Design Considerations for Replacing the 5G NR Physical Layer

Presentation for CoE (4/10/23)

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Acknowledgments.
Certain diagrams have been borrowed from the world's first multimedia book on 5G:
Nishith D. Tripathi and Jeffrey H. Reed, "5G Cellular Communications- Journey and Destination," Multimedia Book, The Wireless University, https://thewirelessuniversity.com/, April 2019.

About the Presenter…

Research Associate Professor (Virginia Tech)
Founder, Aum Research and Consulting (ARC)

Research Projects: Secure and Resilient 5G, secure NTNs, smart traffic intersections, indoor positioning in a smart warehouse, 5G O-RAN portable testbed, Open AI Cellular (OAIC), 6 GHz

World's first multimedia book on 5G! (with Prof. Jeff Reed)

Textbook on Cellular Communications (with Prof. Jeff Reed)

Expertise: 5G, O-RAN, NTN, LTE, IMS

Pioneering work on applications of AI in cellular networks

Contributor to FCC, CTIA, NSF, FTC, GSMA, Scientific American, CNN Business, EE Times University

24 years of wireless industry experience: design, testing, deployment, operations, troubleshooting, and optimization of commercial networks

Presentation Goals

Discover the motivation for replacing the 5G NR PHY layer

Describe different strategies for replacing the NR PHY layer

Summarize the impact of PHY changes on the 5G NR radio protocol stack

Illustrate the impact of PHY layer changes on the 5G NR RAN

Describe the impact of PHY layer changes on the 5GC

Discuss the impact of PHY layer changes on the UE

01 Why Replace NR PHY?

02 NR Protocol Stack

03 NR Replacement Strategies

04 Impact of PHY Changes on RAN

05 Impact of PHY Changes on 5GC

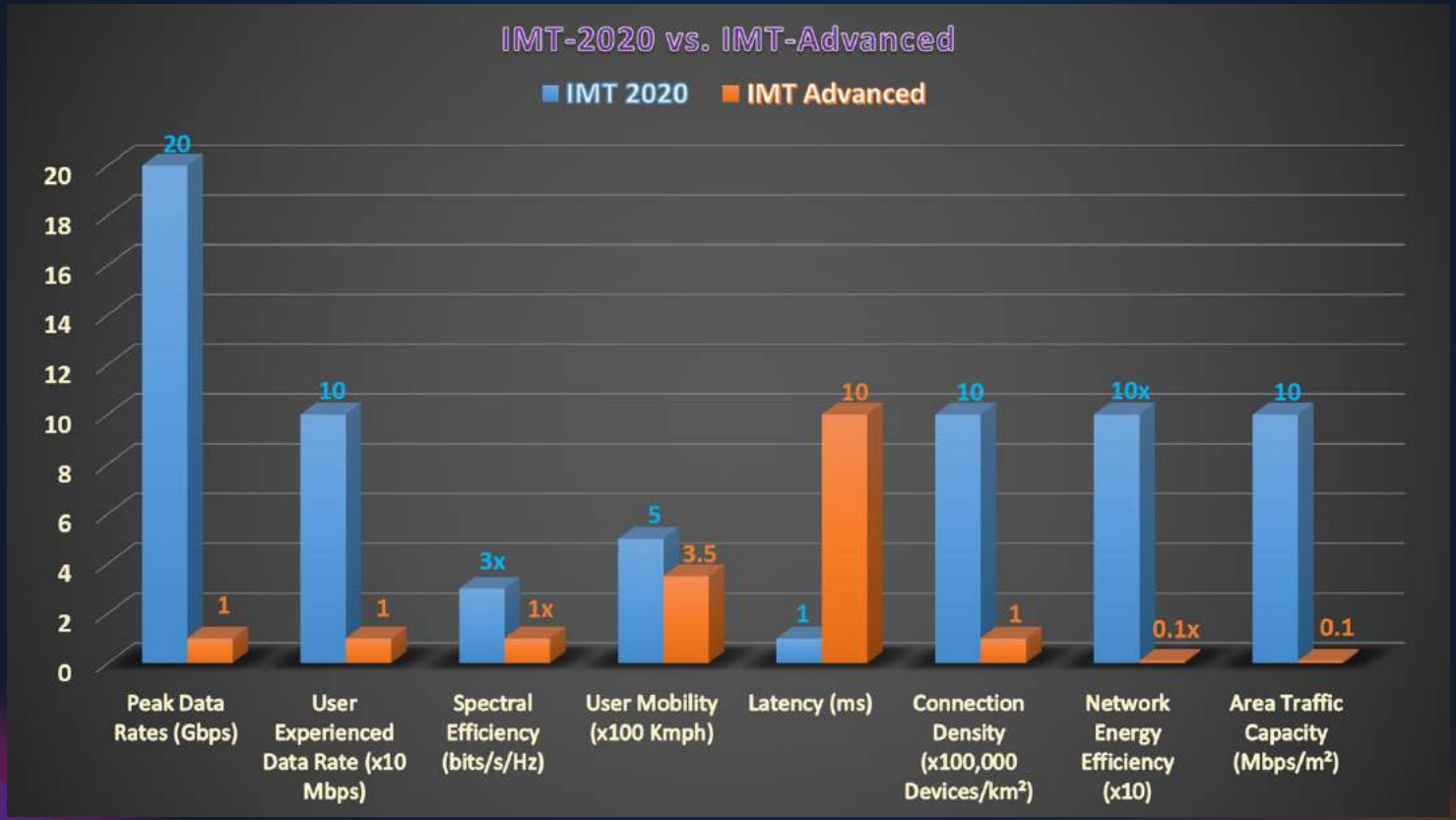
06 Impact of PHY Changes on UE

01

Why Replace NR PHY?

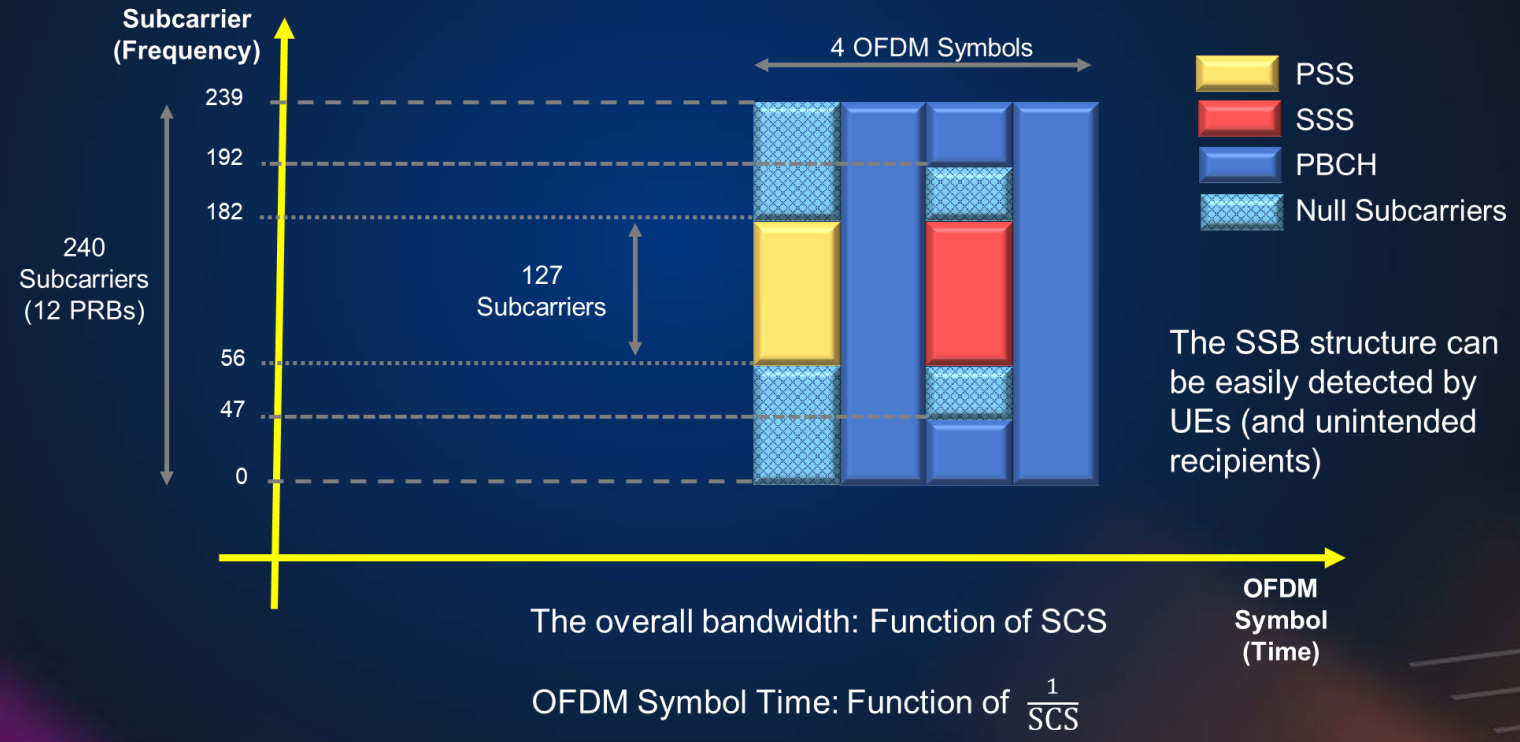
The Power of 5G NR…

- ✓ **New Radio (NR) is a flexible, efficient, and high-performance radio interface of 5G**



Motivation for NR PHY Replacement

- ✓ **Why rock the boat if 5G NR is so efficient, powerful, and flexible?**
  Easy for commercial users to detect signals and channels (e.g., SS/PBCH Block and PDCCHs) but adversaries can also easily attack!

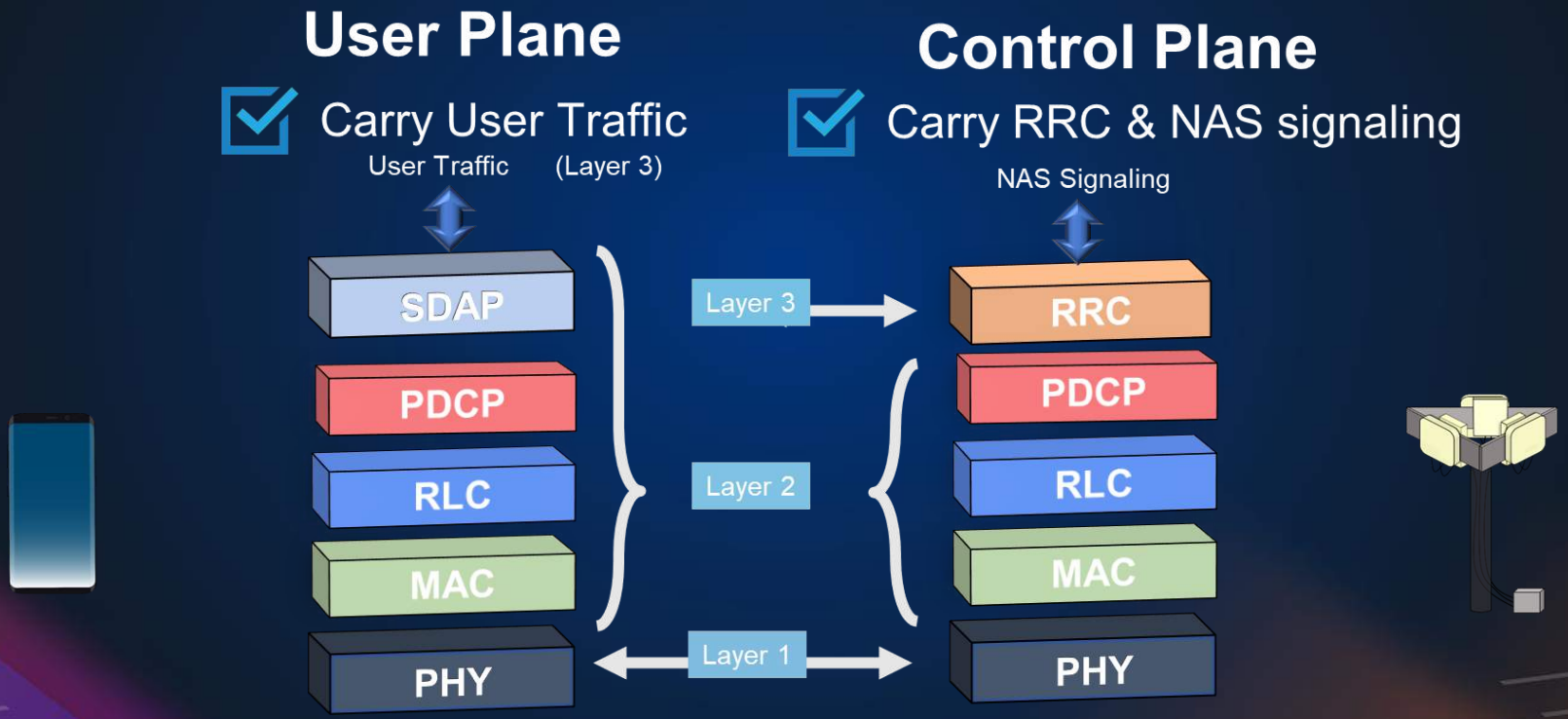


02

NR Protocol Stack

NR Radio Protocol Stack

Q: What exactly are we replacing/changing in the 5G NR radio interface?
The PHY layer does not exist by itself…it needs to work with other layers/protocols!



Example Impact of PHY Changes on NR Protocol Stack

A million-dollar Q: What would happen if we change the NR PHY layer?
Red text: Requires significant changes due to a new PHY layer
Green text: No or minimal impact of a new PHY layer
However, different strategies can be used to accommodate a new PHY layer.

RRC

- ✓ System Information (Cell Selection, Random Access)
- ✓ Mobility signaling (Handover events, Measurements)

PDCP

- ✓ Reuse security (Ciphering & Integrity Protection) and RoHC

MAC

- ✓ Scheduling: Resource Allocation
- ✓ Awareness of the resource grid for the new PHY
- ✓ Reuse HARQ control (Code Block Groups (CBGs) may not be available in new PHY)

SDAP

- ✓ Reuse QoS Flow <--> DRB mapping

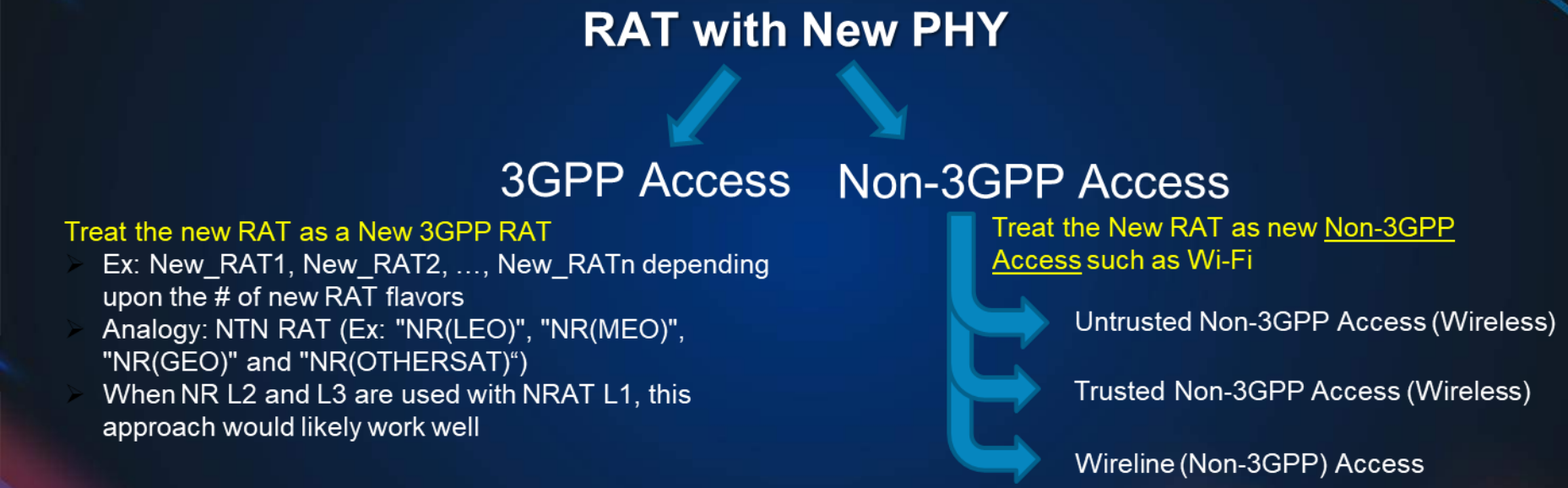
RLC

- ✓ Reuse Transparent Mode, Unacknowledged Mode (DRBs), and Acknowledged Mode
- ✓ Reuse ARQ (Acknowledged Mode)

03

NR PHY Replacement Strategies

New RAT: “New PHY” with Other Protocols



NRAT: New Radio Access Technology

NRAT Strategies

NRAT Offload (like Wi-Fi Offload) [No coordination between 5G and NRAT]

Untrusted Non-3GPP Access

Trusted 3GPP Access

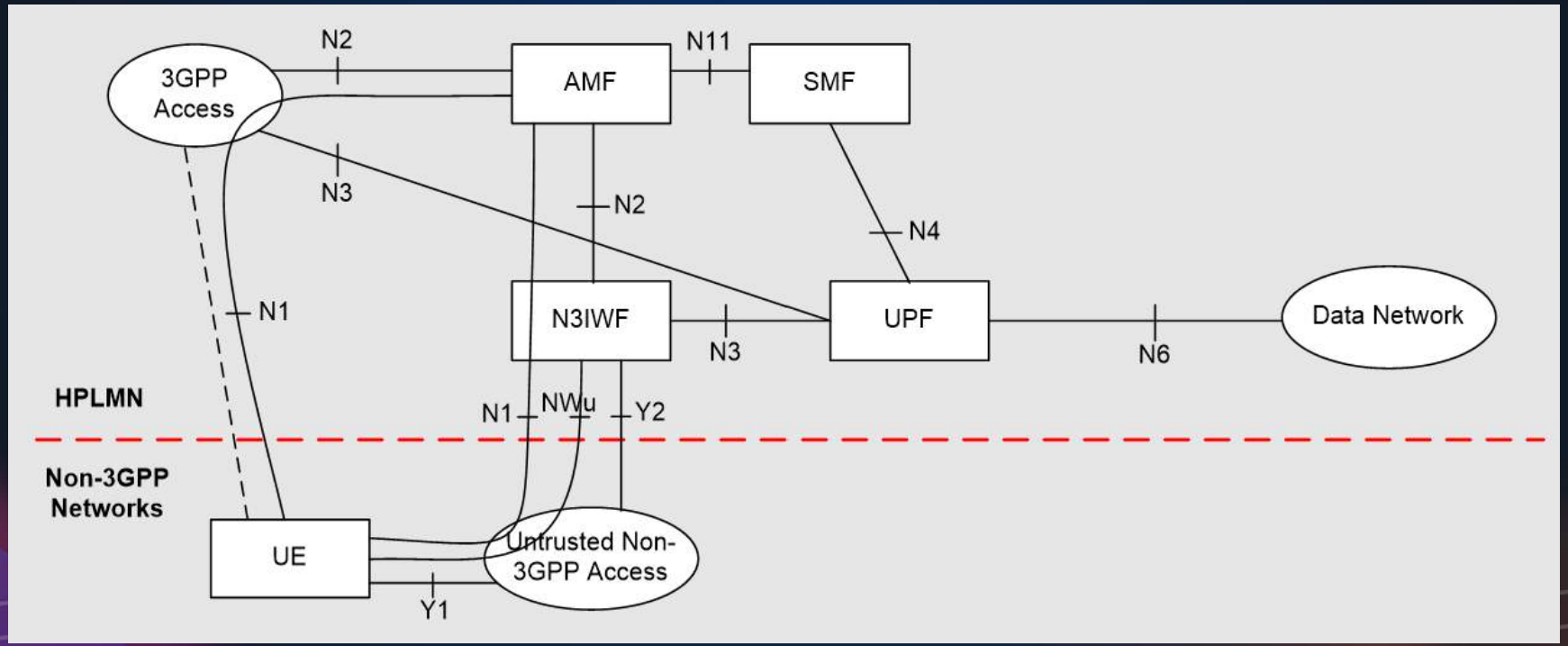
Access Traffic Steering, Switching, and Splitting (ATSSS)

Dual Connectivity (NRAT + NR)

Standalone NRAT with 5GC (multiple flavors)

NRAT as Untrusted Non-3GPP Access

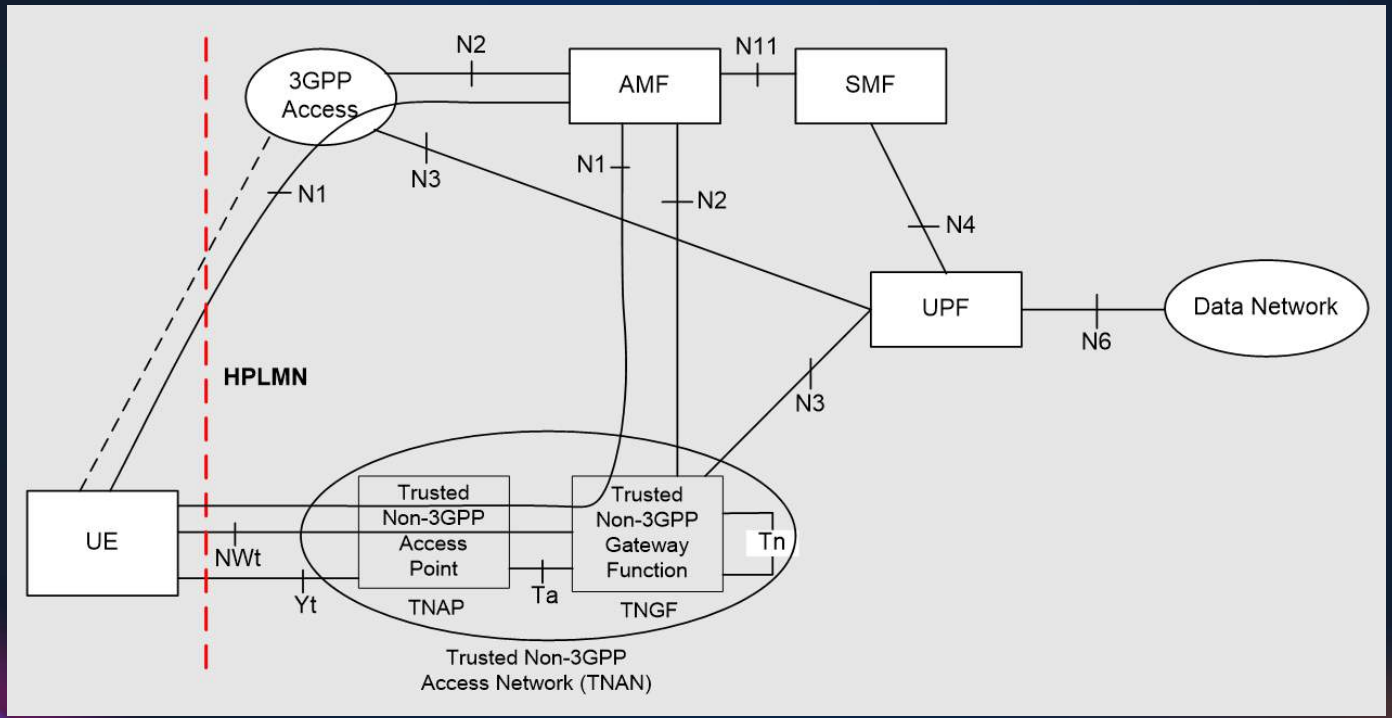
Single RAT access or simultaneous 3GPP access and untrusted NRAT access
All L1, L2, and L3 belong to NRAT; no reuse of NR L1, L2, and L3
The 5GC is used for UE-AMF signaling as well as UE-UPF traffic exchange



Acknowledgment. This diagram has been borrowed from 3GPP specifications.

NRAT as Trusted Non-3GPP Access

Single RAT access or simultaneous 3GPP access and trusted NRAT access
All L1, L2, and L3 belong to NRAT; no reuse of NR L1, L2, and L3
The 5GC is used for UE-AMF signaling as well as UE-UPF traffic exchange



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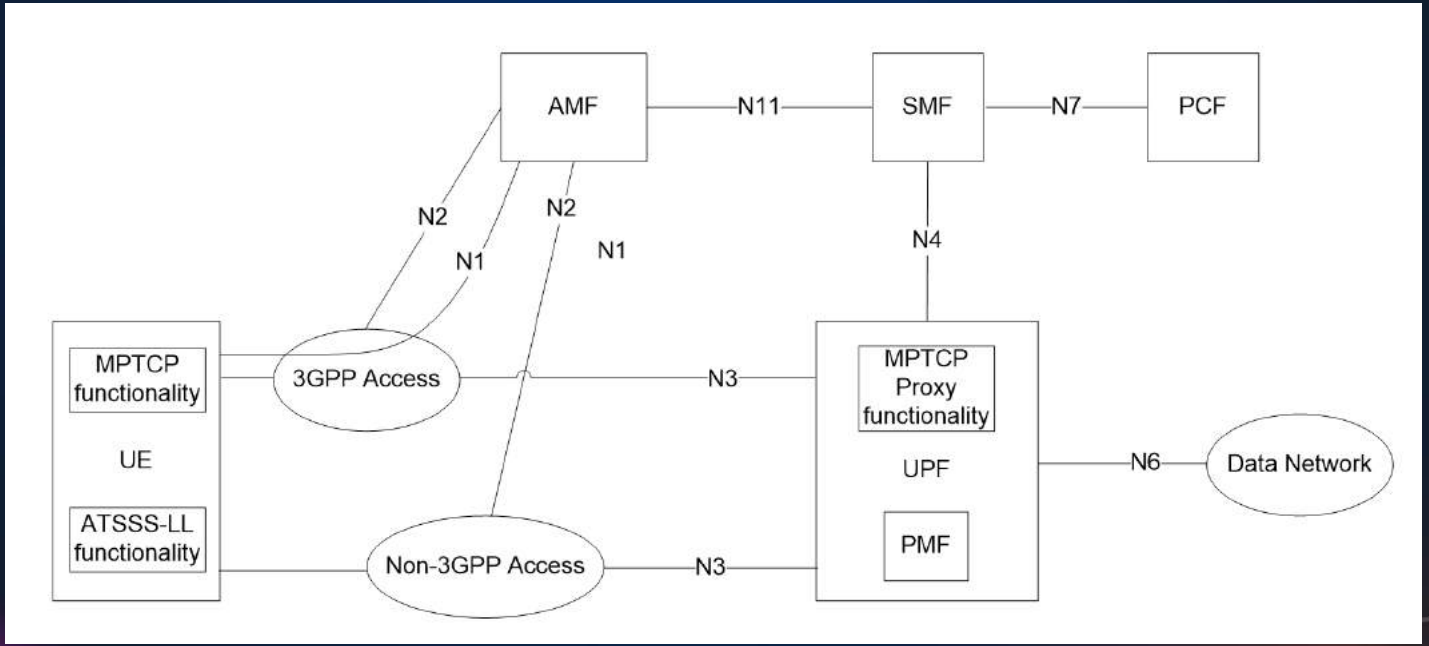
Access Traffic Steering, Switching, and Splitting

Single RAT access or simultaneous 3GPP access and untrusted or trusted NRAT access
All L1, L2, and L3 belong to NRAT; no reuse of NR L1, L2, and L3
The 5GC is used for UE-AMF signaling as well as UE-UPF traffic exchange
More control over the transport of user traffic by the network compared to a non-ATSS scenario



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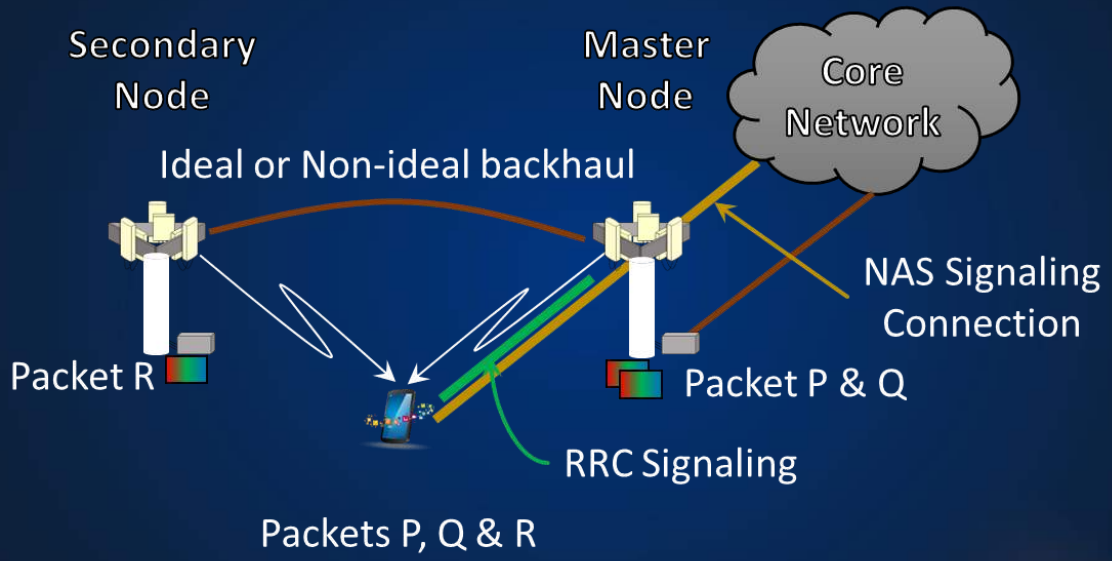
Dual Connectivity (NRAT + NR)

Dual Connectivity:

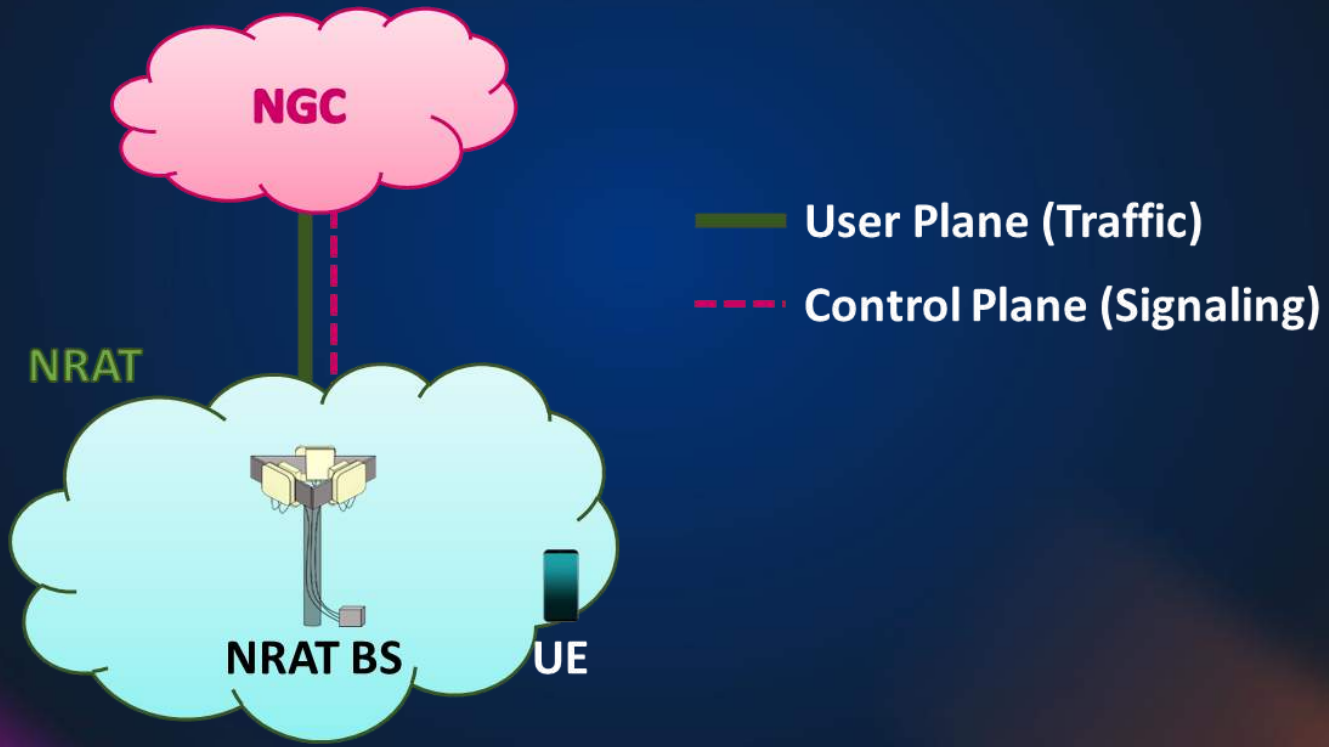
Simultaneous connection of a UE to two Base Stations with independent schedulers



One RAT can provide the Master Node and the other RAT can provide the Secondary Node.
Any RAT (i.e., NRAT or NR) can provide a Master Node.
One RAT or both RATs can be used for data transfer.

Standalone NRAT with 5GC

The NRAT works without any assistance from the NR RAT.
The NRAT BS needs to support Next Generation Application Protocol (NGAP) toward the 5GC.



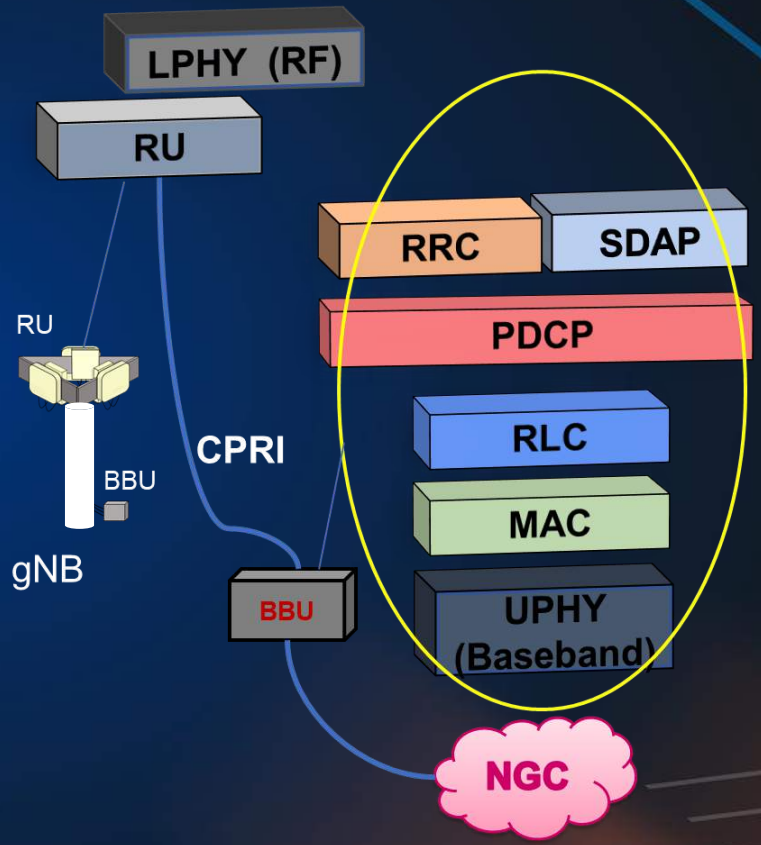
04

Impact of PHY on RAN

Integrated gNB with Separate BBU and RU

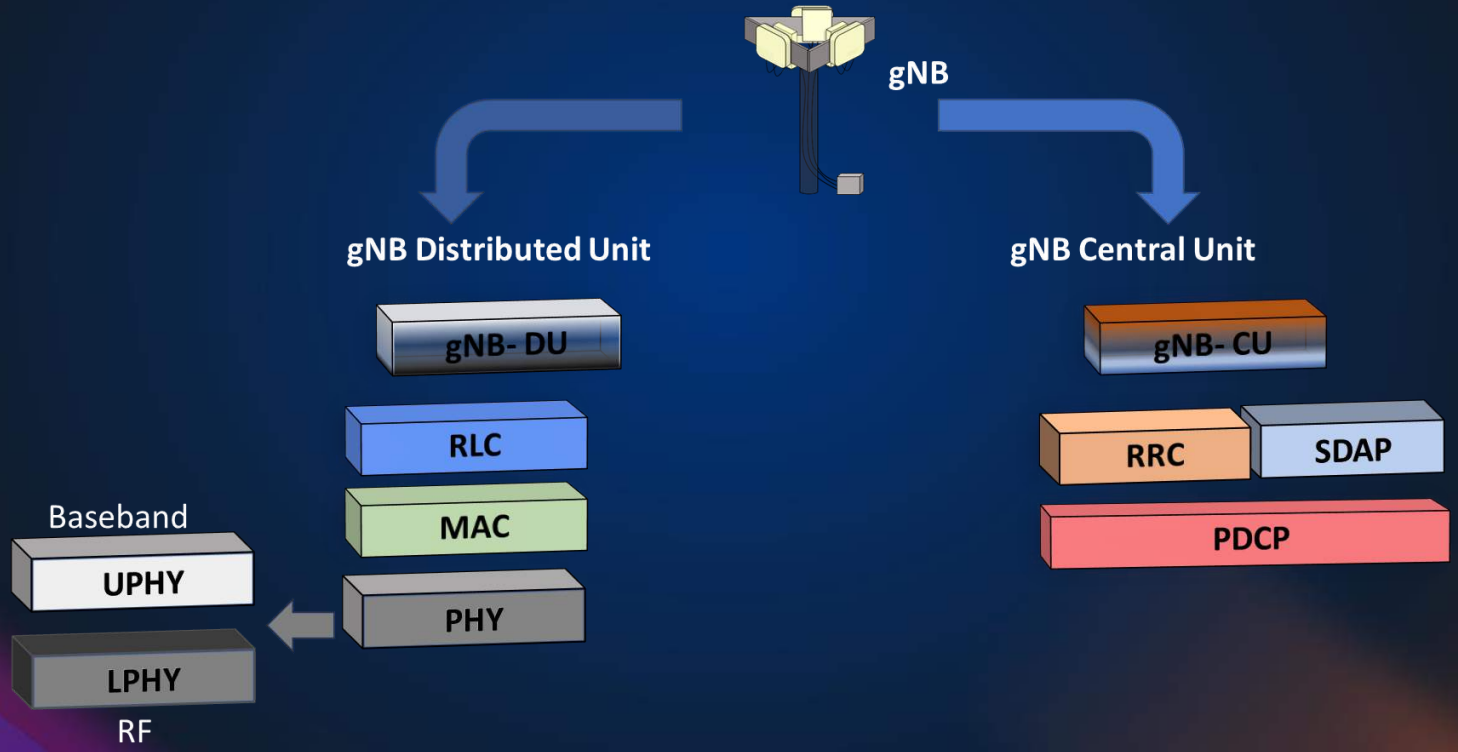
Widely used in LTE and 5G deployments

Significant changes to the BBU due to new NRAT PHY when NR L2 and L3 are reused



Disaggregated gNB (Functional Split 2)

One of the emerging trends for 5G RAN deployments
Significant changes to the gNB-DU when NR L2 and L3 are reused
Some changes in the gNB-CU when NR L2 and L3 are reused



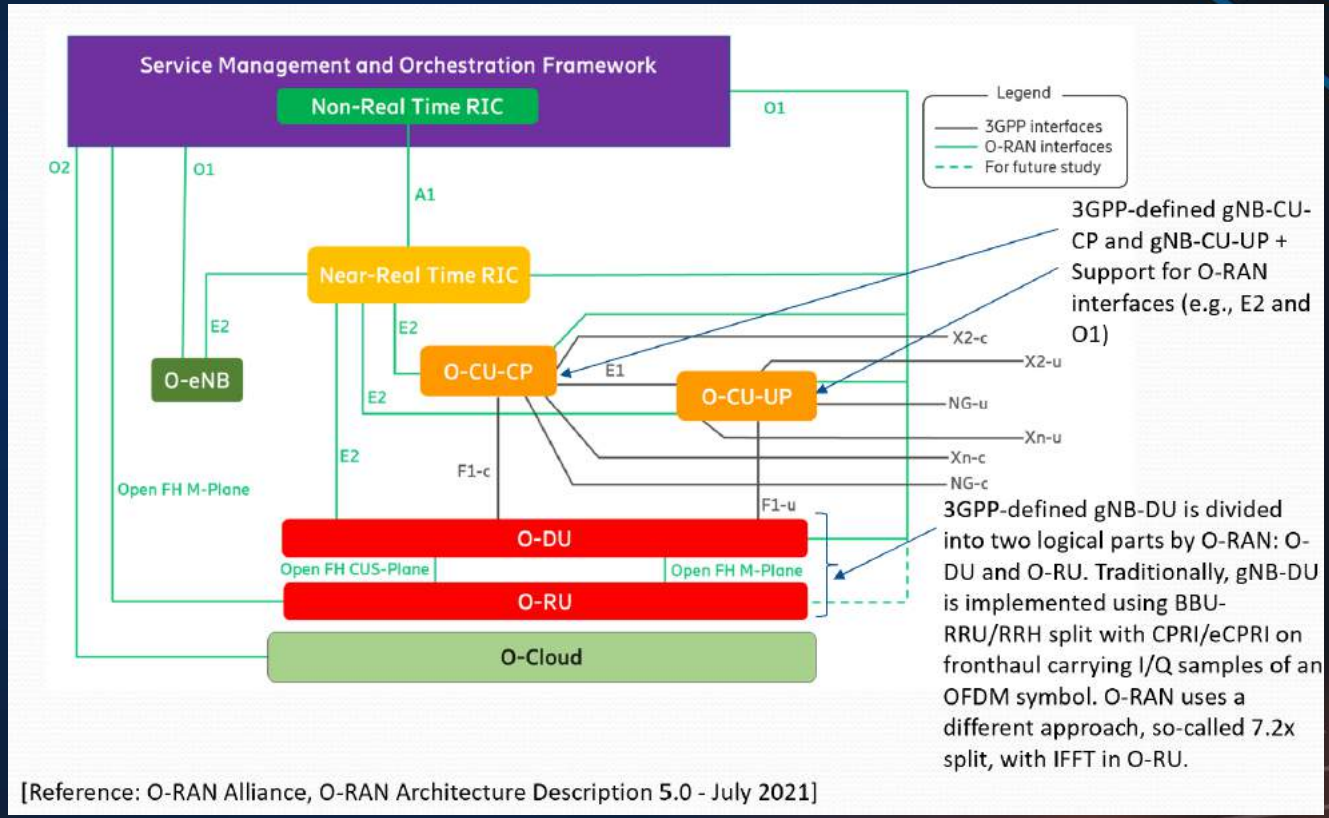
O-RAN-based gNB (Functional Split 7.2x)

Emerging trend for 5G RAN deployments

Developed by the O-RAN Alliance

Openness and Intelligence for RAN

Significant impact of PHY changes on the O-RAN-based 5G RAN



[Reference: O-RAN Alliance, O-RAN Architecture Description 5.0 - July 2021]

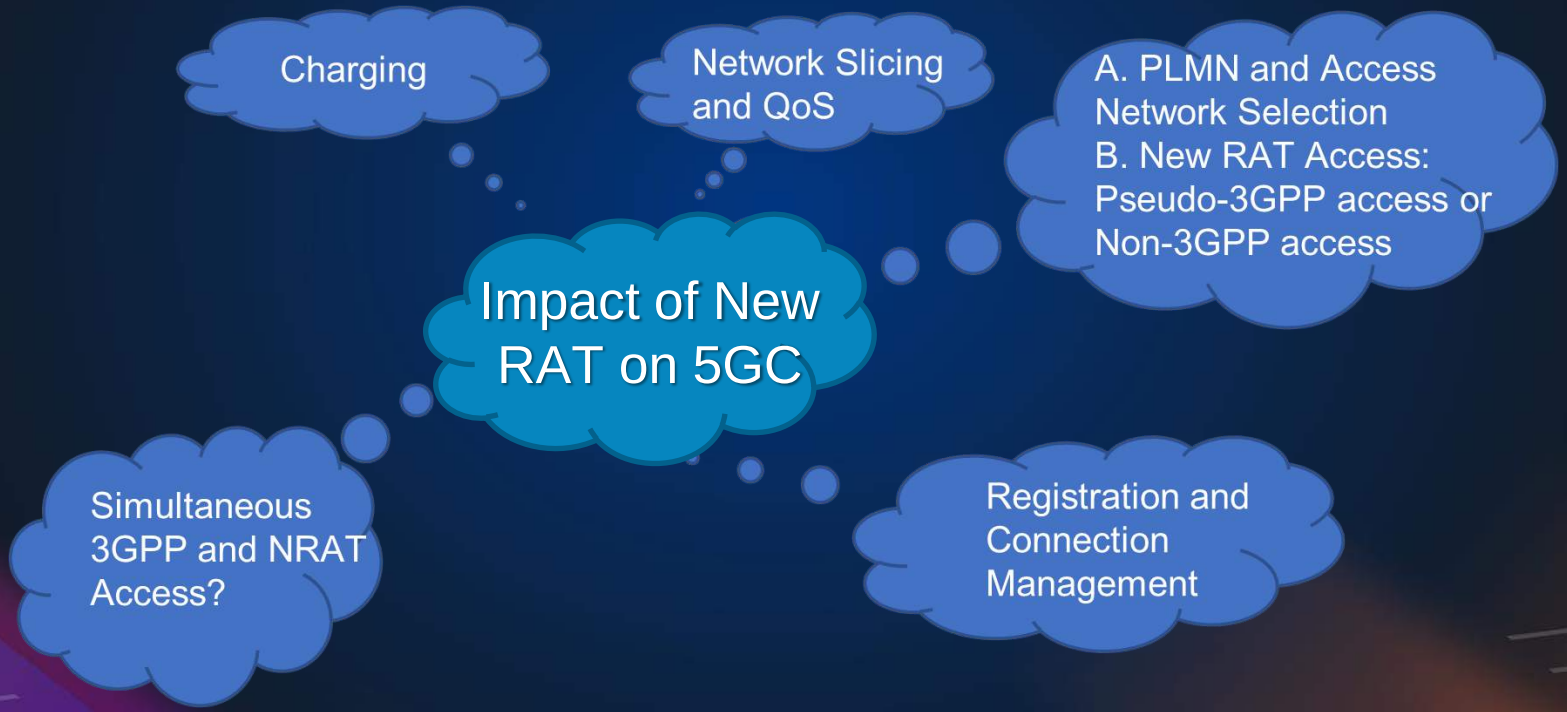
Acknowledgment. This diagram has been borrowed from O-RAN specifications.

05

Impact of PHY on 5GC

5GC Changes due to NRAT

- ✓ **The 5GC does need to be modified to support NRAT but the extent of changes is much smaller compared to RAN and UE changes**



06

Impact of PHY on UE

UE Changes due to NRAT

- ✓ **The UE undergoes significant changes with more changes needed for complex and high-performance NRAT strategies**

Implementation of NRAT PHY

Implementation of NRAT L2 and L3 or modification of NR L2 and L3

Access Network selection using UE policies (provisioned and configured)

RAT measurements for PDU Session transfer

Access Stratum and Non-Access Stratum signaling exchange

User Traffic Exchange via one or more RATs

Key Takeaways

- Different strategies are feasible to support new PHY layer in 5G.
- A new PHY can be supported by new L2 and L3 or modified NR L2 and L3.
- The new PHY layer can be used in a new RAT that can be implemented as (pseudo-) 3GPP access or untrusted/trusted non-3GPP access.
- Significant changes to an integrated gNB, disaggregated gNB, or O-RAN-based gNB are needed to support a new PHY layer.
- The 5GC also needs some changes although the extent of 5GC changes is much smaller compared to the RAN and UE changes.

References

1. Nishith D. Tripathi and Jeffrey H. Reed, “5G Cellular Communications- Journey and Destination,” Multimedia Book, The Wireless University, https://thewirelessuniversity.com/, April 2019.

2. 3GPP, TS 23.501,"System architecture for the 5G System (5GS)," https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3144 .

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5. O-RAN Alliance-RAN Architecture Description," https://orandownloadsweb.azurewebsites.net/specifications.

Thank You!

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