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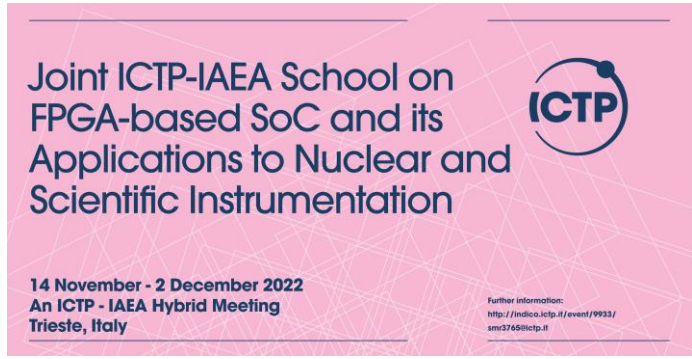

Programmable hardware acceleration in Communication Networks

L. Valcarenghi
Scuola Superiore Sant'Anna, Pisa, Italy

Joint ICTP-IAEA School on FPGA-based SoC and its Applications to Nuclear and Scientific Instrumentation
Nov. 16, 2022, Trieste, Italy

Outline

- Who we are
- 5G mobile networks
- 5G function offloading
- Conclusions

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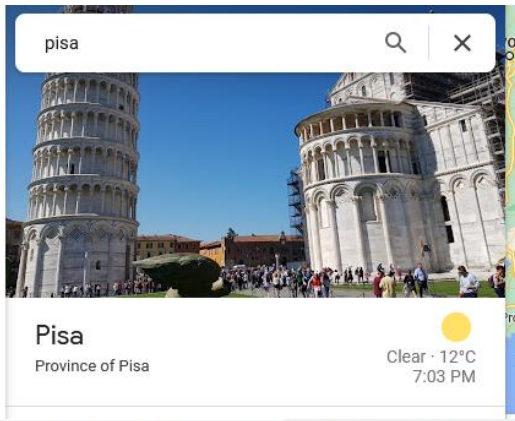
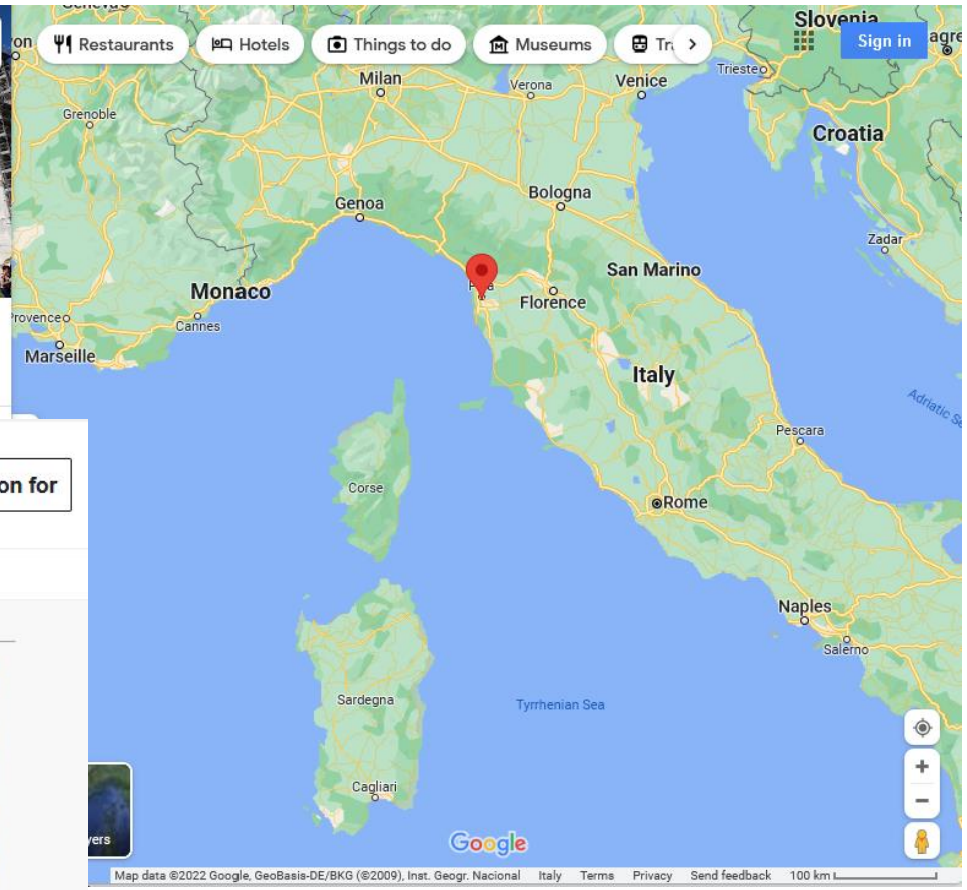
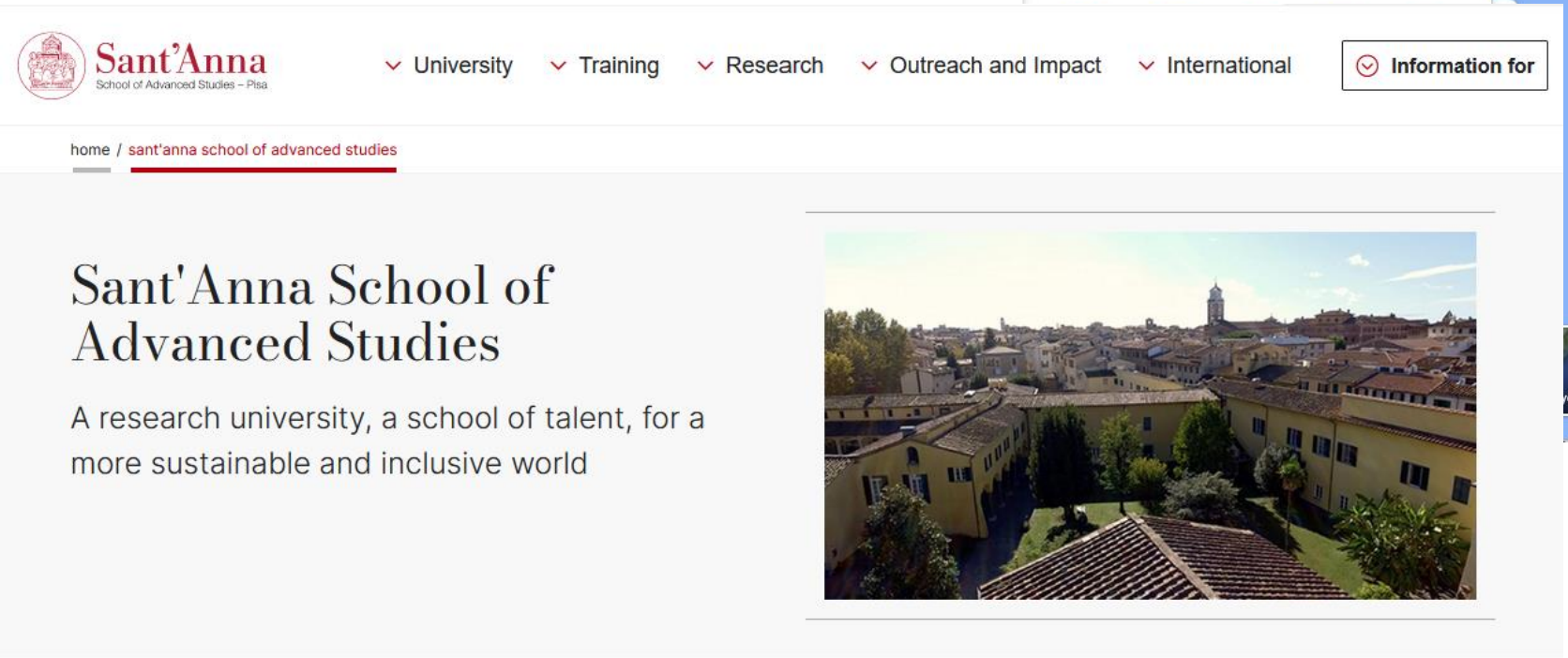
- https://www.santannapisa.it/en
- https://www.youtube.com/user/ScuolaSantanna







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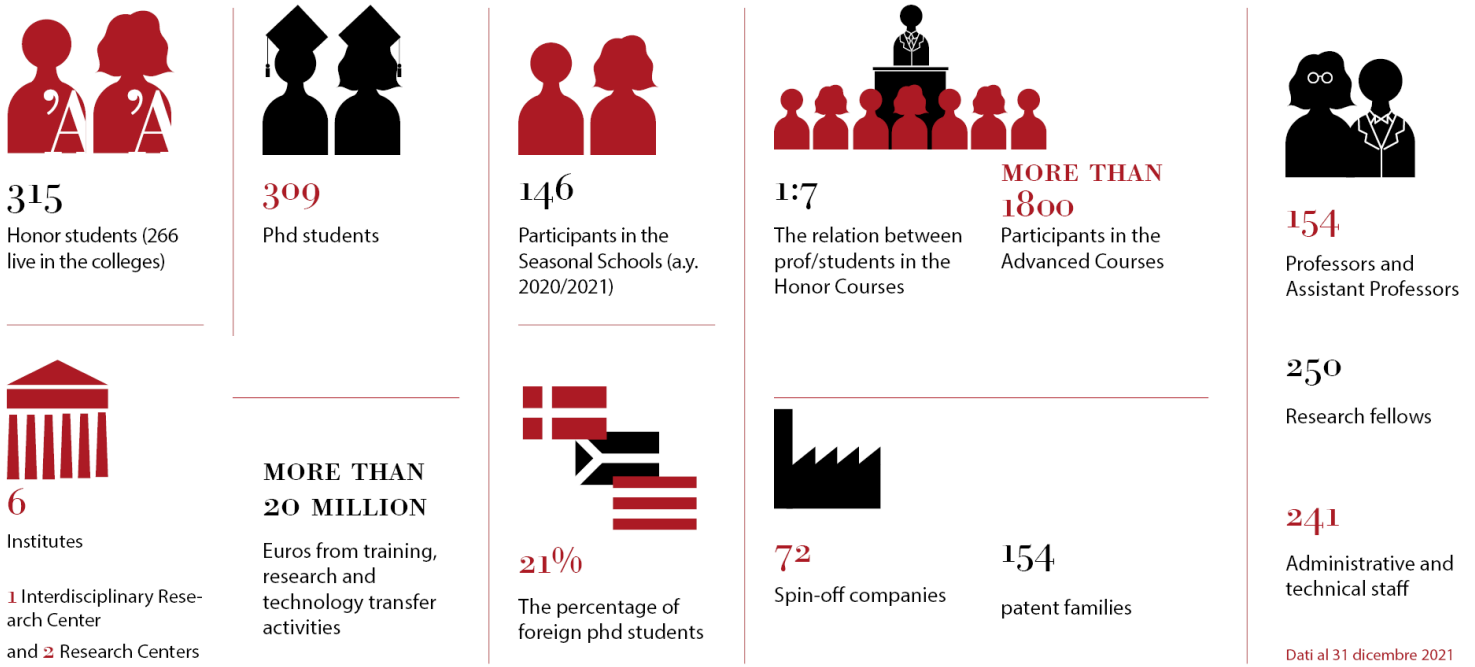
SSSA in Numbers



- Publications
  - number of publications of Scuola Superiore Sant'Anna on Scopus has exceeded 11,500 papers
  - In the 2016-2021 period, Scuola Superiore Sant'Anna accumulated 57,428 citations, with an average of 11.1 citations per product and a weighted impact, in terms of citations, (FWCI) of 1.62

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- 1st a the national level on a census of 17 institutions
- 7th at the european level
- 14th a the international level on a census of 790 institutions

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THE BIOROBOTICS INSTITUTE

The Institute has built a wealth of knowledge in several fields of biorobotics and bionics, such as medical robotics, wearable and collaborative technologies, bioinspired robotics, neuroscience robotics, prosthesis and computational modeling

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DIRPOLIS INSTITUTE

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INSTITUTE OF ECONOMICS

Economics, macroeconomics, models of dynamic systems

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Research, training and social impact in the fields of innovation, sustainability and healthcare

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The TeCIP Institute

- TeCIP Institute= Telecommunications, Computer Engineering, and Photonics Institute

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Retis Real-Time Systems Laboratory

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- Adaptive Resource Management
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- Automatic code generation
- Real-time communication protocols
- Algorithms for energy saving management

InRete

- Networks and services
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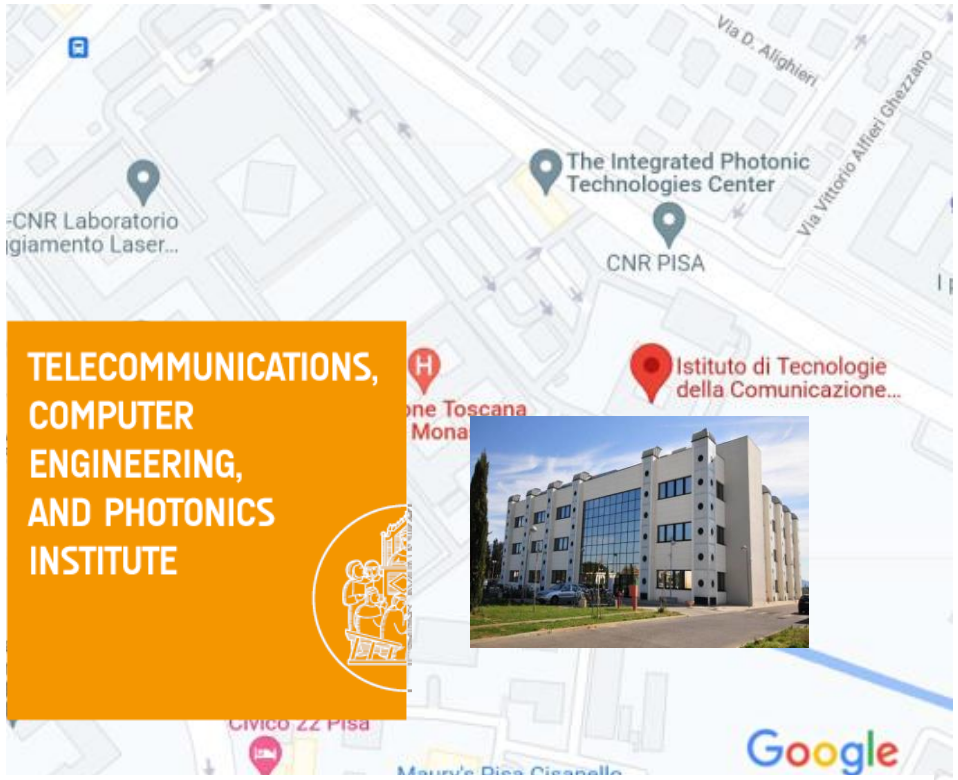
- Optical communication theory and techniques
- Digital and microwave photonics
- Optical sensors and integrated photonic subsystems
- High-capacity optical systems
- Advanced technologies for integrated photonics.



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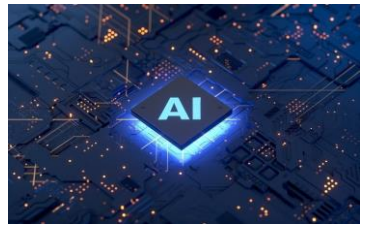
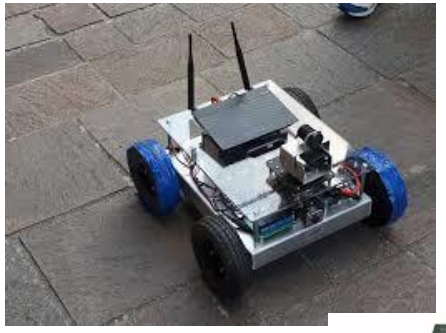
Research





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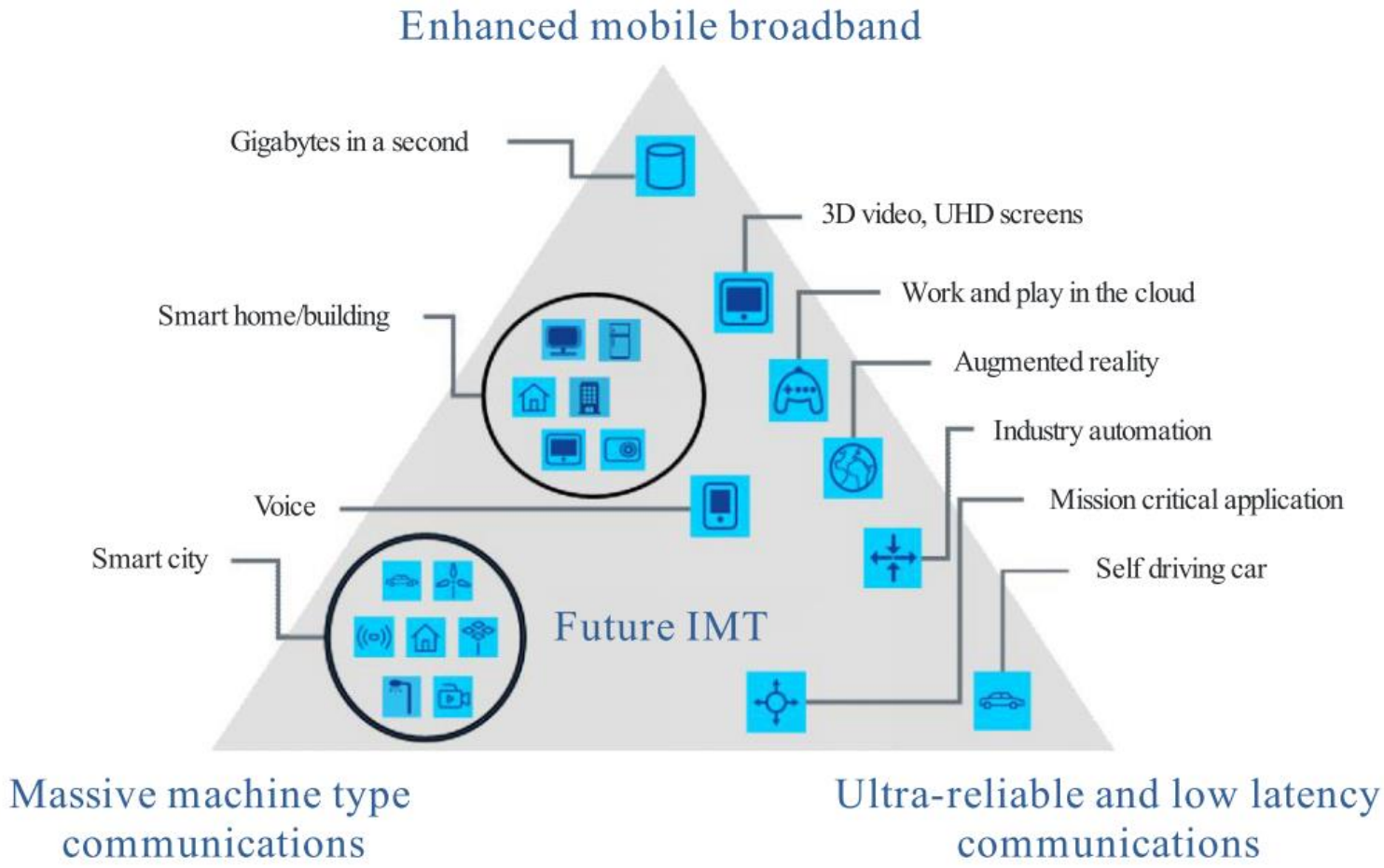
IMT-2020 Usage Scenarios and 5G



Source: Recommendation ITU-R M.2083-0, 09/2015
IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond

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ITU-R M.2150-0

- Recommendation ITU-R M.2150-0 (02/2021), “Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2020 (IMT-2020)”, M Series, Mobile, radiodetermination, amateur and related satellite services
- https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2150-0-202102-I!!PDF-E.pdf
- IMT-2020 specifications, known as 5G, have been developed by 3GPP and consist of long-term evolution (LTE) and new radio (NR) Releases 15 and beyond.
- In 3GPP terminology, the term Evolved-UMTS Terrestrial Radio Access (E-UTRA) is also used to signify the LTE radio interface.
- 5G is a set of radio interface technologies (RITs) consisting of E-UTRA/LTE as one component RIT and New Radio (NR) as the other component RIT.

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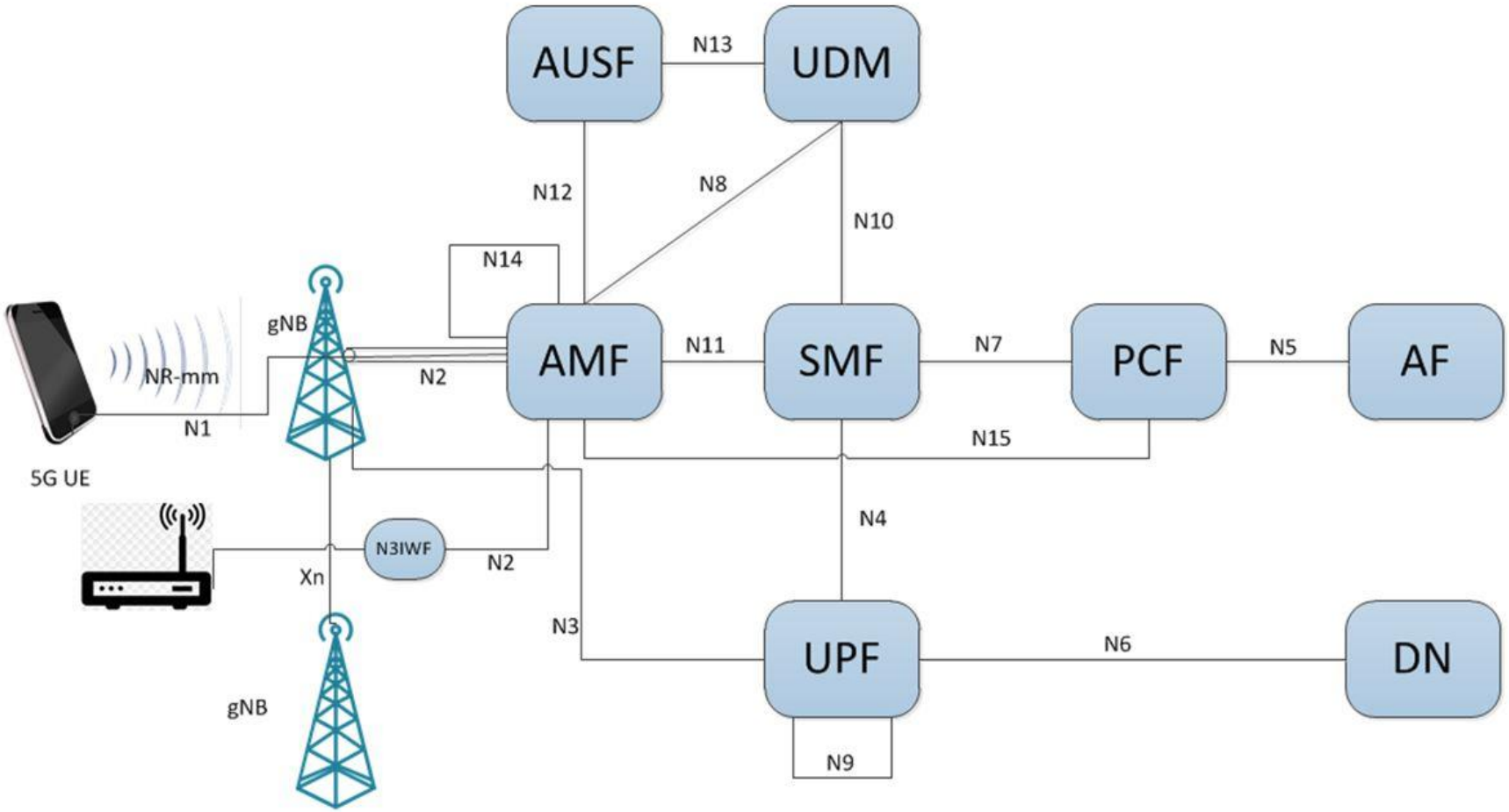
5G Architecture



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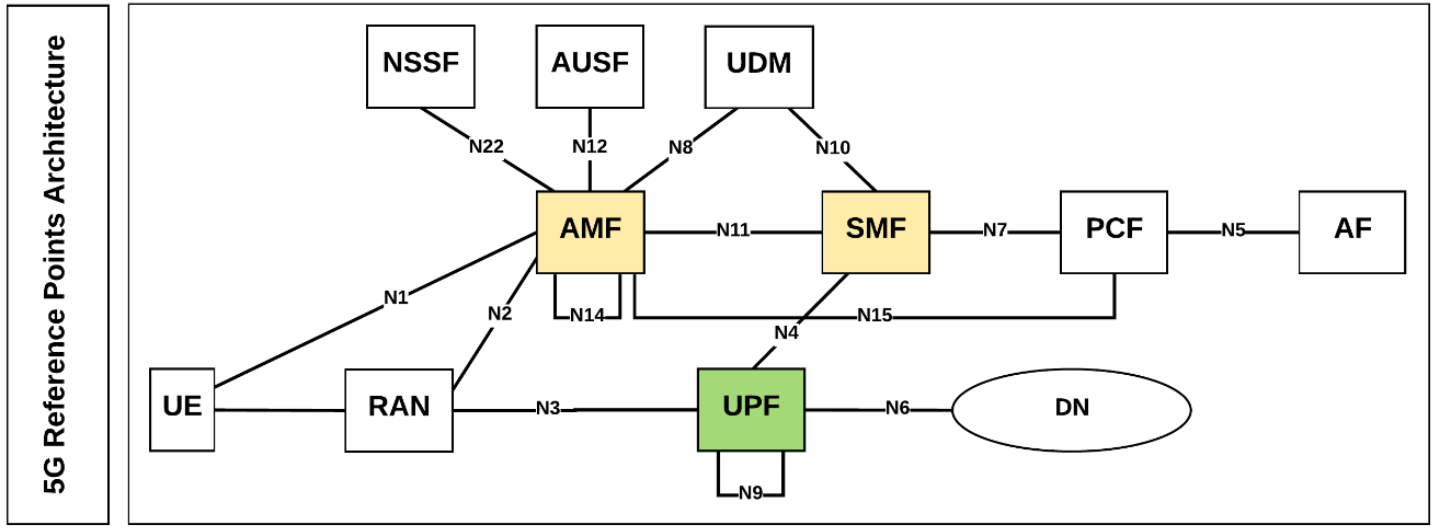
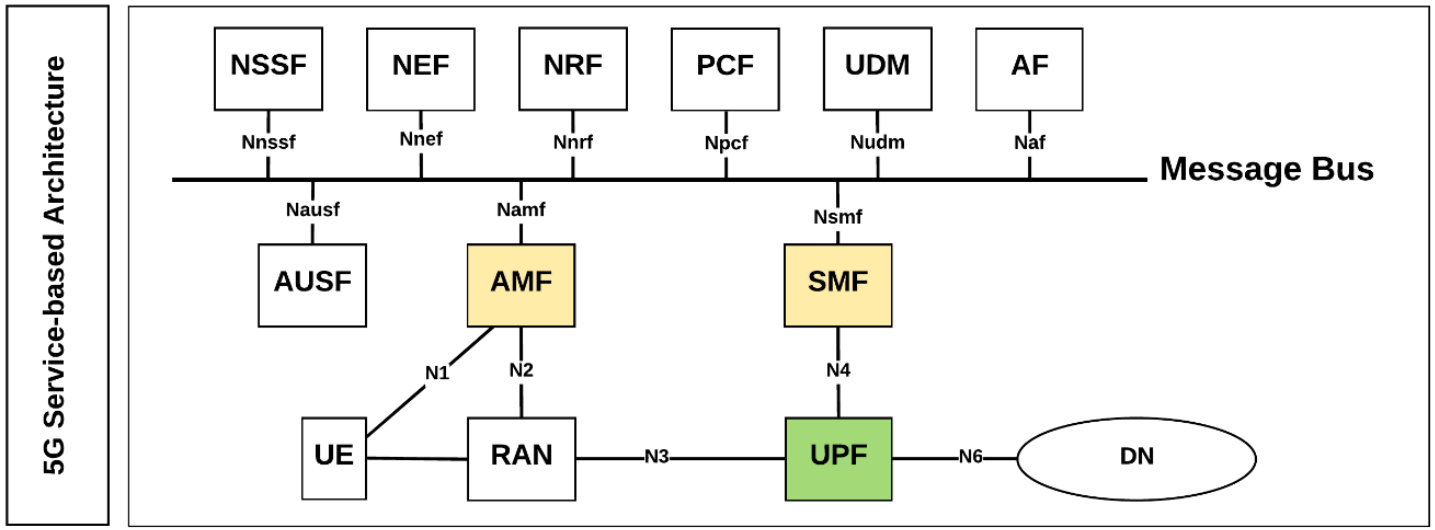
5G Architecture Functional Elements





Source: ETSI TS 123 501 V15.2.0 (2018-06)5G;System Architecture for the 5G System (3GPP TS 23.501 version 15.2.0 Release 15)

AMF: Access & Mobility Management Function
SMF: Session Management Function
UPF: User Plane Function
NEF: Network Exposure Function
NRF: NF Repository Function
NSSF: Network Slice Selection Function
UDM: Unified Data Function
AUSF: Authentication Server Function
PCF: Policy Control Function

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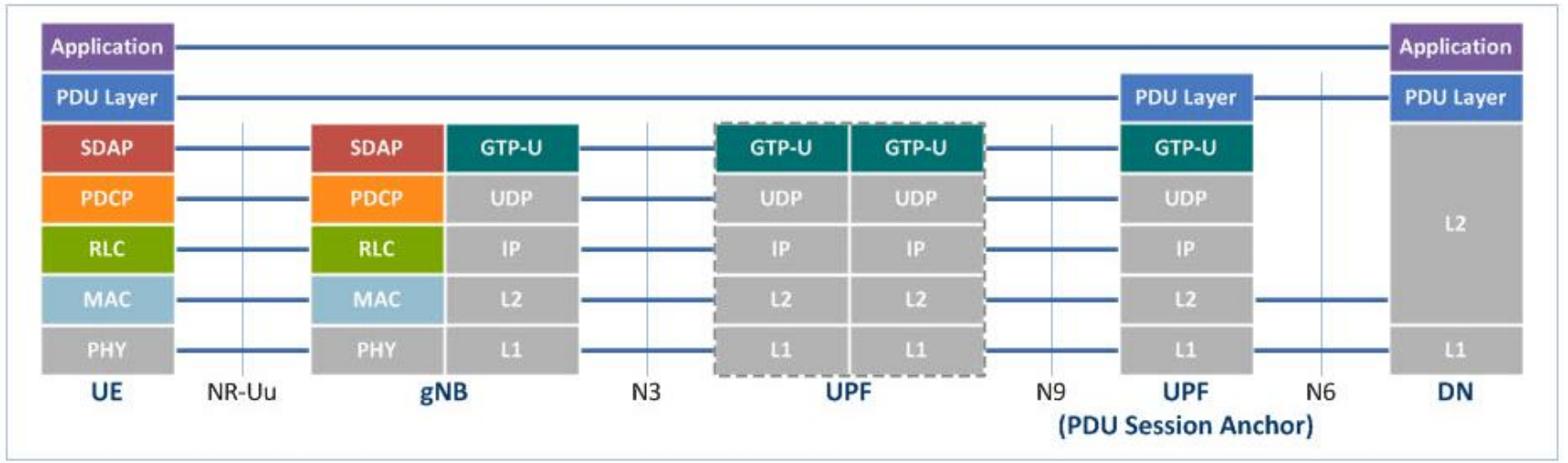
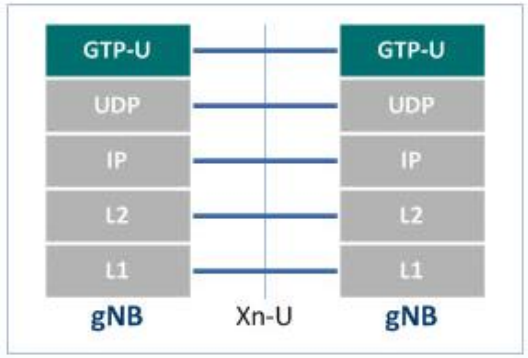
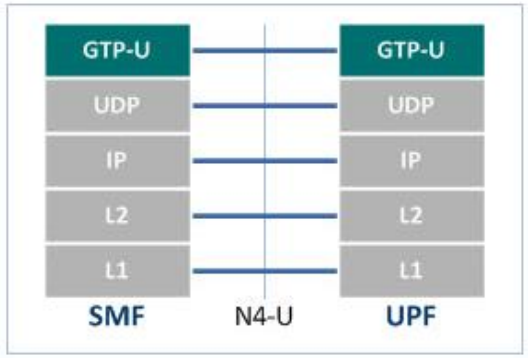
5G Protocol Stack: User Plane



PDU Layer: IP, Ethernet, etc.





DN	: Data Network
gNB	: Next generation NodeB
GTP-U	: GPRS Tunneling Protocol User plane
MAC	: Medium Access Control
PDCP	: Packet Data Convergence Protocol
PDU	: Protocol Data Unit
RLC	: Radio Link Control
SDAP	: Service Data Adaptation Protocol
SMF	: Session Management Function
UE	: User Equipment
UPF	: User Plane Function
Xn-U	: Xn User plane

Source: https://www.netmanias.com/en/post/oneshot/14103/5g/5g-protocol-stack-user-plane-control-plane

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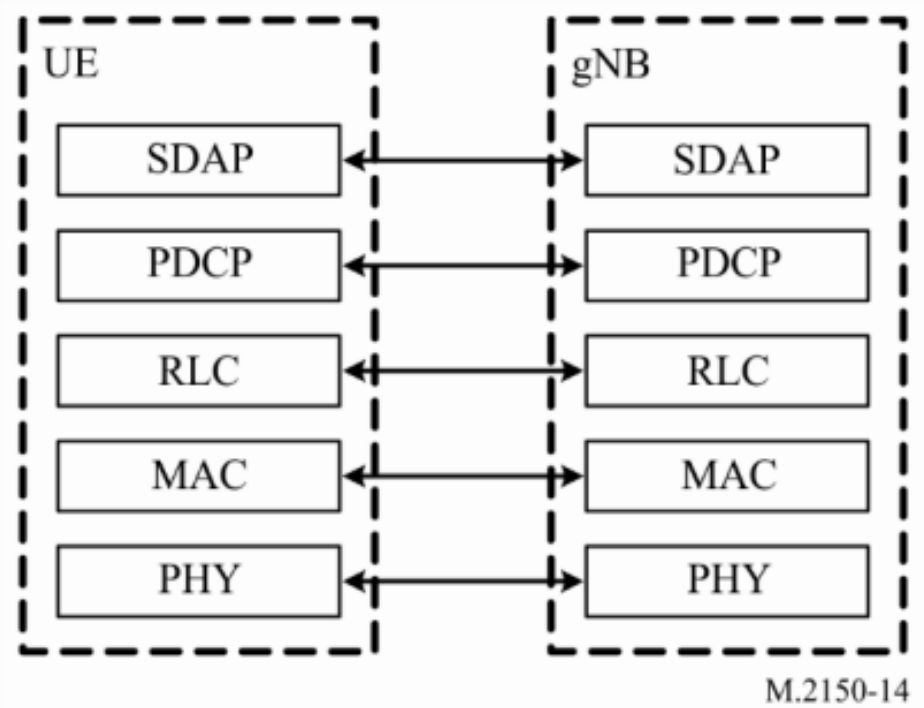
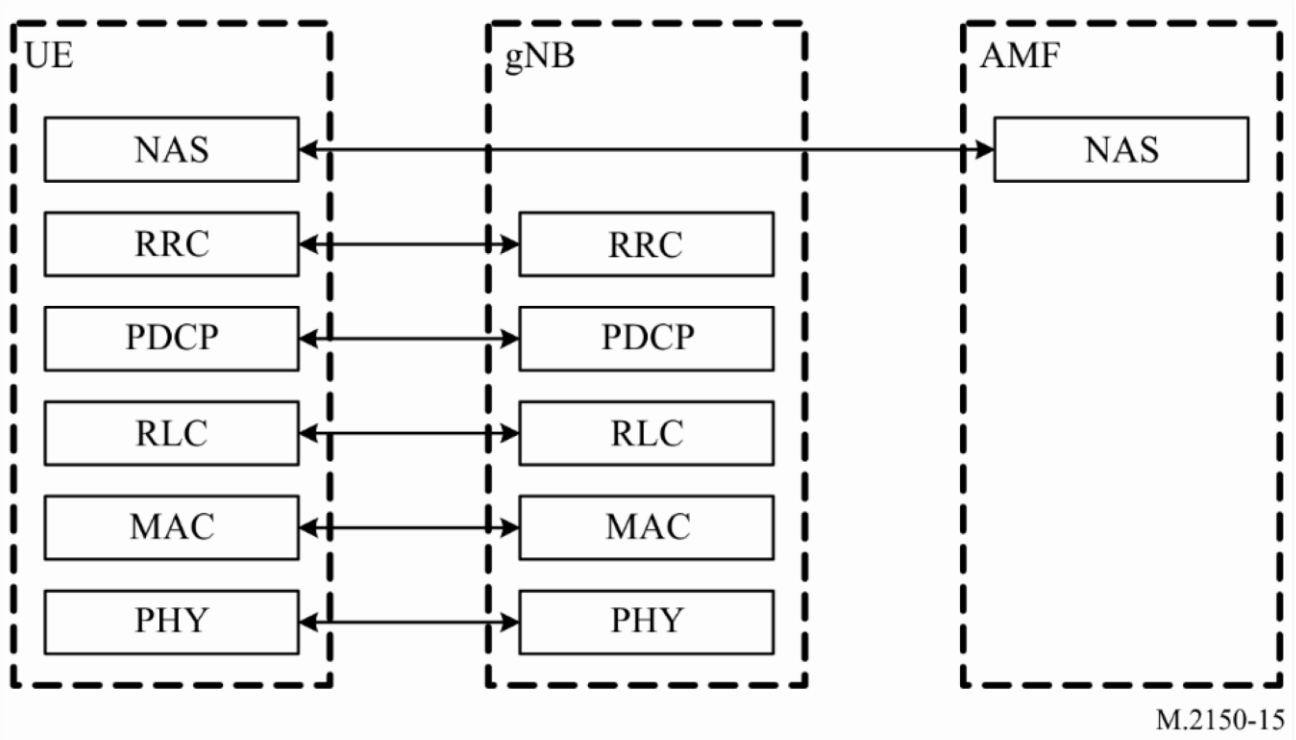
5G Radio Protocol Architecture

User Plane protocol stack



Control Plane Protocol Stack



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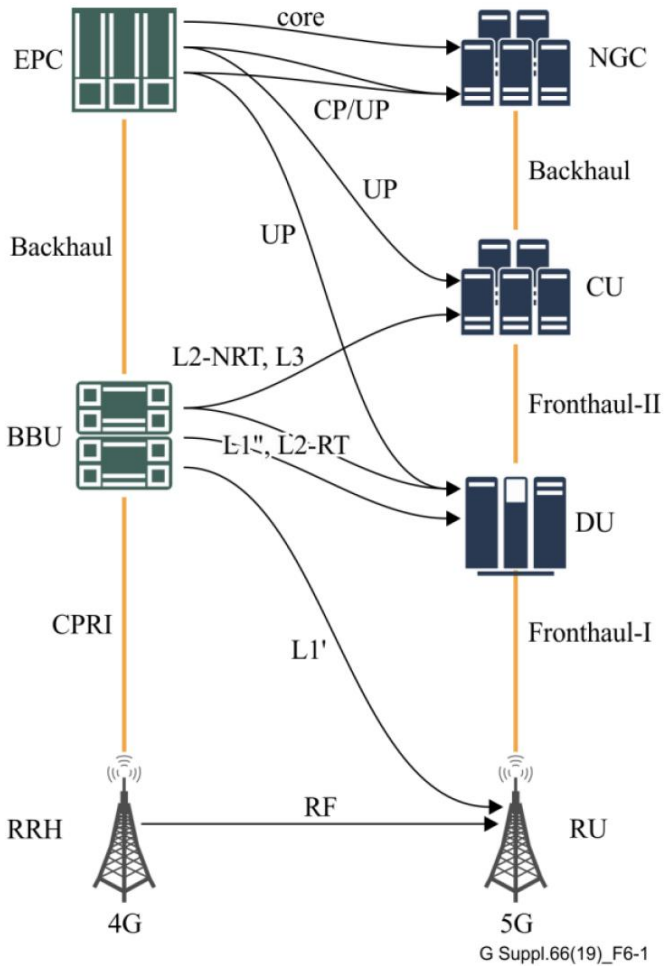
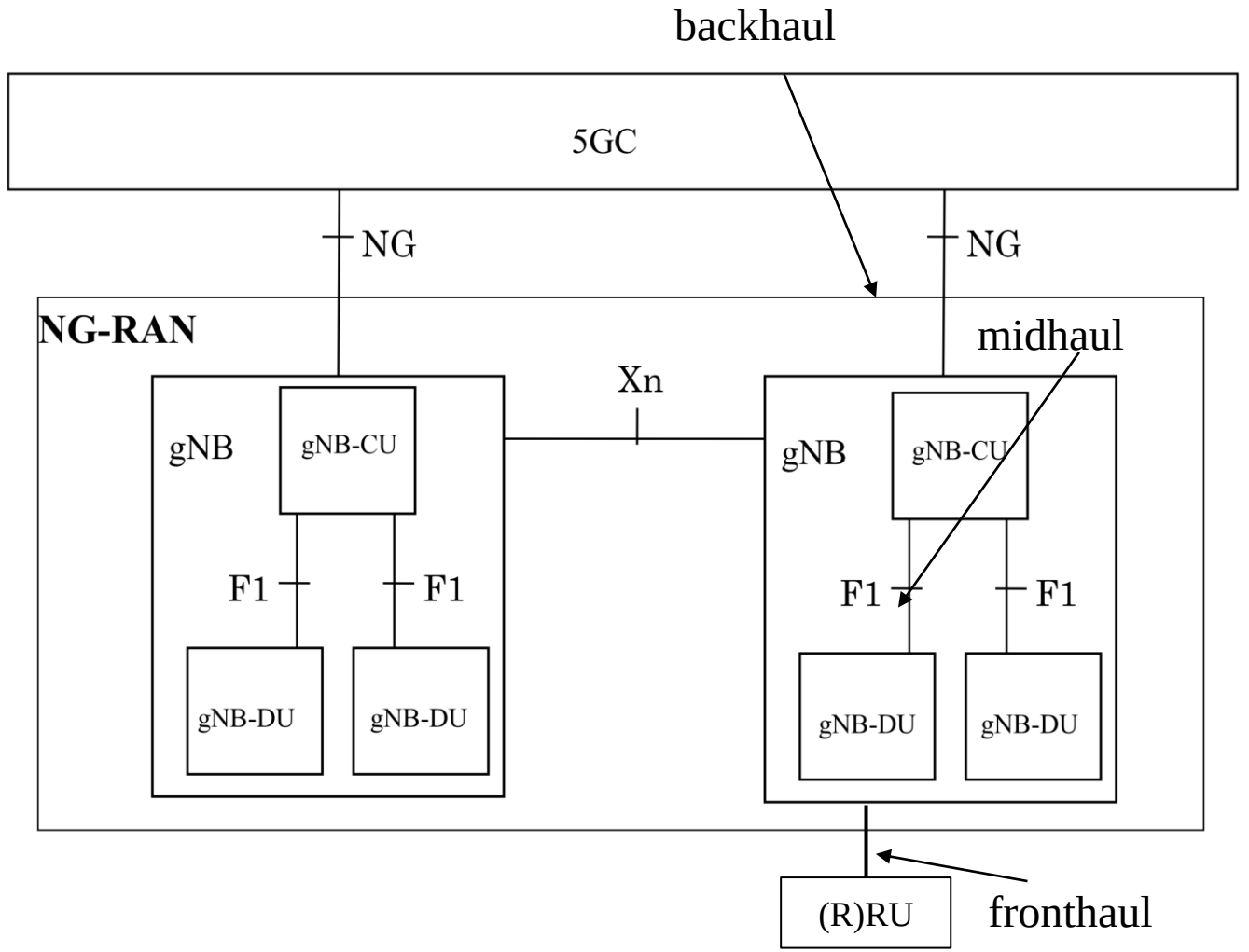
NG-RAN and Disaggreagated gNB





Source: ITU-T, Technical Report, "GSTR-TN5G Transport network support of IMT-2020/5G, 19 October 2018

ITU-T Series G Supplement 66 (09/2020) (G.Sup66), 5G wireless fronthaul requirements in a passive optical network context

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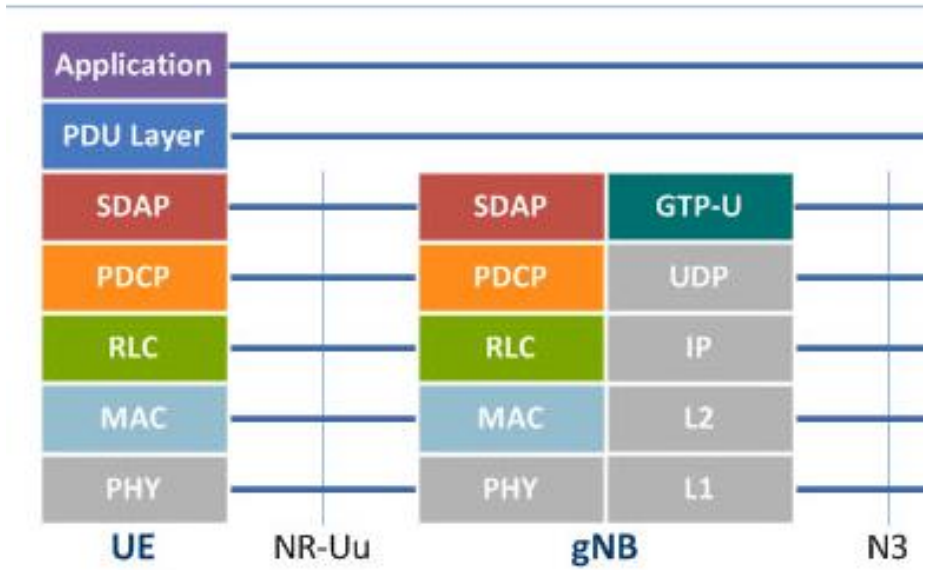
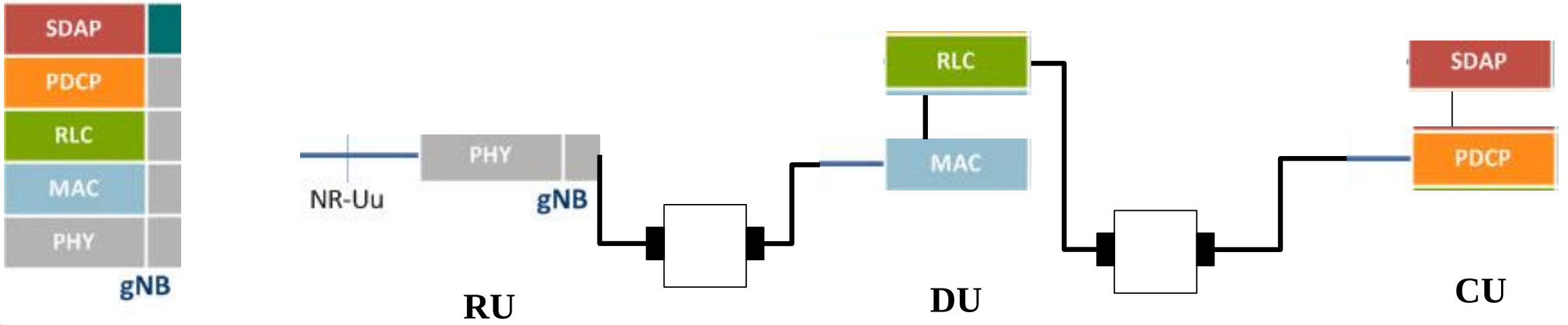
5G Protocol Stack: User Plane





Source: https://www.netmanias.com/en/post/oneshot/14103/5g/5g-protocol-stack-user-plane-control-plane

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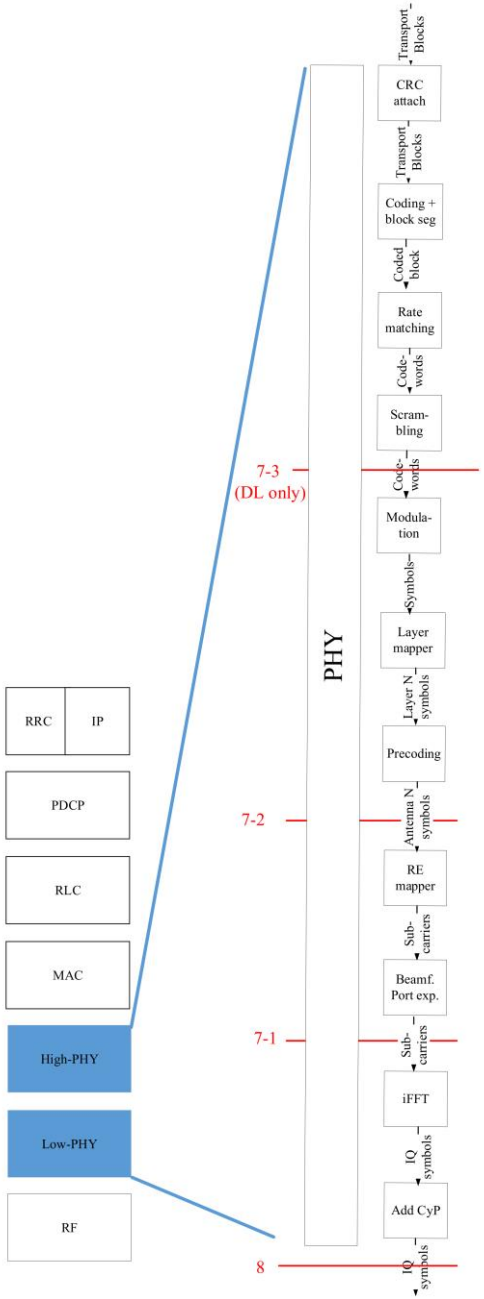
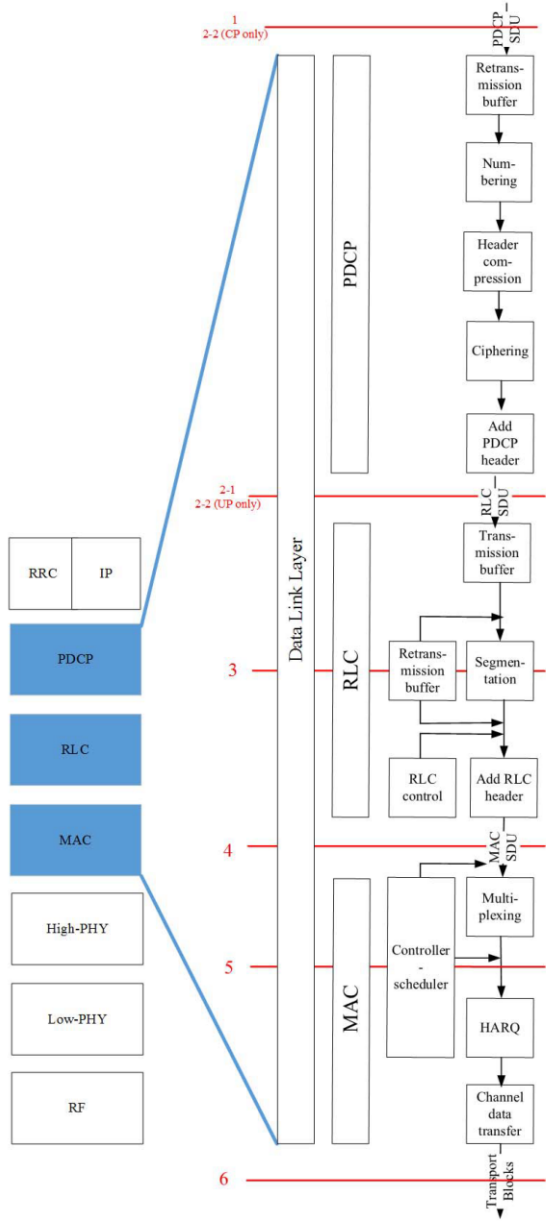
Summary gNB Functional Splits





Source: L. M. P. Larsen, A. Checko and H. L. Christiansen, "A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks," in IEEE Communications Surveys & Tutorials, vol. 21, no. 1, pp. 146-172, Firstquarter 2019, doi: 10.1109/COMST.2018.2868805.

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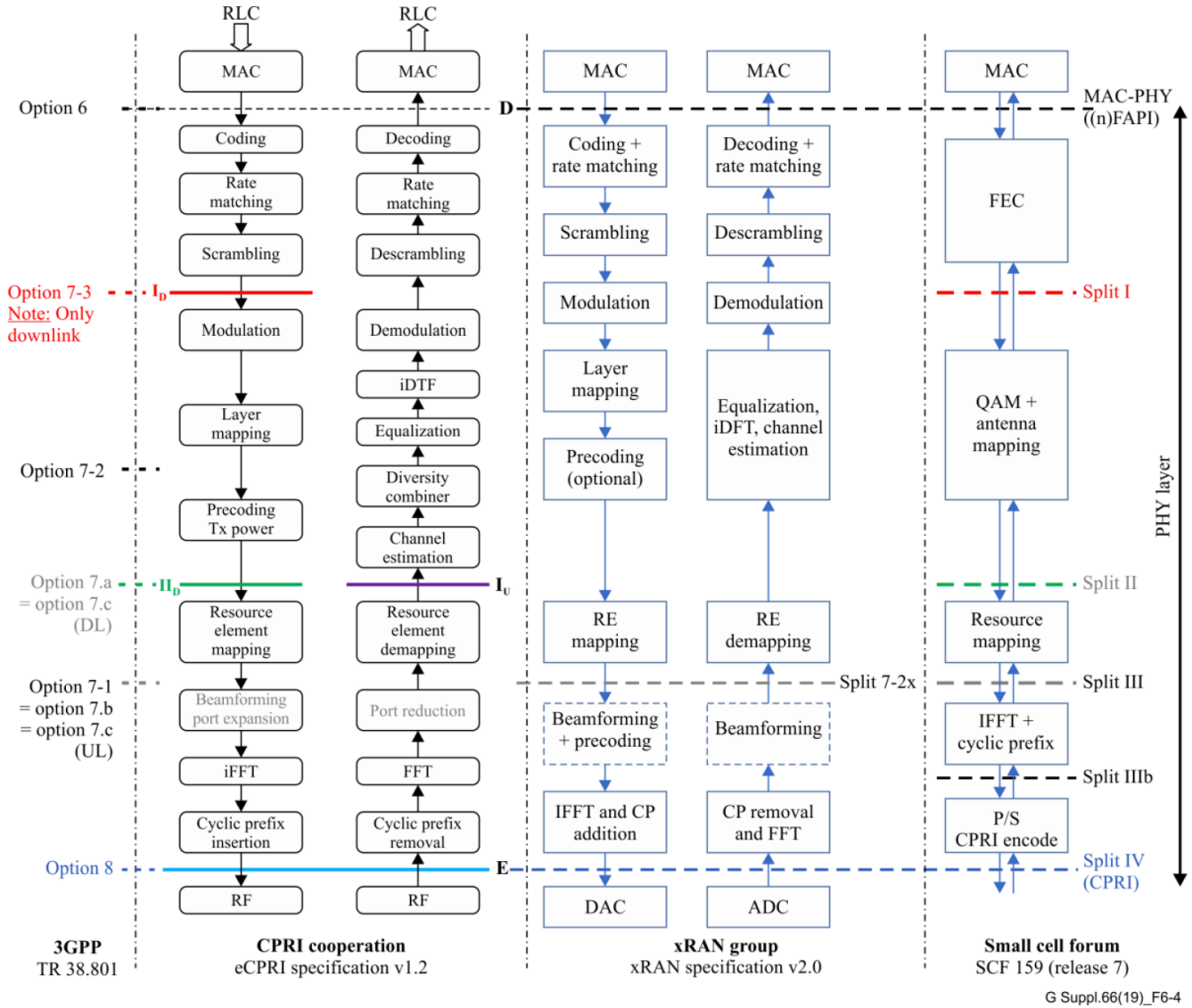
Detailed Comparison of Option 7 Subsplit



Source: ITU-T Series G Supplement 66 (09/2020) (G.Sup66), 5G wireless fronthaul requirements in a passive optical network context

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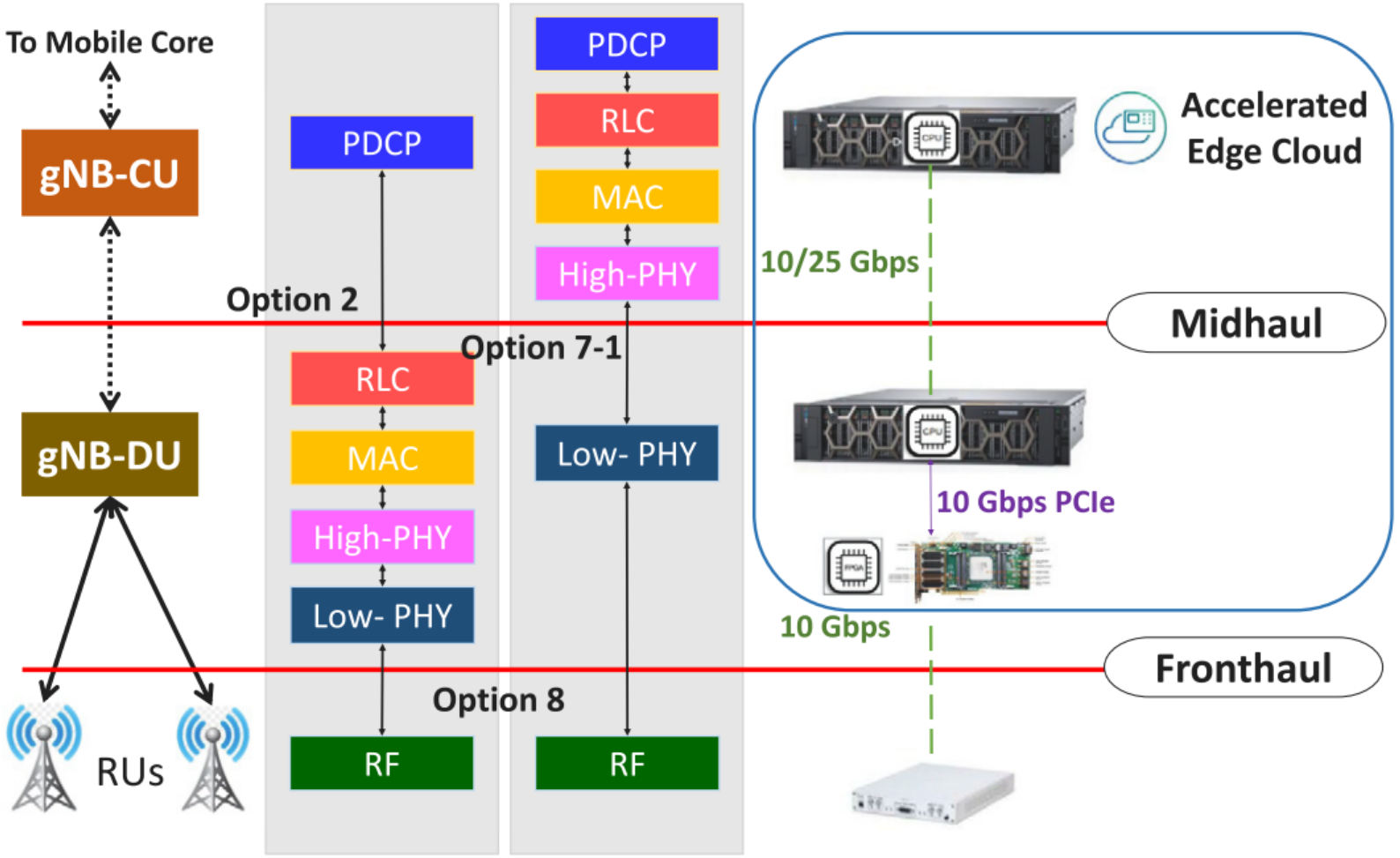
Programmable Hardware Acceleration of 5G Functions



Source: Justine Cris Borromeo, Koteswararao Kondepu, Nicola Andriolli, Luca Valcarenghi, "FPGA-accelerated SmartNIC for supporting 5G virtualized Radio Access Network," Computer Networks, Volume 210, 2022, 108931, ISSN 1389-1286, https://doi.org/10.1016/j.comnet.2022.108931.

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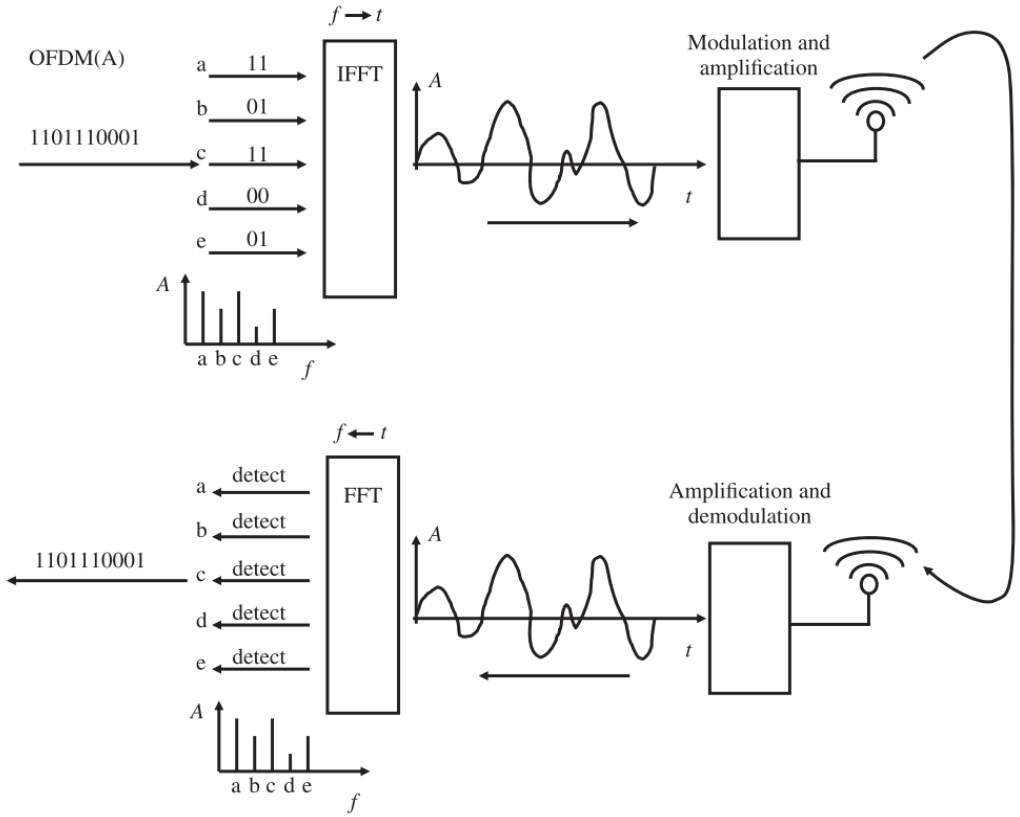
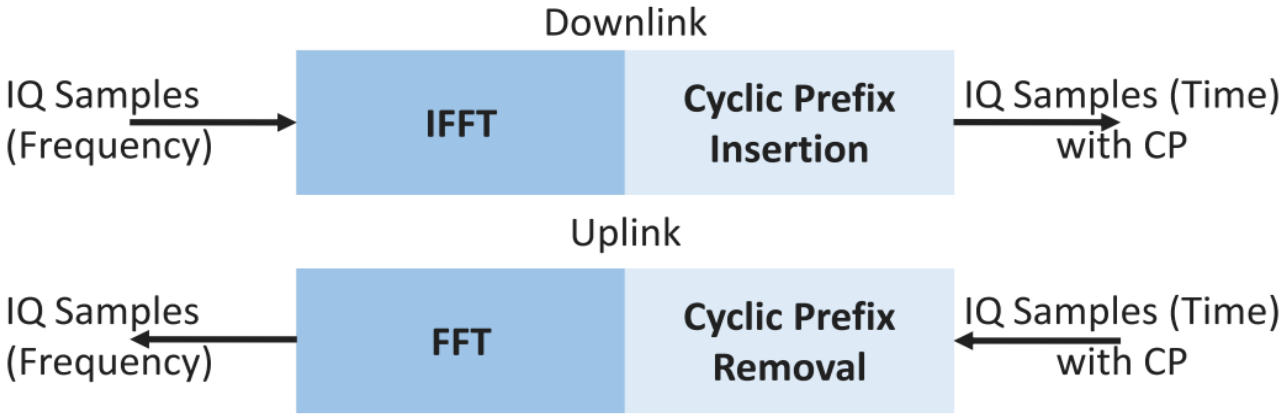
FFT/IFFT and OFDM





$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{nk}; k = 0, 1, \ldots, N-1$$

Samples in the frequency domain

Samples in the time domain

$$W_N^{nk} = e^{-j2nk\pi/N}$$

Number of subcarriers = FFT points

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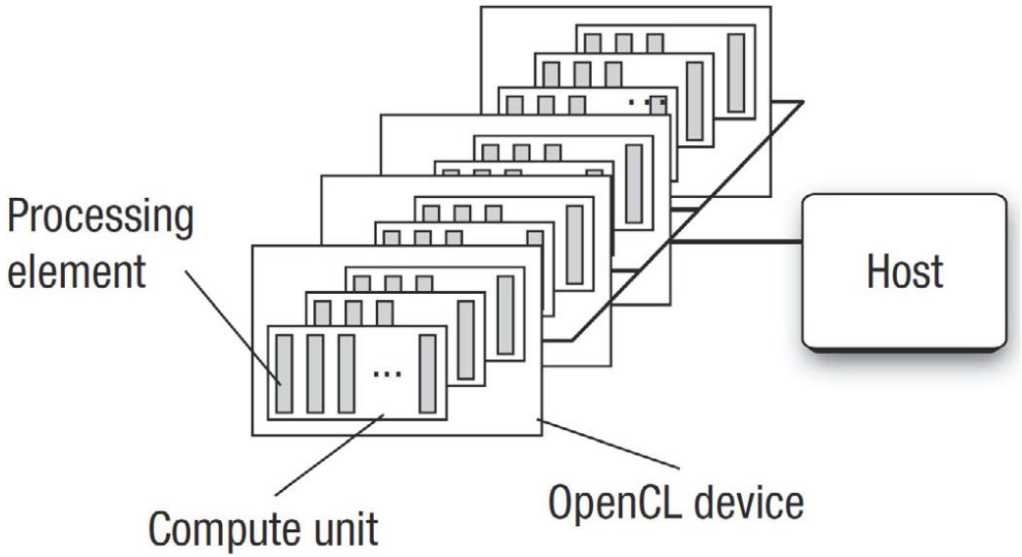
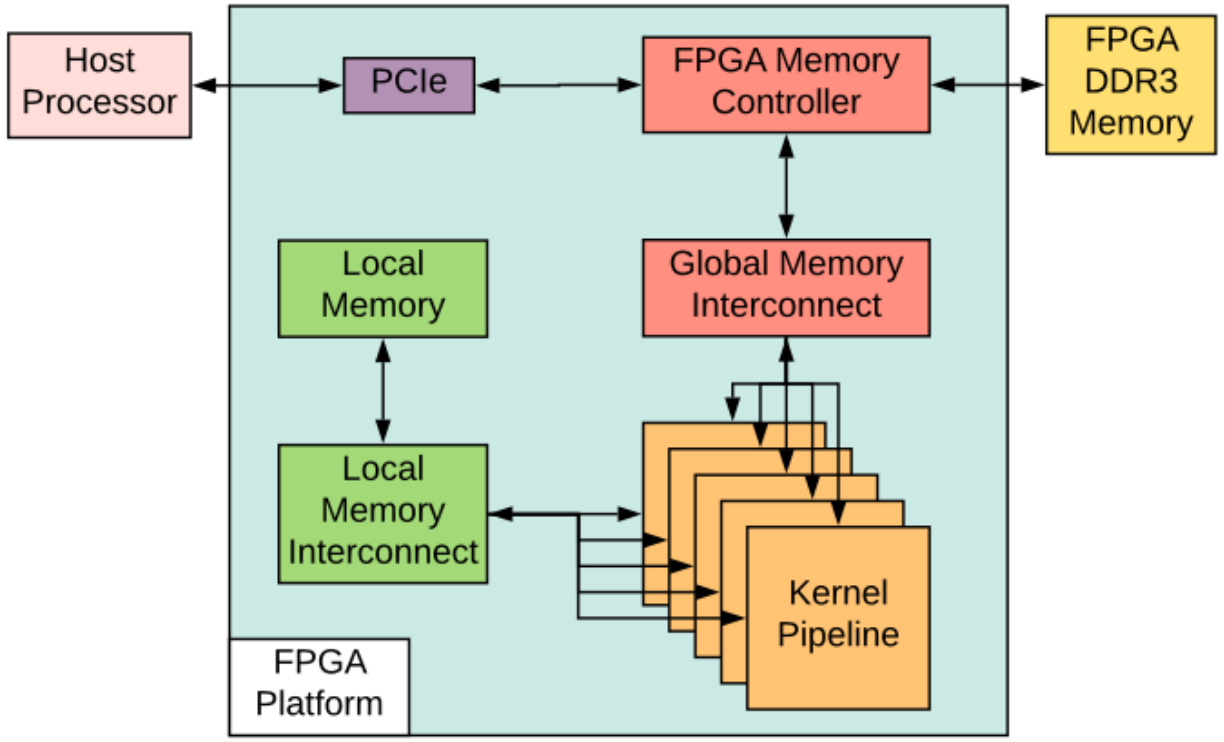
Open CL for Programmable Hardware and Software Integration





Source: F. Civerchia, M. Pelcat, L. Maggiani, K. Kondepu, P. Castoldi and L. Valcarenghi, "Is OpenCL Driven Reconfigurable Hardware Suitable for Virtualising 5G Infrastructure?," in IEEE Transactions on Network and Service Management, vol. 17, no. 2, pp. 849-863, June 2020, doi: 10.1109/TNSM.2020.2964392.

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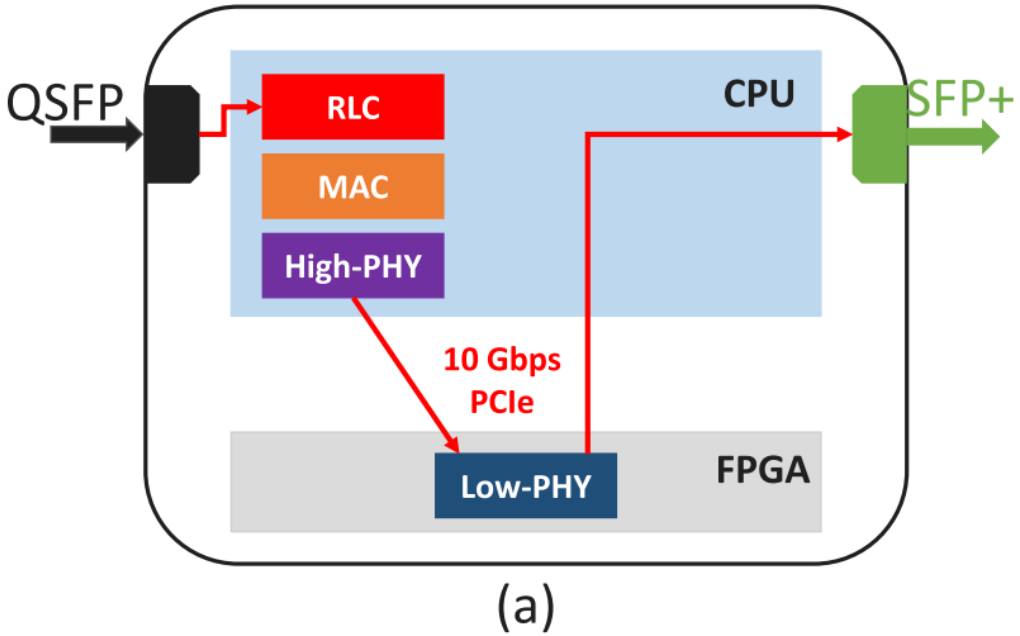
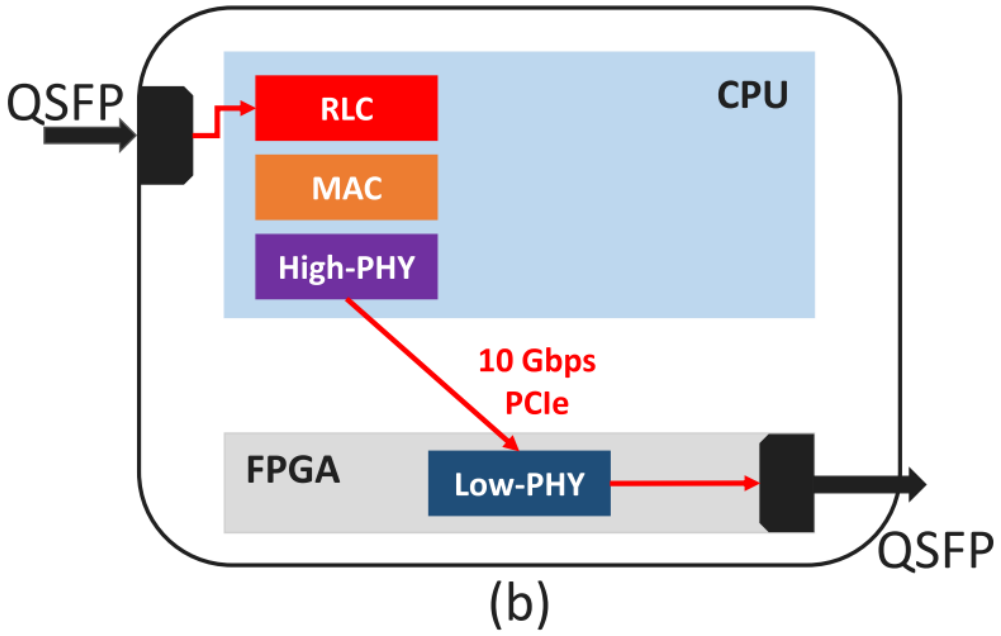
SmartNIC-based Implementation





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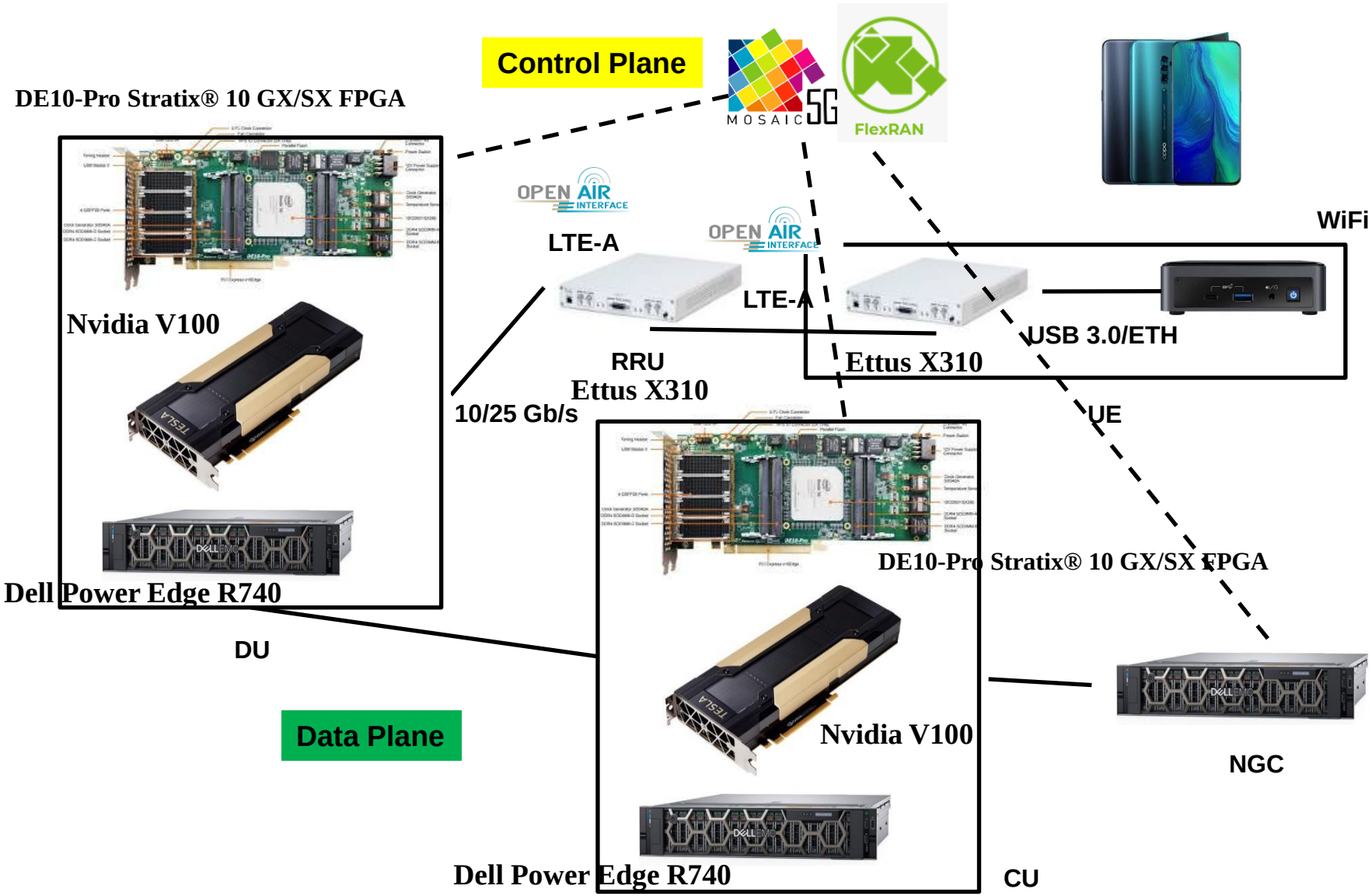
SSSA 5G Testbed Setup



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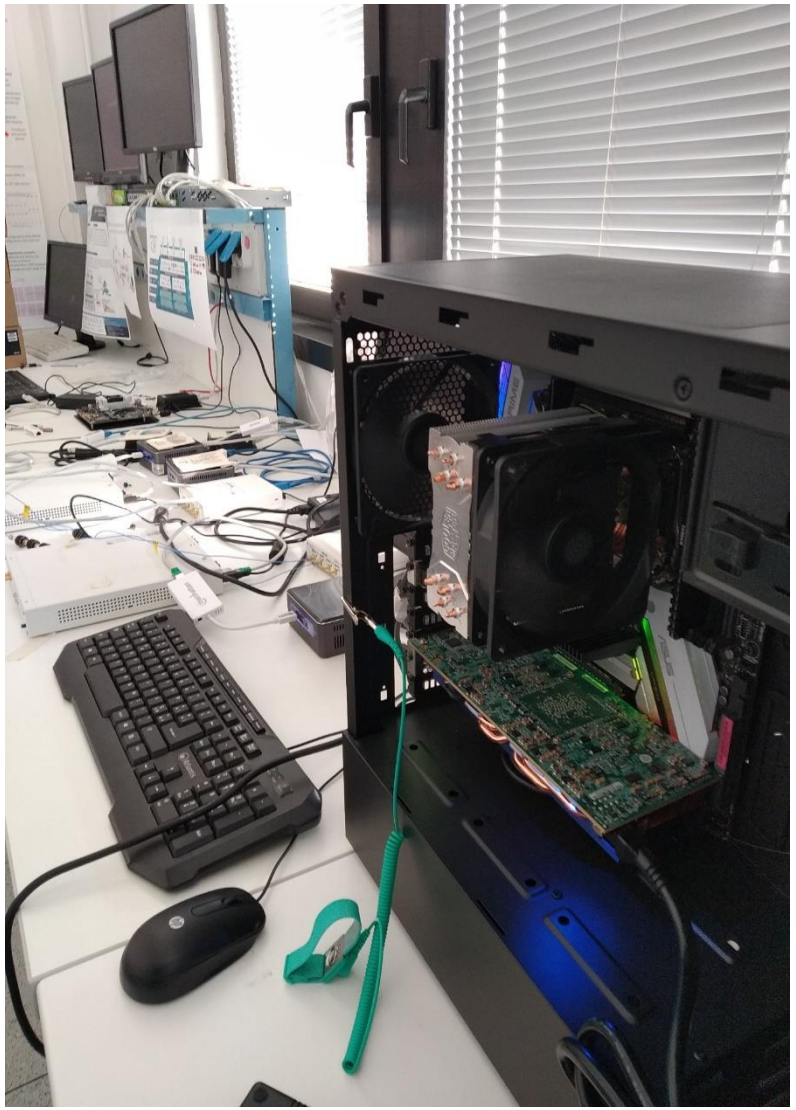
5G Testbed Setup Picture



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Performance Evaluation for IFFT Implementation

- DU Low-PHY functions are offloaded onto a DE10-pro development board with Stratix 10 FPGA, two 8 GB DDR4 memory modules and PCIe v3.0 with 16 slots at 32 GB/s bandwidth
- The CPU-based implementation is executed in an Intel Core i7-7700K@4.2 GHz and based on Intel Advanced Vector Extension 2 (AVX2)
- The GPU-based implementation *clfft* and *cufft* is based on an NVIDIA Tesla T4 GPU featuring 320 NVIDIA Turing tensor cores,16 GB GDDR6 memory modules, and PCIe v3.0 with 16 slots

Table 3
OpenCL optimization result on 128 OFDM symbols.

	Version 1	*Version 2*	*Version 3*	*Version 4*	*Version 5*
Processing time [μs]	34.37	23.5	23.45	21.4	15.43
Logic gate utilization	14%	25%	21%	19%	21%
DSP utilization	<1%	5%	4%	3%	3%
Memory utilization	2%	2%	2%	3%	5%
RAM utilization	4%	6%	6%	7%	11%
Kernel frequency [MHz]	239.23	366.7	285.63	484.26	484.78

Table 4
FPGA resources and kernel operating frequency of Low-PHY layer functions with different IFFT points.

	128	*256*	*512*	*1024*	*2048*
Logic gate utilization	21%	26%	36%	51%	66%
DSP utilization	3%	3%	8%	14%	14%
Memory utilization	5%	6%	11%	15%	15%
RAM utilization	11%	13%	16%	23%	23%
Kernel frequency [MHz]	484.78	461.68	390.93	299.67	146.26

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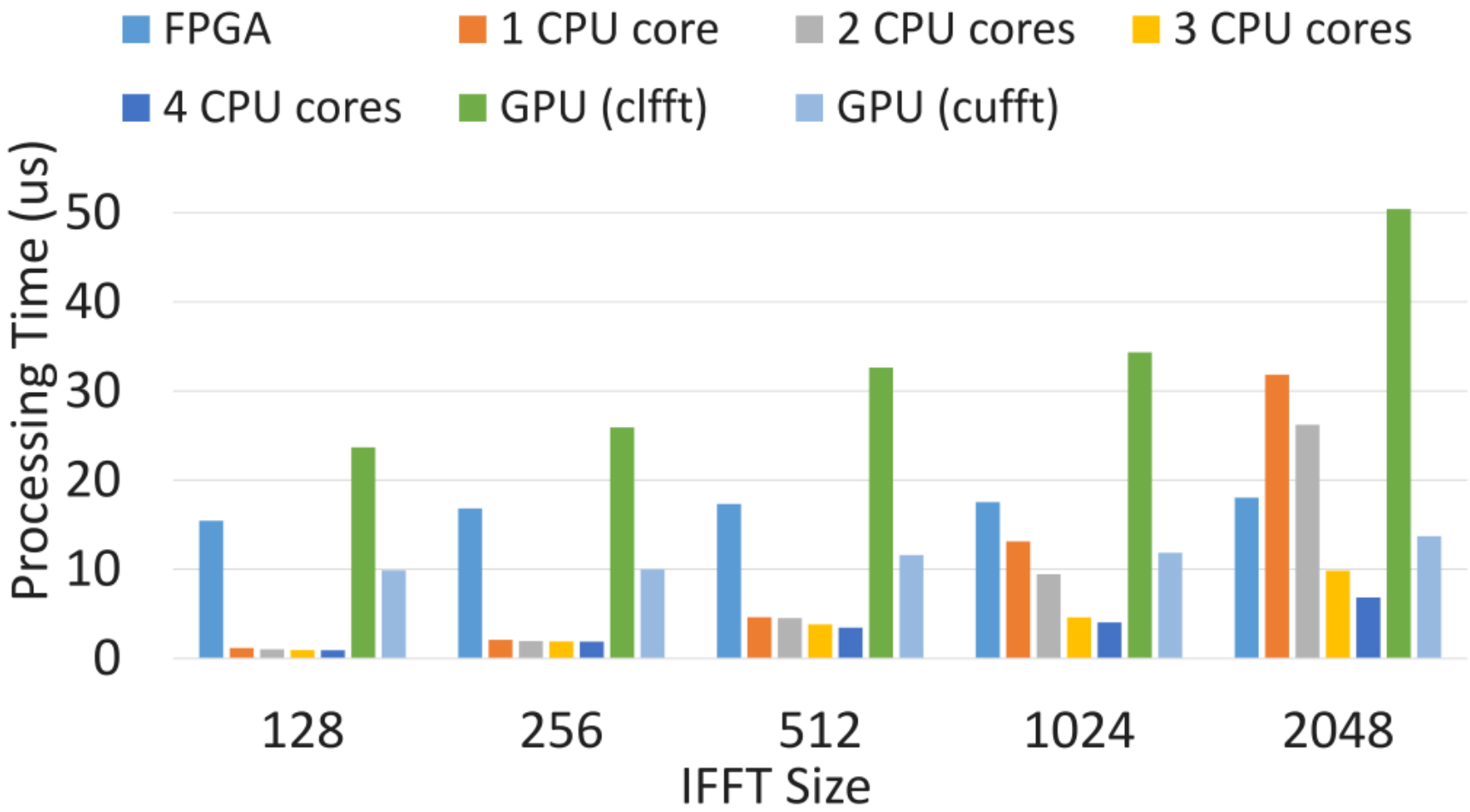
FPGA, CPU, and GPU Comparison: Processing Time



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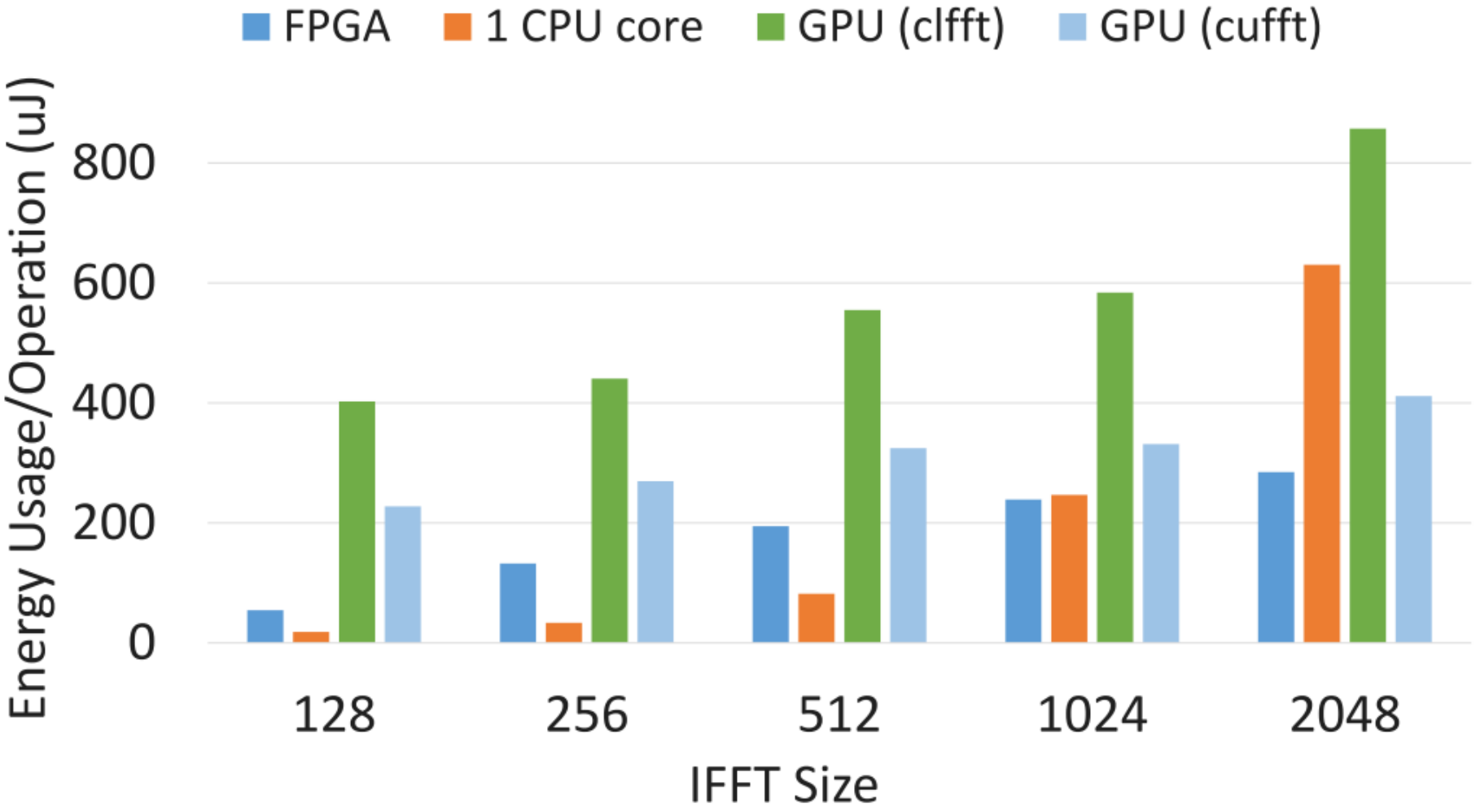
FPGA, CPU, and GPU Comparison: Energy Consumption



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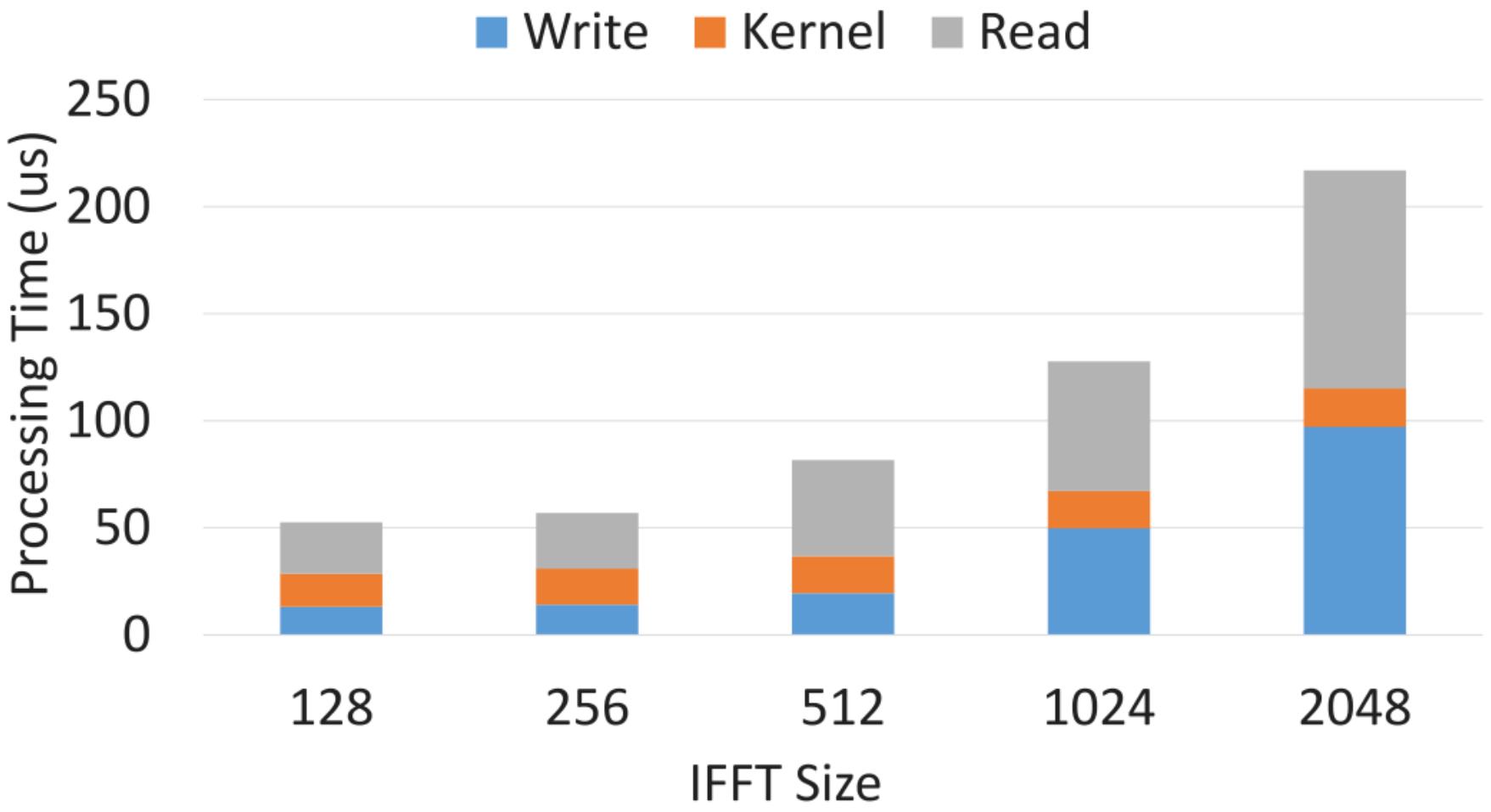
FPGA-based Implementation: Processing Time Contributions



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Conclusions

- Application of FPGA processing in 5G PHY
- Short processing time and energy consumptions a re achievable
- Bottleneck: data transfer
- Need for SmartNIC

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Open position

- https://www.santannapisa.it/en/assegni-di-ricerca-e-selezioni-incarichi-esterni/institute-communication-information-and-1

TELECOMMUNICATIONS, COMPUTER ENGINEERING, AND PHOTONICS INSTITUTE

Sant'Anna
School of Advanced Studies – Pisa

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BRAINE

ECSEL Joint Undertaking

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THANKS !!!

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