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

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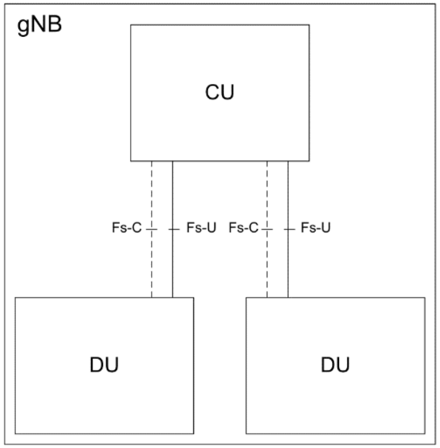
Globecom 2017, 4-8 December 2017 – Singapore, Singapore

Summary

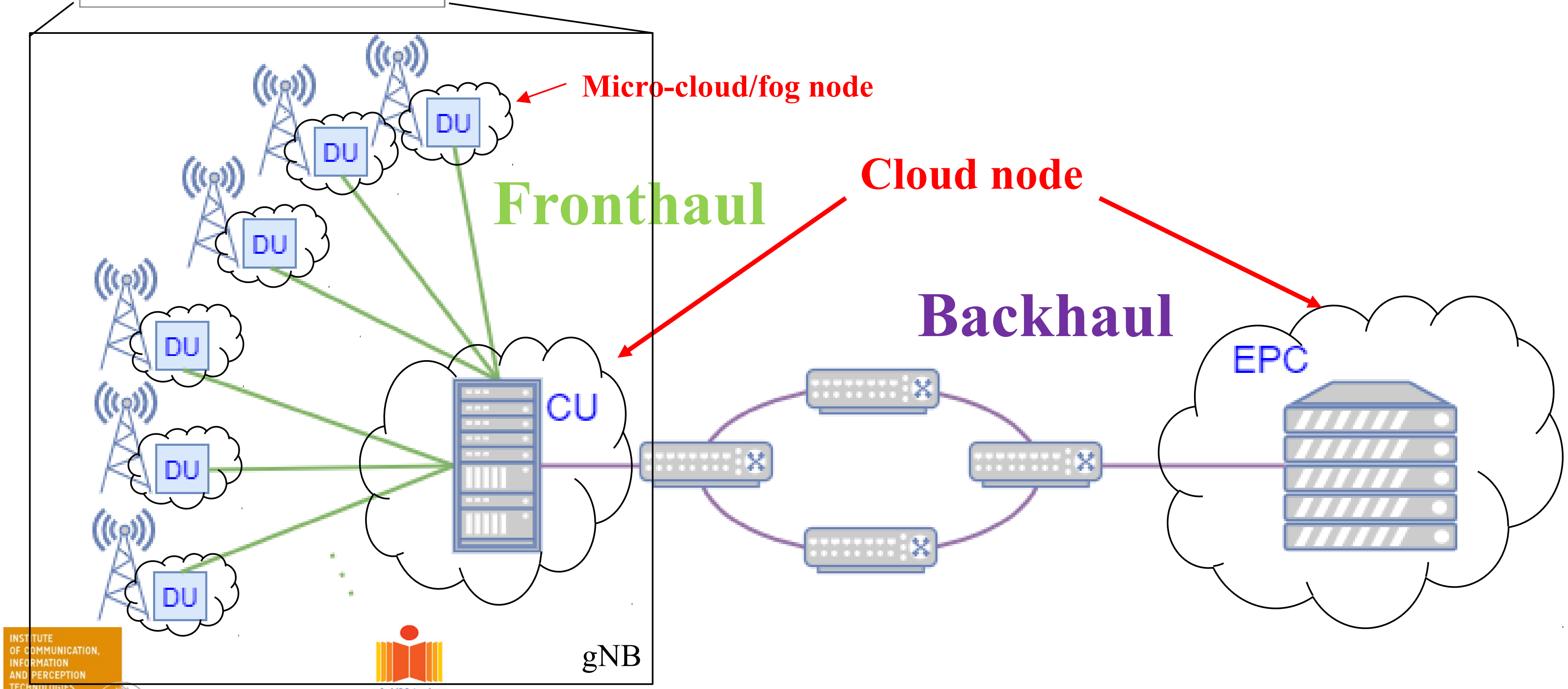
- Virtualized New Radio Access Network (RAN)
- Virtual Network Function (VNF) performance evaluation
- Implementation of EPC and RAN functions in ARNO-5G testbed
- Experimental Results
- Conclusions

Virtualized New RAN



- gNB functional split
  - Distributed Unit (DU)
  - Central Unit (CU)

- RAN split
  - Fronthaul
  - Backhaul

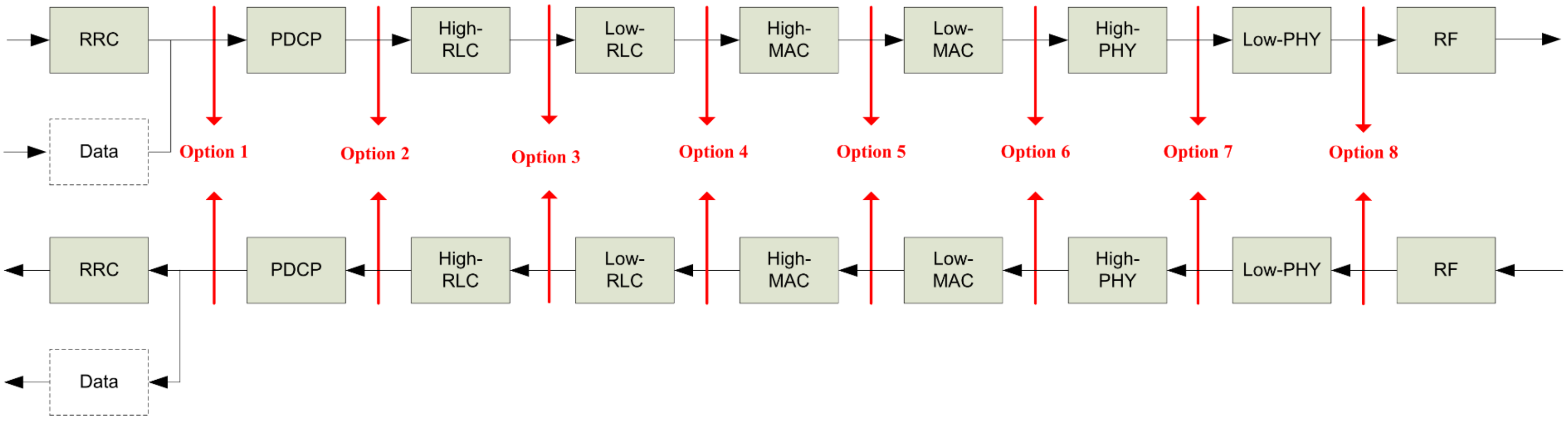

Micro-cloud/fog node

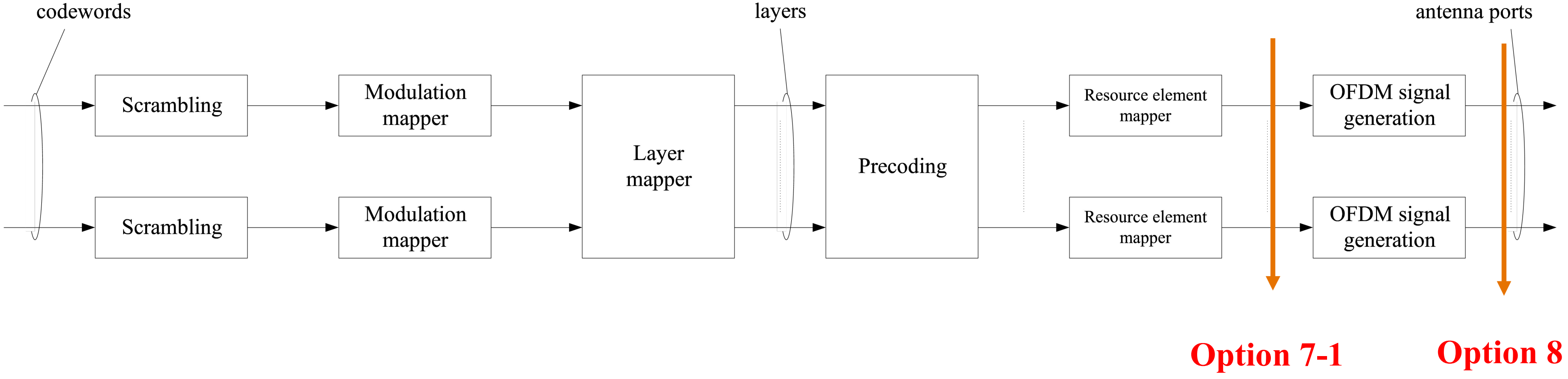
Cloud node

Fronthaul

Backhaul

gNB Functional Splits (3GPP TR 38.801)





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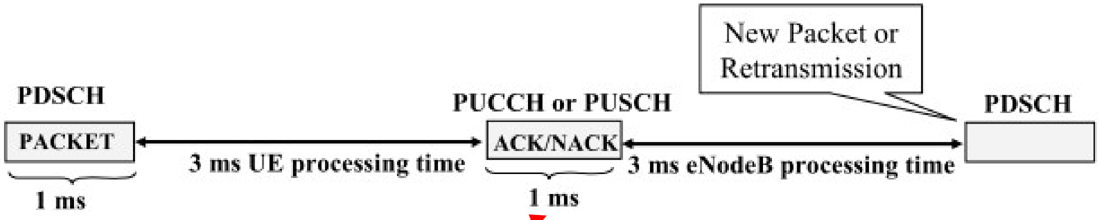
Fronthaul requirements (TR 38.801)

	Opt. 1	Opt. 2	Opt. 3-2	Opt. 3-1	Opt. 5	Opt. 6	Opt. 7-3 (only for DL)	Opt. 7-2	Opt. 7-1	Opt. 8
Transport NW latency requirement	Loose				Not yet clarified	Tight				
Transport NW Peak BW requirement	N/A	Lowest	in between (higher on the right)							Highest
	No UP req.	baseband bits						Quantized IQ (f)		Quant. IQ (t)
	-	Scales with MIMO layers							Scales with antenna ports	

Protocol Split option[1]	Max. allowed one way latency [ms]
Option 7c	*[250us]*
Option 8	*[250us]*

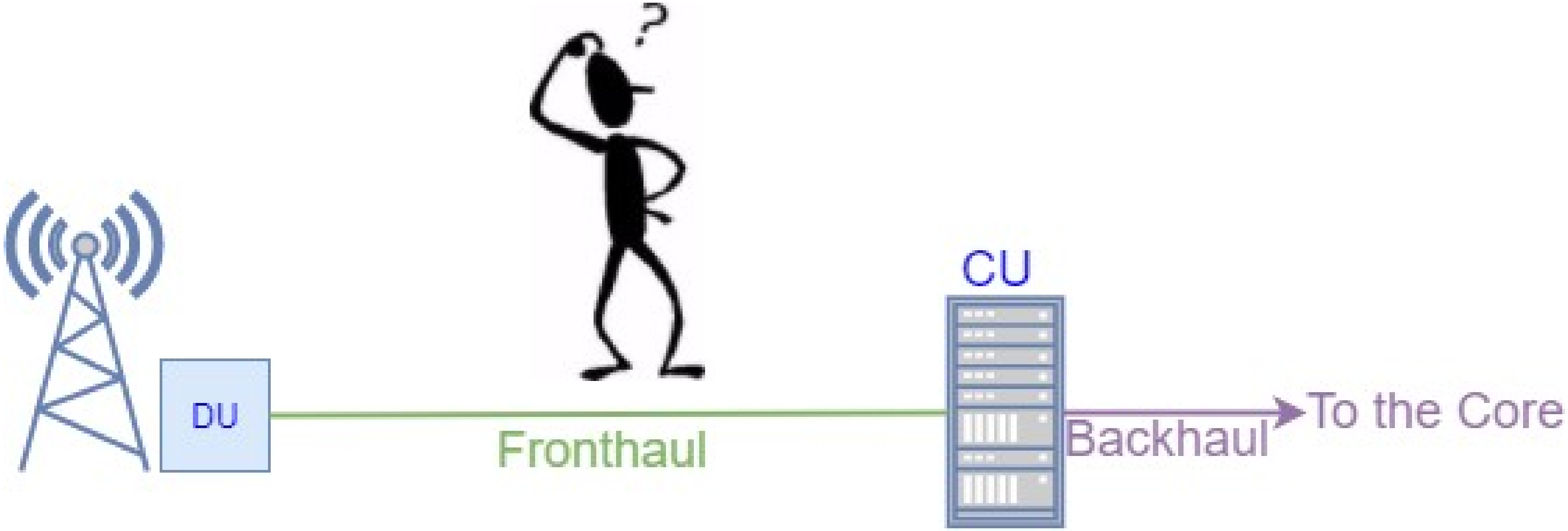


due to 4ms HARQ process

Source: LTE for UMTS: Evolution to LTE-Advanced, 2nd Edition, Harri Holma, Antti Toskala ISBN: 978-0-470-66000-3

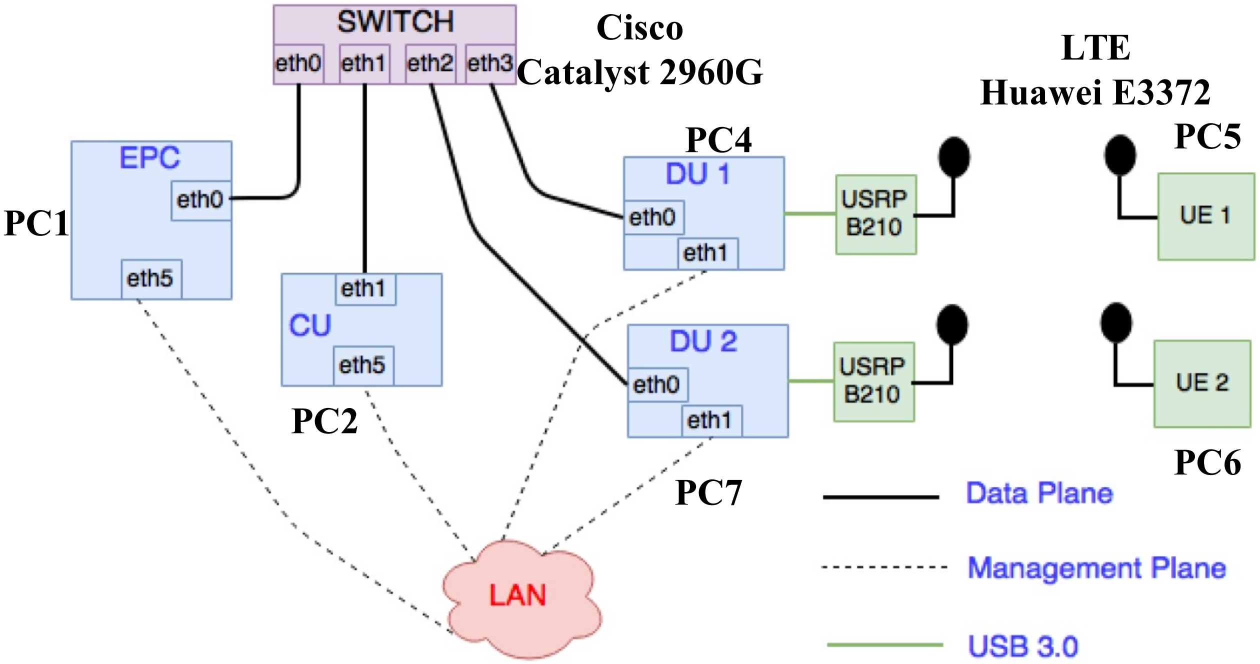
Study objective

1. Are the extra levels of abstraction impacting the fronthaul latency constraints?
2. Does the jitter impact the fronthaul link performance?



Functional element placement in the ARNO-5G testbed

arnotestbed.santannapisa.it



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

Devices Name	Devices Type	Processor Type	OS
PC 1	mini-pc (Up-board First Generation)	Intel Atom x5-Z8350 Quad Core Processor	Ubuntu 14.04 (4.7 kernel)
PC 2	Dell T410 PowerEdge desktop servers	Intel Xeon E5620	Ubuntu 14.04 (3.19 low-latency kernel)
PC 4	Mini-ITX	Intel I7 7700 Quad Core (@ 4.0GHz)	Ubuntu 14.04 (3.19 low-latency kernel)
PC 5	mini-pc (Up-board First Generation)	Intel Atom x5-Z8350 Quad Core Processor	Ubuntu 14.04 (4.7 kernel)
PC 6	mini-pc (Up-board First Generation)	Intel Atom x5-Z8350 Quad Core Processor	Ubuntu 14.04 (4.7 kernel)
PC 7	Desktop Computer	Intel i7 4790 (@ 3.60 GHz)	Ubuntu 14.04 (3.19 low-latency kernel)

Mobile Network Software – OpenAirInterface

- For the Core and RAN implementation the OpenAir interface software is used.

Core Implementation

- openair-cn
- Implements the EPC 3GPP specs
- Contains the implemention of:
  - ✓ Home Subscriver Server (HSS)
  - ✓ Mobile Management Entity (MME)
  - ✓ Serving Gateway (S-GW)
  - ✓ PDN Gateway (PDN-GW)

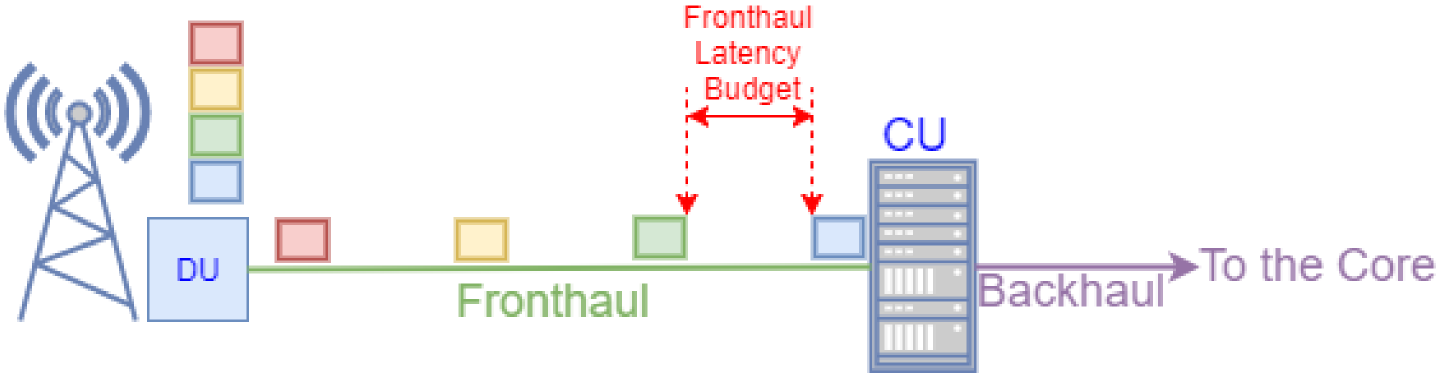
RAN Implementation

- openairinterface5g
- Implementation of Rel 10 LTE of:
  - ✓ Evolved NodeB (eNB);
  - ✓ User Equipment (UE).
- Implemented functional splits options:
  - ✓ IF4p5 → Option 7-1 (intra-PHY split)
  - ✓ IF5 → Option 8 (PHY-RF split)

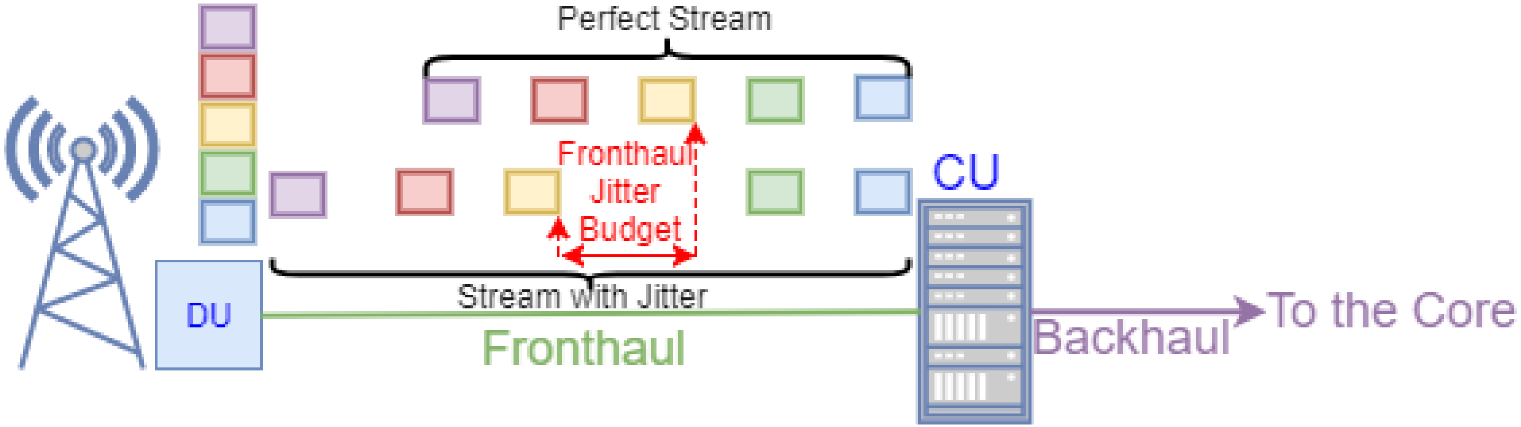
	Option 7-1	
	Uplink Direction	**Downlink Direction**
DU	FFT, CP removal and PRACH filtering	IFFT, CP addition and PRACH filtering
CU	Rest of PHY functions and the higher layers	Rest of PHY functions and the higher layers

Performance Evaluation Parameters

- **Allowable latency budget**: allowable one-way fronthaul latency between DU and CU



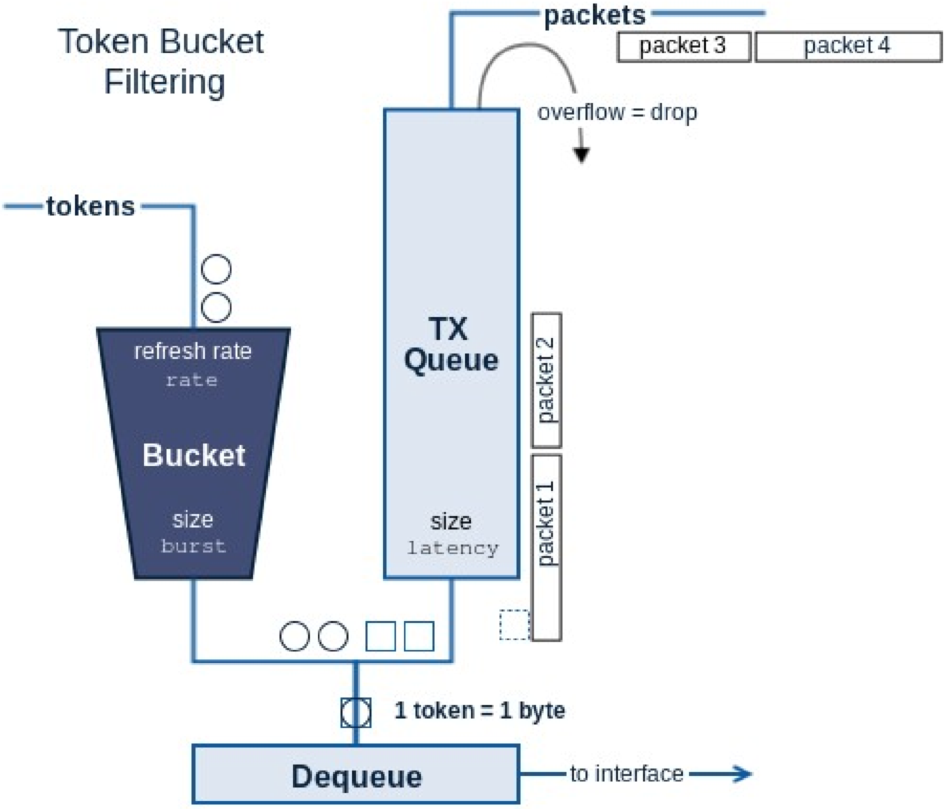
- **Allowable jitter budget**: allowable one-way fronthaul jitter between DU and CU



Emulations of Latency and Jitter on the fronthaul

- The linux utility traffic control ¨tc-netem¨ is used

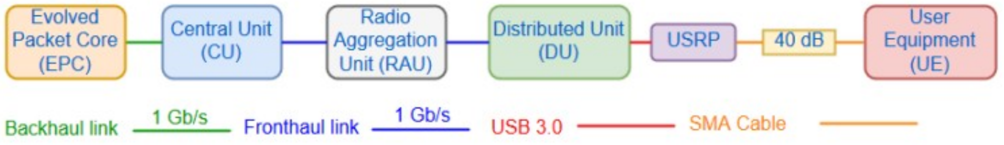
- A delay d0 is applied to the DU Ethernet interface towards the CU.
- A delay d1 is applied to the CU Ethernet interface towards the DU.
- Evaluation of the frontahul latency budget:
  - ✓ d0 and d1 are increased with steps of 10 μs until DU, CU and UE disconect.
- Evalution of the fronthaul jitter budget:
  - ✓ A jitter following a normal distribution is added to the latency values d0 and d1 with standard deviation increased of steps of 5μs.



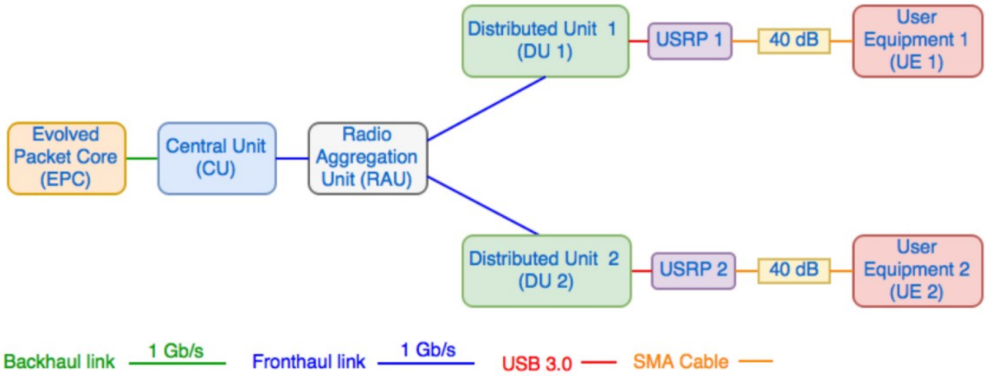
Source: https://www.excentis.com/blog/use-linux-traffic-control-impairment-node-test-environment-part-2

Considered scenarios

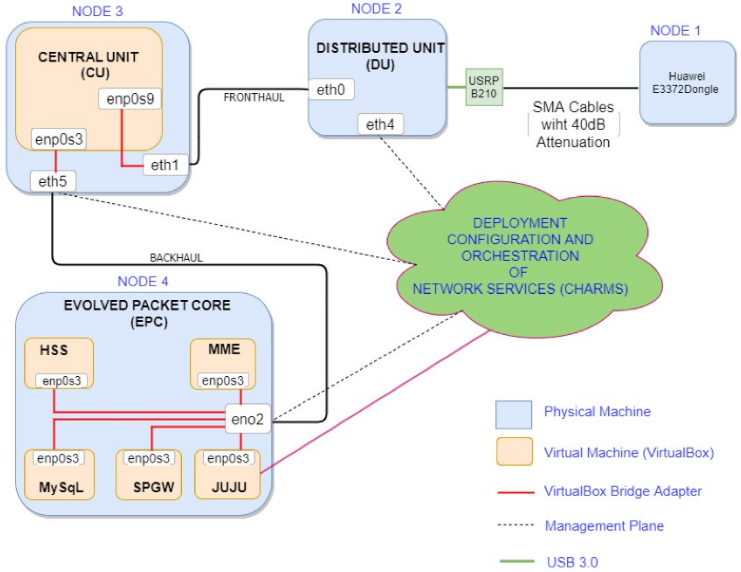
- Scenario 1:
  - All functional elements deployed in bare metal



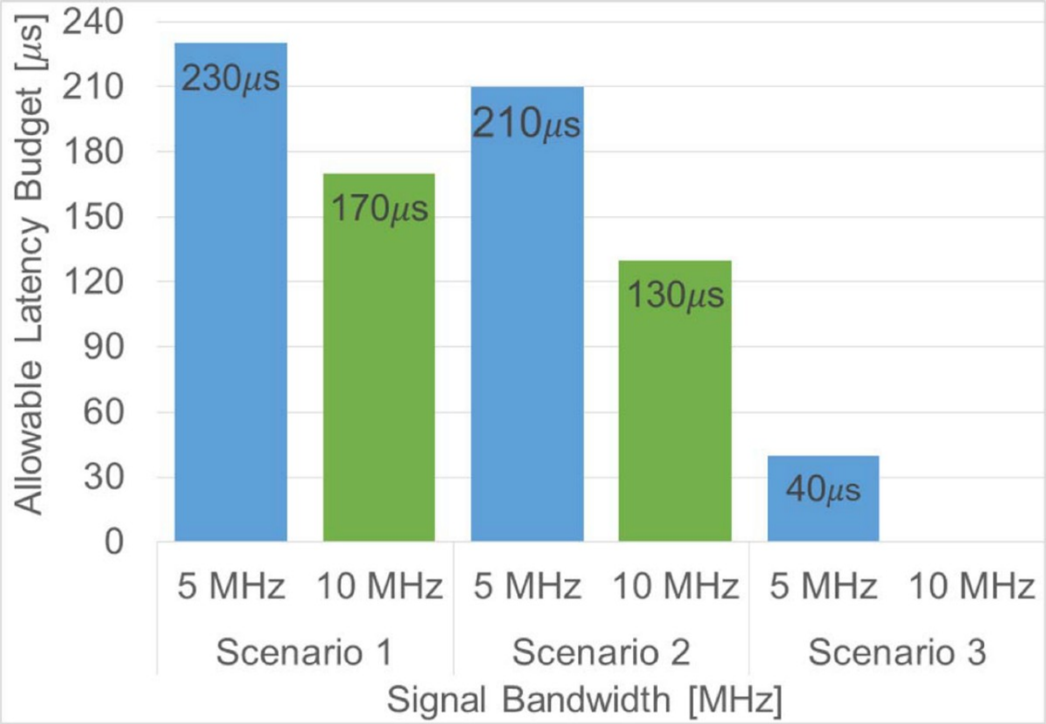
- Scenario 2:
  - Two DUs in bare metal connected to two instances of CU running in the same bare metal



- Scenario 3:
  - CU and EPC virtualized through VirtualBox
  - DU in bare metal
  - All functional elements based on juju charms and managed through Juju.



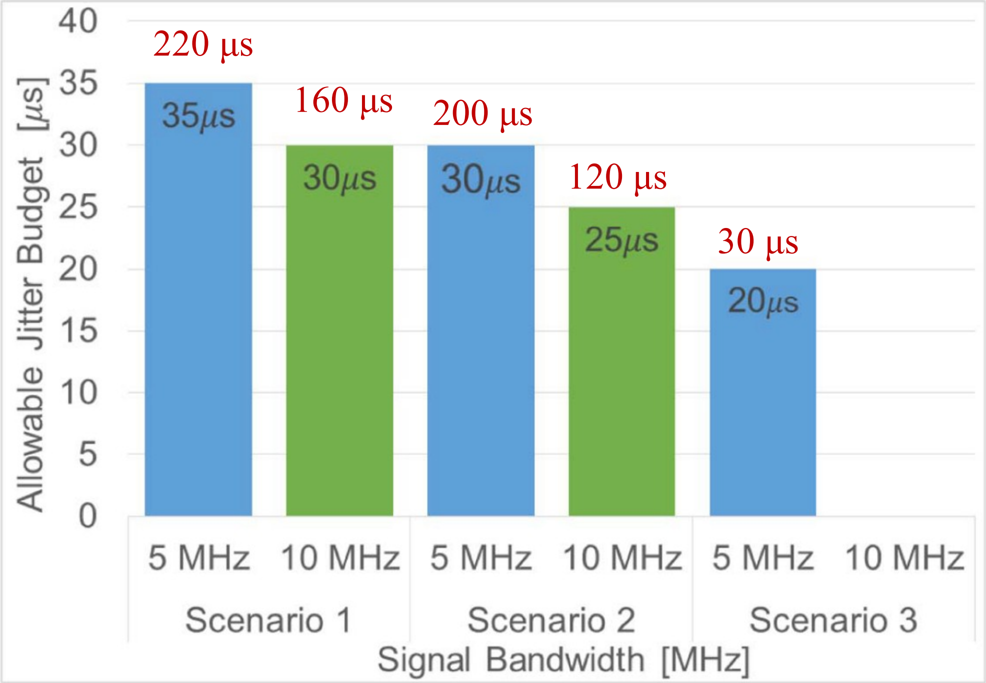
Allowable Latency Budget



- Allowable latency budget always below 250 µs
- Allowable latency budget decreases if the signal bandwidth and if the number of DUs connected to the same CU increases due to heavier processing
- Allowable latency budget is much lower if mobile network functions are virtualized

Impact of Allowable Jitter Budget on Allowable Latency Budget

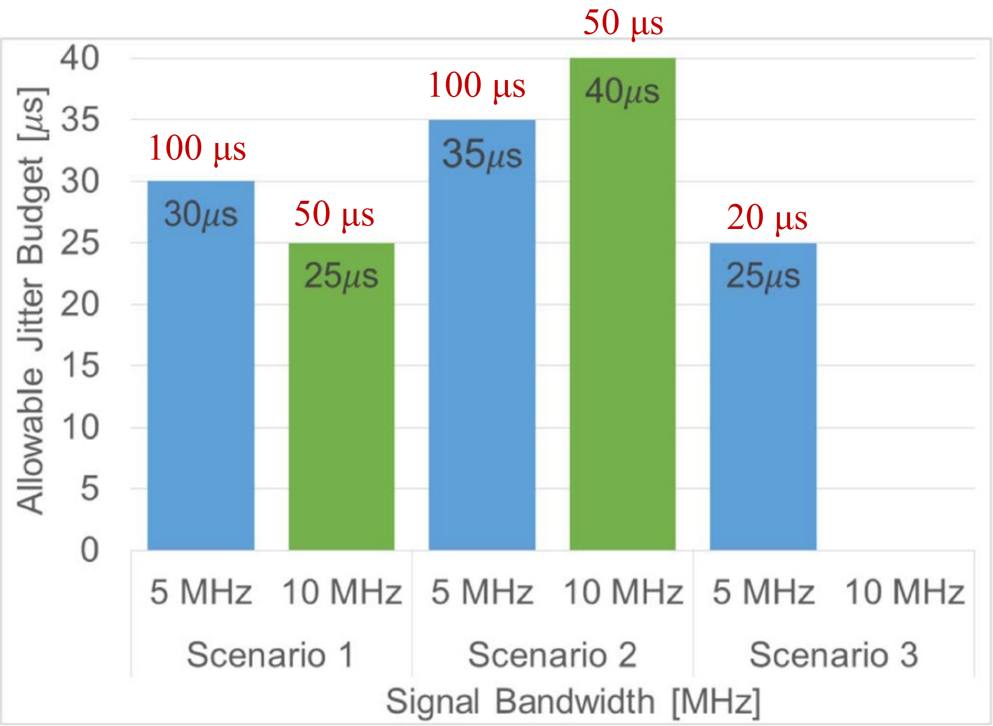
- The Jitter is applied to a latency value close to the fronthaul allowable latency budget
- The fixed latency value is choosen according to the scenario



- Jitter negatively impacts latency budget

Allowable Jitter Budget

- The Jitter is applied to a latency value far to the fronthaul allowable latency budget
- The fixed latency value is choosen according to the scenario



- Jitter negatively impacts fronthaul because there are periods in which not enough samples (i.e., modulation symbols) can be delivered to the PHY layer

Conclusions

- Experimental evaluation of the impact of virtualizing eNB functions on the fronthaul latency and jitter budget
- Functional split Option 7-1 (i.e. intra-PHY) and Option 8 (PHY-RF) are applied
- No virtualization
- Virtualization based on Virtualbox
- The fronthaul latency bandwidth reduction depends on the considered signal bandwidth (i.e. 5 MHz, 10 MHz) and on the number of functions running in the same device
- Virtualization decreases the allowable latency budget
- A jitter of at most 40 us can be tolerated

thank you!

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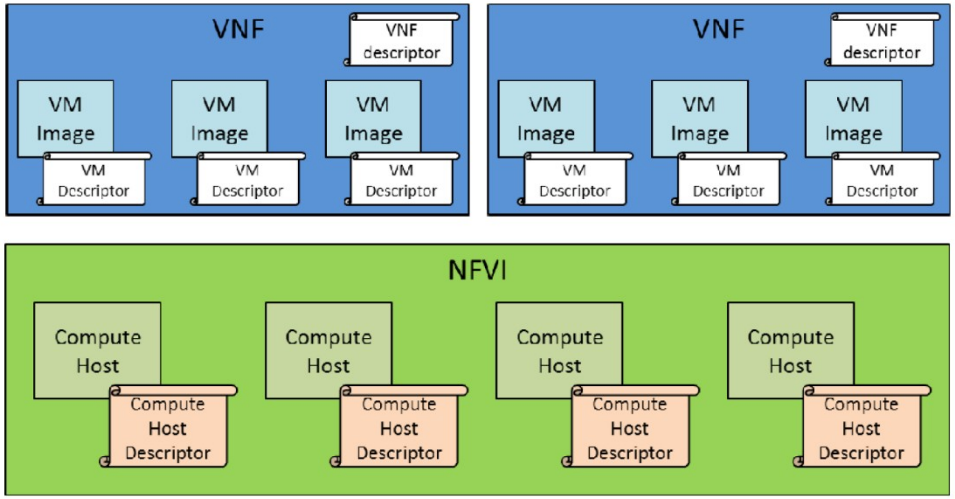
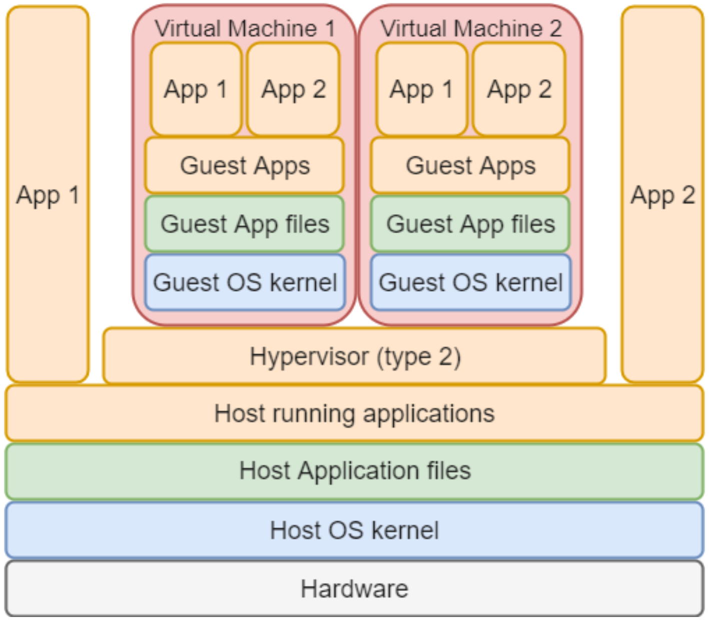
Backup Slides

gNB Virtualization

- ETSI (ETSI GS NFV-PER 001 V1.1.1 (2014-06)) descriptors:
  - Virtual Network Function (VNF)
  - Virtual Machine (VM)
  - Compute Host
- What virtualization implies:
  - ✓ applications running in the guest host have “to cross” several layers of abstraction.
  - ✓ Extra levels of abstraction reduce workload performance.
- Different virtualization types:
  - ✓ Hypervisor-based virtualizations:
    - ✓ allow to fully emulate a CPU architecture and OS;
  - ✓ Container-based virtualizations:
    - ✓ utilizes kernel features to create an isolated environment of the process using the host hardware.





Fronthaul requirements (TR 38.801)

	Opt. 1	Opt. 2	Opt. 3-2	Opt. 3-1	Opt. 5	Opt. 6	Opt. 7-3 (only for DL)	Opt. 7-2	Opt. 7-1	Opt. 8
Transport NW latency requirement	Loose				Not yet clarified	Tight				
Transport NW Peak BW requirement	N/A	Lowest	in between (higher on the right)							Highest
	No UP req.	baseband bits						Quantized IQ (f)		Quant. IQ (t)
	-	Scales with MIMO layers							Scales with antenna ports	

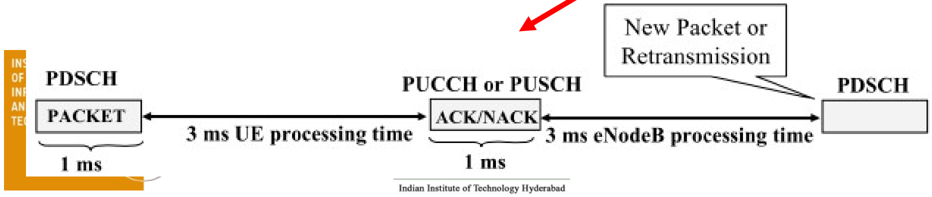
Protocol Split option[1]	Required bandwidth	Max. allowed one way latency [ms]
Option 7c	*[DL:10.1~22.2Gb/s]* *[UL:53.8~86.1Gb/s]*	[250us]
Option 8	*[DL:157.3Gb/s]* *[UL: 157.3Gb/s]*	[250us]

To be reviewed

due to 4ms HARQ process

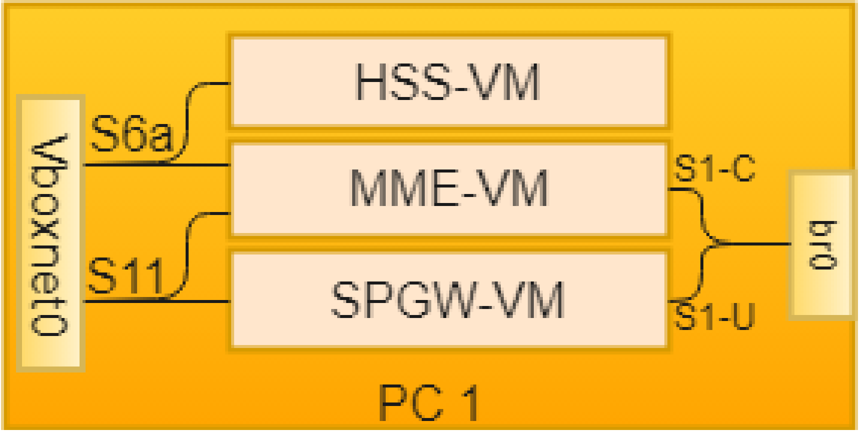
ASSUMPTIONS

Items	Assumption	Applicability
Channel Bandwidth	[100MHz(DL/UL)]	All options
Modulation	[256QAM(DL/UL)]	
Number of MIMO layer	[8(DL/UL)]	
IQ bitwidth	[2*(7~16)bit(DL), 2*(10~16)bit(UL)]	Option 7a Option 7b Option 7c
	[2*16bit(DL/UL)]	Option 8
Number of antenna port	[32(DL/UL)]	Option 7b Option 7c(UL) Option 8


New Packet or Retransmission
PDSCH
PACKET
1 ms
3 ms UE processing time
PUCCH or PUSCH
ACK/NACK
1 ms
3 ms eNodeB processing time
PDSCH
Indian Institute of Technology Hyderabad

Source: LTE for UMTS: Evolution to LTE-Advanced, 2nd Edition
Harri Holma, Antti Toskala
ISBN: 978-0-470-66000-3

Virtualized EPC and CU Network configuration



- HSS-VM:
  - ✓ 1 Virtual Interfaces in host-only networking (s6a interface);
- MME-VM:
  - ✓ 1 Virtual Interfaces in host-only networking mode (S6a interface);
  - ✓ 1 Virtual Interfaces in bridge networking mode (S1-C interface);
- SPGW-VM:
  - ✓ 1 Virtual Interfaces in host-only networking mode (S11 interface);
  - ✓ 1 Virtual Interfaces in bridge networking mode (S1-U interface)
- CU-VM:
  - ✓ 1 Virtual Interfaces in bridge networking mode (S1-U and S1-C interfaces);
  - ✓ 1 Virtual Interfaces in bridge networking mode (fronthaul link).