARNO-5G testbed is the possibility of virtualizing different Radio Access Network (RAN) and Evolved Packet Core (EPC) functions to test the virtualized RAN and EPC limits and compare them with the deployment in physical machines.

II. THE ARNO-5G TESTBED

Fig. 1 shows the ARNO-5G testbed. In this section the function deployment utilized to conduct the performance evaluation reported in this paper is described but alternative deployments are possible exploiting the same hardware.

The EPC and the functional elements belonging to it (i.e., the Serving Gateway (S-GW), the Public Data Network Gateway (PDN-GW), the Mobile Management Entity (MME) and
the Home Subscriber Server (HSS)) are deployed in a mini-
puter (Up-board) featuring an Intel Atom x5-Z8350 Quad Core
Processor and hosting Ubuntu 14.04 LTS with a 4.7 kernel
(directly precompiled by OpenAirInterface (OAI) team).

The Radio Aggregation Unit (RAU) consists of a Cisco
Catalyst 2960G switch, referred to as SWITCH in Fig. 1. The
RAU becomes a necessary network element because of the
point-to-multipoint architecture between the CU and the DU.
The RAU forwards the communication from the CU to several
DUs.

The CU is deployed in a desktop server with Intel Xeon
E5620 and hosting Ubuntu 14.04 with 3.19 low-latency kernel.
It is connected by a 1 Gigabit Ethernet link to the EPC and
by a 1 Gigabit Ethernet link to the DU as well.

The first DU (DU1) is deployed in a Mini-ITX featuring
an Intel i7 7700 Quad Core @ 4.0 GHz and hosting Ubuntu
14.04, 3.19 low-latency kernel. This machine is connected
to the CU by a 1 Gigabit Ethernet link. It is also connected
through USB 3.0 link to an Ettus B210 for implementing the
Radio Frequency (RF) front-end.

The second DU (DU2) is deployed on a desktop computer
with an Intel i7 4790 @ 3.60 GHz and hosting Ubuntu 14.04
with 3.19 low-latency kernel. Also the DU2 is connected
through USB 3.0 link to an Ettus B210 for implementing the
RF front-end. The Ettus B210 USRP device is a fully
integrated, single-board, Universal Software Radio Peripheral
(USRP) platform and acts as radio front-end performing Digita-
To Analog and Analog to Digital Conversion (DAC/ADC).

The UEs (i.e., UE1 and UE2) consists of Huawei E3372 LTE
dongles. The dongles support LTE category 4 and Frequency-
division duplexing (FDD) communication systems in the fol-
lowing bands: 900 MHz, 1800 MHz, 2100 MHz and 2600
MHz.

The utilized mobile network software is the OpenAirInter-
face (OAI) by Eurecom. The current OAI platform includes
an implementation of 3GPP LTE Release 10 for UE, eNB,
MME, HSS, S-GW and PDN-GW on standard Linux-based
operating system. In particular, the OAI software stack of the
LTE protocol provides different layers such as PHY, RLC,
MAC, PDCP and RRC. The latest OAI development branch
was used to evaluate the considered scenarios.

Moreover, OAI platform provides C-RAN based functional
split evaluation. The functional splits implemented by the
OAI platform are the IF5 and IF4.5 also known as Option
8 and Option 7-1 in the 3GPP terminology [3]. In our study
we consider a signal bandwidth equal to 5 MHz and 10
MHz, corresponding to 25 and 50 Physical Resource Blocks
(PRBs) with the Option 7-1 scenario. In this split in the
uplink direction, Fast Fourier Transform (FFT), Cyclic Prefix
(CP) removal and possibly Physical Random Access Channel
(PRACH) filtering functions reside in the DU and the rest of
PHY functions reside in the CU. In the downlink direction,
Inverse Fast Fourier Transform (IFFT) and CP addition func-
tions reside in the DU, the rest of PHY functions reside in
the CU. In other word, the Option 7-1 functional split is made
before/after the resource mapping/demapping respectively.

III. PERFORMANCE EVALUATION PARAMETERS AND
EVALUATION SCENARIOS

This paper evaluates experimentally the maximum latency
(i.e., the one way delay between DU and CU) and jitter
(i.e., packet delay variation) that Option 7-1 functional split
can tolerate in the fronthaul, referred to as allowable latency
budget and allowable jitter budget respectively. For Option 7-
1 split the one-way latency constraint specified by 3GPP is
250 $\mu$s [3], mainly due to the 4 ms limit of the Hybrid ARQ
(HARQ) [13]. However, no jitter constraint is specified.

The latency and jitter experienced along the fronthaul link
is emulated by means of the linux utility traffic control tc [14].
The tc utility is capable of increasing the delay and jitter that
a packet experiences on a link by storing it in the output
interface for a specified amount of time before its transmission
on the link. A delay $d_0$ is applied to the ethernet interface
of the machine in which the DU is deployed and a delay
$d_1$ is applied to the ethernet interface of the machine
in which the CU is deployed. In this way a one-way latency
is inserted in the fronthaul link. For reaching the allowable
latency budget, $d_0$ and $d_1$ are increase with steps of 10
$\mu$s. To evaluate the allowable jitter budget instead, $d_0$ and
$d_1$ consists of two components: a fixed mean latency and
an additional random latency following a normal distribution
whose standard deviation is increased with steps of 5 $\mu$s. In
the latter evaluation two different scenarios are considered.
In the first one we set the mean latency close to the allowable
latency budget and we varied the jitter in order to understand
if the jitter could cause a reduction of the threshold. In the
second jitter evaluation scenario we fixed the mean latency
quite far from the allowable latency budget and the variation
of the jitter values was made to understand if jitter could be
an additional constraint for the fronthaul. More details about
how to emulate the packet delay by using the $tc$ command can
be found in [14].

In the performed experimental evaluation different scenarios
are considered as described as follows.

Fig. 2 shows the considered Scenario 1, where a single DU
is connected to a single CU through the RAU. In this
scenario, we bind a single interface with a single UDP port
number and all the RAN and EPC functional elements are
run on physical machines. It is worth mentioning that NGFI
can support point-to-multipoint topology between CU and DU,
thus a new element is required. It is called RAU which can
interface with CU and carries transport for several DUs [15].

Fig. 3 shows Scenario 2 in which two DUs are connected
with a single CU. In order to deploy such scenario we bind
a single interface at the CU by using different UDP port numbers
to serve two different DUs at the same time. All the RAN

![Fig. 2. Scenario 1: Single DU and Single UE](image-url)
and EPC functional elements run in physical machines. The two DUs are running in two different physical machines, as depicted in the block diagram in Fig. 3 while two OAI CU instances, running in the same physical machine, are connected to the corresponding DUs.

![Fig. 3. Scenario 2: Multiple DUs and Multiple UEs](image)

Fig. 4 shows the virtualized CU and EPC setup by exploiting JuJu orchestration framework and OAI platform [16], [17]. In particular, the set of Charms (network services) managed by JuJu performs the functional split option 7-1 as specified in 3GPP [3]. This experimental setup contains different Charms such as: MYSQL database, OAI-HSS, OAI-MME, OAI-Serving/Packet Gateway for the EPC, OAI-eNB configured to act as a CU and OAI-DU with attached USRP radio frequency frontend. Each of these services is executed inside virtual machines (running Ubuntu 16.04), exploiting VirtualBox tool, except for the OAI-DU which runs in a physical machine, a MiniITX with Intel I7 7700 Quad Core @ 4.0 GHz running Ubuntu 14.04.

In all the aforementioned scenarios the UEs are static and connected to the DU through coaxial cables with 40 dB attenuation. The other experimental parameters are shown in Table I.

| Parameter               | Value                  |
|-------------------------|------------------------|
| Experiment Duration     | 100000 TTIs            |
| Frame Duration          | 10 ms                  |
| Duplexing Mode          | FDD                    |
| PHY Layer Abstraction   | NO                     |
| Number of DUs           | 2                      |
| Number of UEs           | 2                      |
| Carrier Bandwidth       | 5MHz, 10 MHz           |

### IV. Experimental Results

In this section the allowable latency and jitter budgets are evaluated. To calculate the allowable latency and jitter budgets, we use the `tc` command to add delay to network interfaces and TCP traffic is generated by using `iperf` tool to check the UE connectivity stability.

Fig. 5 shows the allowable latency budgets for the considered Scenario 1, Scenario 2 and Scenario 3 with different signal bandwidth values (i.e., 5 MHz and 10 MHz). Results show that in all the scenarios the allowable latency budget is always below the 250 µs one-way latency constraint specified by 3GPP [3]. Moreover, it can be noticed that the allowable latency budget decreases if the signal bandwidth and if the number of DUs connected to the same CU increases. The dependence on the signal bandwidth is due to the heavier processing required by the higher number of utilized PRBs. The dependence on the number of CU is similarly due to the higher number of processes running in the same machine. Finally, by comparing the results obtained in Scenario 3 with the ones obtained in Scenario 1 and Scenario 2, it can be noticed that the maximum fronthaul latency that can be tolerated is much lower if mobile network functions are virtualized (i.e., Scenario 3) than if mobile network functions run in physical machines (i.e., Scenario 1 and 2). This phenomenon depends on VM core capacity and other VM parameters. Note that, in Scenario 3 with 10 MHz signal, the UE is not capable of communicating with the EPC because the large number of samples cannot reach the CU on time due to encapsulation delay and transit time across the RAU.

Latency requirements for different functional splits to serve high capacity New RAN architecture have been specified in the 3GPP [3]. However, it is not clear how different functional splits can be affected by jitter. Thus, the second set of experiments aims at investigating whether the jitter impacts the allowable latency budget found in the first set of experiments. In the considered experiments, we vary the jitter while keeping the fronthaul latency fixed and within the above allowable latency budget.

Fig. 6 shows the obtained jitter results in Scenario 1, Scenario 2 and Scenario 3. In particular, in Scenario 1 the latency is set to 220 µs for the 5 MHz and is set to 160 µs when a 10 MHz signal bandwidth is considered. The obtained
allowable jitter budget in this case is equal to 35 $\mu$s and 30 $\mu$s for the 5 MHz and 10 MHz signal bandwidth, respectively.

For Scenario 2, the experiments are carried out by setting a fixed latency on the fronthaul link equal to 200 $\mu$s and 120 $\mu$s for 5 MHz and 10 MHz, respectively. The allowable jitter budget is equal to 30 $\mu$s for the 5 MHz and 25 $\mu$s for the 10 MHz as depicted in Fig. 6.

In Scenario 3, the experiments are carried out by setting a fixed latency on the fronthaul link equal to 30 $\mu$s for 5 MHz signal bandwidth. The obtained allowable jitter budget is 20 $\mu$s. Note that, even in this case, for 10 MHz the UE cannot connect because the considered testbed system with virtualized CU has only 4 cores. However, it has been verified that the UE is capable of connecting if a virtual CU with 8 cores is utilized with no additional delay on the fronthaul link.

By comparing the results reported in Fig. 5 and in Fig. 6, it can be deducted that jitter negligibly impacts the allowable latency budget.

To observe the impact of the sole jitter on the fronthaul link, that is to find the allowable jitter budget, the latency value is set far from the allowable latency budget depicted in Fig. 5. The obtained results are shown in Fig. 7 for Scenario 1, Scenario 2, and Scenario 3. In both Scenario 1 and Scenario 2, the latency is set to 100 $\mu$s and 50 $\mu$s for signal bandwidths 5 MHz and 10 MHz, respectively. In Scenario 1, the obtained allowable jitter budgets are 30 $\mu$s and 25 $\mu$s for 5 MHz and 10 MHz signal bandwidth, respectively. Whereas, in Scenario 2, the obtained allowable jitter budgets are 35 $\mu$s and 40 $\mu$s for 5 MHz and 10 MHz signal bandwidth, respectively. In Scenario 3, the experiments are carried out by setting a fixed latency on the fronthaul equal to 20 $\mu$s for 5 MHz signal bandwidth. The obtained jitter budget is 25 $\mu$s, and no communication was observed in case of 10 MHz signal bandwidth.

From the presented results, we can observe that when the jitter overcomes a certain threshold DU and CU are not capable of communicating. Indeed, the jitter cannot be higher than 40 $\mu$s because, if the jitter is large, the are periods in which not enough samples (i.e., modulation symbols) can be delivered to the PHY layer.

V. CONCLUSIONS

This paper presented the experimental evaluation of the impact of virtualizing eNB functions on the fronthaul latency budget. It also showed the maximum sustainable fronthaul jitter. The experimental evaluation was performed in a testbed utilizing OpenAirInterface as mobile network software, desktop computers, and USRPs.

Results showed that by increasing the instances of CU running in the same machine the allowable fronthaul latency budget decreases of some tens of microseconds due to the higher number of computations required in the same machine. Similarly, but in the order of more than fifty microseconds, it happens if the signal bandwidth increases. Moreover, if eNB functions are run in virtual machines the allowable latency
budget further decreases, in the order of hundreds of microseconds, due to the higher number of computations required by the virtualization engine. Finally, the fronthaul jitter evaluation showed that jitter negligibly impact the allowable latency budget. However, the allowable jitter budget is in the order of tens of microseconds in all the considered scenarios.

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