Understanding Mobile Wireless Network as an Routing/Switching Engineer

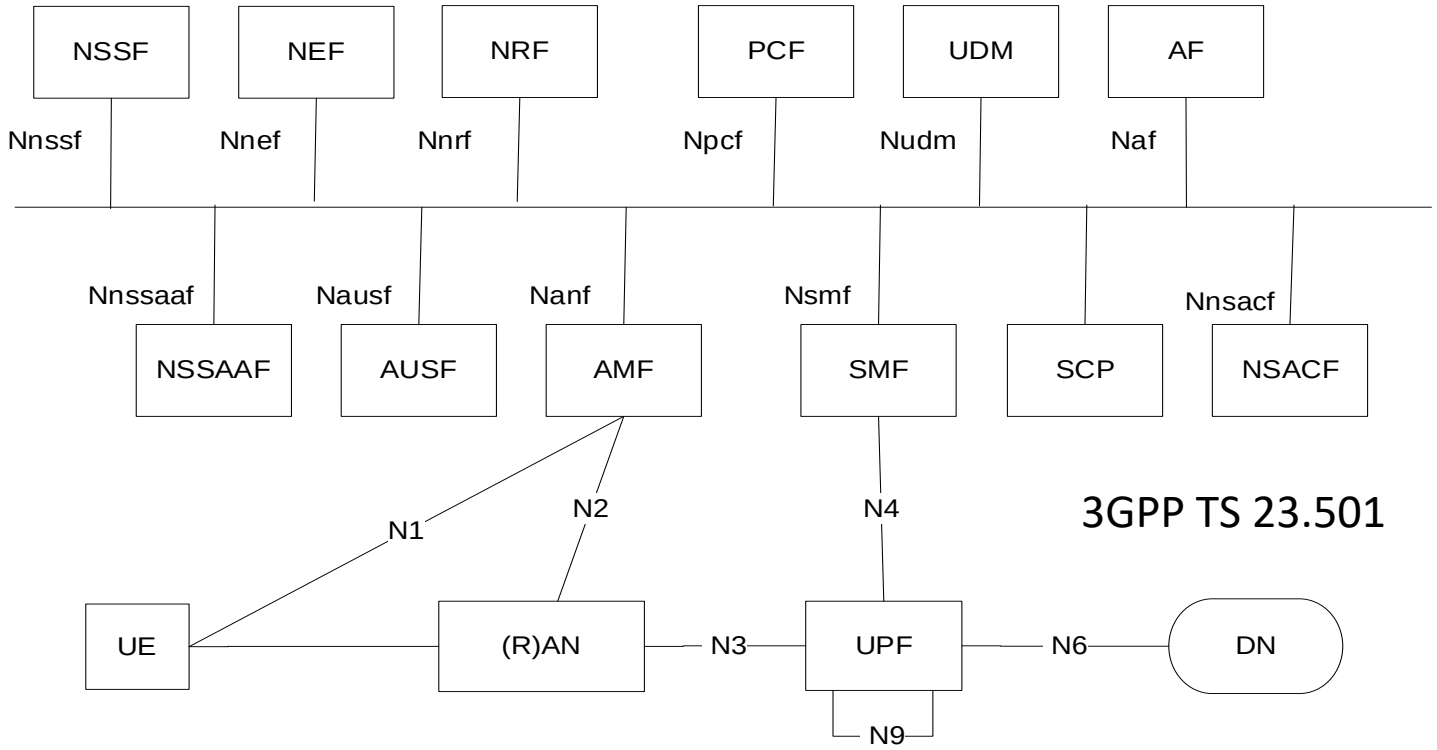
Jeffrey Zhang

Juniper Networks

Agenda

- *5G Architecture - from a routing/switching POV*
- GTP Tunneling and Mobility
- MEC, URLLC, and LAN-type Services
- Transport, QoS, and Slicing

The 5G Architecture



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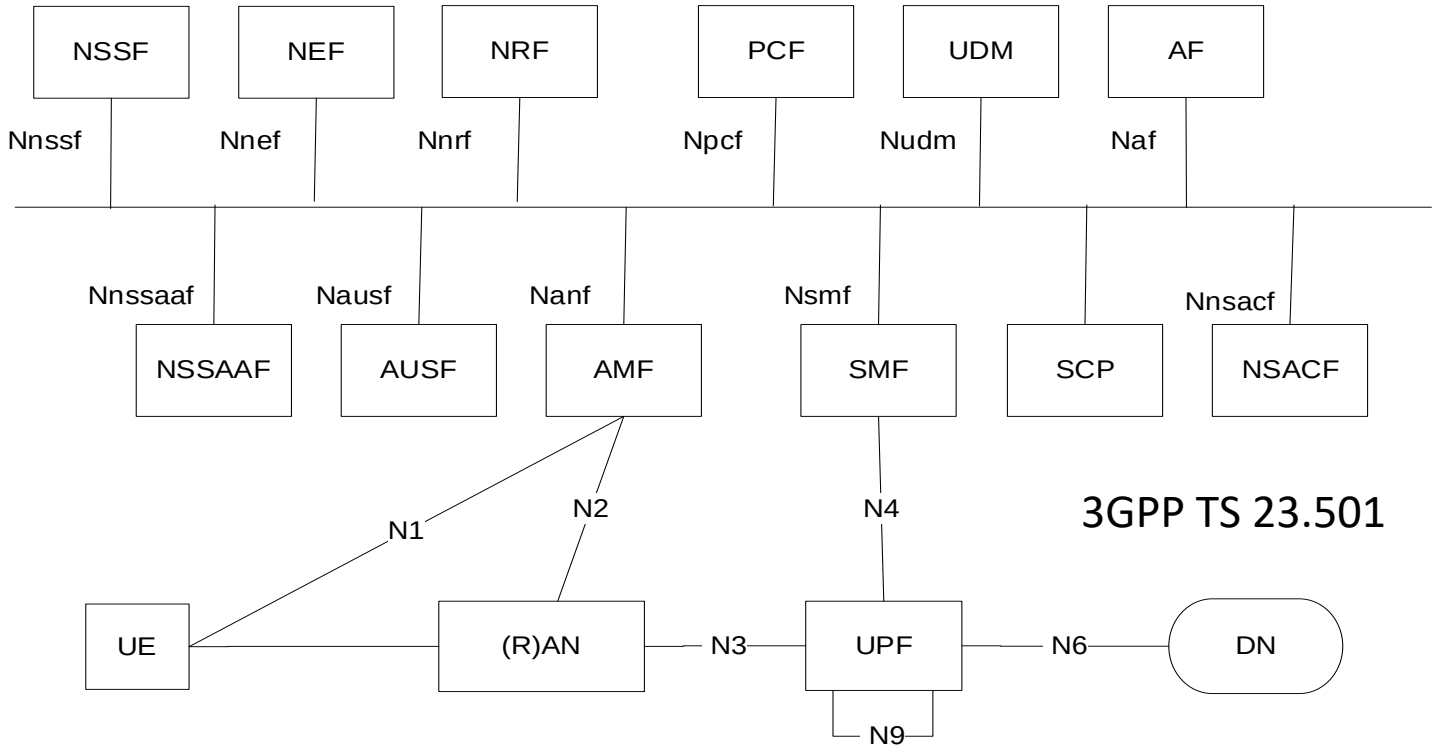
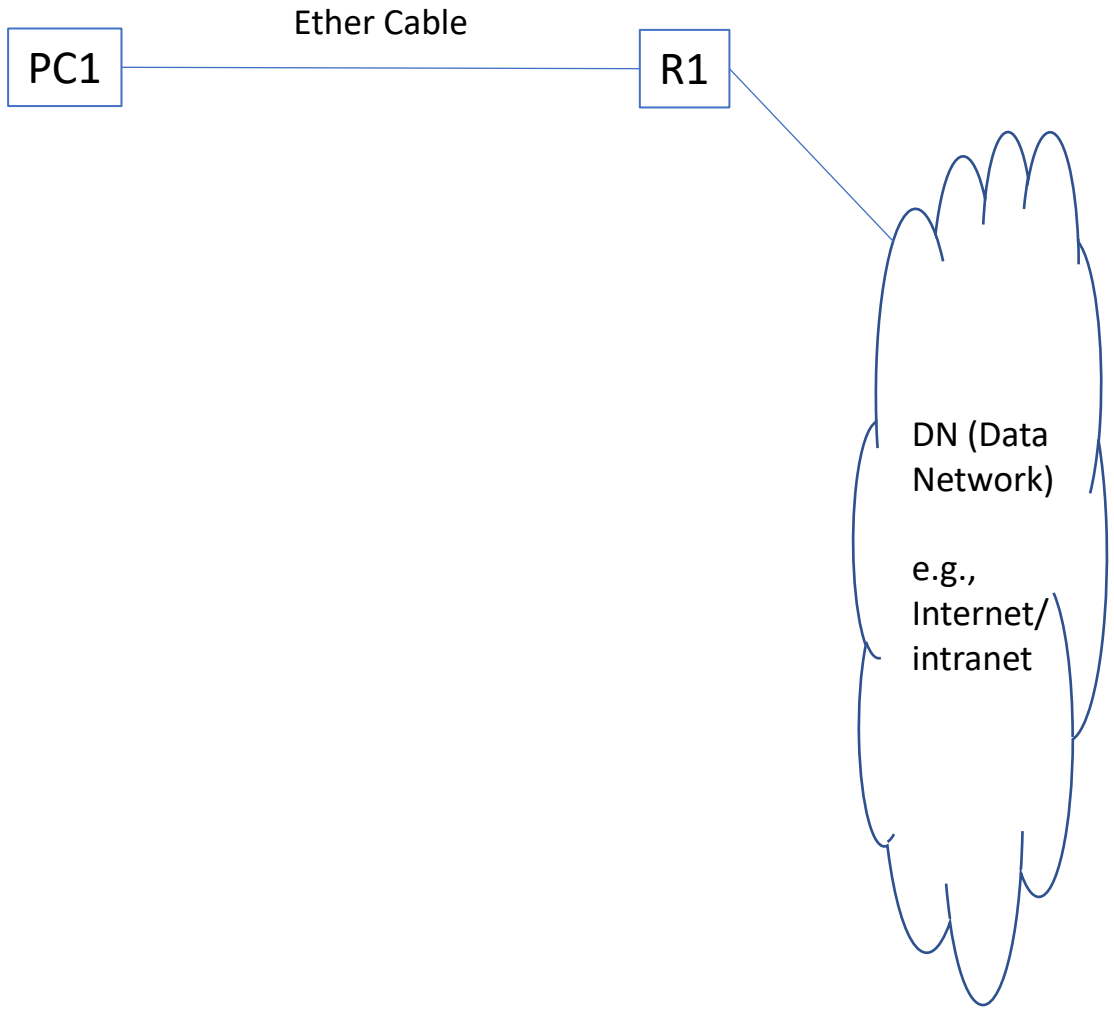
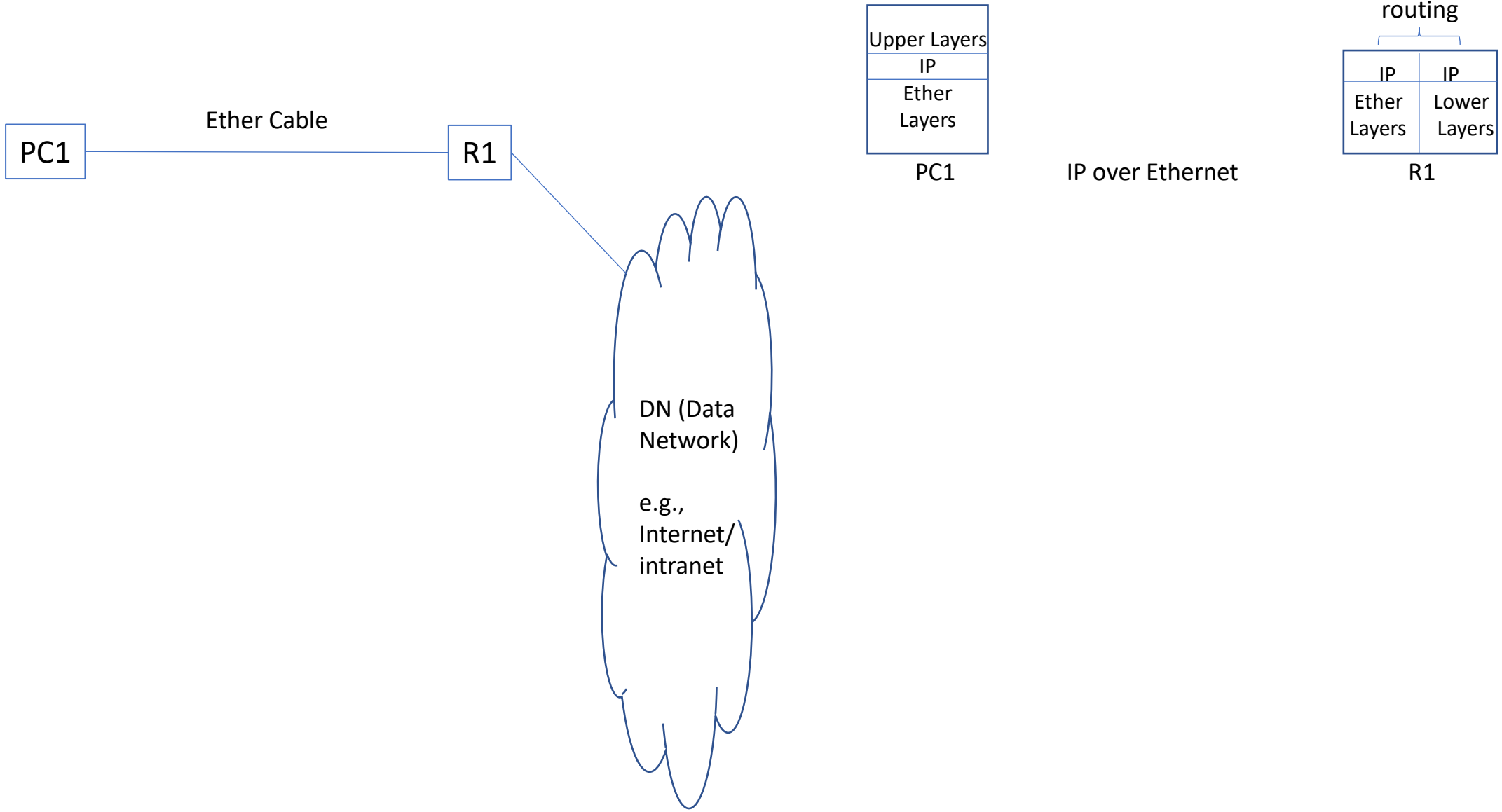


Seems daunting …

Let’s take one step back to our comfort zone …


Ether Cable
PC1
R1
DN (Data Network)
e.g., Internet/ intranet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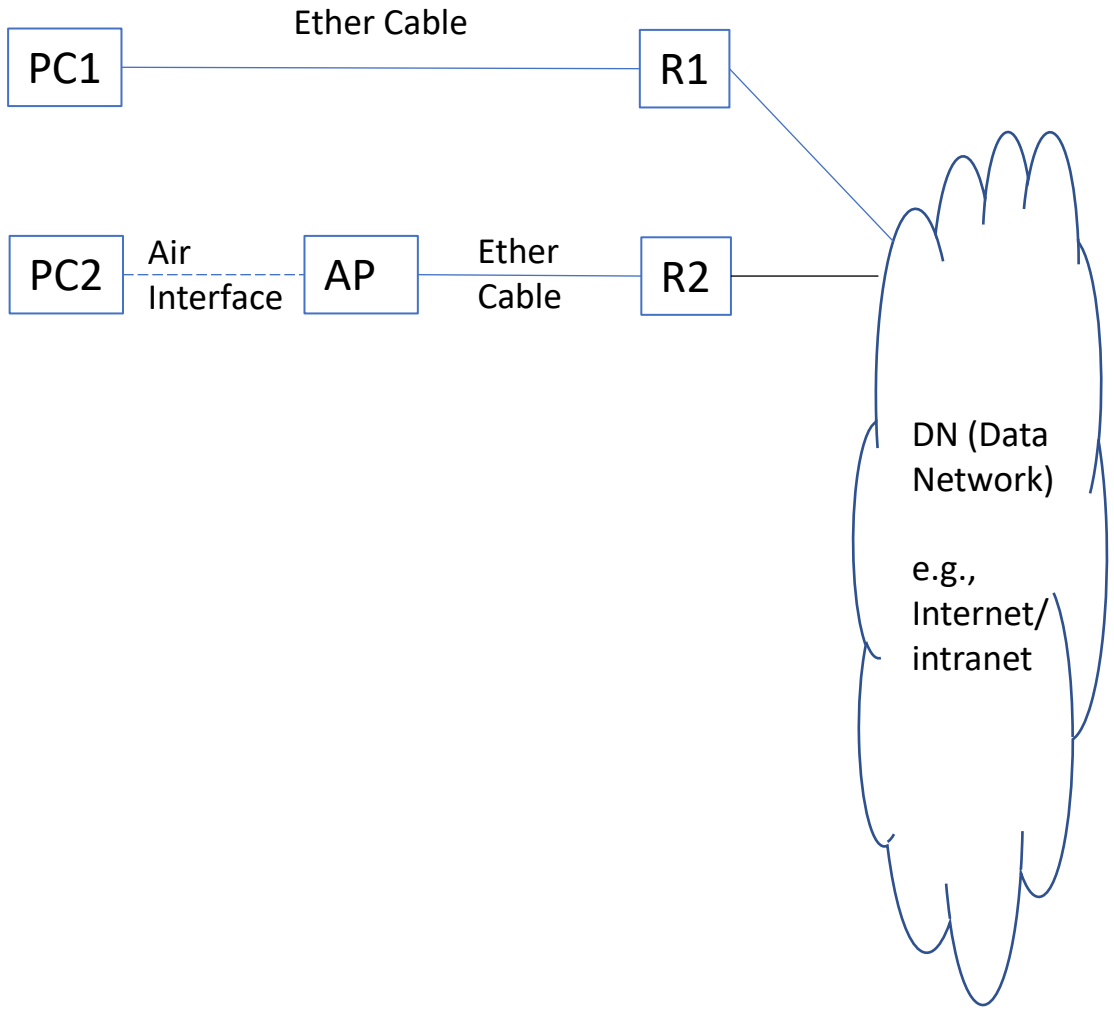
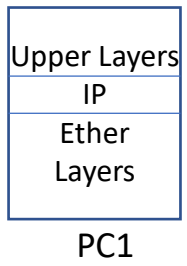
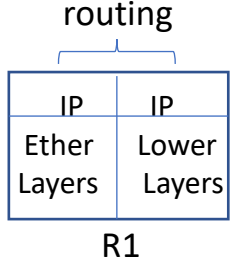
IP over Ethernet
routing
IP
IP
Ether Layers
Lower Layers
R1





PC1

IP over Ethernet



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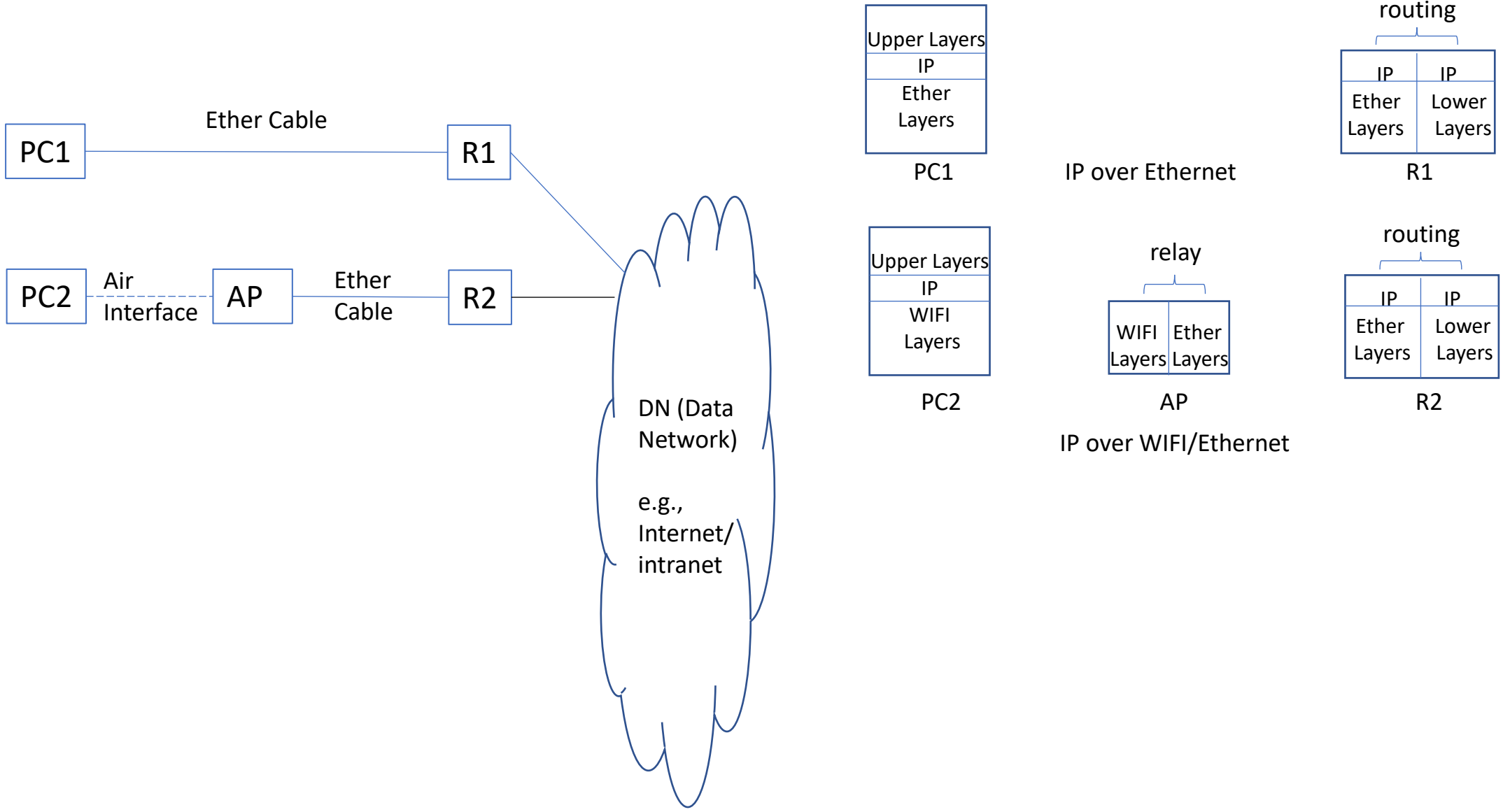
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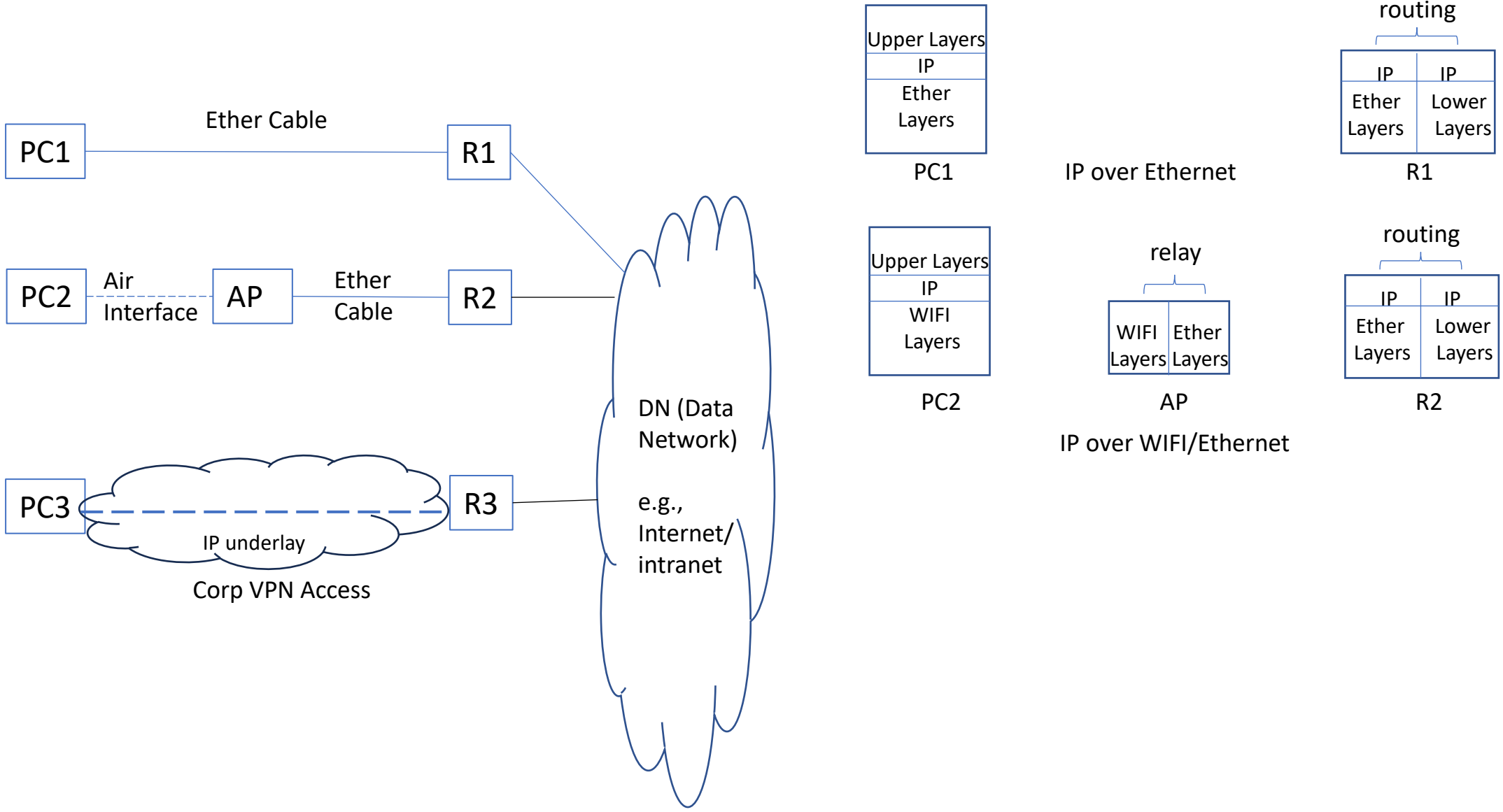
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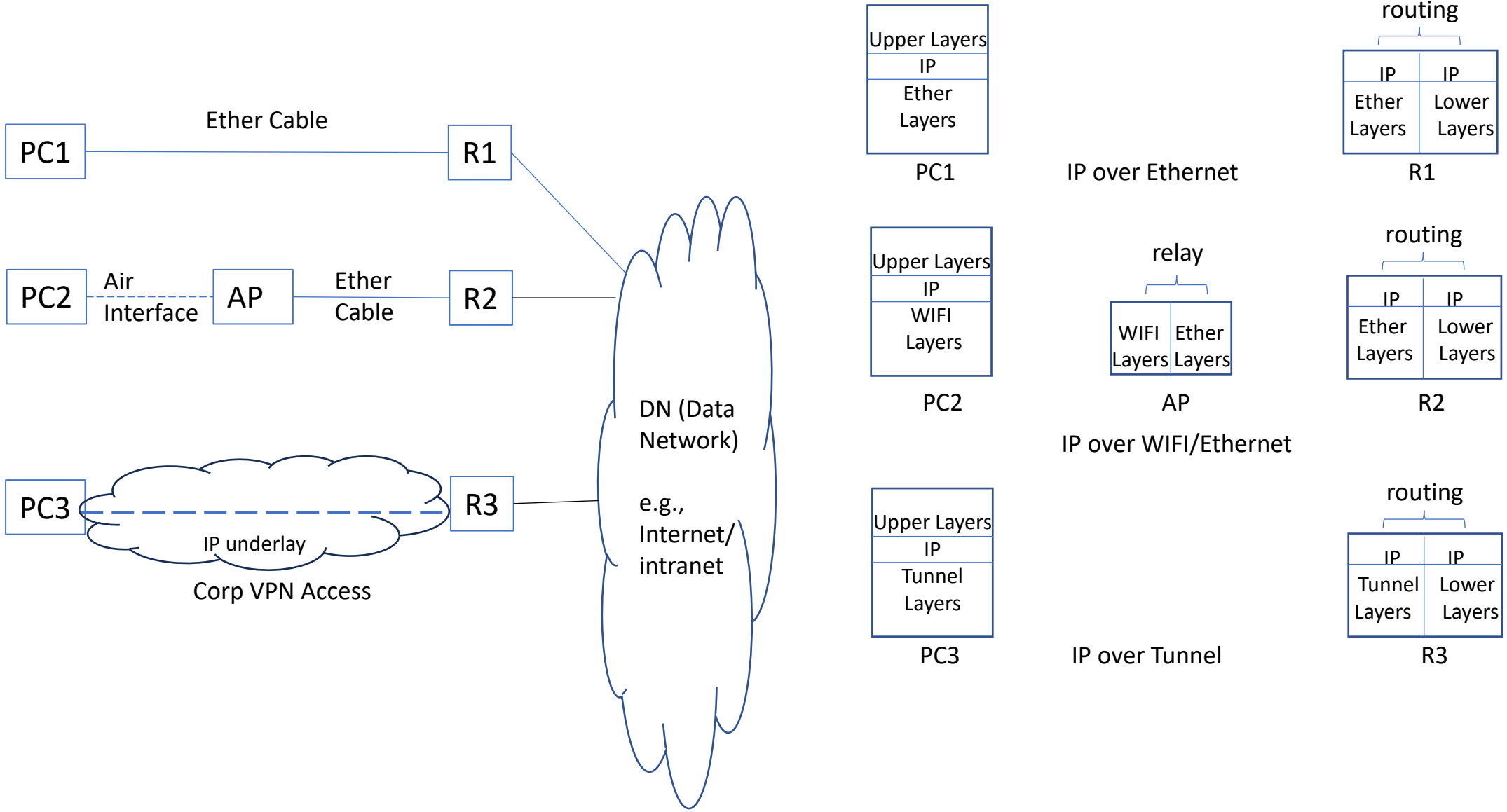
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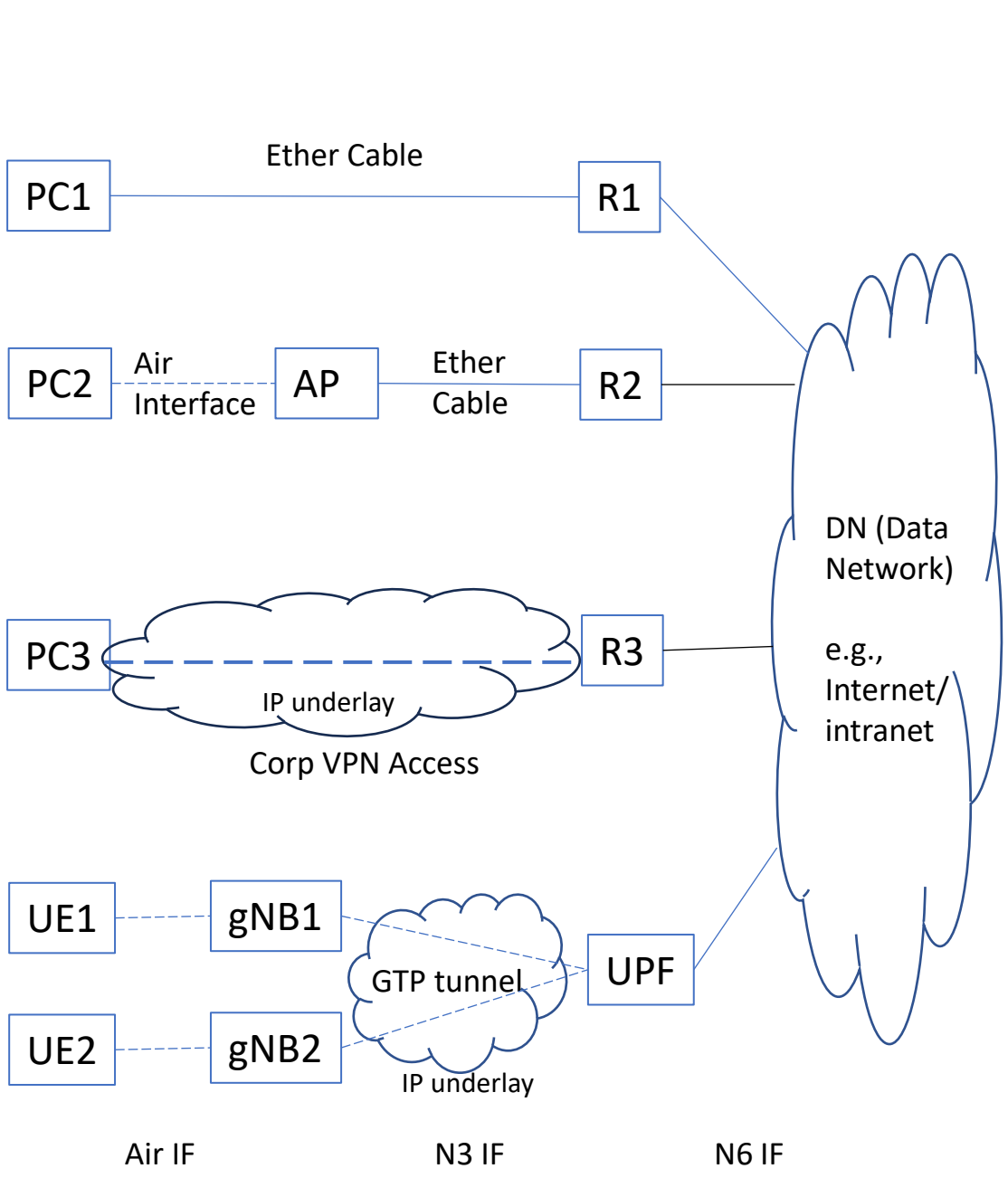
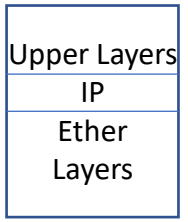
R3





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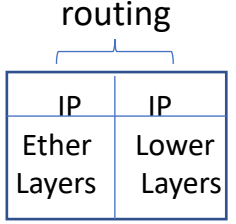
IP over Ethernet



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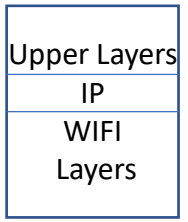
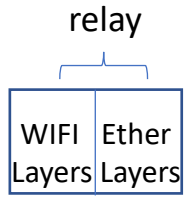
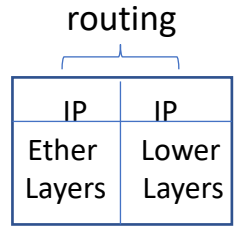


PC2

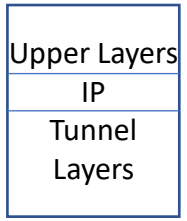


AP



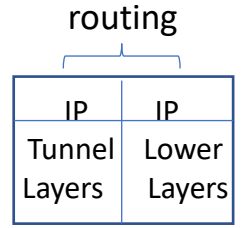
R2

IP over WIFI/Ethernet



PC3

IP over Tunnel



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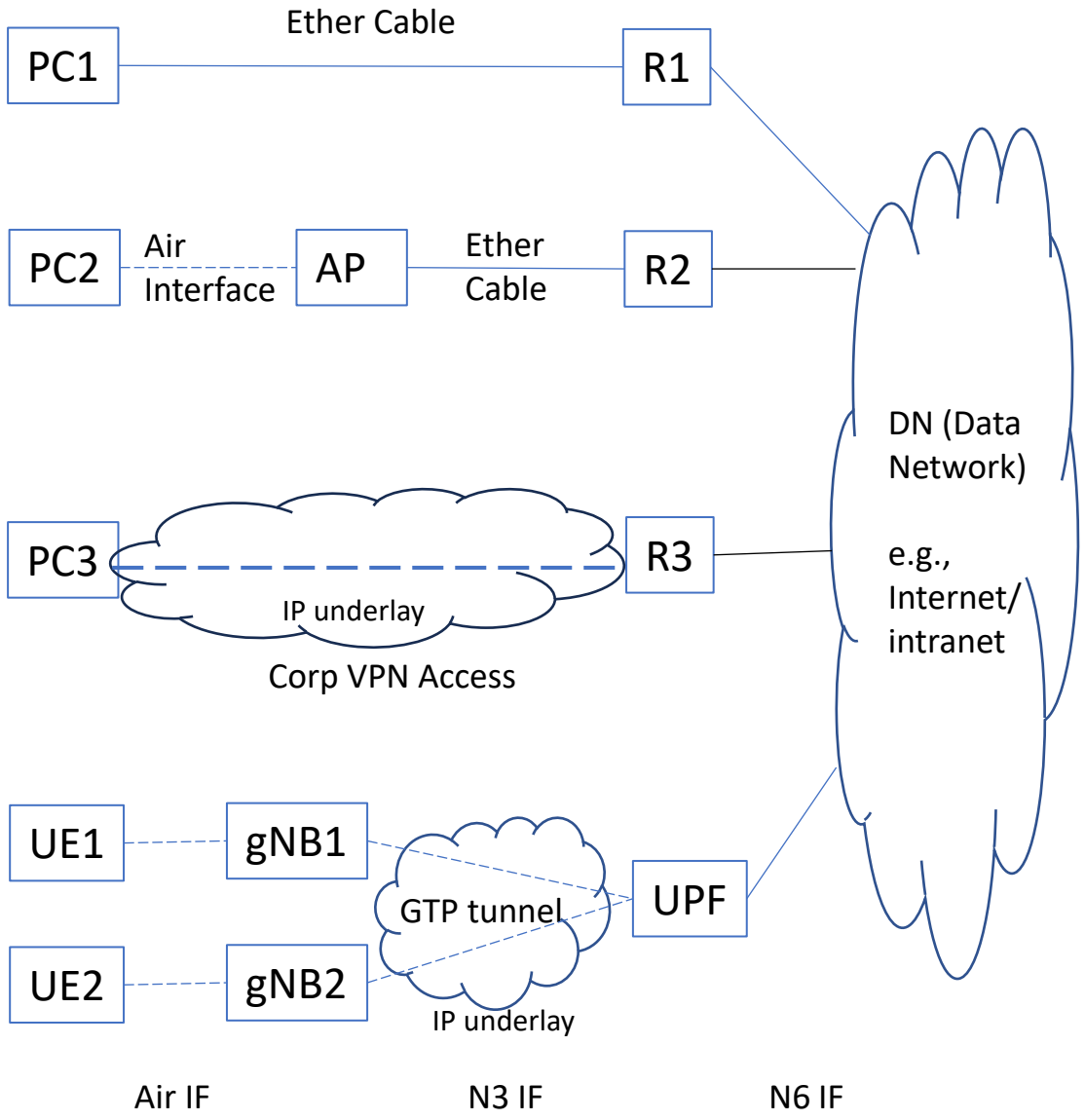

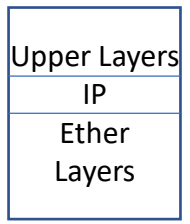

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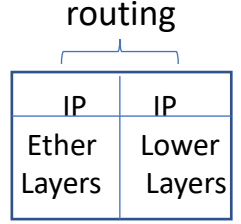

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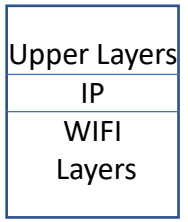
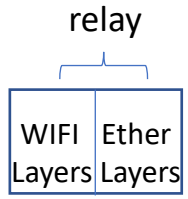


PC2



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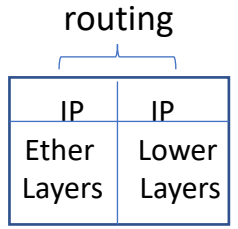
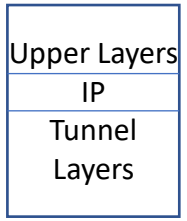


R2

IP over WIFI/Ethernet



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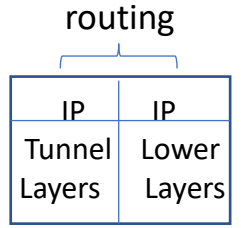

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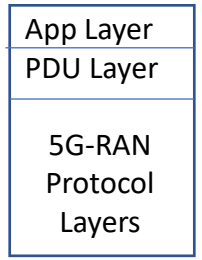
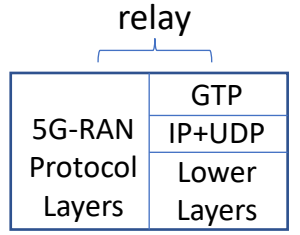
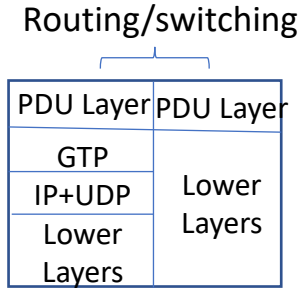


UE



gNB



UPF

PDU (IP/Ether) over RAN/GTP

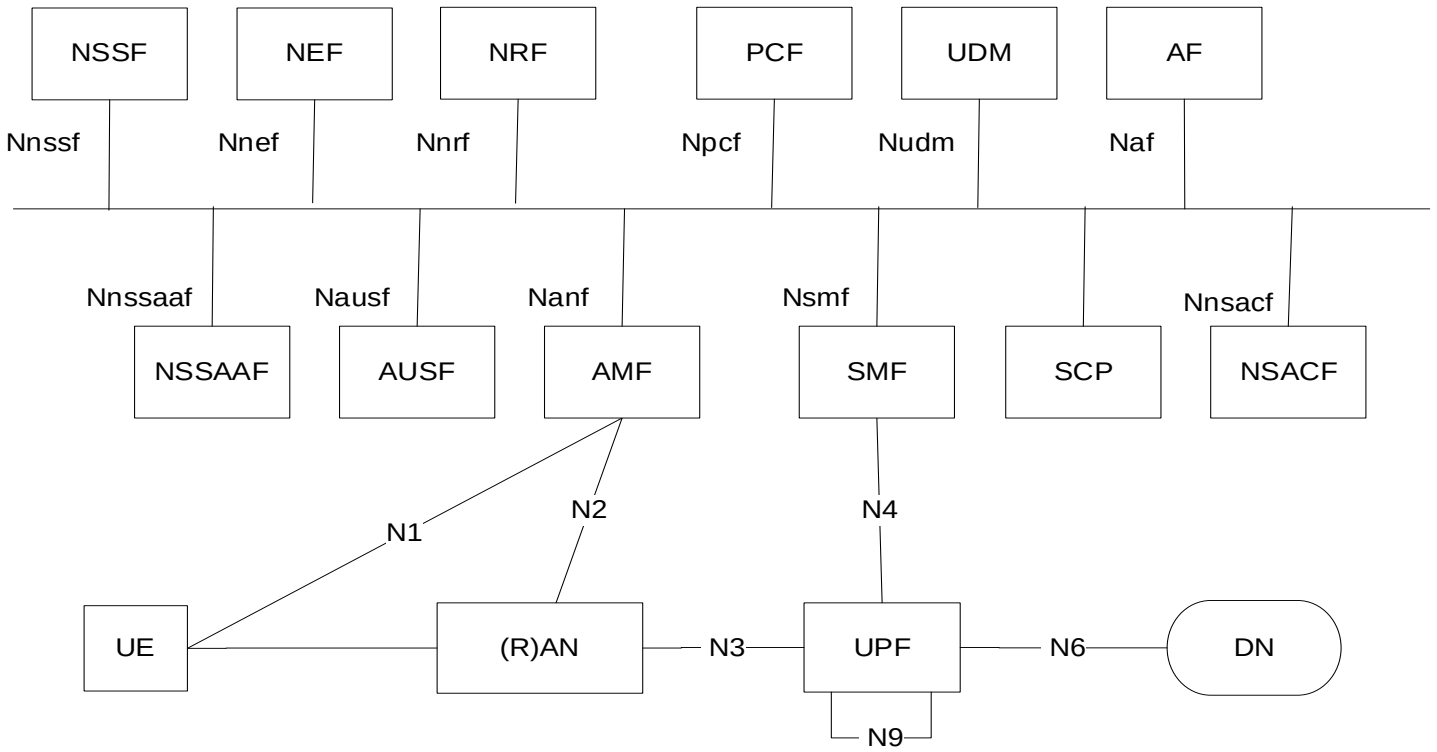
Commonalities

- IP over the lower layers
  - Ether cable, WIFI, tunnel, Air IF + GTP tunnel, etc.
- The PC/UE's IP header comes after the lower layer header
  - Ether/Air/tunnel header
- The PC/UE is assigned an IP address, typically by the Rx/UPF
- Rx/UPF does IP routing to/from the Data Network
- WIFI AP is sort of like a gNB
  - The lower layer has two parts: WIFI Air IF + Ether, or, 5G Air IF + GTP tunnel
  - In a large sophistic WIFI network, APs are connected by an L2 network and PCs can move about

Differences

- UEs can move around – from one gNB to another
  - Mobility management
- UE Authentication & Authorization
  - Access Management
  - Compared to simple password-based management in a simple WIFI network
- Other functionalities
  - Billing & Charging
  - Security, Slicing, QoS & Traffic Steering
- Control Plane and User/Data Plane Separation (CUPS)
- Standardized Management Plane as part of the system

Looking at the 5G architecture Again



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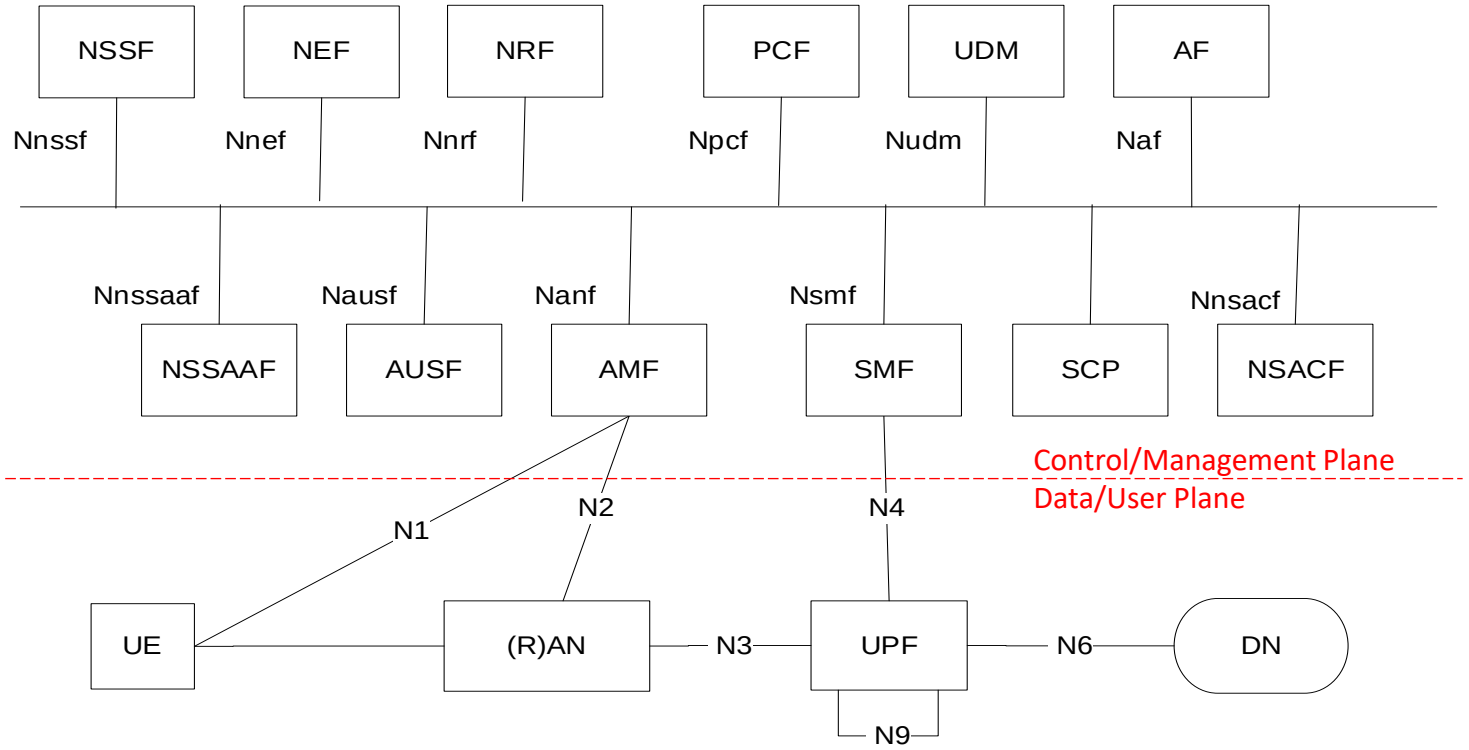

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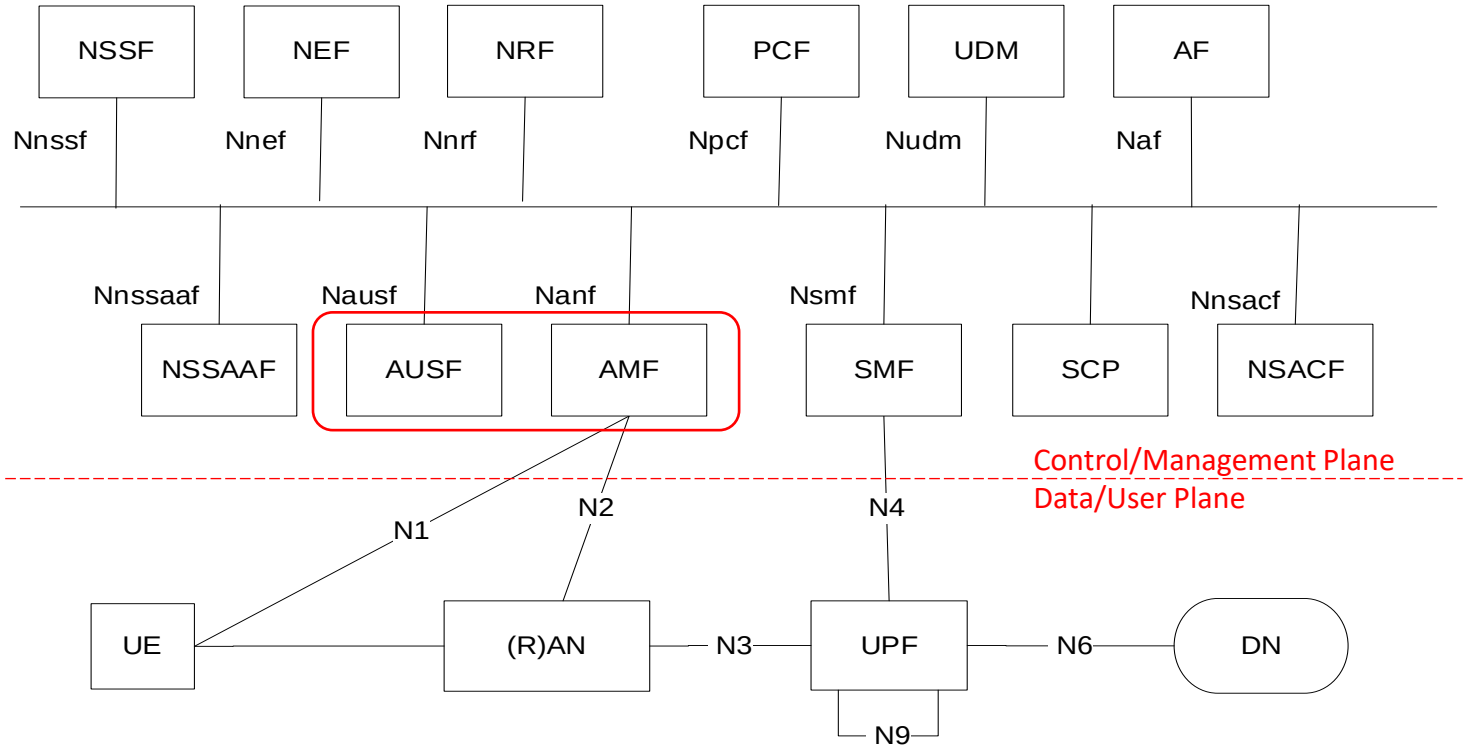

- AUSF+AMF: Access & Mobility Management

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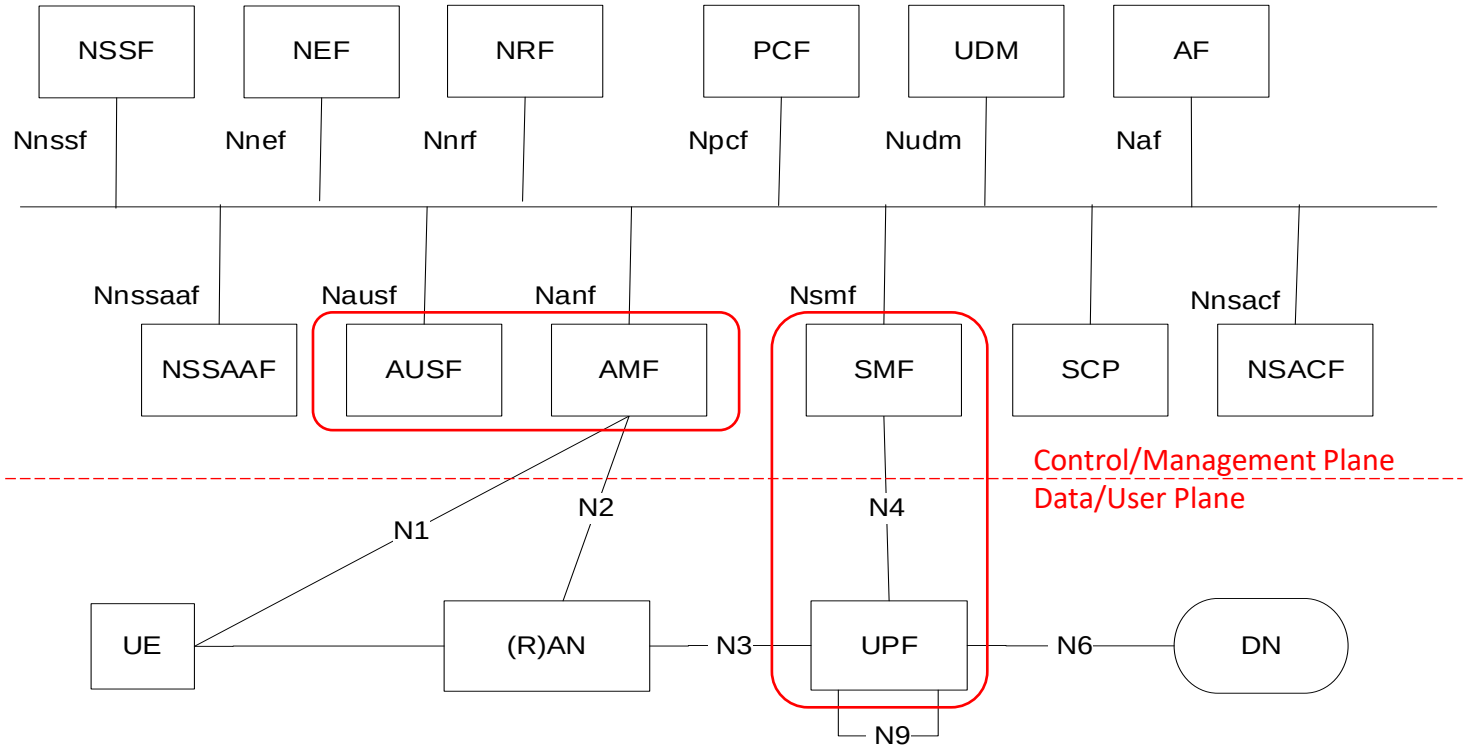


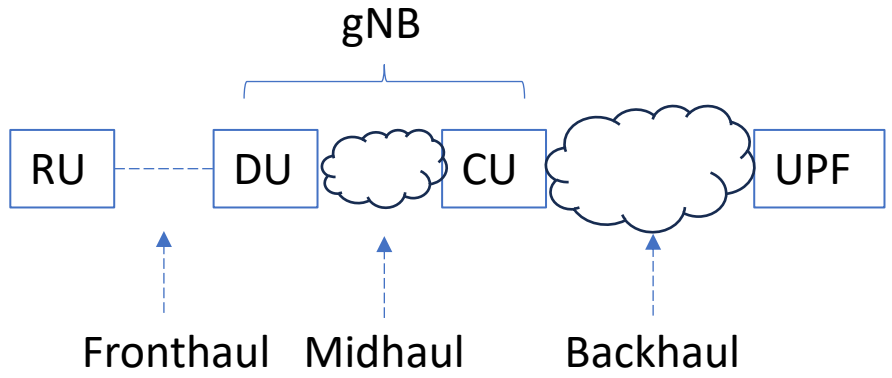
- AUSF+AMF: Access & Mobility Management
- SMF + UPF: Router/BNG

RAN vs. CN

- Radio Access Network
  - More about the gNBs (5G) and eNBs (4G) functionalities than the “network”
- Core Network
  - All control plane components plus UPF
  - Not a topological concept; more about functionalities than the “network”
- RAN disintegration & centralization
  - Time-sensitive handling remains closer to the UEs: RU/DU
  - Non-real-time handling moves up to edge DCs: CU
- CN distribution
  - UPFs may be distributed to edge or far-edge DCs for MEC

xHaul

- 3G/4G's NodeBs/eNBs are distributed – closer to the towers
- With 5G, gNBs are split into Distributed Units (DUs) and Centralized Units (CUs) with CUs moving away from the towers
- Midhaul transport between CUs and DUs
  - Packet-based: IP/MPLS-based VPN/EVPN
- Fronthaul between DUs and RUs (Radio Units)
  - CPRI → Ethernet



Relationship of IETF/IEEE Technologies

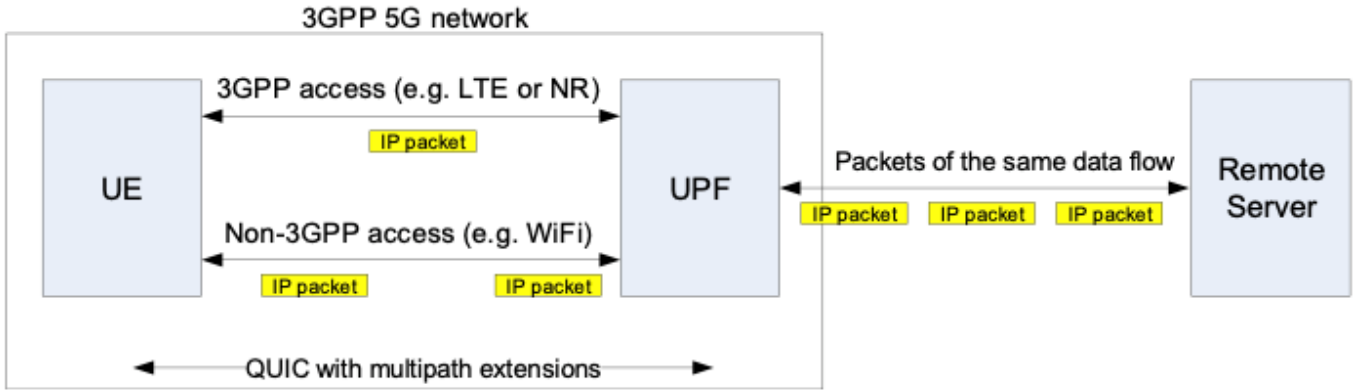
- Mobile Wireless Networks provide IP/Ethernet access services over a mobile infrastructure
  - IP/Ethernet PDU sessions
  - Including VPN services – just like IP VPN and EVPN
- User/Data plane interfaces are GTP tunnels over IP
  - GTP is defined/maintained by 3GPP but is based on IETF technology
- What a typical IETFer likely cares about
  - How to provide IP transport securely/deterministically
  - UPF's routing/switching functionality

IETF/3GPP Process/model

- IETF – a loose, decoupled model
  - We specify individual protocols/features as building blocks
    - Individual drafts -> WG drafts -> RFCs: feature by feature
  - Vendors implement the features and operators deploy the features a la carte
  - We don’t mandate a management plane
- 3GPP – a strict “software-release”-like model
  - Individual features are proposed, discussed and some are admitted to a release
    - A release specifies the entire system to provide mobile communication services
  - Management plane is an integral part of each release
  - Each meeting is like a “code review for a software release”
  - Vendors implement releases and operators deploy releases
  - Each generation of mobile networks has several releases

IETF/3GPP Interaction

- 3GPP specifications reference IETF specifications
  - For the IETF technologies they use
  - E.g., the GTP specification references 9 RFCs
- Some technologies are designed with close IETF/3GPP collaboration
  - E.g., RFC9543 (IETF Slicing), [draft-ietf-teas-5g-ns-ip-mpls]
  - E.g., draft-ietf-quic-multipath



- Liaison Process [RFC3113]
  - Official Channel between IETF and 3GPP

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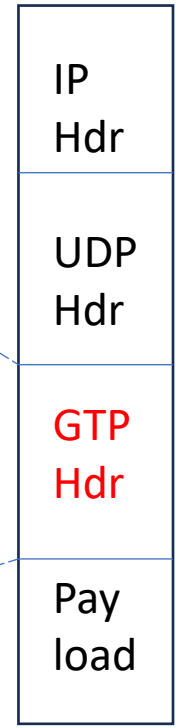
GPRS Tunneling Protocol

- IP/UDP-based communication protocol for *General Packet Radio Services*
  - within CN; between CN and RAN
- GTP-C vs. GTP-U
- Unless explicitly stated, in this presentation GTP refers to GTP-U

GTP-U Header

Octets	Bits 8	7	6	5	4	3	2	1
1	Version			PT	(*)	E	S	PN
2	Message Type							
3	Length (1st Octet)							
4	Length (2nd Octet)							
5	Tunnel Endpoint Identifier (1st Octet)							
6	Tunnel Endpoint Identifier (2nd Octet)							
7	Tunnel Endpoint Identifier (3rd Octet)							
8	Tunnel Endpoint Identifier (4th Octet)							
9	Sequence Number (1st Octet)[1) 4)]							
10	Sequence Number (2nd Octet)[1) 4)]							
11	N-PDU Number[2) 4)]							
12	Next Extension Header Type[3) 4)]							

TEID

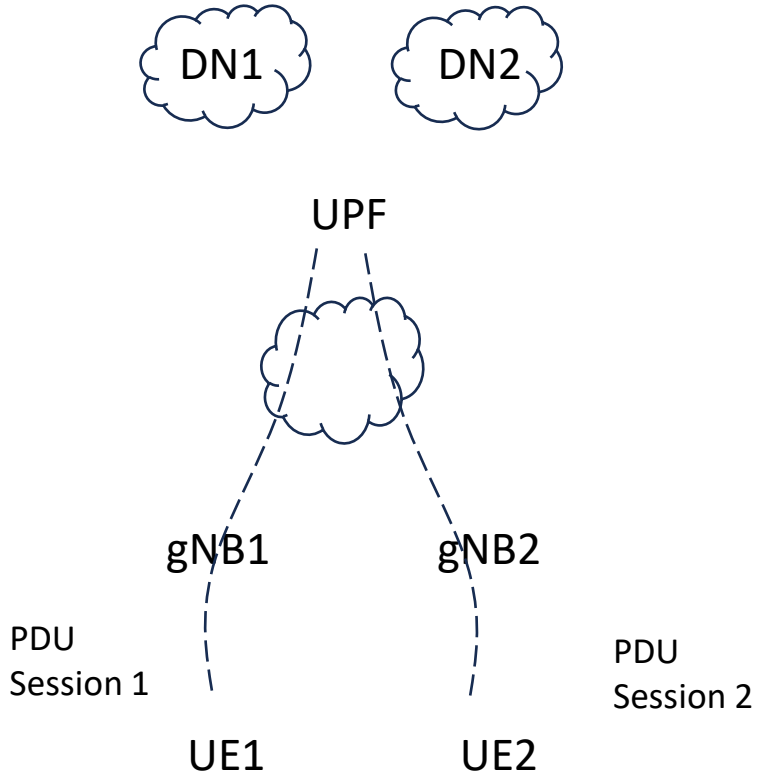


(*) This bit is a spare bit. It shall be sent as '0'. The receiver shall not evaluate this bit.
1) This field shall only be evaluated when indicated by the S flag set to 1.
2) This field shall only be evaluated when indicated by the PN flag set to 1.
3) This field shall only be evaluated when indicated by the E flag set to 1.
4) This field shall be present if and only if any one or more of the S, PN and E flags are set.

Source: ETSI TS 129 281

<Tunnel Endpoint, Tunnel Endpoint ID>

- A Tunnel Endpoint ID (TEID) is an ID assigned for a PDU session
  - By the Tunnel endpoint, not for the Tunnel Endpoint



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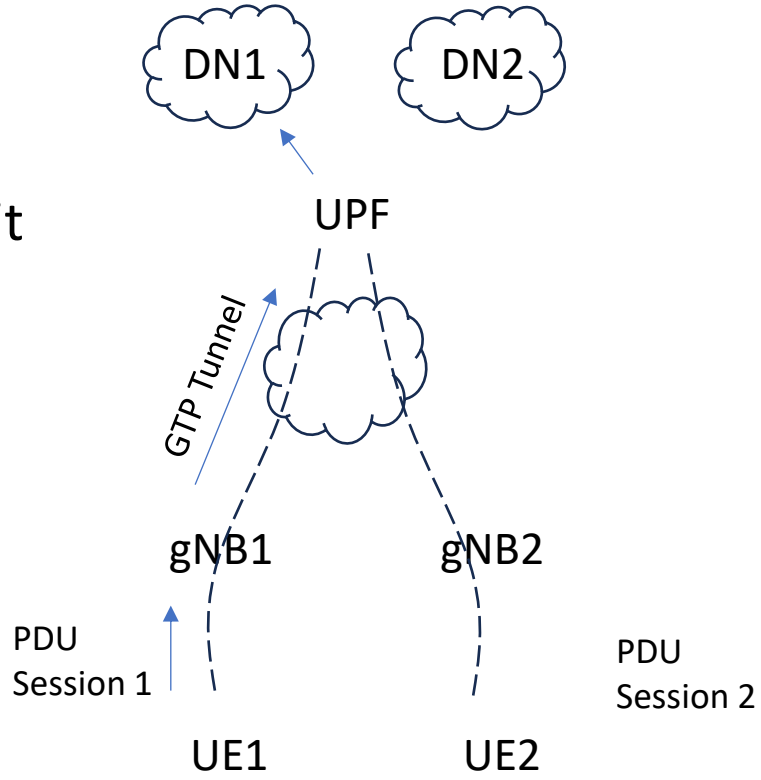
- When a gNB sends an UpLink (UL) packet (from a UE) to a UPF, it encapsulates the packet with an IP/UDP/GTP header
  - DST IP address: UPF
  - TEID: learned from the AMF, assigned by the UPF
  - The UPF decapsulates the outer headers and routes it to the corresponding DN associated with the TEID



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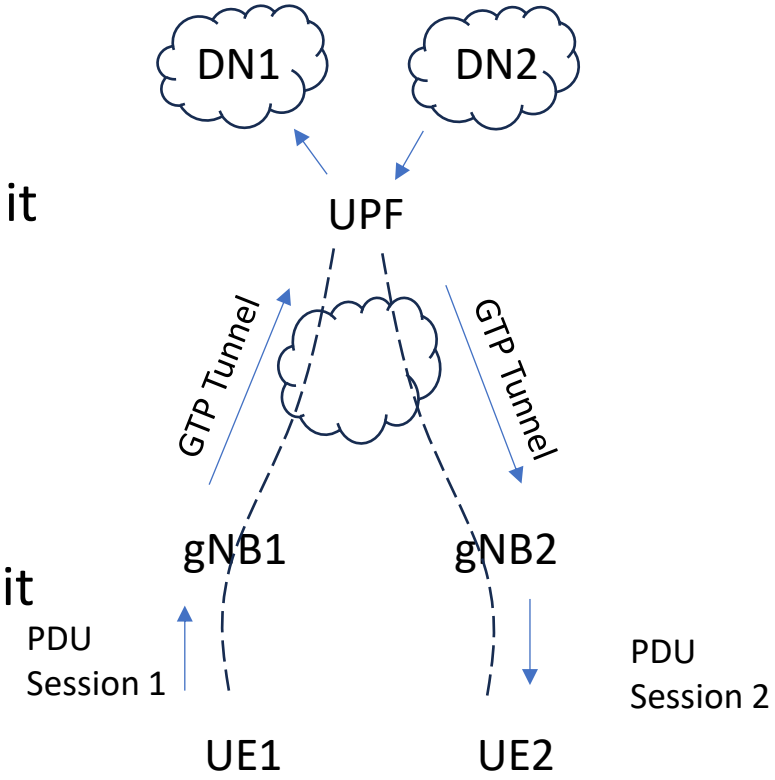
  - TEID: learned from the AMF, assigned by the UPF
  - The UPF decapsulates the outer headers and routes it to the corresponding DN associated with the TEID
- When a UPF sends a DownLink (DL) packet (for a UE) to a gNB, it encapsulates the packet with an IP/UDP/GTP header
  - DST IP address: gNB
  - TEID: learned from the SMF, assigned by the gNB
  - The gNB decapsulates the outer headers and relays it to the corresponding PDU session identified by the TEID



GTP Tunnel vs. IETF Pseudo Wire

GTP

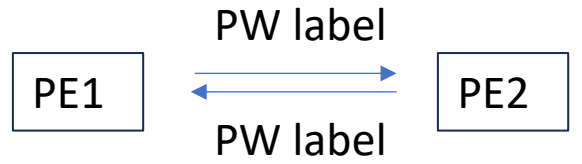
- IP/Ethernet payload for a PDU session
  - PDU sessions between many gNBs and fewer UPFs
- <Tunnel Endpoint, TEID>
  - TEID assigned by endpoint
- For each PDU session identifer:
  - AMF tells the gNB, and asks for a TEID
    - Tells the TEID to the SMF – for DL traffic
    - Tells the gNB the UPF's TEID – for UL traffic
  - SMF tells the UPF, and asks for a TEID
    - Tells the TEID to the AMF – for UL traffic
    - Tells the UPF the gNB's TEID – for DL traffic

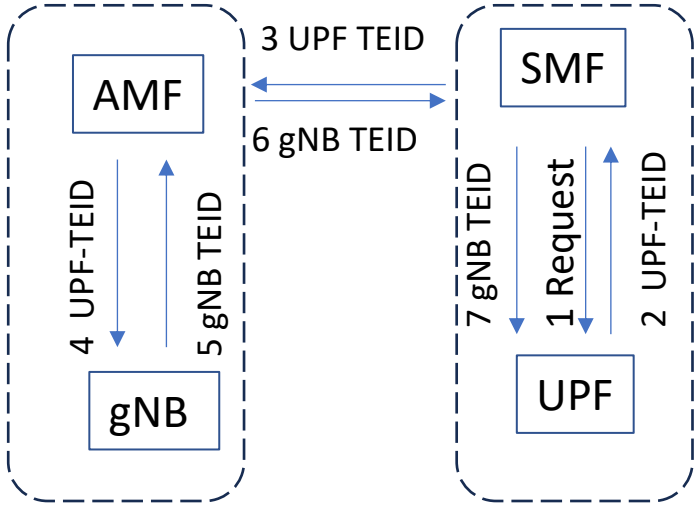
IETF PW

- L2 payload for a PW
  - PWs between peer PEs
- <label for endpoint, PW label>
  - PW label assigned by endpoint
- Both ends provisioned with the PW identifier and the other end
  - One end sends its PW label to the other end
    - And receives the other end's PW label

CUPS – Control/User Plane Separation

- A traditional wireline PE has both a control plane and a data plane
  - Control plane runs distributed routing protocols
    - E.g., LDP/BGP that distribute PW labels
- An AMF/gNB pair is comparable to the control/data plane of a spoke PE
- An SMF/UPF pair is comparable to the control/data plane of a hub PE
- One AMF can control many gNBs, and one SMF can control many UPFs





Mobility Handling

- When a UE moves, its PDU sessions may need to attach to a new/target gNB and detach from an old/source gNB while the UPF does not change
- The AMF:
  - Tells the target gNB the moving PDU session's ID, the UPF address, and the UPF's TEID
    - The target gNB starts sending UL traffic to the UPF
  - Asks the target gNB for a TEID and tells it to the SMF
  - Asks the source gNB to release the tunnel/resources for the session
- The SMF tells the UPF the target gNB address and its TEID
  - The UPF starts sending DL session traffic to the new gNB
- Make-before-break mechanisms to ensure session continuity
  - no traffic loss
  - in-order delivery

Agenda

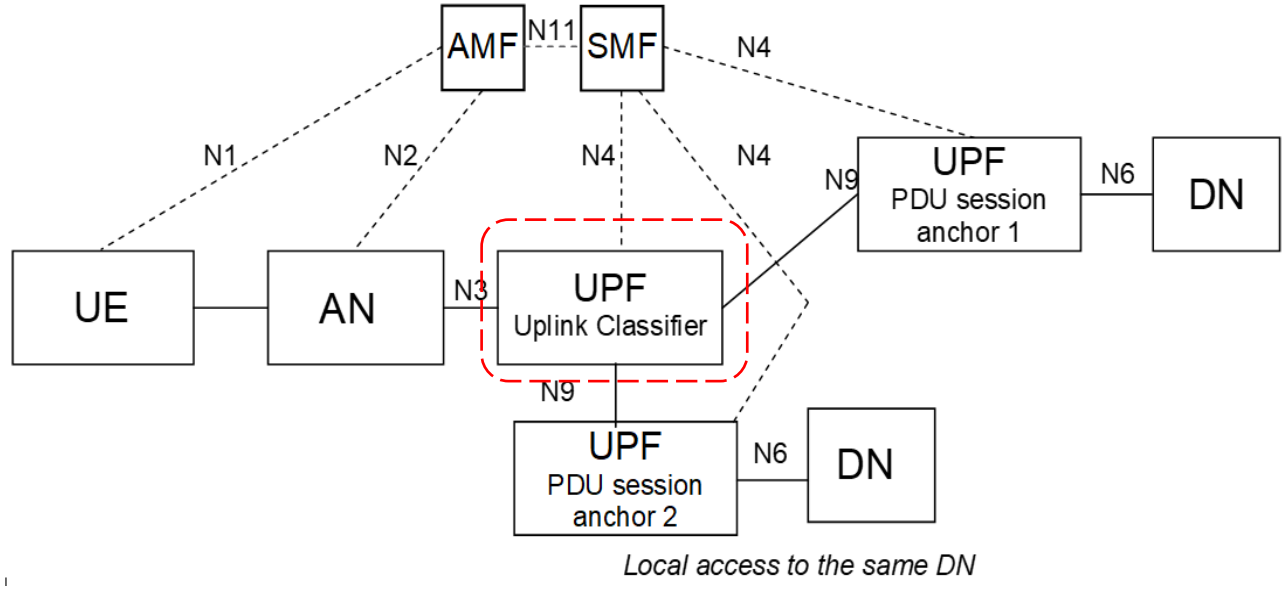
- 5G Architecture - from a routing/switching POV
- GTP Tunneling and Mobility
- *MEC, URLLC, and LAN-type Services*
- Transport, QoS, and Slicing

MEC/URLLC

- UPFs may be centrally deployed
  - This is ok for to/from Internet traffic (via few UPFs)
- For scenarios where low latency is critical, application servers need to be deployed close to the UEs
  - In Edge Computing DCs near the gNBs
  - This means UPFs also need to be near the gNBs
- ULCL UPF vs. Distributed UPF

ULCL-UPF

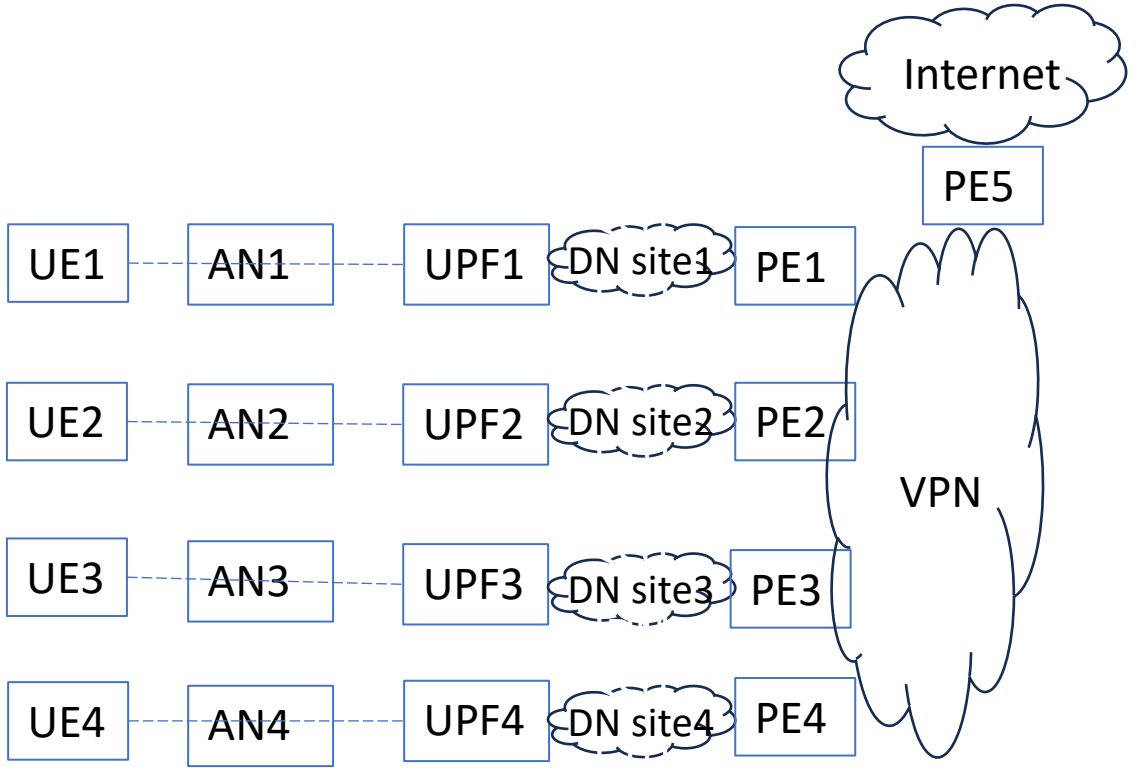
- The gNB continues to tunnel UL traffic to the central UPF
- An intermediate UL Classifier (ULCL) UPF examines all session traffic, intercepts some traffic and redirects to a local UPF
  - Per filtering rules from the SMF
- The UE IP address does not change even when it moves



AN (Access Node) is a generic term; gNB is one kind of AN

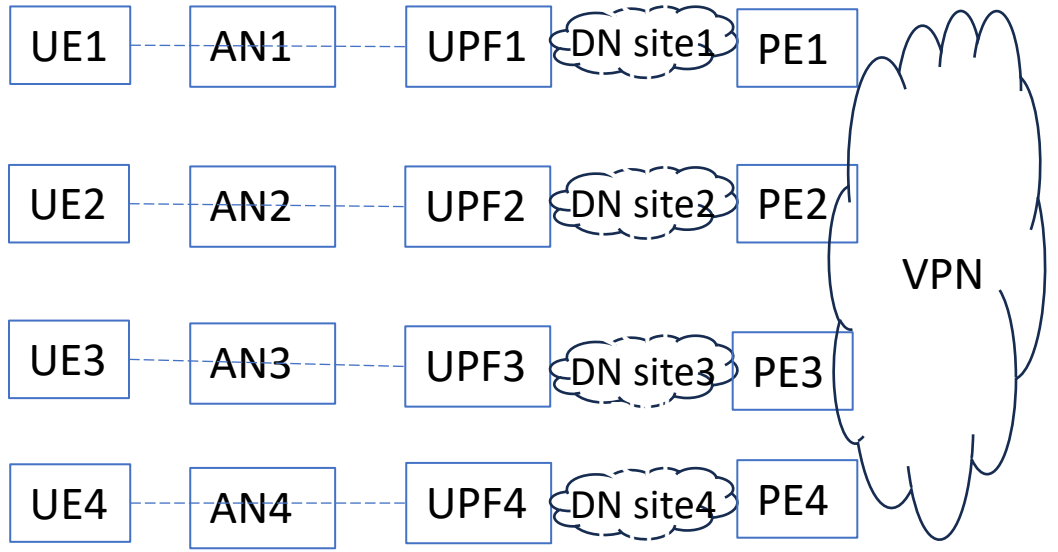
Distributed UPFs

- UPFs distributed close to gNBs
- DN sites also distributed, and connected via VPN
- UE IP addresses change when it moves from one UPF to another
  - UPFs advertising host routes can address this, though not specified by 3GPP
  - In case of Ethernet PDU session, MAC address does not change and they're advertised like host IP addresses



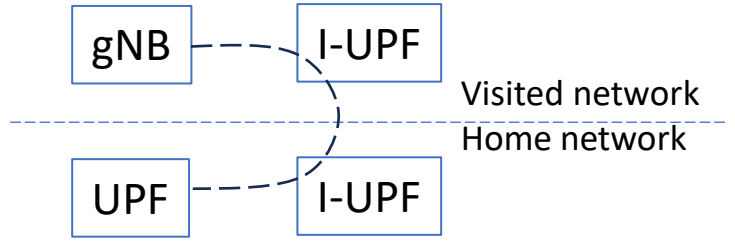
5G LAN-type Services

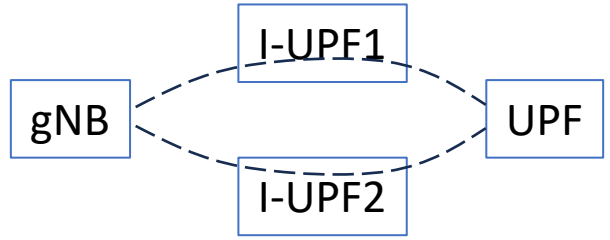
- Consumer 5G services are mainly north-south for Internet access
  - UE-UE traffic is rare
  - UE-MEC traffic is optimized via either ULCL or distributed UPFs
- 5G LAN-typer services for business:
  - East-west UE-UE traffic is normal
    - Distributed UPFs make more sense to avoid traffic tromboning via a central UPF
  - Different DNs for different business customers
  - Identical to wireline IPVPN/EVPN at the service level
    - Specified independently; could be integrated for seamless wireline/wireless VPN services



I-UPF and Wireline ASBRs/ABRs

- For home-routed roaming, a PDU session spans between a visited gNB and a home UPF
- Even in the non-roaming case, the SMF can specify that a PDU session go through some specific I-UPFs
- In both cases, several GTP tunnel segments are stitched together by I-UPFs
  - An incoming GTP packet's TEID maps to a new TEID for a new GTP endpoint
- This is just like the MPLS label swapping at:
  - AS Boundary Routers (ASBRs) between ASes
  - Area Border Routers (ABRs) between IGP areas





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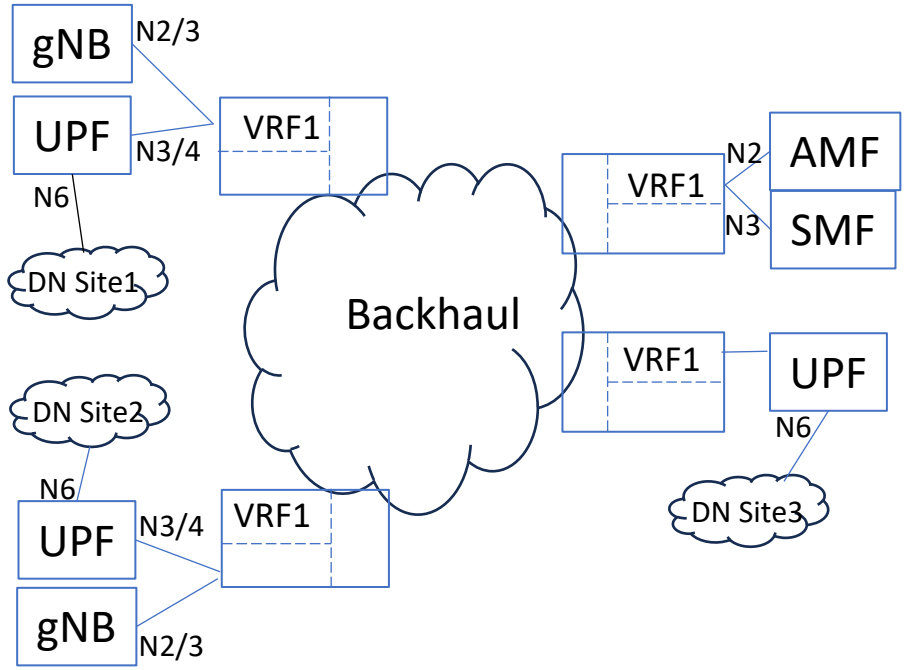
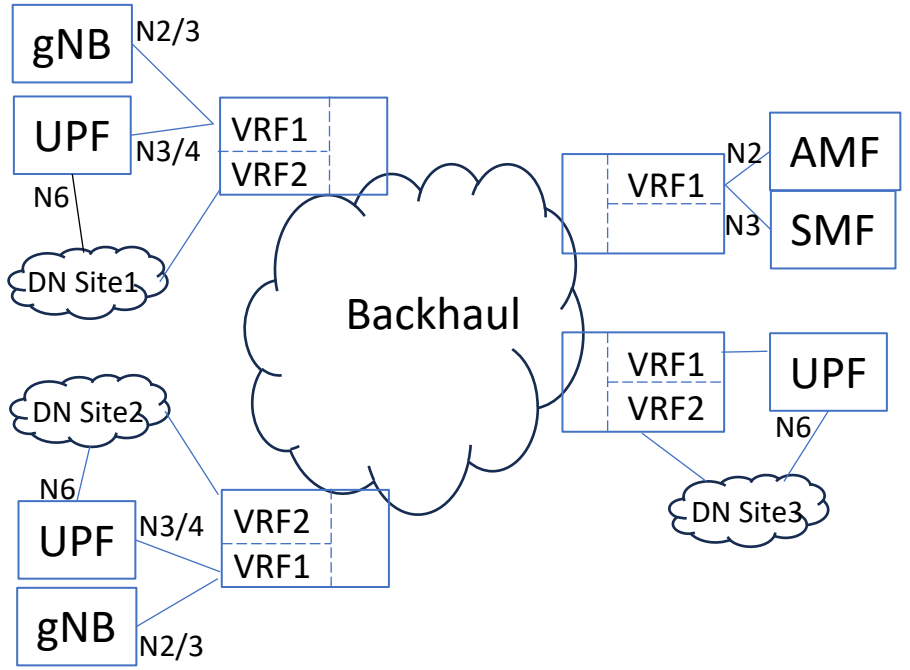
Transport Network

- The GTP tunnels are IP-based
  - Typically via an IPVPN over a converged infrastructure for wireline and wireless.



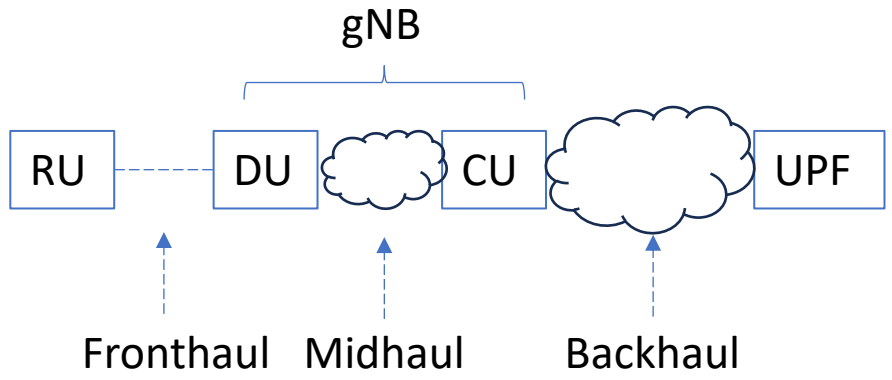
Transport Network

- The GTP tunnels are IP-based
  - Typically via an IPVPN over a converged infrastructure for wireline and wireless.
- An IPVPN/EVPN typically connects the distributed DN sites over the same infrastructure as well



xHaul

- 3G/4G's NodeBs/eNBs are distributed – closer to the towers
- With 5G, gNBs are split into Distributed Units (DUs) and Centralized Units (CUs) with CUs moving away from the towers
- Midhaul transport between CUs and DUs
  - Packet-based: IP/MPLS-based VPN/EVPN
- Fronthaul between DUs and RUs (Radio Units)
  - CPRI → Ethernet



QoS and Slicing

- Internet QoS is coarse – DiffServ-based
- BNG provides hierarchical per-subscriber QoS on the access interface
- 5G provides more sophisticated QoS
  - Mainly for the air interface
  - When traffic goes through the GTP, 5G QoS is mapped to transport QoS
- QoS and Slicing can be independent or intertwined
  - QoS can be provided w/ or w/o slicing
  - Different slices can have different QoS requirements/characteristics

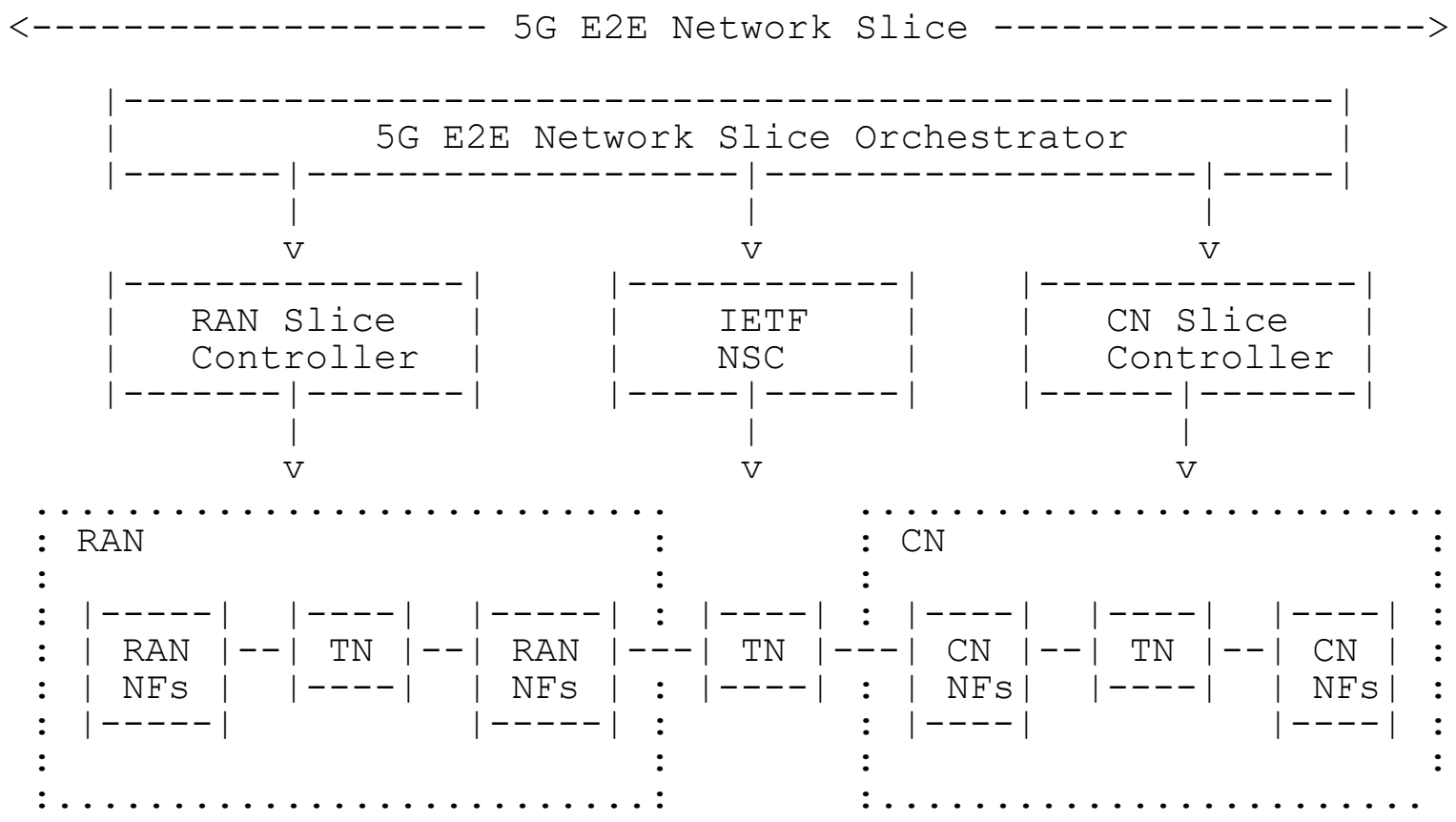
General/5G Slicing

- A Network Slice is a logical partition of a network
  - For meeting a set of specific network performance objectives
- 5G Network Slice
  - A logical network that provides specific network capabilities and network characteristics, supporting various service properties for network slice customers [3GPP 28.530]
  - With appropriate isolation, resources, and optimized topology ... These resources are from the RAN, CN Network Functions, and the underlying infrastructure [draft-ietf-teas-5g-ns-ip-mpls]
  - An E2E 5G Network Slice spans across RAN/CN and (transparently over) TN (Transport Network)

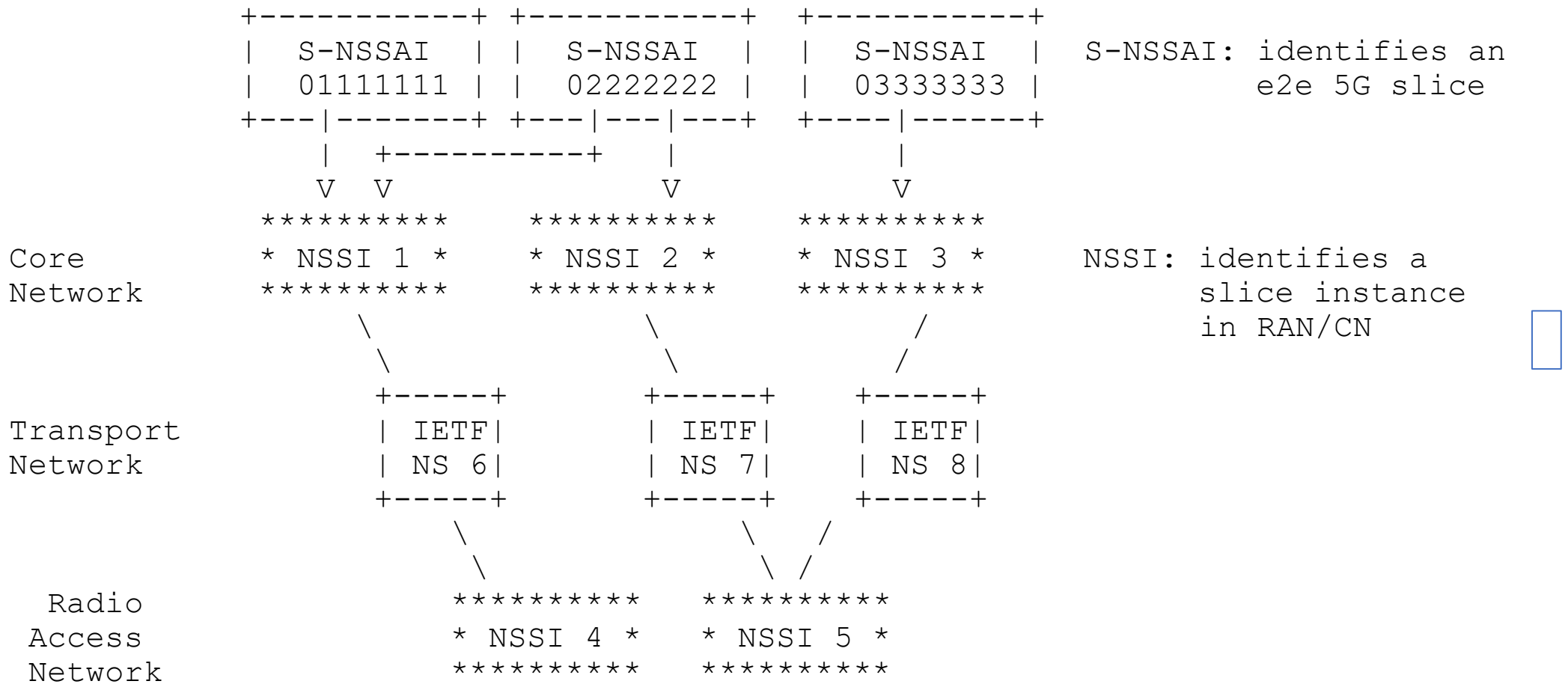
TN/IETF Slicing

- TN slice: A slice in the 5G Transport Network domain
  - [draft-ietf-teas-5g-ns-ip-mpls]
  - To isolate, guarantee, or prioritize Transport Network resources for Slice Services. Resources examples: buffers, link capacity, or even Routing Information Base (RIB) and Forwarding Information Base (FIB).
- IETF Slicing
  - [RFC9543]
  - Network slicing in the context of networks built from IETF technologies

[draft-ietf-teas-5g-network-slice-application]



[draft-ietf-teas-5g-network-slice-application]



Summary

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