RAN Slicing: Challenges, Technologies, and Tools

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Provide an overview of 4G, 5G and RAN slicing

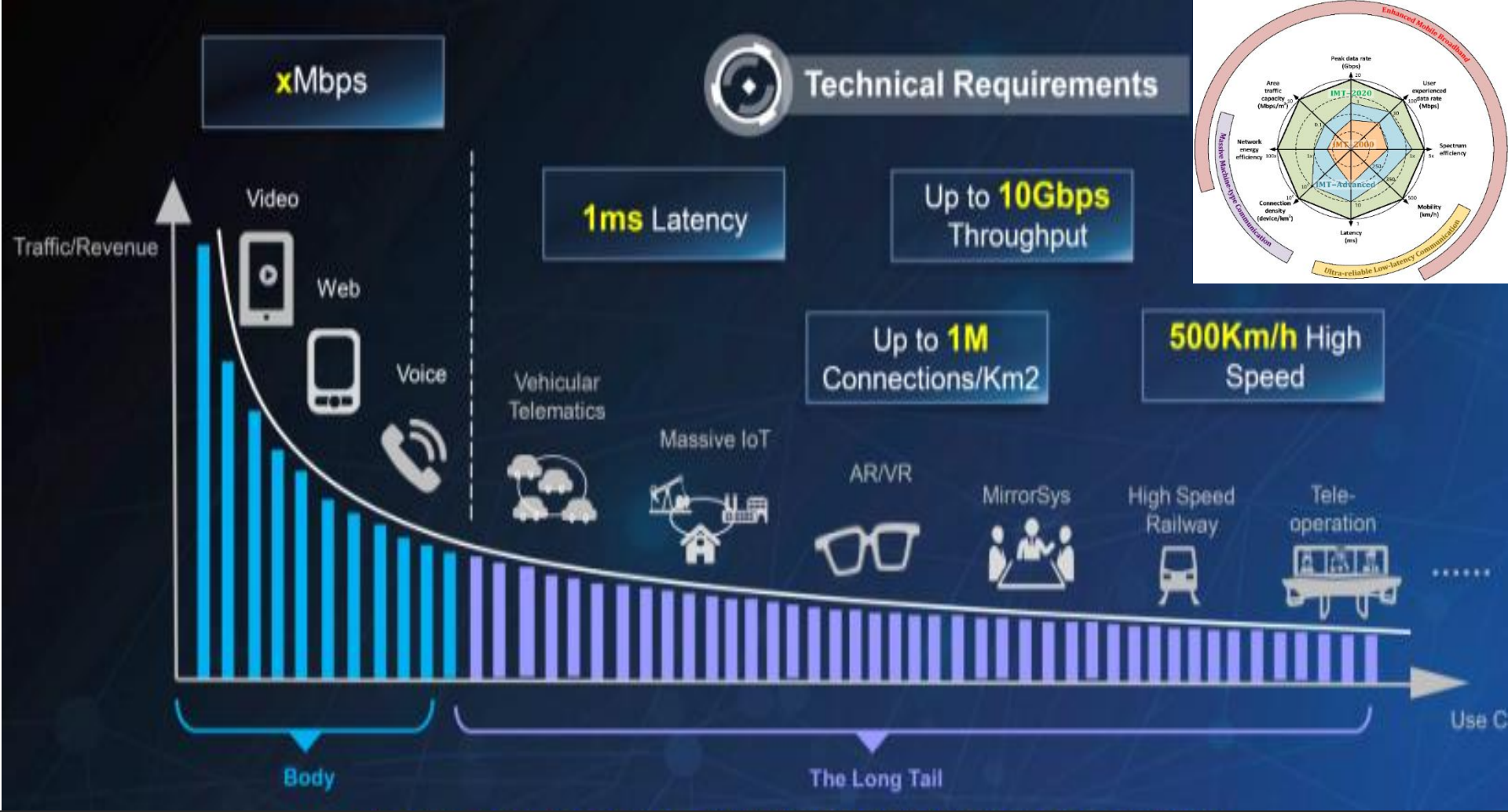
Highlight the importance and timeliness of **softwarization, virtualization, and disaggregation** of RAN to enable **multiservice multi-tenant** RAN toward So-RAN architecture

Cover a **well-balanced research** topics and challenges

Tutorial Objectives


5G shall enables
Connected, Controlled, and Flexible Network as a service
Digital Society
Value Creation
Consistent experience
Sustainable business model

5G Promises

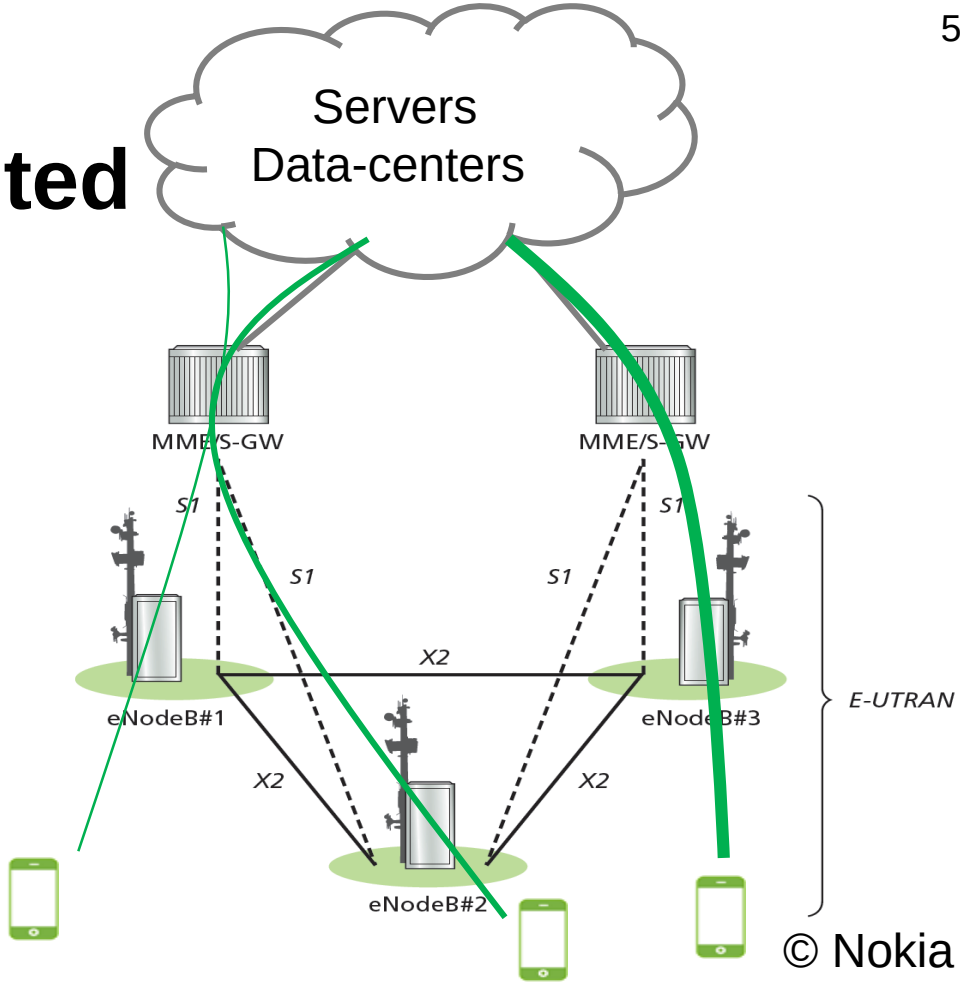


LT→ Driving Forces of 5G

Communication-Oriented

Today's 4G is designed for a limited number of UCs

- Throughput-optimized
- Fixed
- Rigid



Is 4G enough?

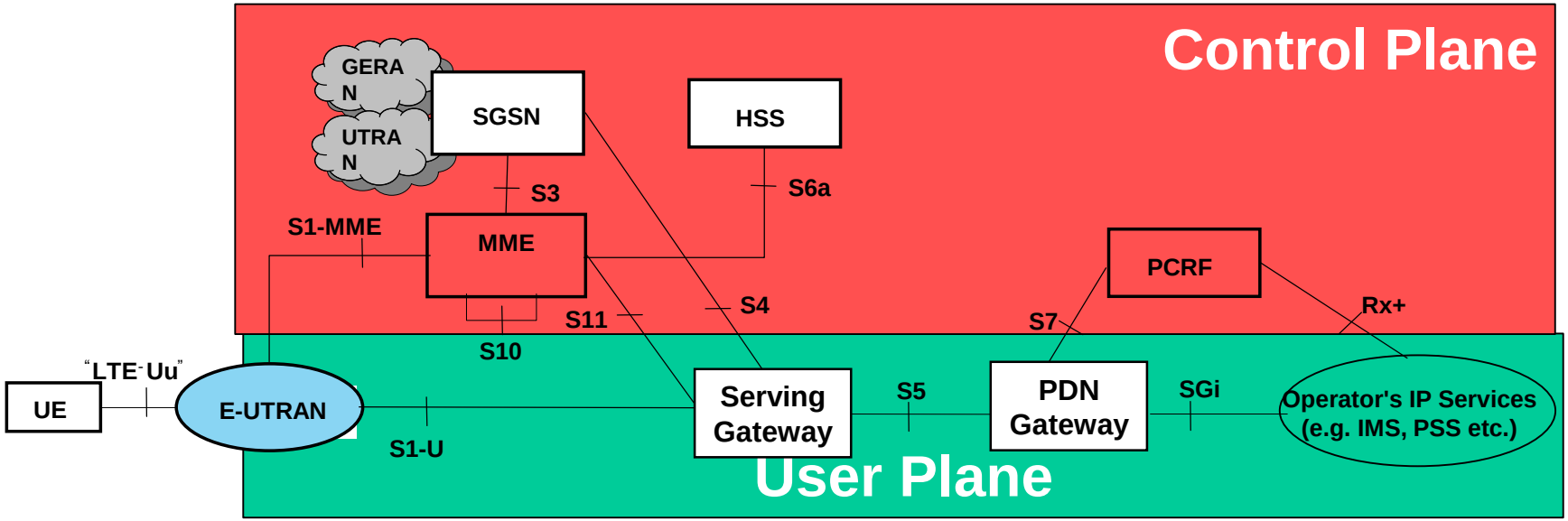
Monolithic BS

Stateful network entities

Transactional communication mode

Certain level of CP and UP separation

Common entity for user mobility and session management



Communication-oriented 4G

Multi-operator RAN(MORAN)

Shared RAN nodes, dedicated spectrum, but separated CN per operator

Multi-operator CN (MOCN)

Shared RAN nodes and spectrum, but separated CN per operator with proprietary services

Gateway CN (GWCN)

shared RAN and part of core networks

Dedicated core (DECOR)

Deploy multiple dedicated CNs (DCNs) within a single operator network

One or multiple MMEs and SGWs/PGWs, each element

Evolved DECOR (eDECOR)

UE assisted DCN selection

Network Node Selection Function (NNSF) at RAN to select directly the proper DCN towards which the NAS signaling needs to be forwarded

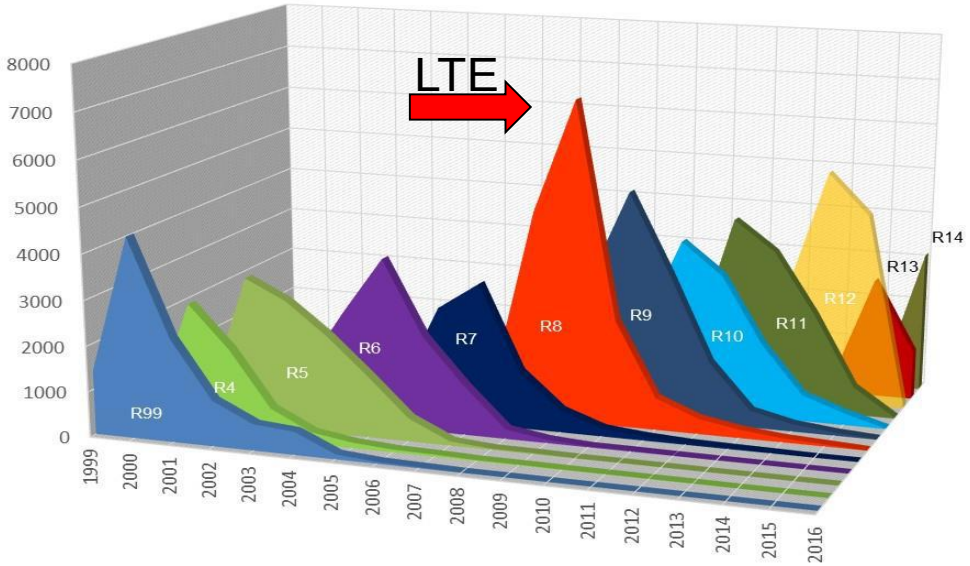
Congestion control and load balancing among multiple DCN with shared MME

4G Network Sharing Models

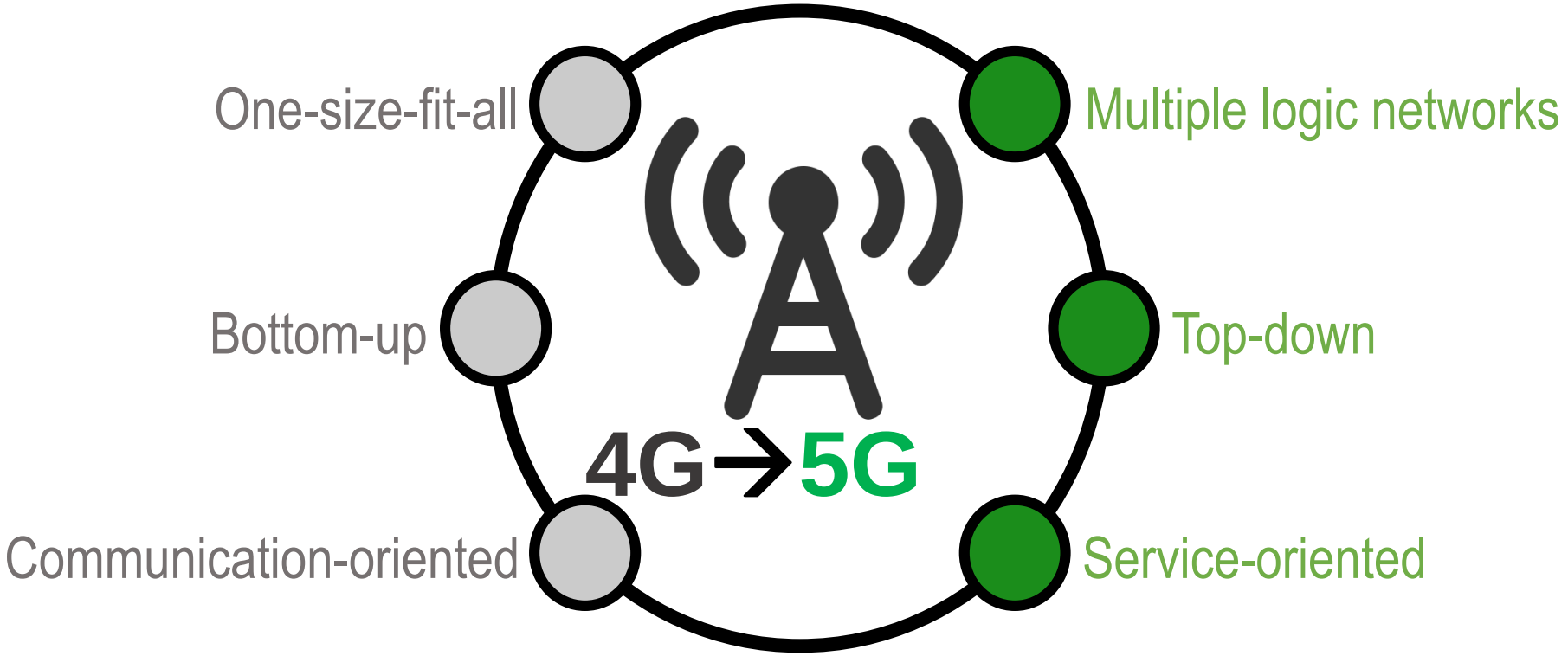
Mindful about

3GPPP facts and figures

514 Companies from 45 Countries
50,000 delegate days per year
40,000 meeting documents per year
1,200 specifications per Release
10,000 change requests per year

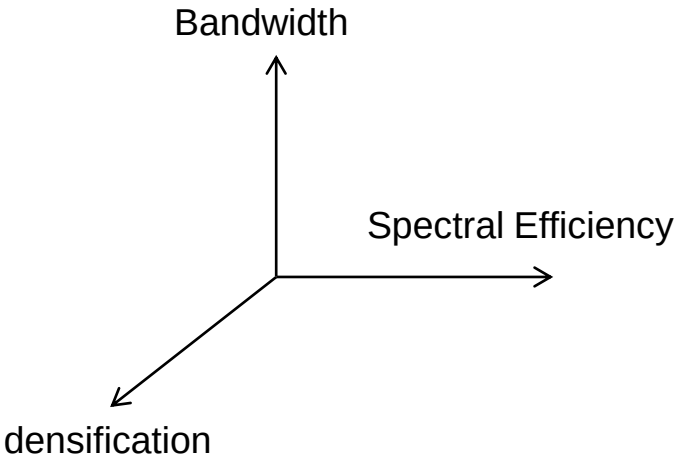


3GPP R8 Facts and Figures

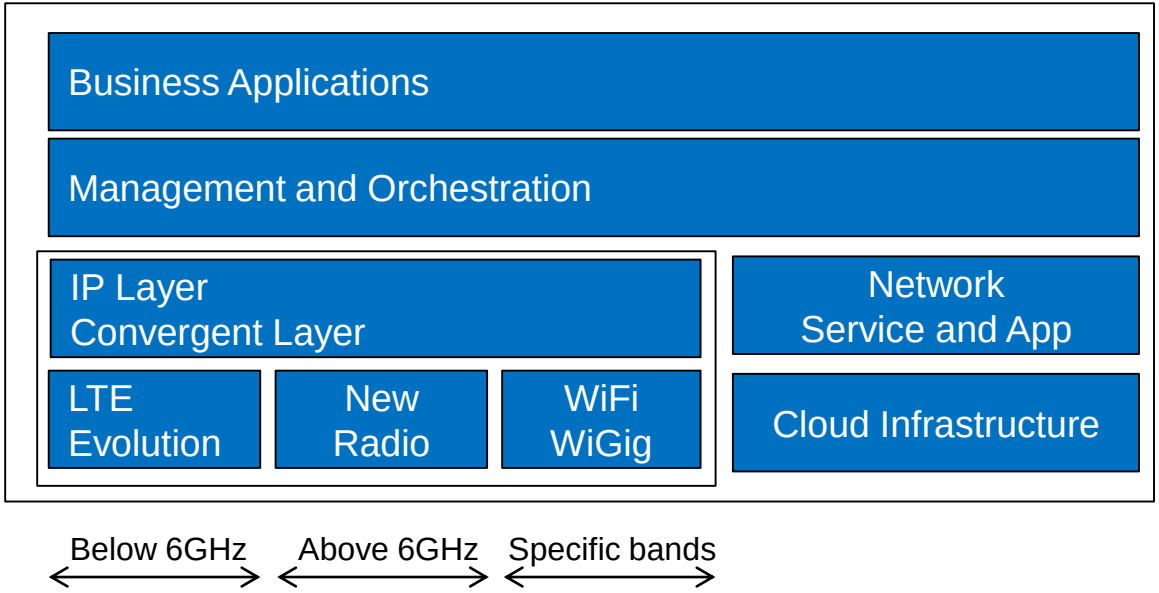


Evolution from 4G to 5G

Dimension in increasing capacity

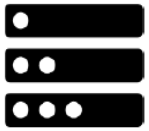


Overall 5G Components



5G is not just a new radio/spectrum, but also a new architecture and business helper

5G : A Paradigm Shift



Software Defined Networking

Fog Computing
Edge Computing

SDN/NFV Orchestration

Network Function Virtualization

Cloudification Virtualization

Contextual Networking

Heterogeneous Networking

Self Organization Networking

Ultra dense network

Advanced MIMO

Advanced waveforms

Millimeter Wave

Carrier Aggregation of discontinuous bands

Flexible and high capacity backhaul

Single channel full duplexing

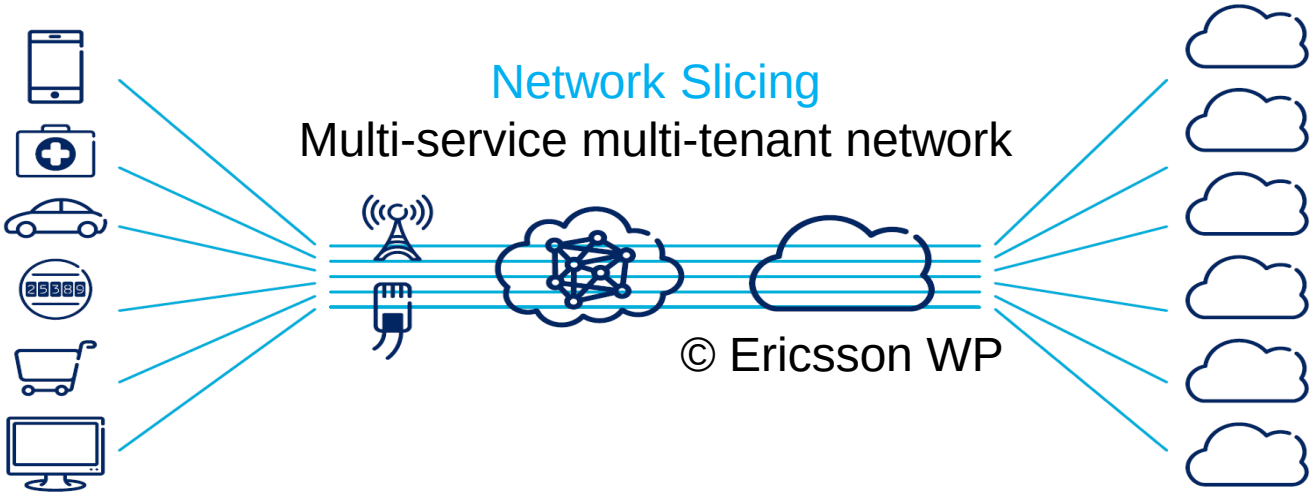
New Spectrum Allocations

More Flexible Spectrum

5G Technology Enablers

Turn physical infrastructure into multiple logical networks, one per service instance: **One-Network, Many-Service**

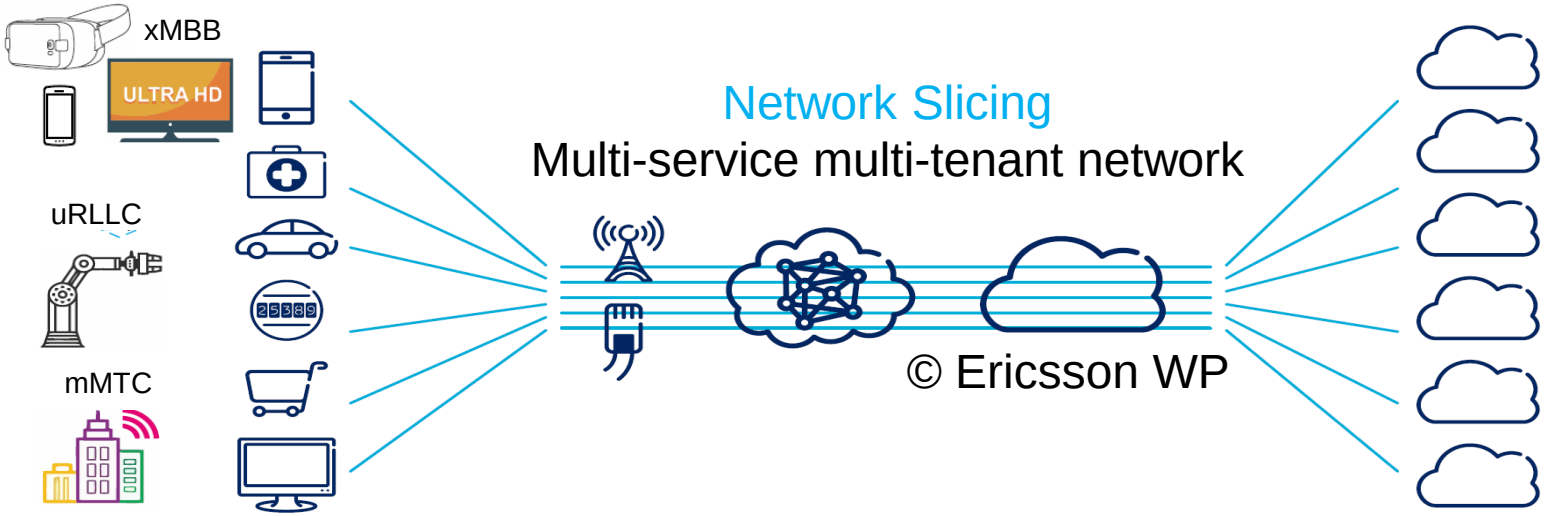
NOT a one-size fits all architecture **NOT** a Dedicated Network



Service-oriented 5G

5G novel usage scenarios: eMBB, uRLLC, mMTC

Multi-disciplinary approach with the fusion of computing, communication, information, and IT



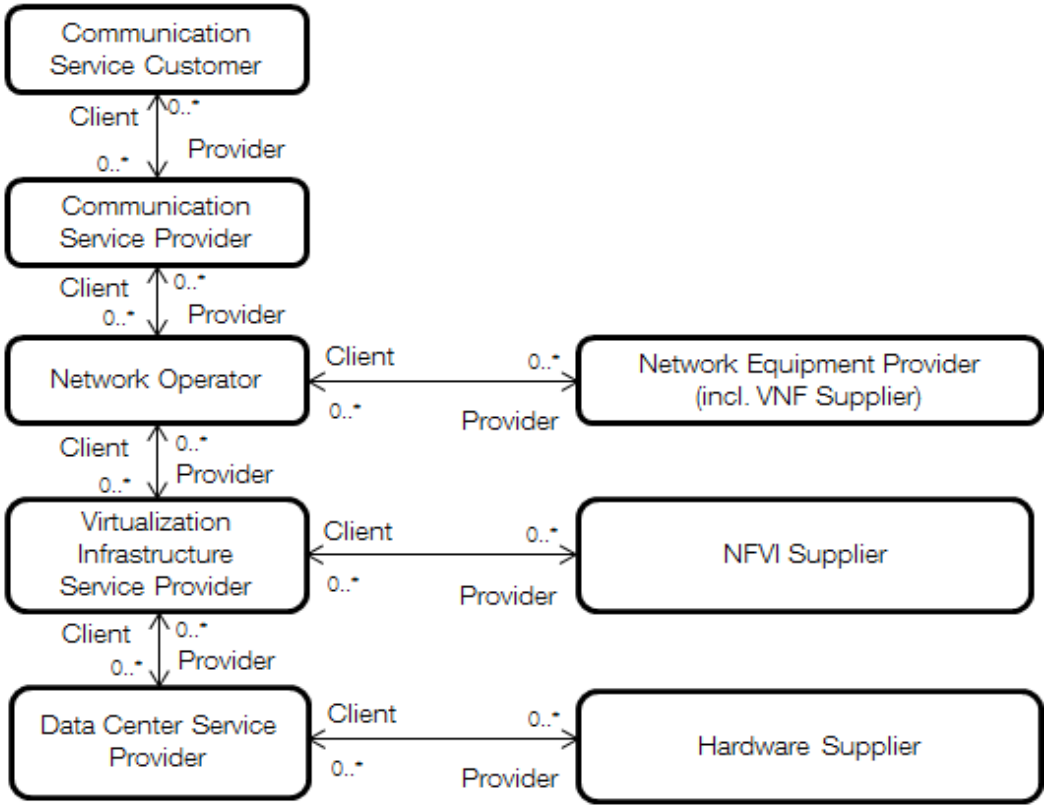
Service-oriented 5G

3GPP Role Model (3GPPP 28.801)

E.g.: End user,
Small & Medium Entreprise,
Large entreprise,
Vertical,
Other CSP, etc.

Network Slicing evolves the value-chain of telecom industry:

Decoupling of Players, but the reality might be different



Service-oriented 5G

3GPP Re-Architects Mobile Network

	3G	4G	5G
Downlink waveform	CDMA	OFDM	OFDM, SCFDMA
Uplink waveform	CDMA	SCFDMA	OFDMA, SCFDMA
Channel coding	Turbo	Turbo	LDPC (data) / Polar (L1 contr.)
Beamforming	No	Only data	Full support
Spectrum	0.8 – 2.1 GHz	0.4 – 6 GHz	0.4 – 90 GHz
Bandwidth	5 MHz	1.4 – 20 MHz	Up to 100 MHz (400MHz for >6GHz)
Network slicing	No	No	Yes
QoS	Bearer based	Bearer based	Flow based
Small packet support	No	No	Connectionless
In-built cloud support	No	No	Yes

3GPP 5G Features

(1) Ultra-flexible radio-access configurations

Higher bandwidth

Higher spectral efficiency (bits/s/Hz/m2)

Bandwidth parts: tailor bandwidth to UE class (like eMTC narrowbands/widebands)

Network slicing : new abstractions for service classification down to L1

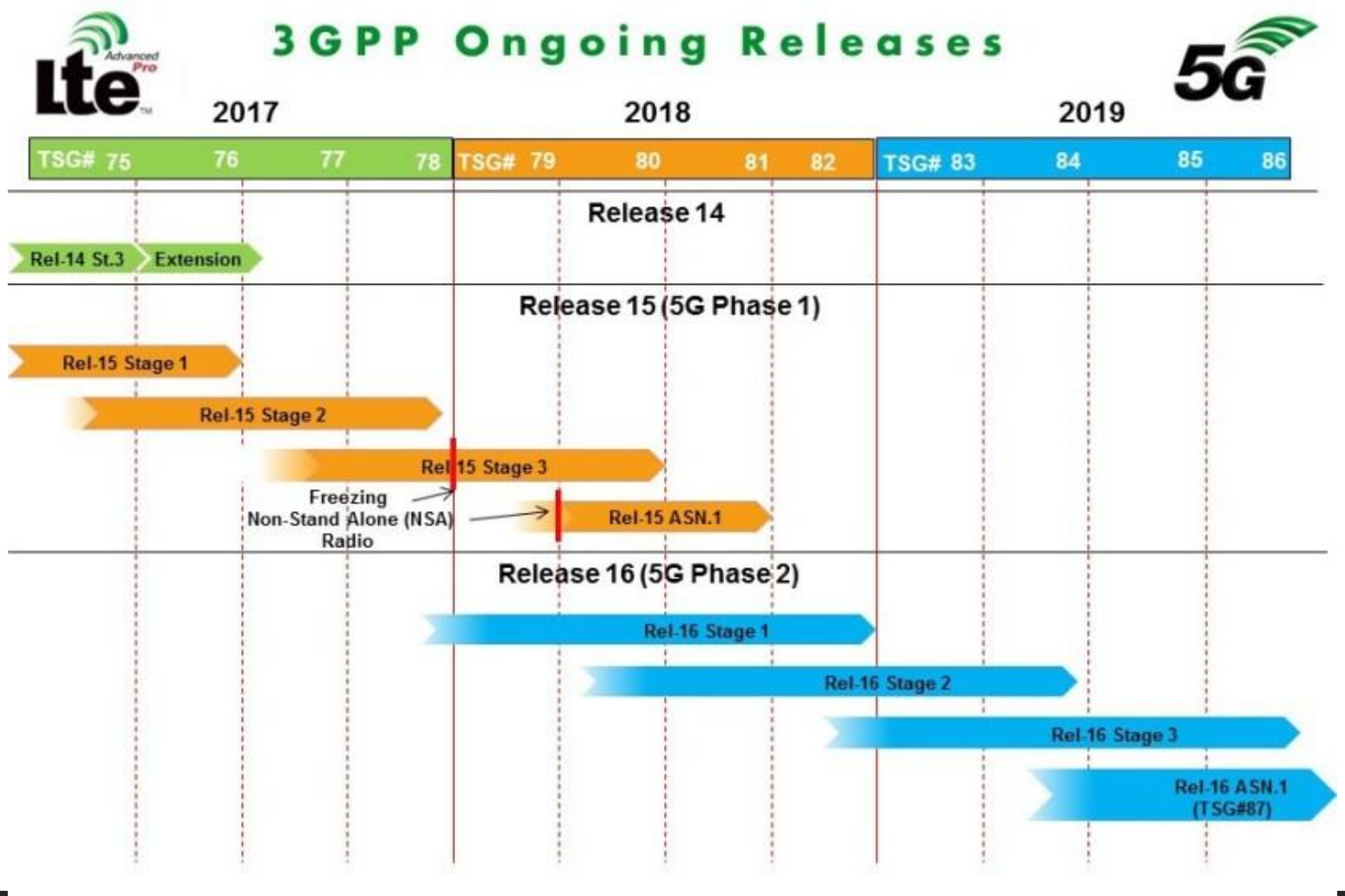
(2) Compatibility with 4G/5G cores (NSA & SA mode)

5G dual-connectivity (non-standalone operation)

Interconnection of evolved 4G eNodeB (ng-eNB) with 5G core

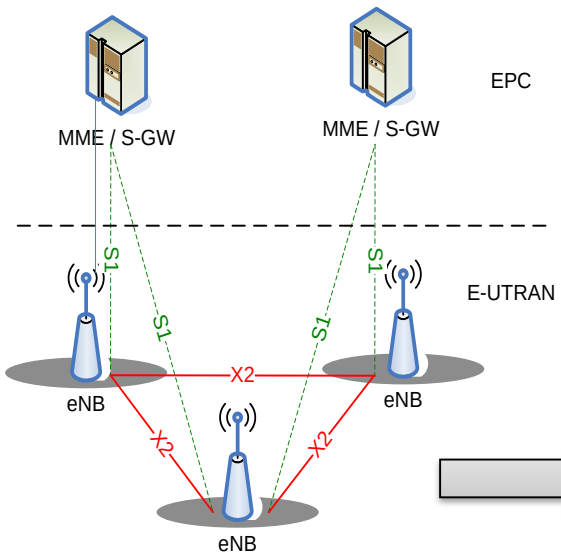
(3) Service-oriented 5G core with cloud-native architecture

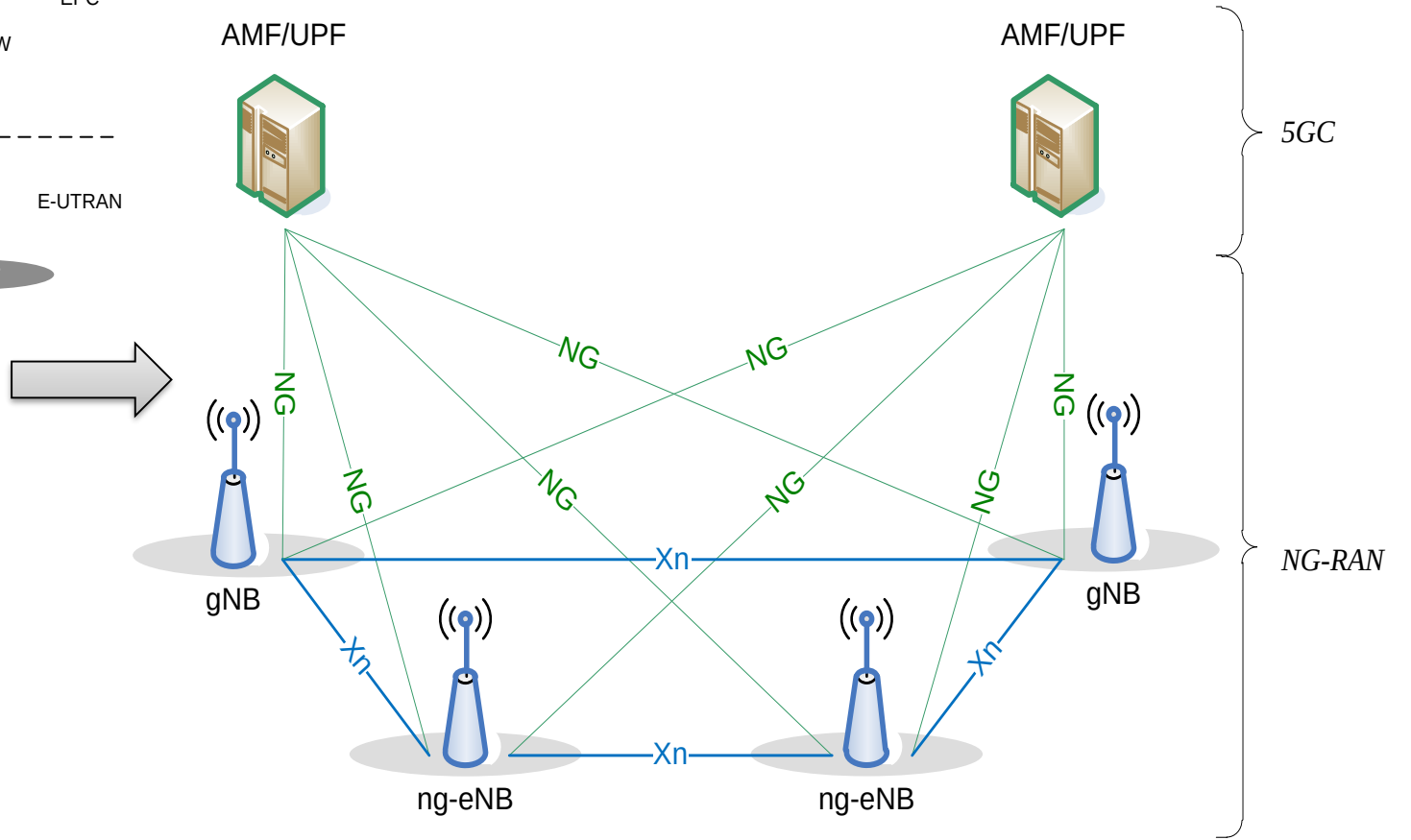
5G Main Objectives



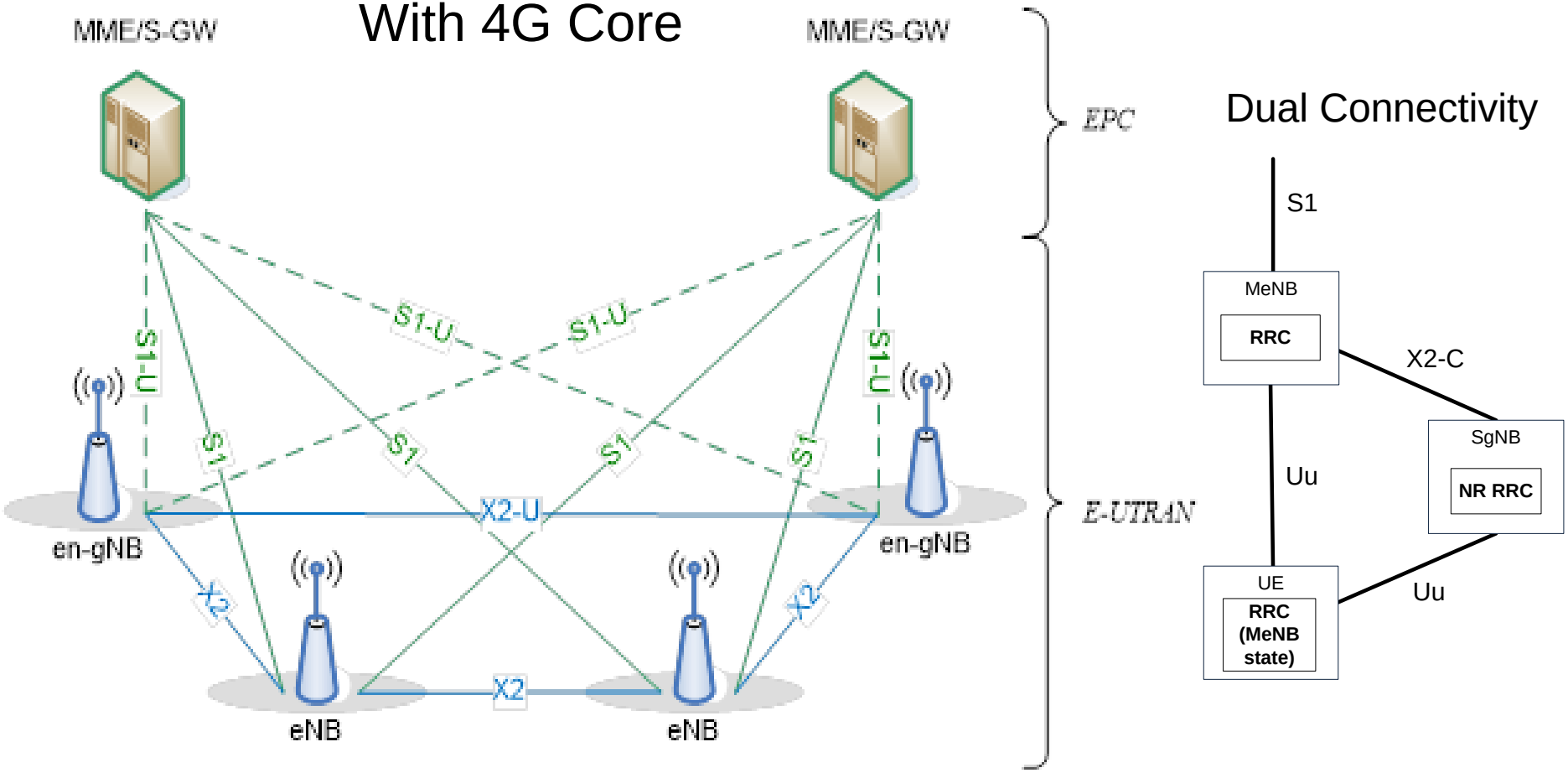
3GPP Releases

5G Architecture





Overall 5G Architecture



Overall 5G Architecture

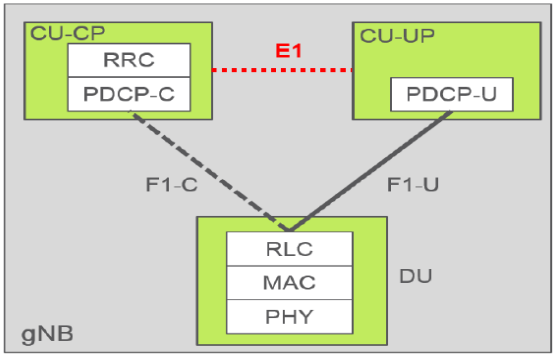
3GPP Re-Architects Mobile Network

3 Tier RAN Node

CU0 →DU[0-n] → RRU[0-m]

Functions Split

CP - UP split

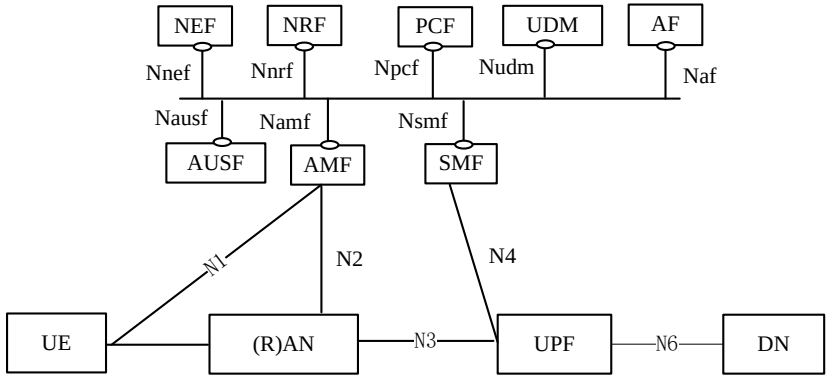


Service-Oriented CN

service catalog and discovery

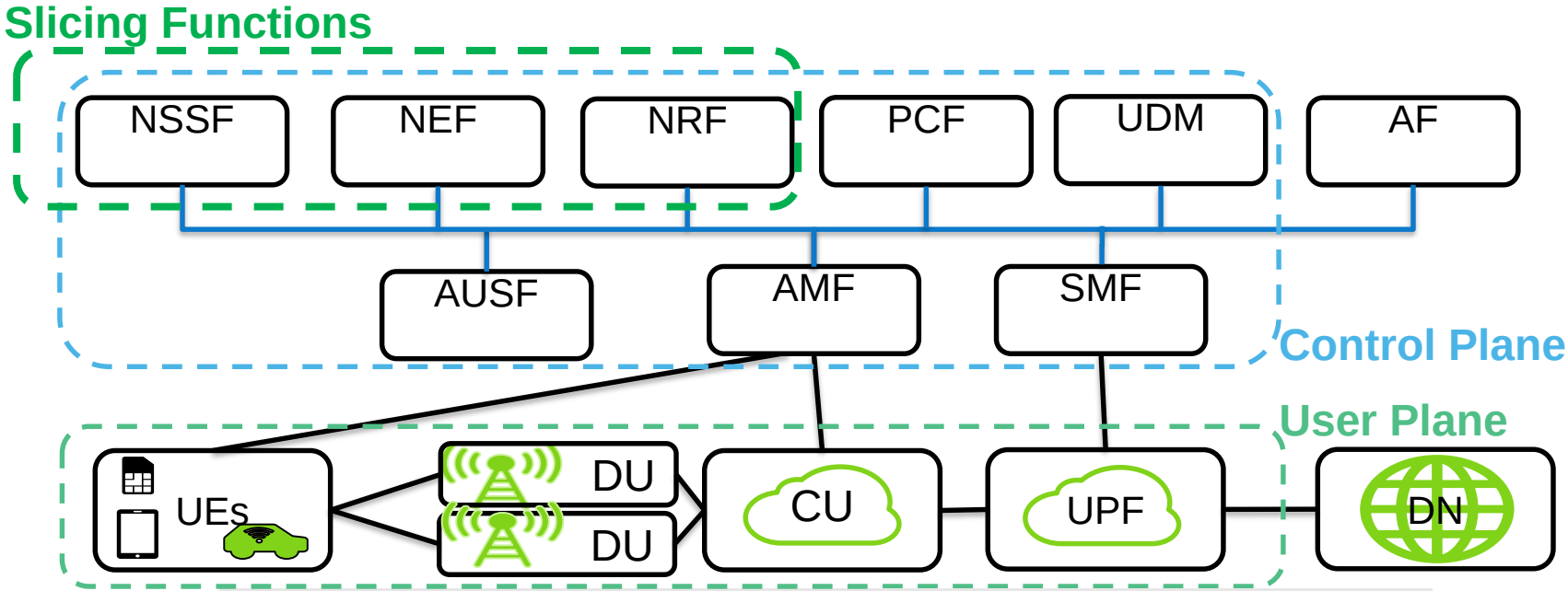
Slice selection function

CP - UP split



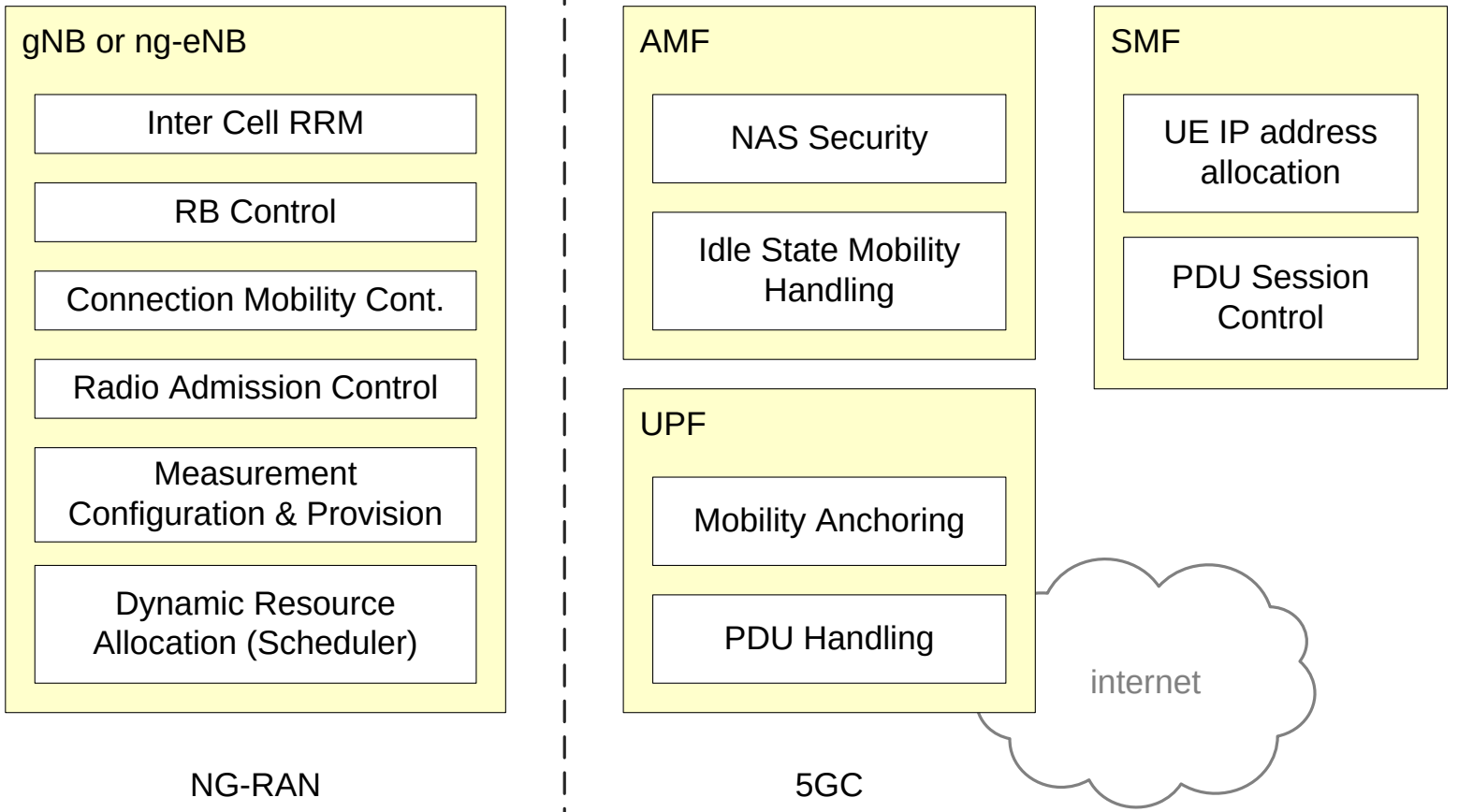
3GPP 5G RAN and CN

3GPP Re-Architects Mobile Network



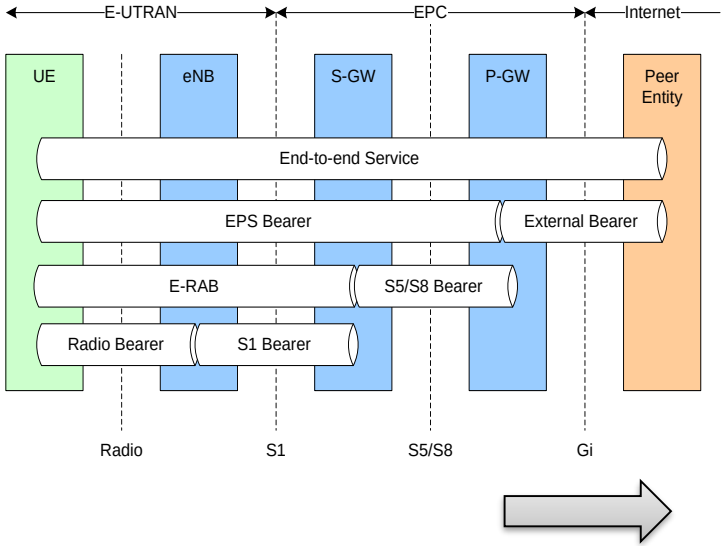
AMF	Access & Mobility Management Function	SMF	Session Management Function
AUSF	Authentication Server Function	UPF	User Plane Function
NRF	**Network Repository Function**	AF	Application Function
UDM	Unified Data Management	PCF	Policy Control Function
NSSF	**Network slice selection function**	NEF	Network Exposure Function

3GPP 5G RAN and CN

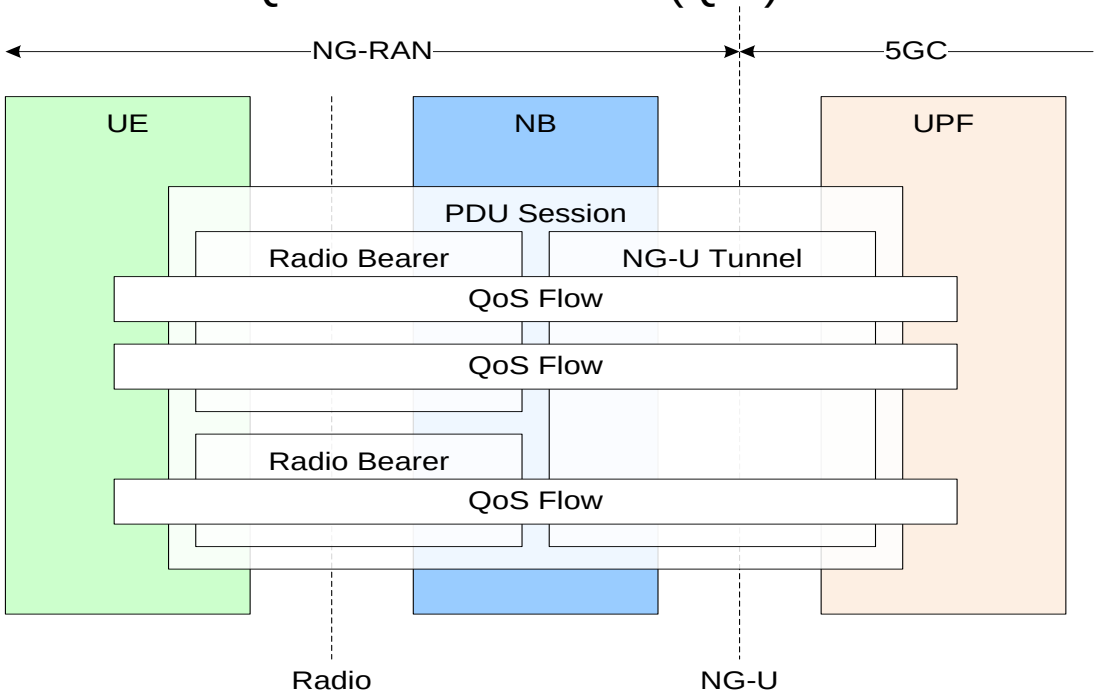


Functional Split : RAN & CN

QoS Class Indicator (QCI)

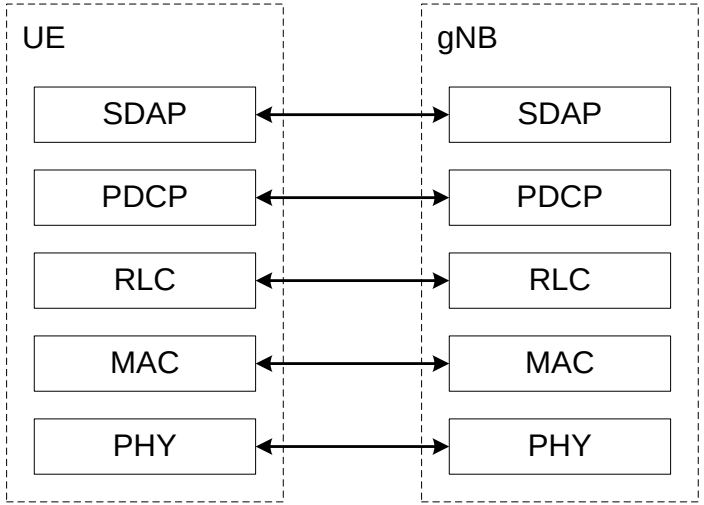


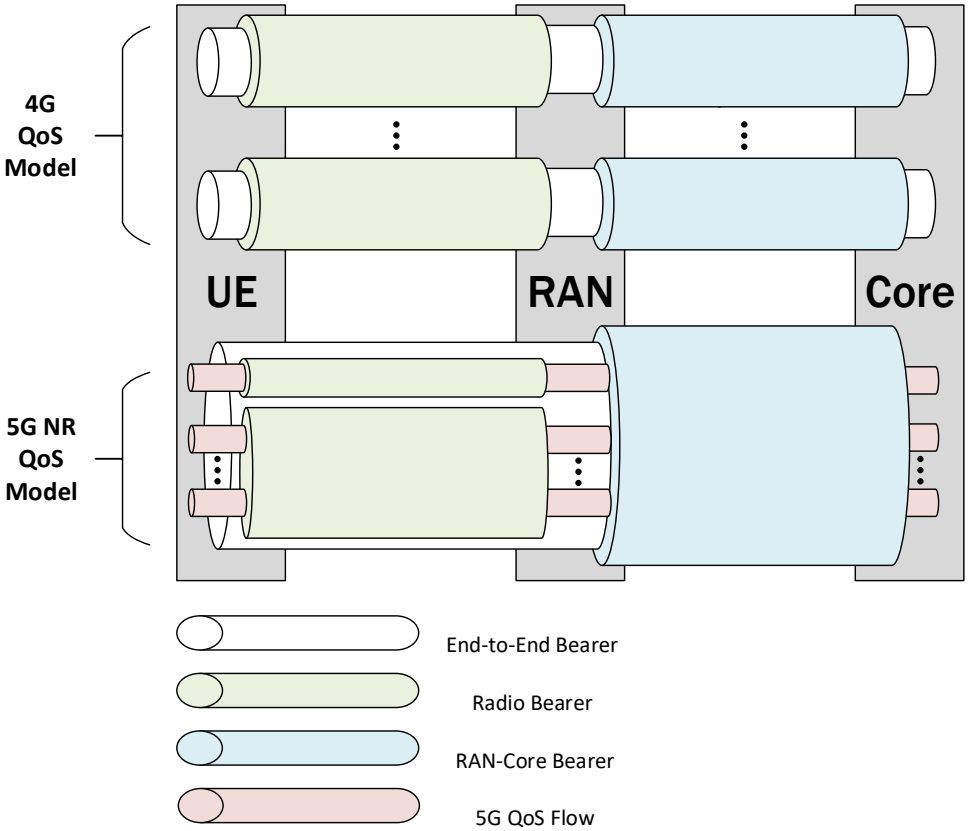
QoS Flow Indicator (QFI)



5G Flow-level QoS FW

Newly introduced SDAP layer
- Reflective QoS
- Explicit Configuration



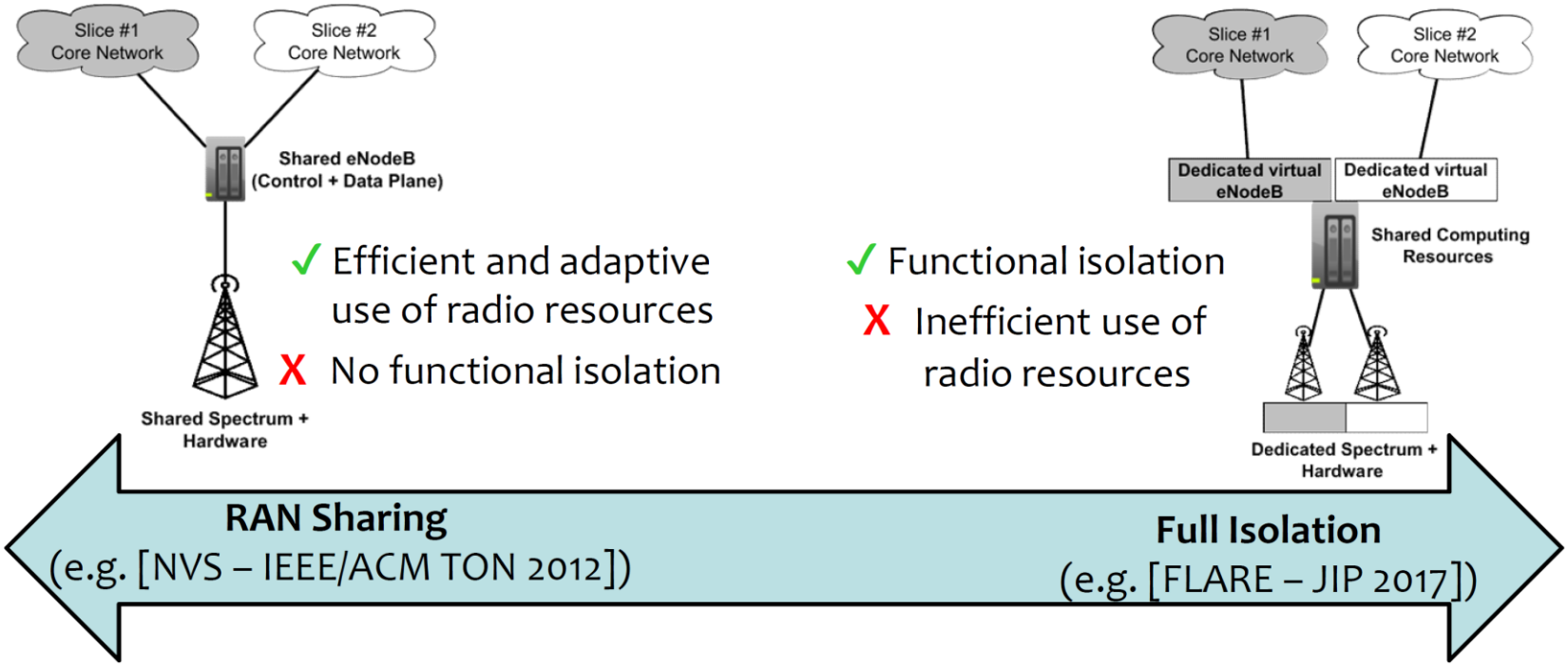


4G LTE : 1:1 mapping of EPS bearer to DRB
5G NR : One or more QoS flows may be mapped onto one DRB.

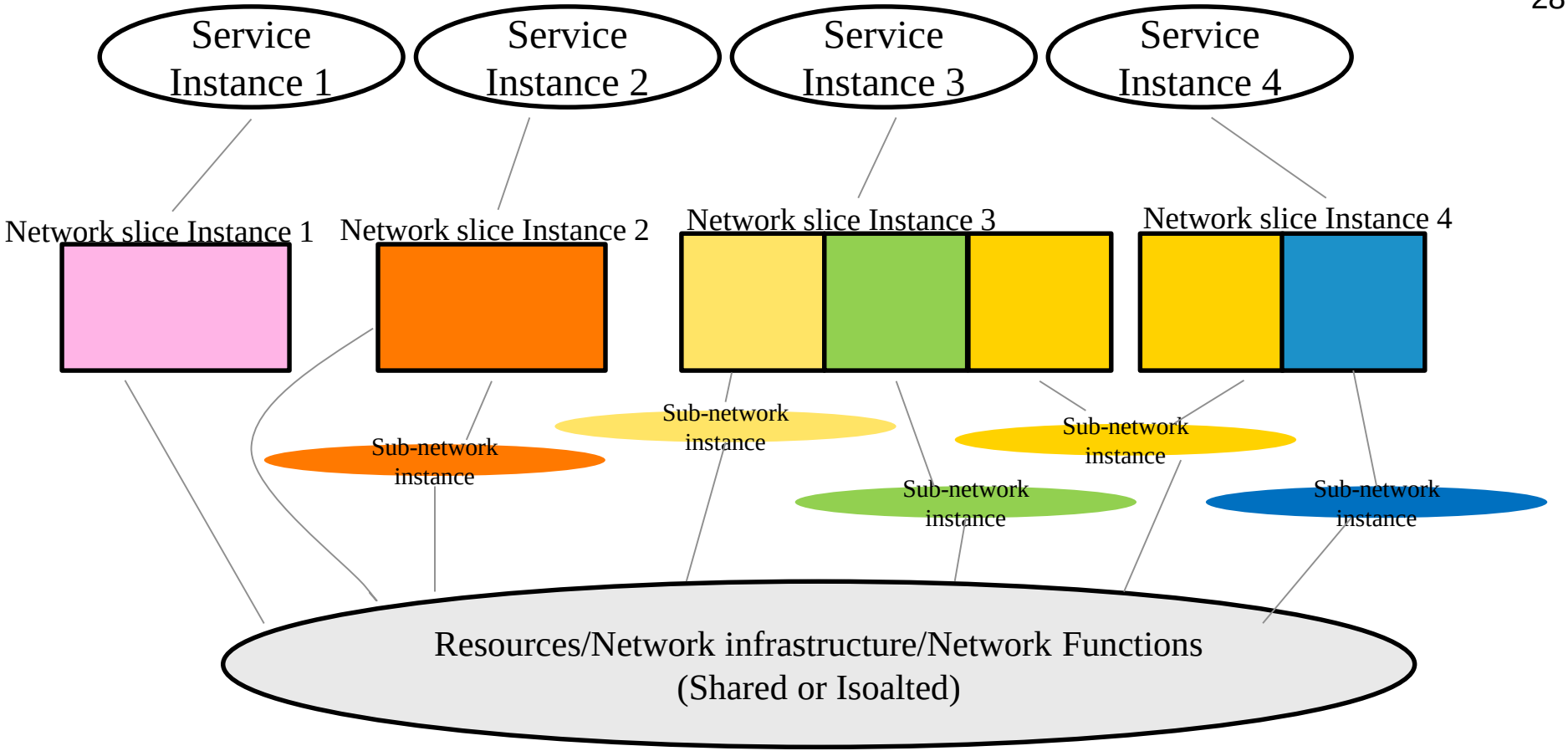
5G Flow-level QoS FW

Network Slicing

Network Slicing



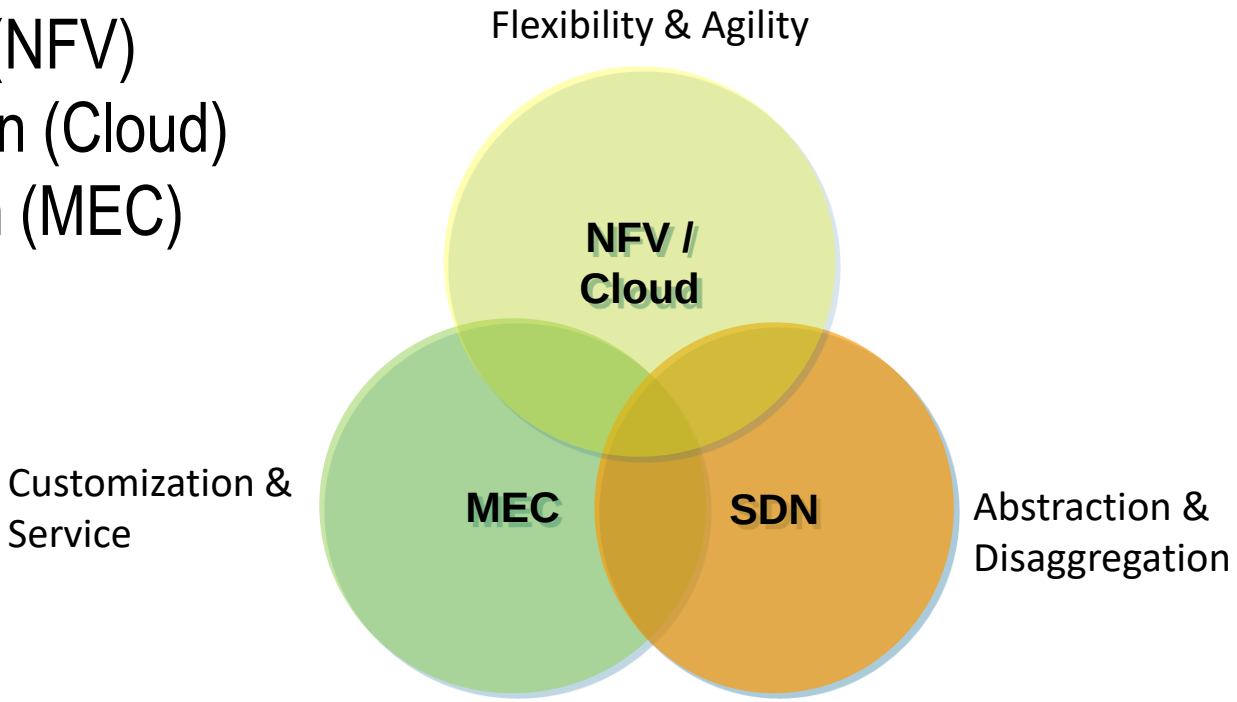
Sharing vs. Isolation



Network Slicing Concept

Multi-service multi-tenant network

1) Softwarization (SDN)
2) Virtualization (NFV)
3) Disaggregation (Cloud)
4) Customization (MEC)

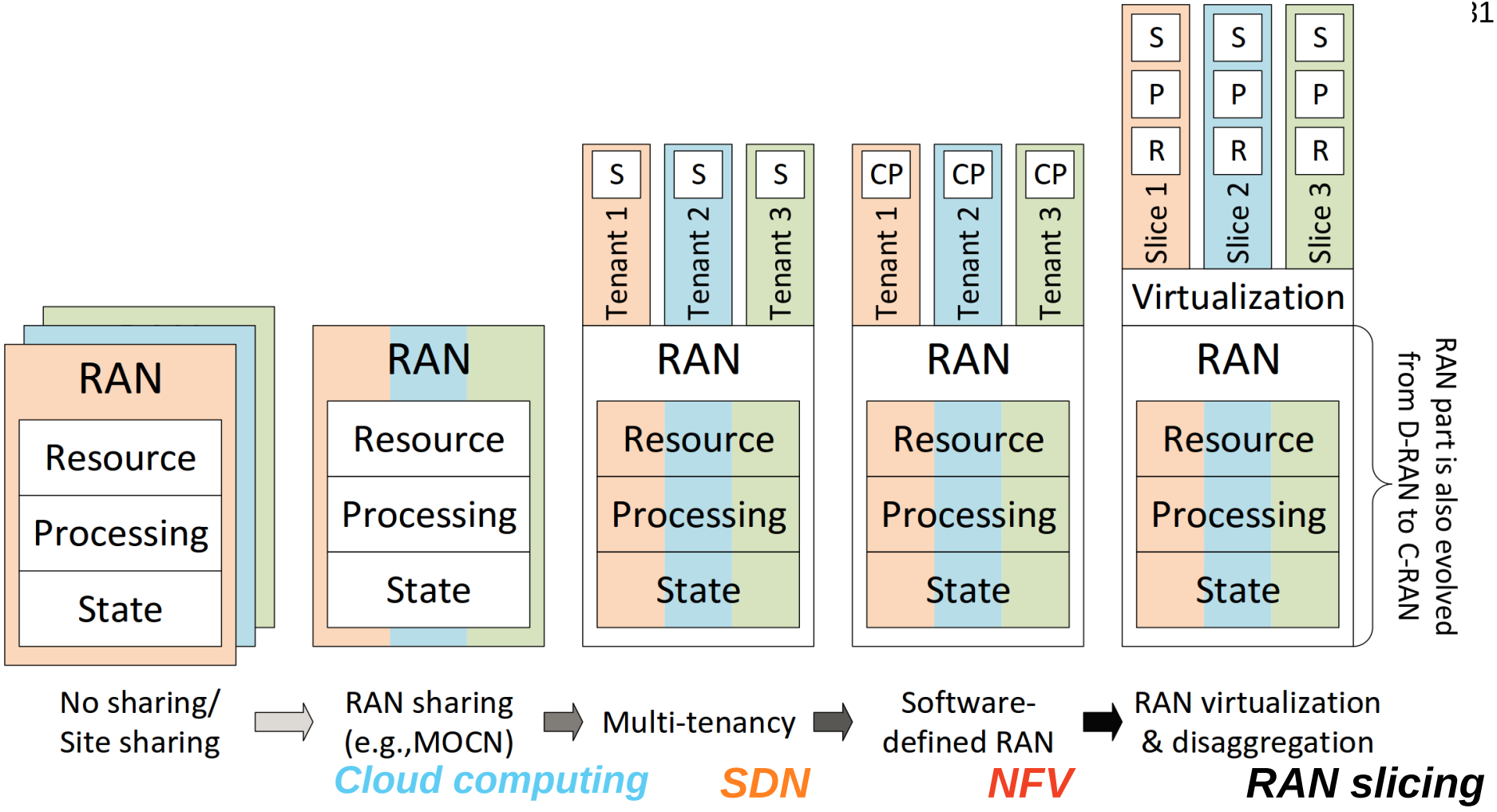


Slicing Technology Enablers

Multi-service multi-tenant network

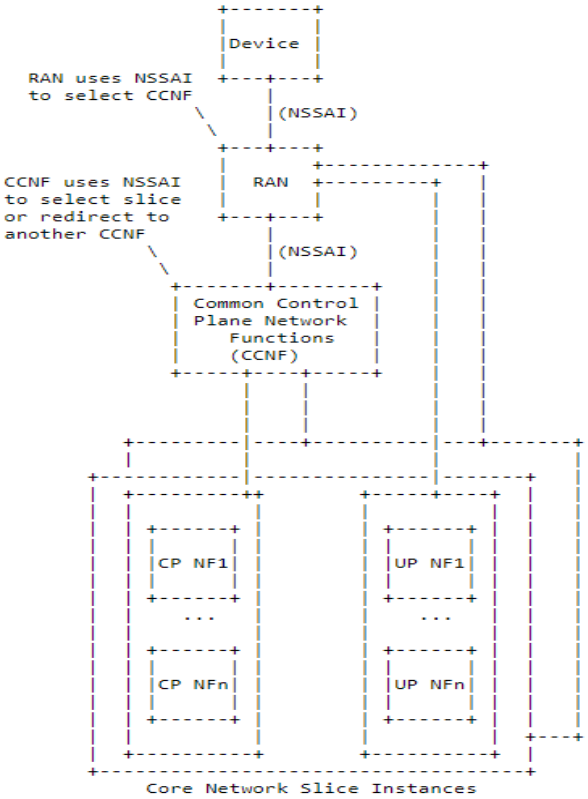
1) Softwarization (SDN)
2) Virtualization (NFV)
3) Disaggregation (Cloud)
4) Customization (MEC)

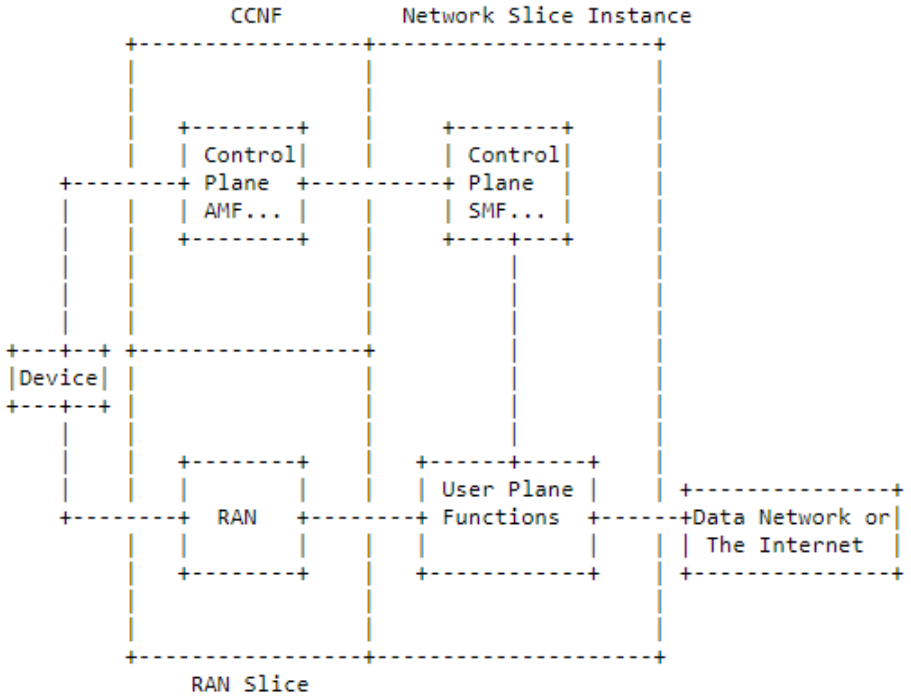
Slicing Technology Enablers



Evolution of RAN Slicing

3GPP re-architects mobile networks





3GPP Network Slicing

S-NSSAI – single network slice selection assistance information

SST– slice type, describes expected network behavior

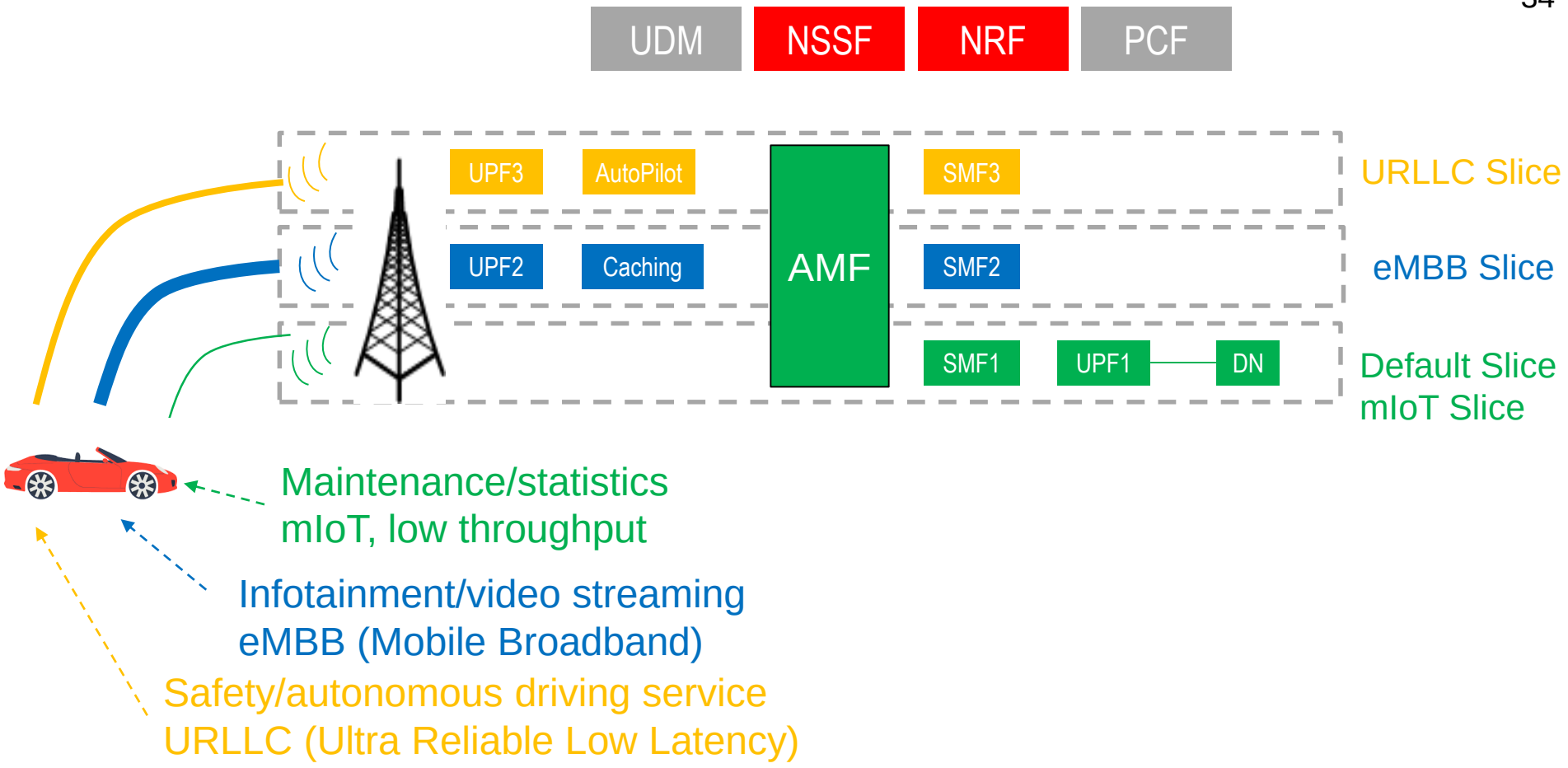
SD – slice differentiator, optional, further differentiation

S-NSSAI can have standard or network-specific values

Standard SST values: eMBB (1), URLCC (2), MIoT(3)

NSSAI is a collection of max 8 S-NSSAI

UE sends NSSAI – basd on which related slice(s) are selected

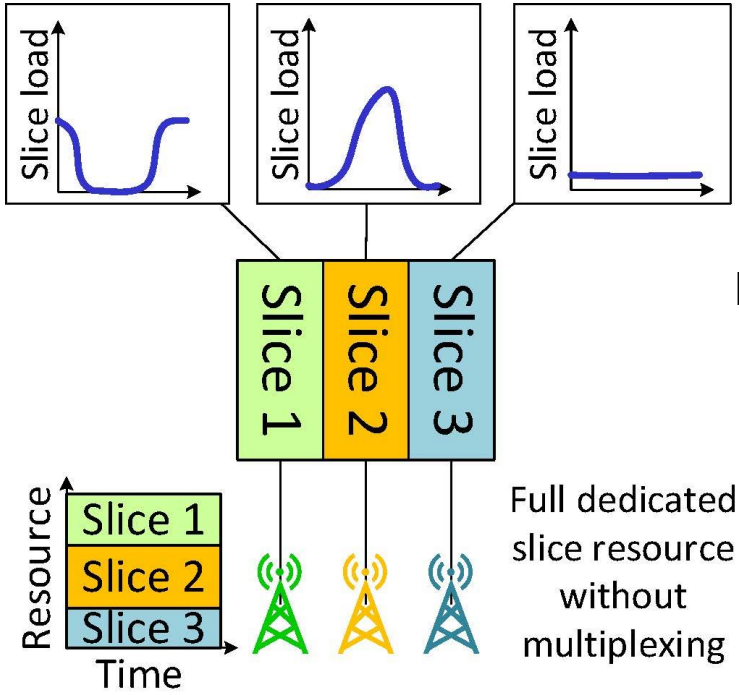


Dedicated or Shared Functions

Dedicated or Shared Resources?

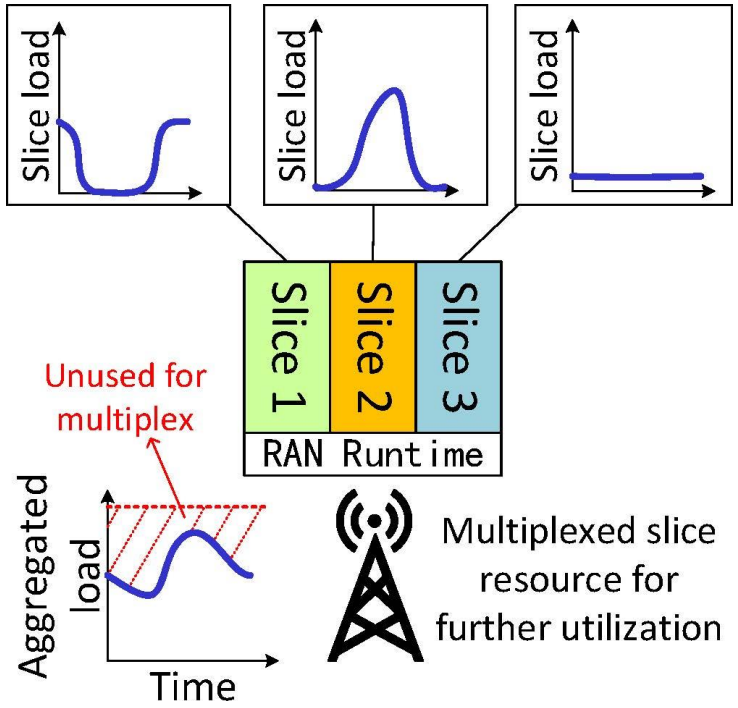
Dedicated or Shared Resources?

Multiplexing Gain



Full dedicated slice resource without multiplexing

Network slicing



Multiplexed slice resource for further utilization

Benefit: Efficient use of radio resources

Dedicated or Shared Resources

RAN Slicing Models

Network slicing definitions

- 3GPP, NGMN, IETF, GSMA

Properties

- Virtual network space
- Customization
- Isolation and sharing
- Programmability

Current State of network slicing

- CN slicing →3GPP solution
- RAN slicing →Under study

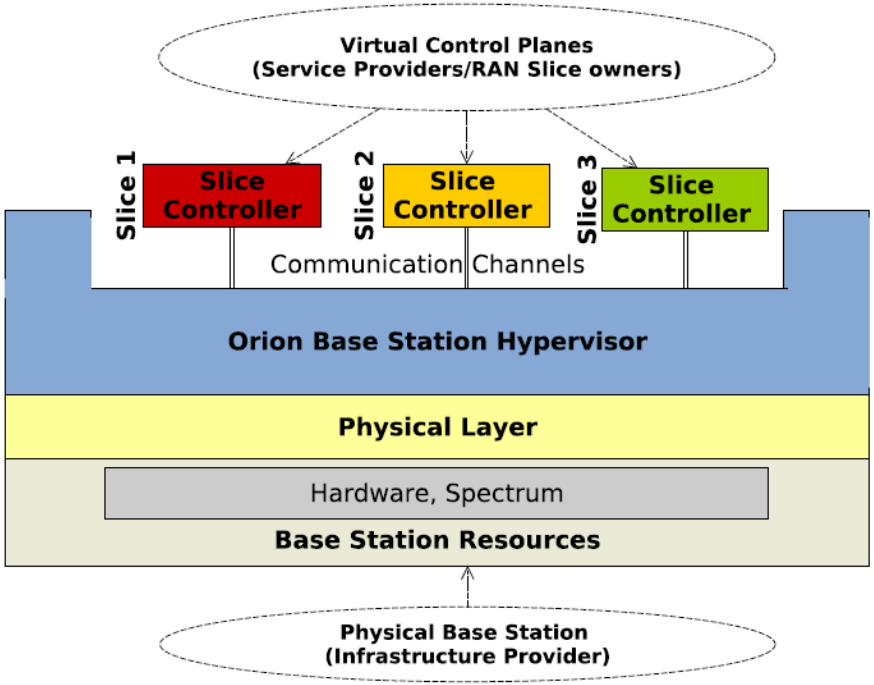
Authors (Year)	Deploy RAN	Radio resource	CP function	UP function
FLARE (2017)	**D-RAN**	**Dedicated spectrum allocation**	**Dedicated**	**Dedicated**
Rost et al. (2017)	D-RAN	Physical resource sharing	Split into cell and user-specific	Dedicated till real-time RLC
Ksentini & Nikaein (2017)	D-RAN	Flexible resource sharing	Dedicated	Shared
ORION (2017)	**D-RAN**	**Virtualized resource sharing**	**Split into cell and user-specific**	**Dedicated till PHY**
RAN runtime (2018)	D-RAN & C-RAN	Flexible resource customization &multiplexing	Split into cell and user-specific	Different levels of isolation & sharing

RAN Slicing : Tiny SoA

RAN slicing system

(1) Isolate slice-specific control logics while keeping common CP/UP functions

(2) Share radio resources in virtualized or physical form



Components

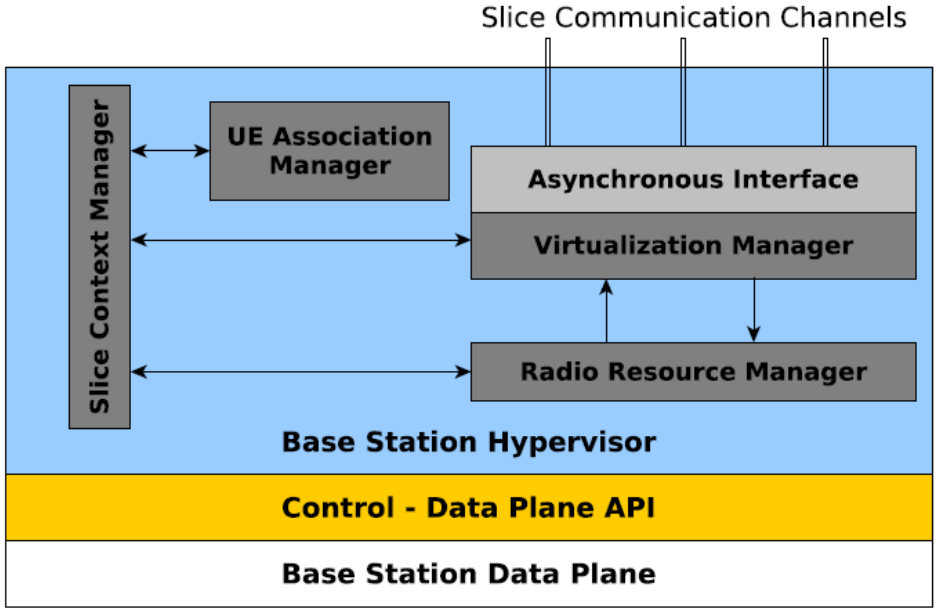
(1) **Slice context manager** performs lifecycle management of each slice (SLA, active UEs, admission control)

(2) **Virtualization manager**

- provides a generic form of abstraction for virtualizing radio resources and data plane state
- presents a virtual/isolated view to each slice virtual control plane

(3) **Radio resource manager** allocates physical resources among slices

(4) **UE association manager** handles slice discovery by UEs and maps UEs to slices



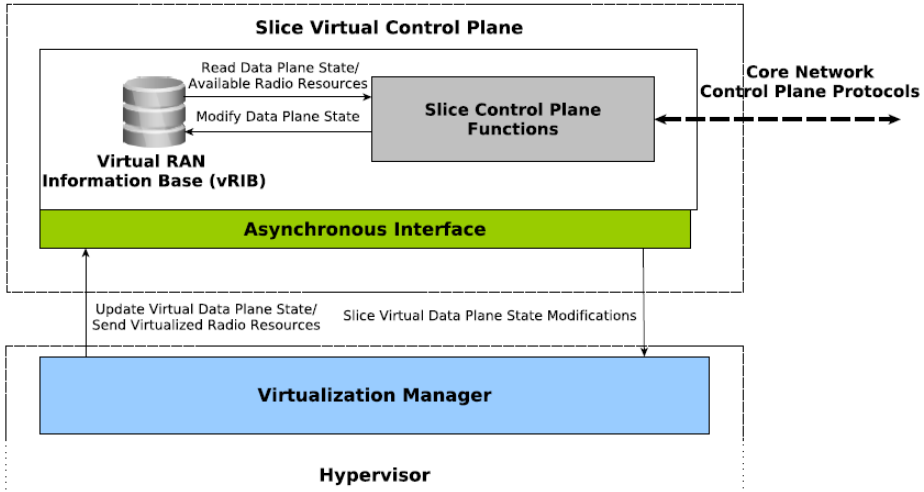
Virtual Control Plane

(1) Interacts with the underlying infrastructure via the virtualization Manager of the Hypervisor

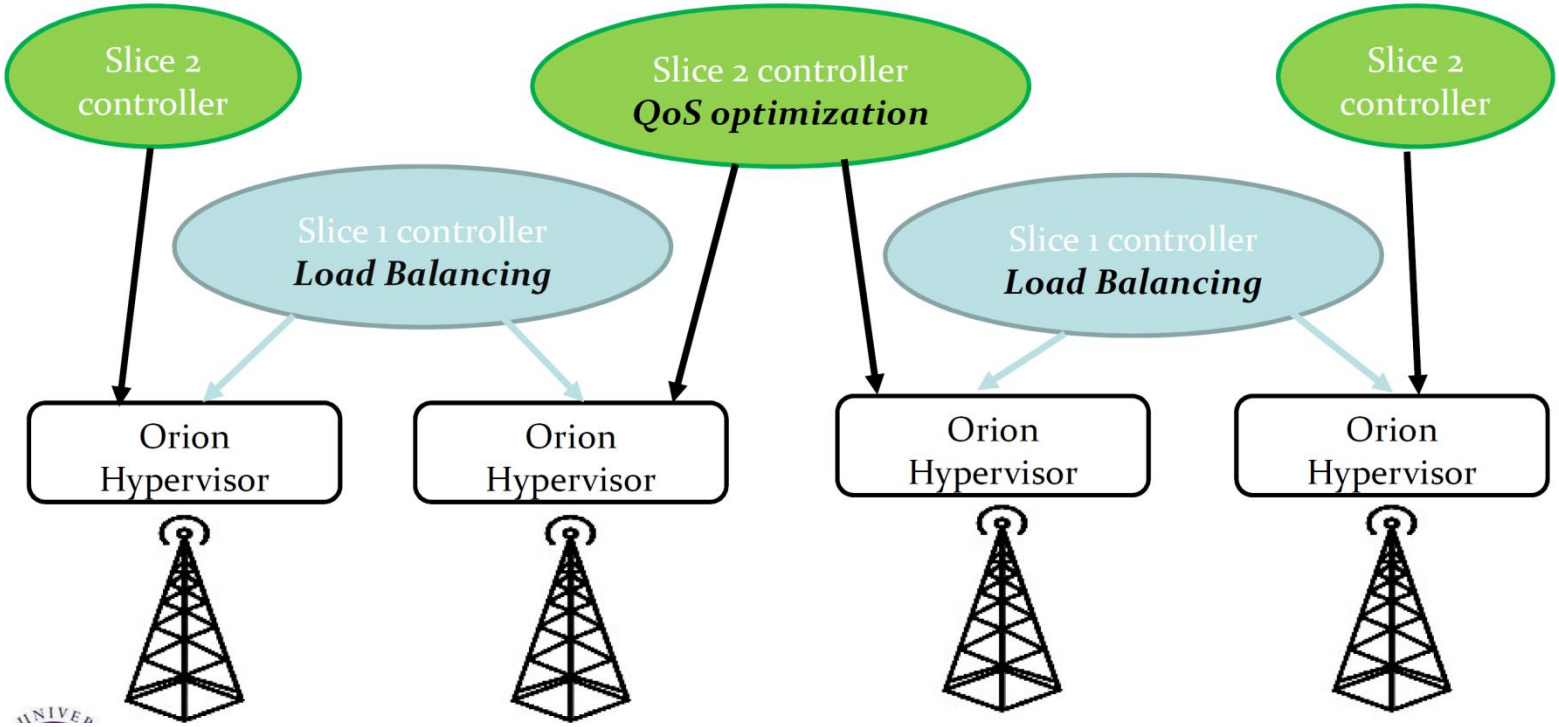
- translated into control-data APIs

(2) Operates over vRIB, the locally maintained state of virtual radio resources and data plane

- Slice network view and state



ORION RAN Slicing System

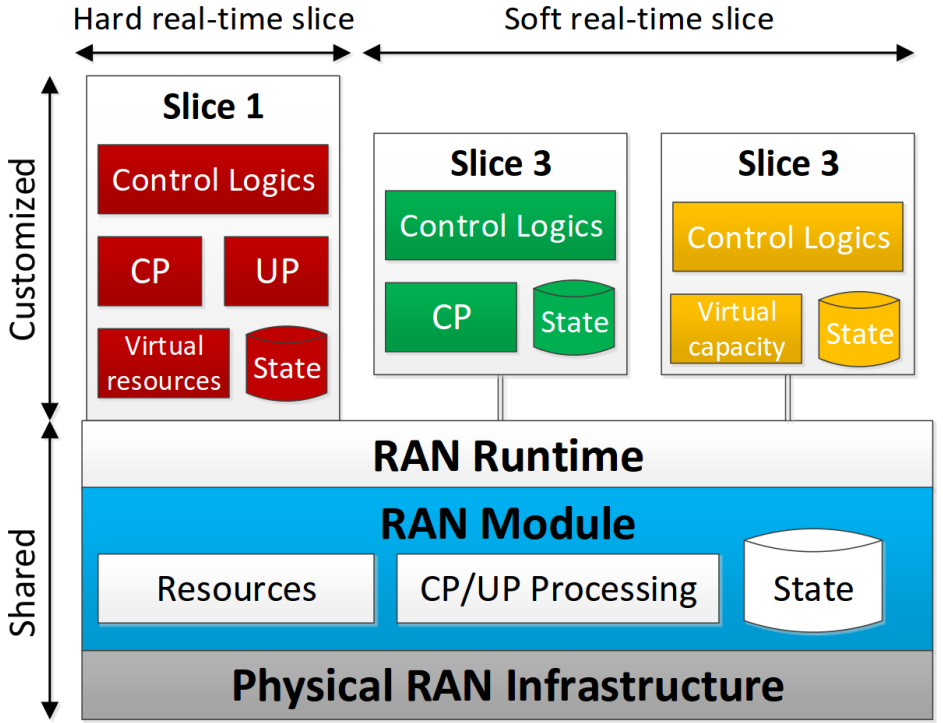


RAN Slicing Execution Env.

(1) run multiple virtualized RAN module instances with different level of isolation and sharing

(2) Pipeline RAN functions to either via multiplexed or customized CP/UP functions

(3) Share radio resources in virtualized or physical form



RAN Runtime

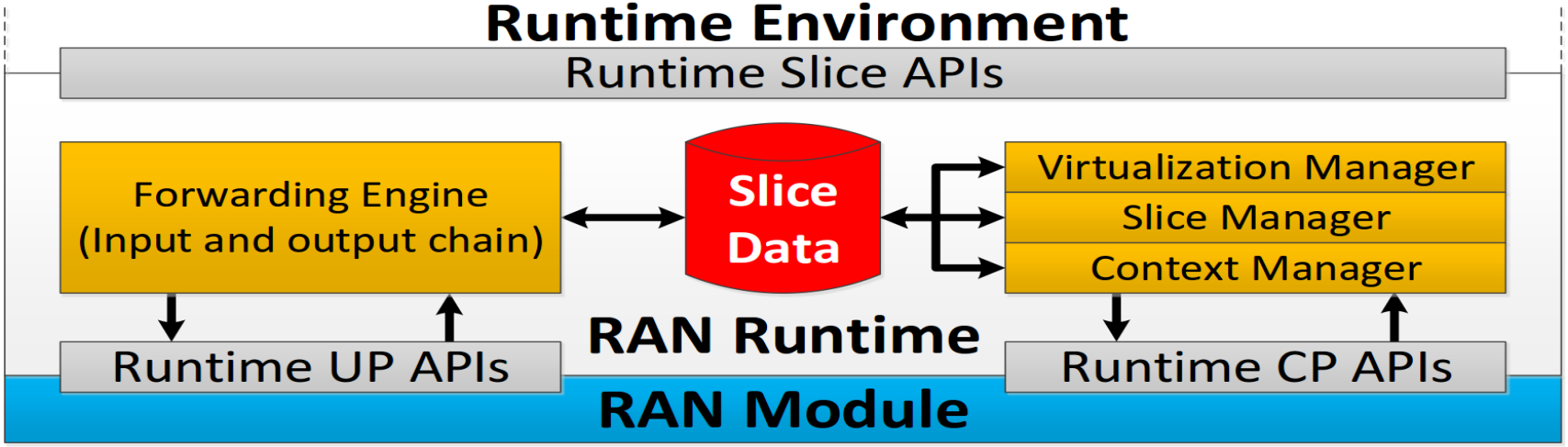
(1) Slice data: Slice context and RAN module context

(2) Context manager: Manage slice data and perform CRUD operation

(3) Slice manager: slice life-cycle, program forwarding engine, conflict resolution

(4) Virtualization manager: resource abstraction, partitioning, and accommodation

(5) Forwarding engine: establish slice-specific UP path



RAN Runtime

RAN Slicing Model

Resources Radio spectrum resources, e.g., carriers, resource blocks, bandwidth

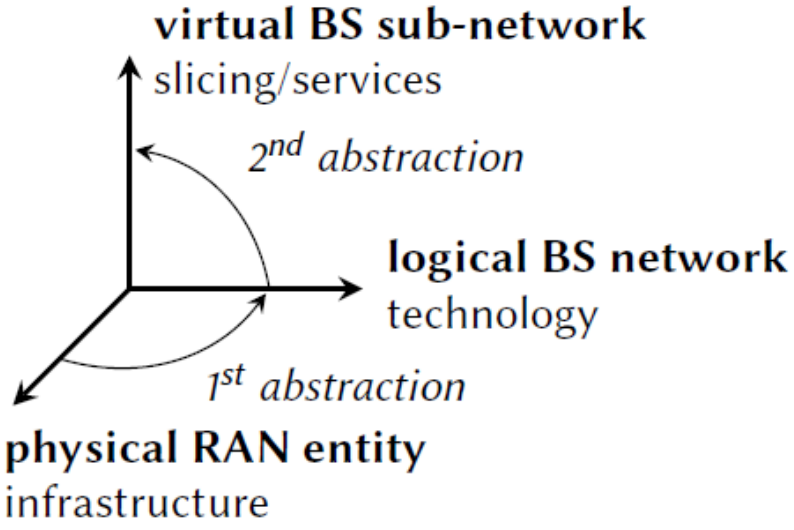
Processing Functional block for CP/UP operations, delimited through functional block and described with capabilities

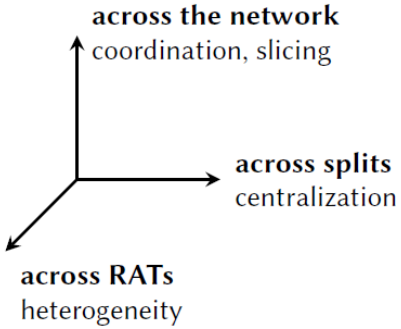
State Status of BS CP/UP processing and associated configuration

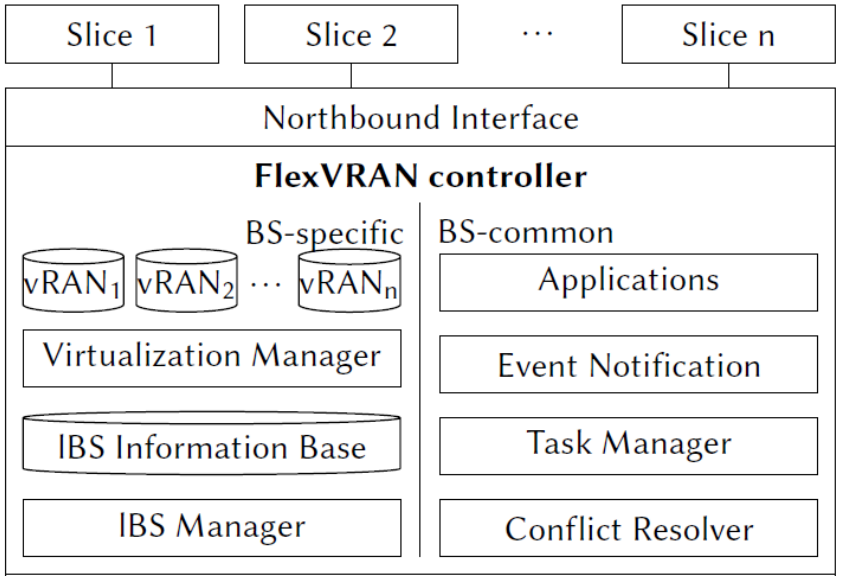
RAN Runtime

vRAN

2-level Abstractions

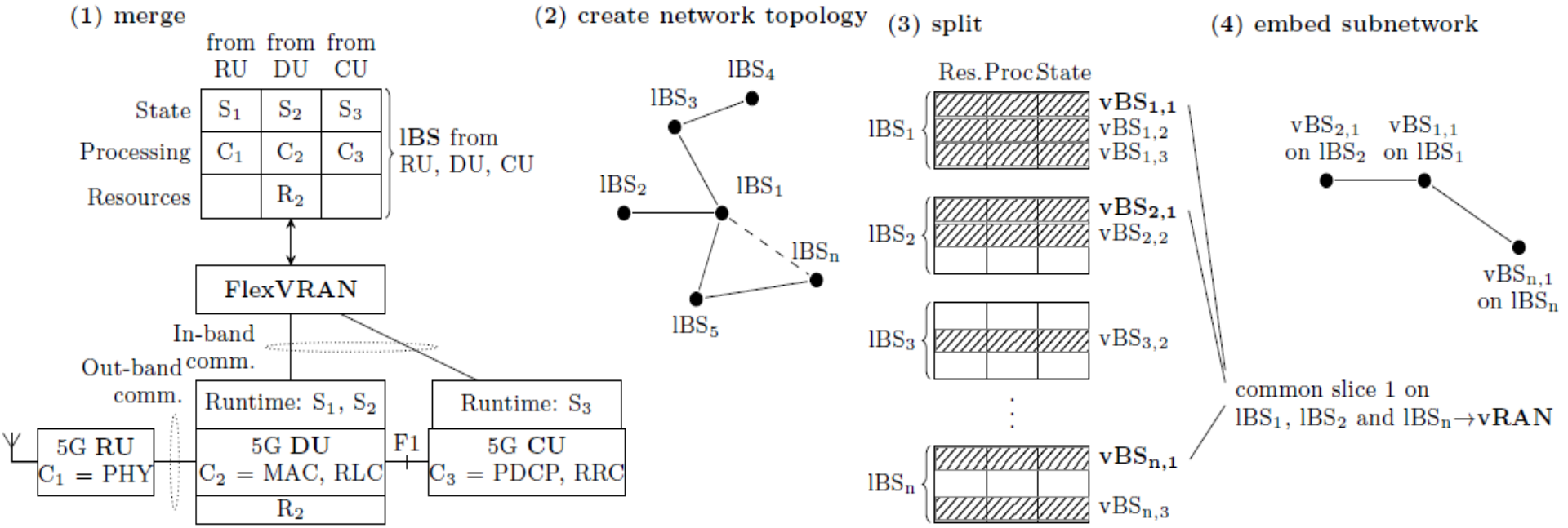






RAN Runtime

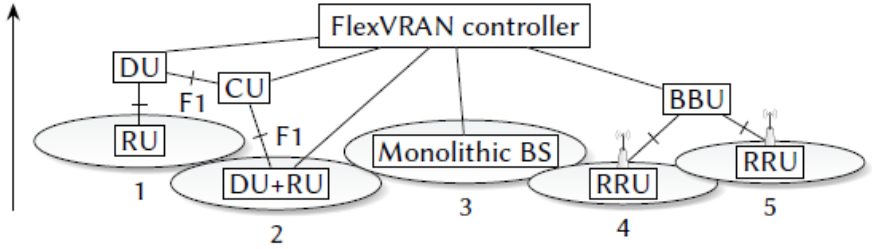
vRAN Subnets enabled by 2-level Abstractions



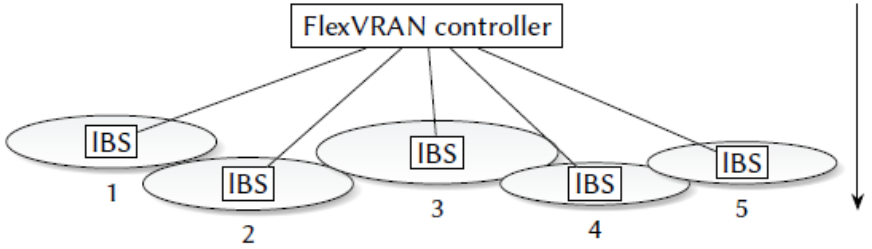
RAN Runtime

Virtual-RAN Example

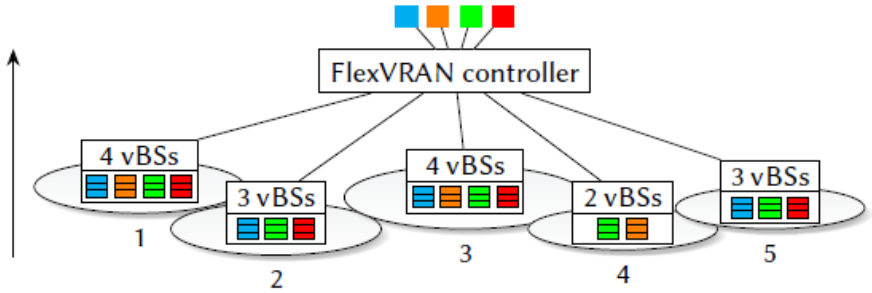
1. Heterogeneous, disaggregated RAN



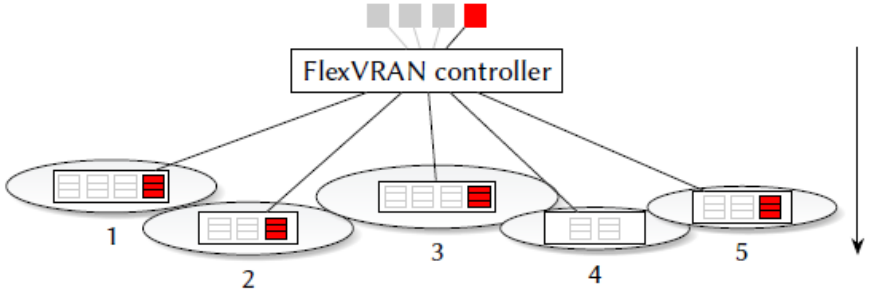
2. Homogeneous view for infrastructure owner



3. Embedded slices, infrastructure owner view

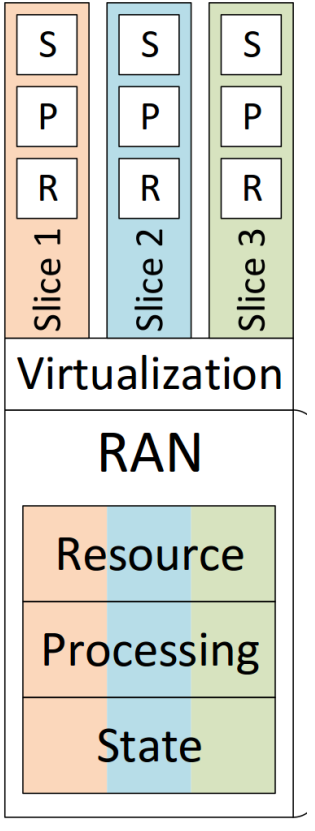


4. Embedded slices, slice owner view



RAN Runtime

Slice Enforcement



Spectrum Isolation or sharing

Spectrum scarcity

Spectrum heterogeneity

Spectrum efficiency

5G integrates heterogeneous spectrums

New applications, particular bands/numerology

Process policies defined by various stakeholders

Customized programmable control logics per applications

Policy and rules

General policy
Operator policy
Sensing data
LSA policy
Spectrum management rule
BS group membership


```
"enb": [
  {
    "freq_min": val,
    "freq_max": val,
    "max_tx_power": val,
    "fdd_spacing": val,
    "band": val
  }
]
```

SMA Policy

Spectrum slicing

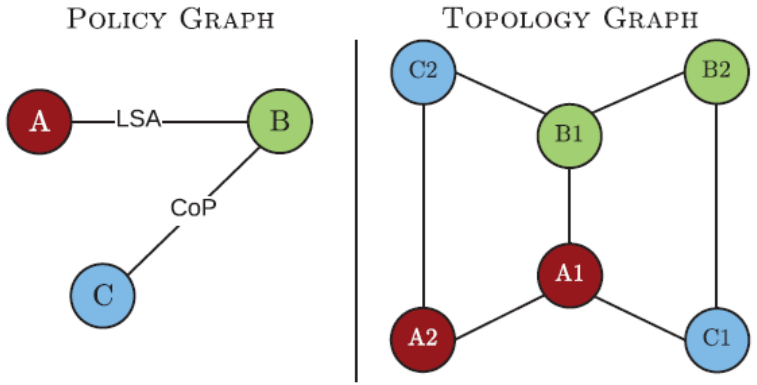
Network Graph

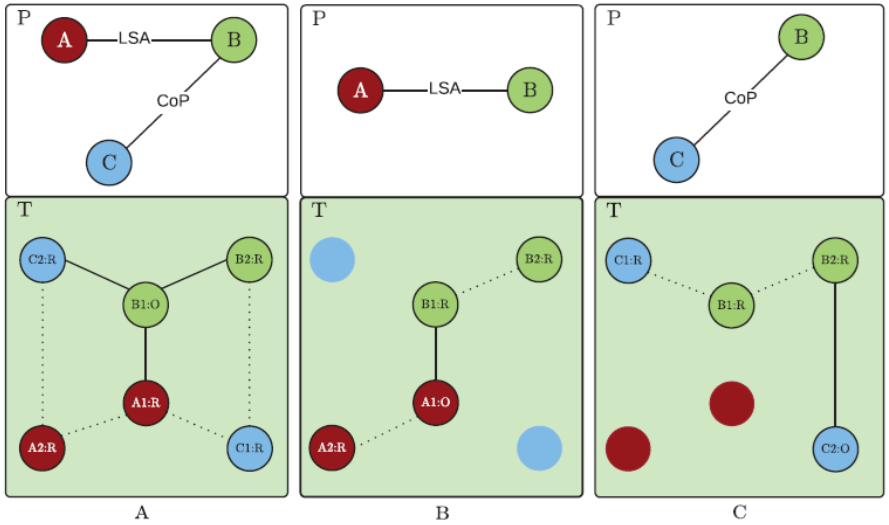
1) Policy graph: sharing agreement/policy between MNOs

- LSA and CoPrimary

2) Topology (T) graph: geographic relationship of operators' cells regarding spectrum sharing

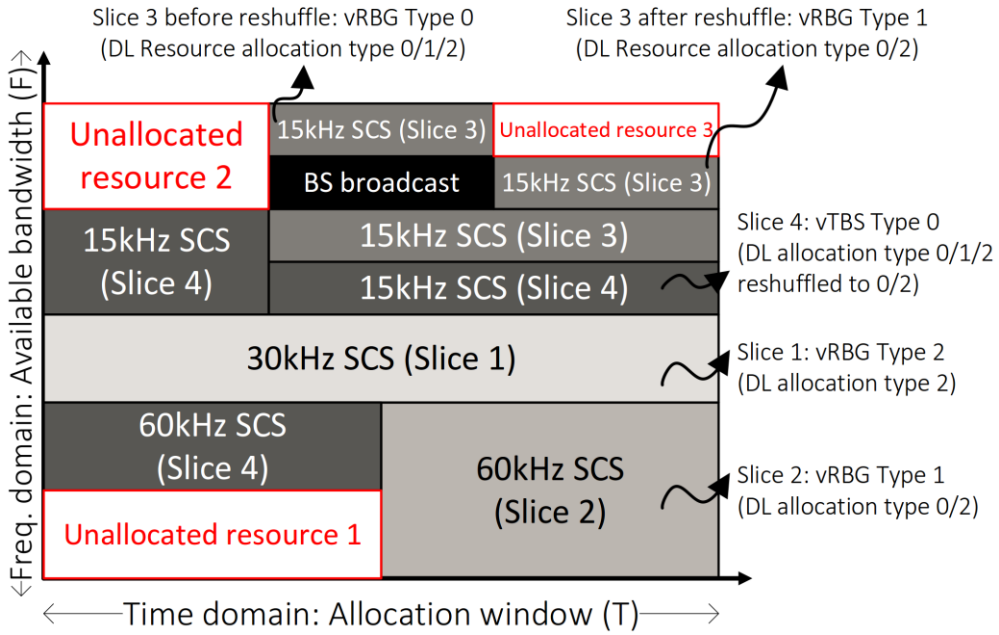
3) Spectrum sharing subgraphs (P+T) : match offering cells (e.g. B1:O) and requesting cells (e.g. A1:R)





Spectrum Slicing

1) Flexible Numerology
2) Bandwidth Parts
3) Abstraction

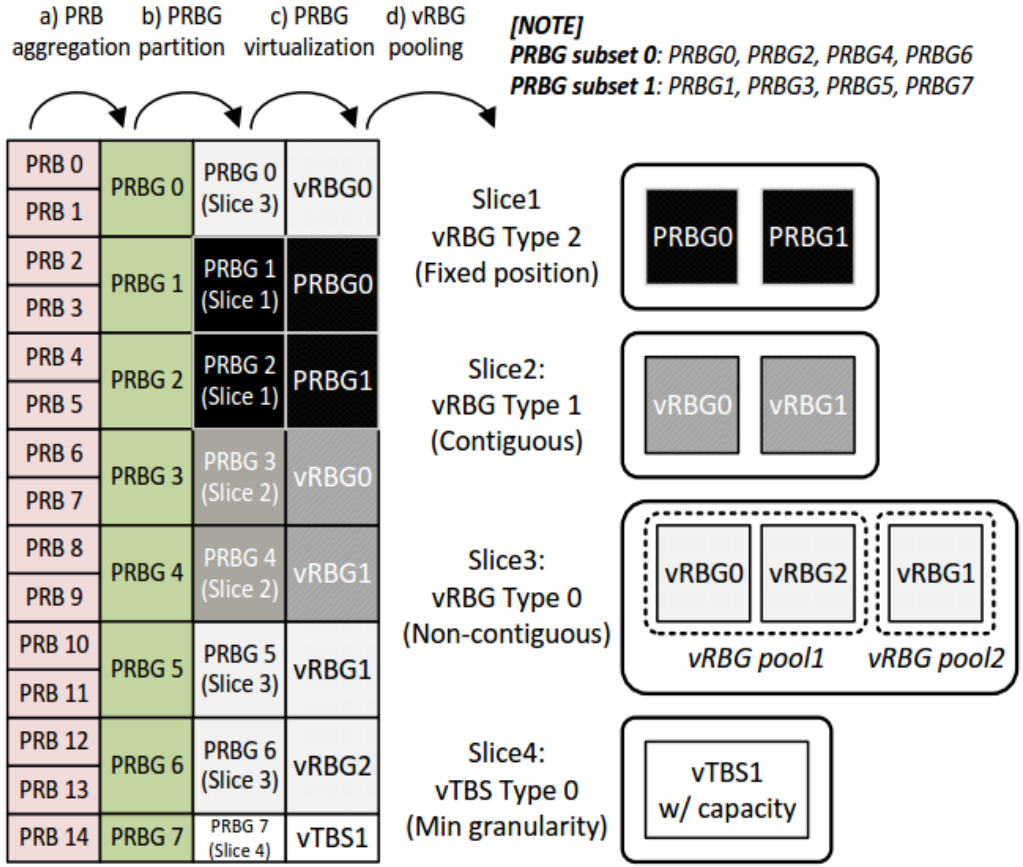


Requested resources	Abstraction types (Resource granularity)	DL allocation type	UL allocation type
Resource Block	vRBG Type 0 (Non-contiguous)	Type 0, Type 1, Type 2 distributed	Type 1
	vRBG Type 1 (Contiguous)	Type 0, Type 2 localized	Type 0
	vRBG Type 2 (Fixed position)	Type 2 localized	Type 0
Capacity	vTBS Type 0 (Min RBG granularity)	All Types	All Types

Resource Slicing

4 Steps to radio resources abstraction:

(1) Aggregation
(2) Partitioning
(3) Virtualization
(4) Polling
(5) Slice resource allocation
(6) Slice Scheduling & Accommodation
(7) Multiplexing/preemption

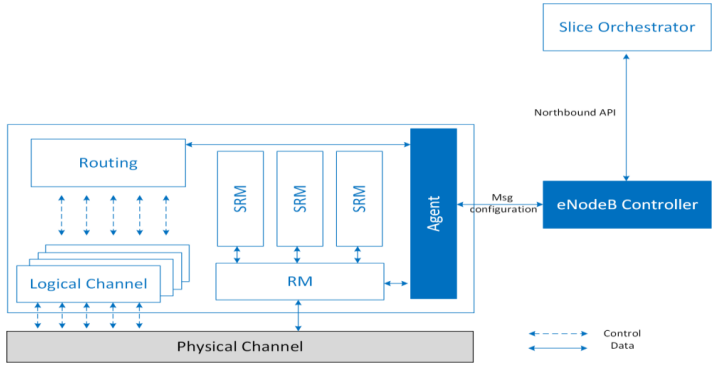


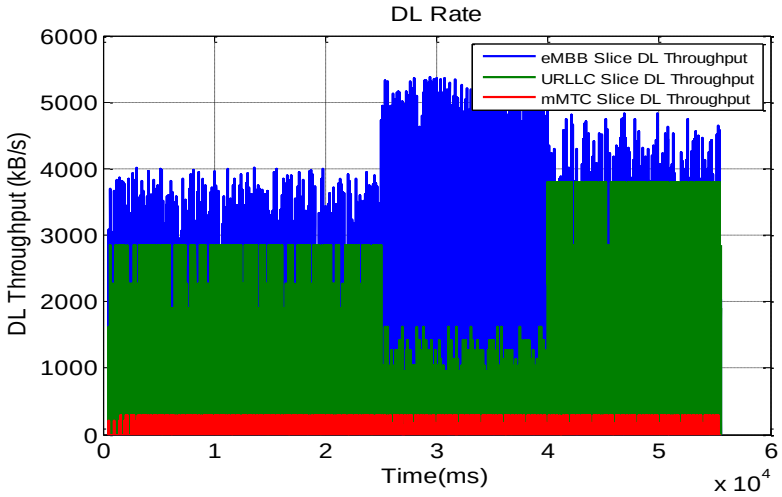
Resource Slicing

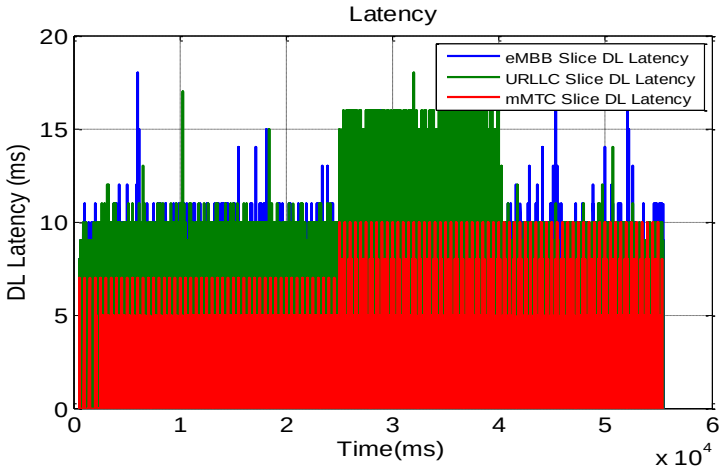
Inter-Slice Resource Partitioning and Polling

3 Slices

1. Slice-specific scheduling, SRM
2. Dynamic Resource partitioning, RM
   - Enforce policy over time







Resource Slicing

Slice programmability: Service differentiation via RRM policy enforcement

Super user

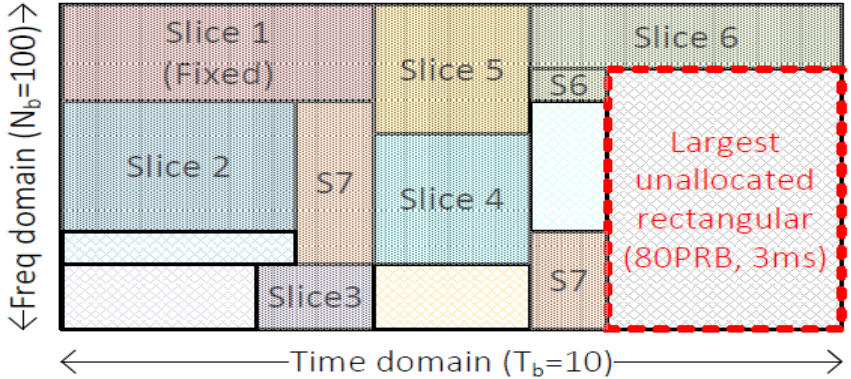
Platinum user

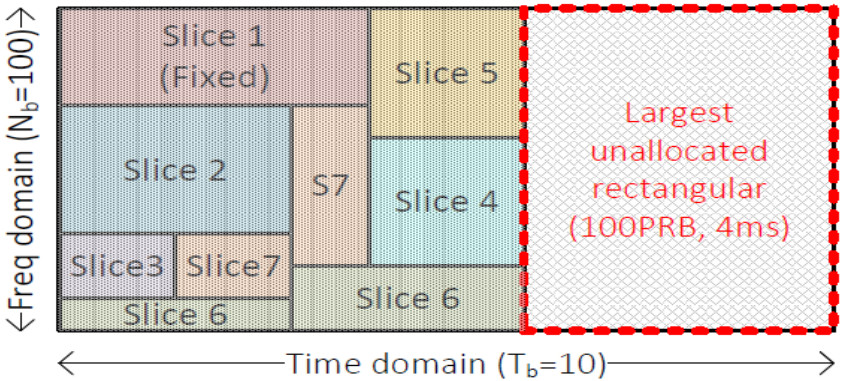
Gold user

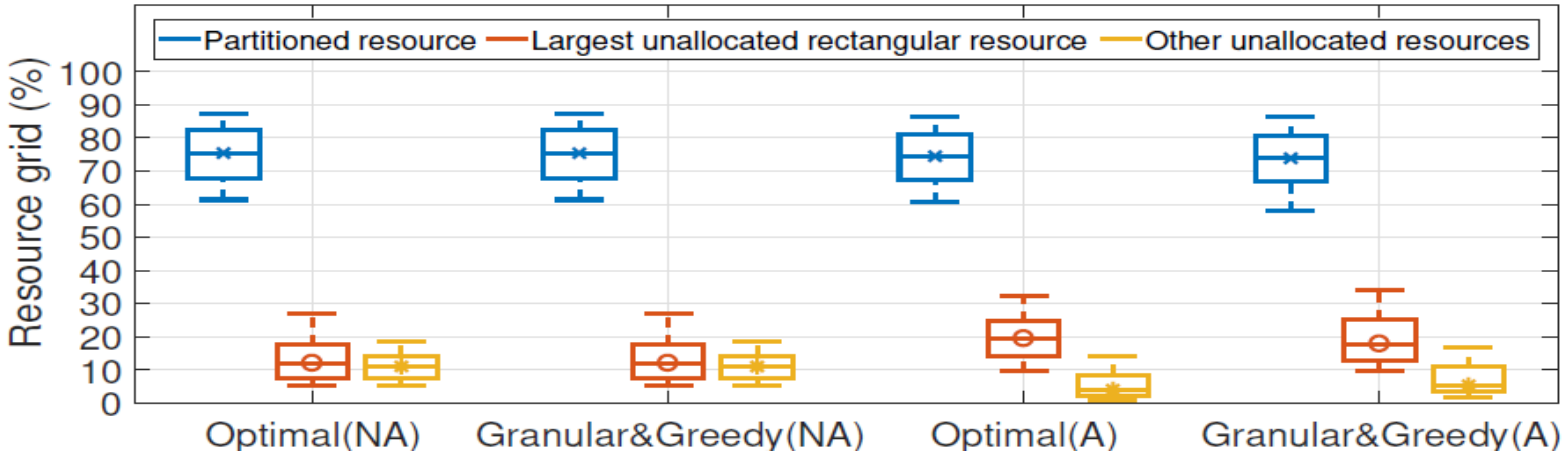
Silver user

Bronze user

Resource Slicing

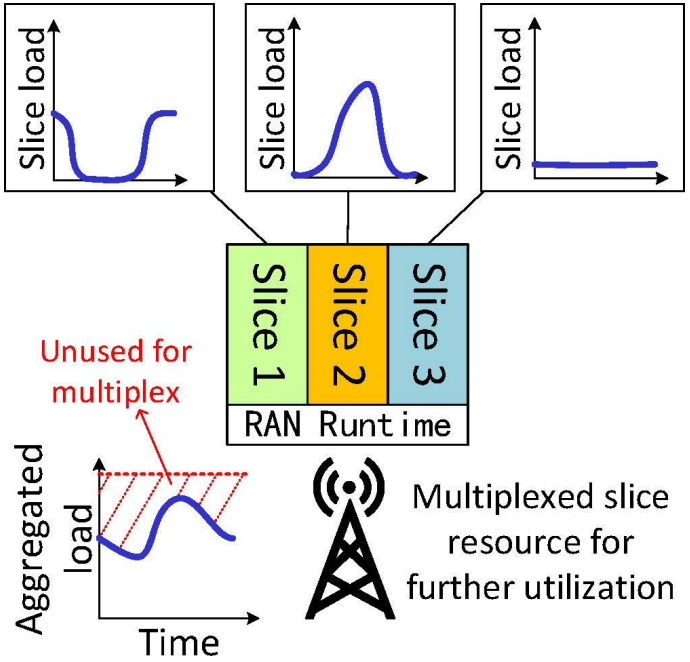


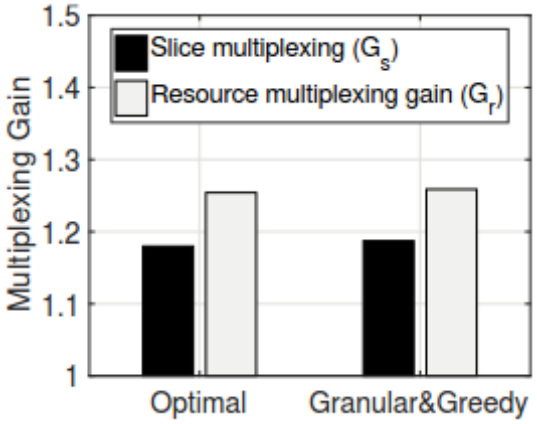




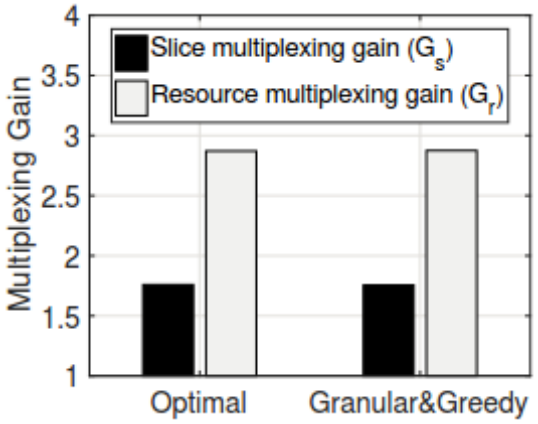
Resource Slicing

Multiplexing Gain





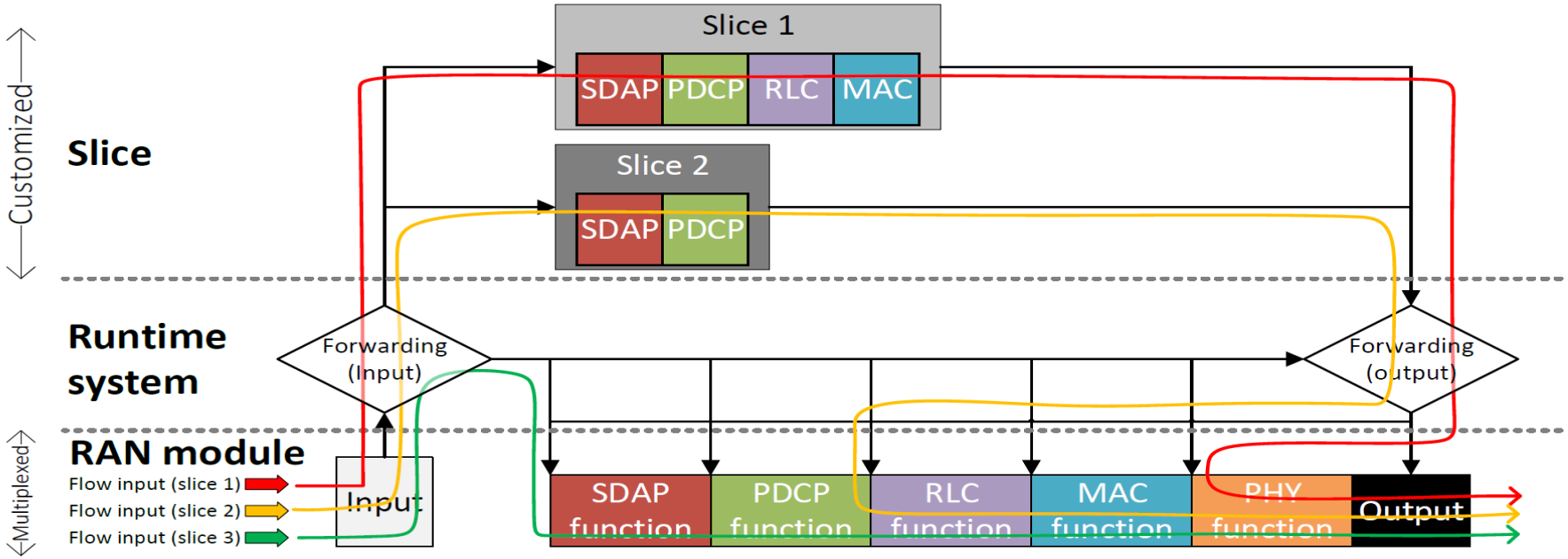
High traffic arrival rate



Low traffic arrival rate

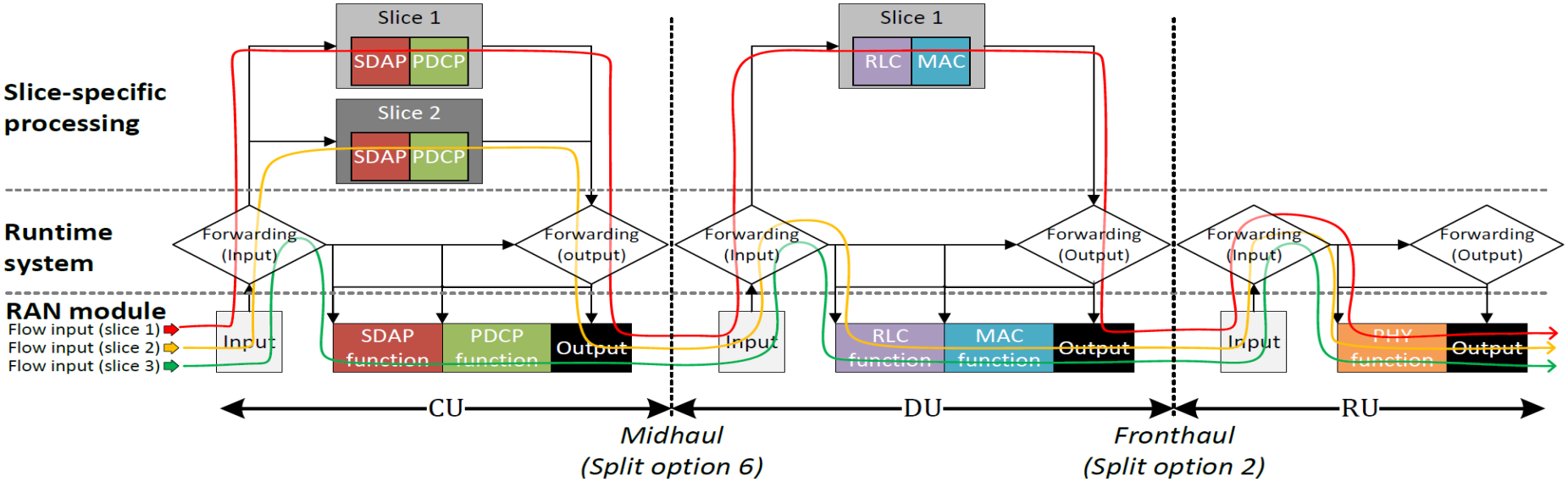
Resource Slicing

Function Customization in Monolithic BS



Process Slicing

Function Customization in Disaggregated BS

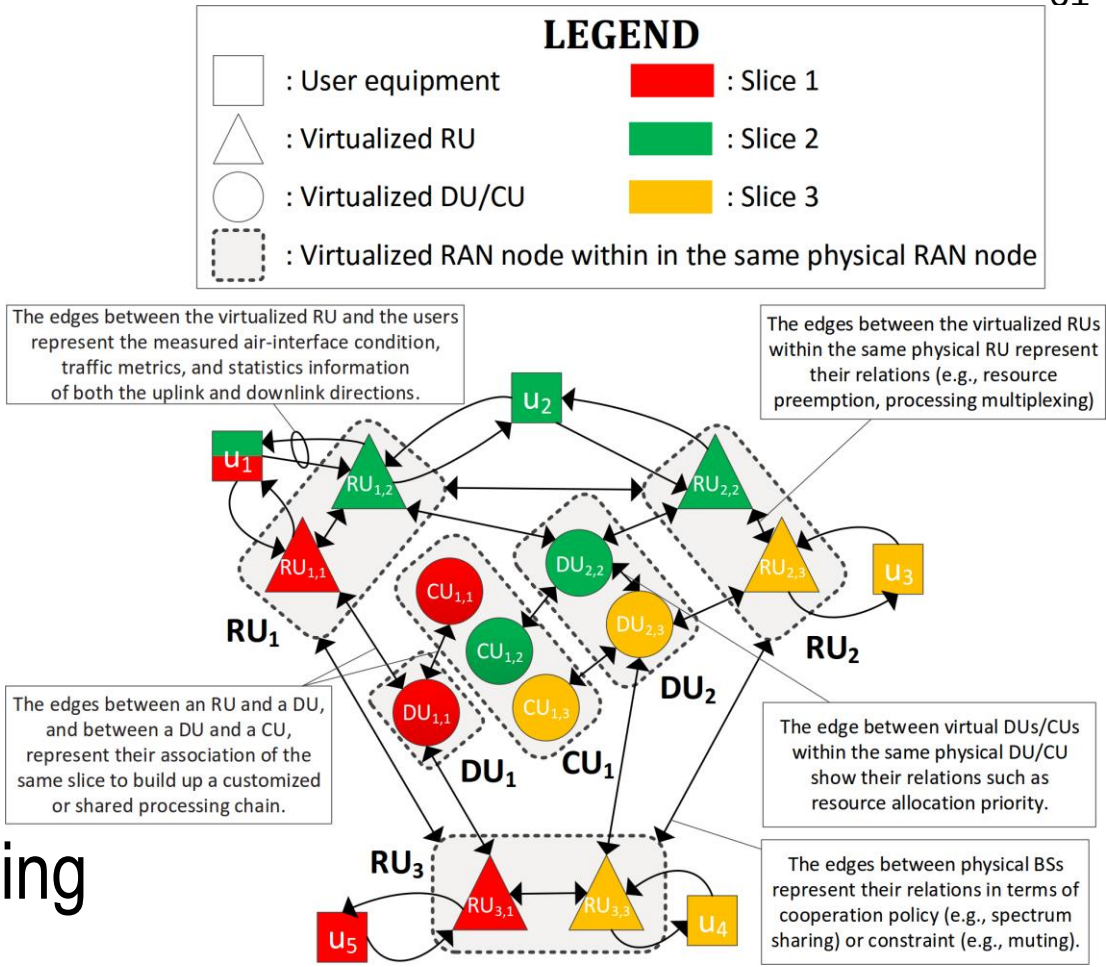


Process Slicing

1) Graph partitioning to embed a slice state

2) Subgraphs per a slice
- Shared BS-common
- Isolated slice-specific

3) State sharing among slices through graph merging



State Slicing

Conclusion

Fusion of Computing, Information and Cellular technologies

(a) 5G and beyond is not only New Radio and verticals, it is also an evolution in General-Purpose computing for wireless networks

(b) More and more software technologies (NFV,SDN,MEC) and Data (mining, analytics) jointly with radio signal processing

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Conclusion

3GPP 5G Network started from Rel. 15 phase 1

Flow-level QoS
Heterogeneous and disaggregated spectrum and RAT
Multi-level Network Slicing
Cloud Native Architecture
Open Interfaces and Edge computing

Conclusion

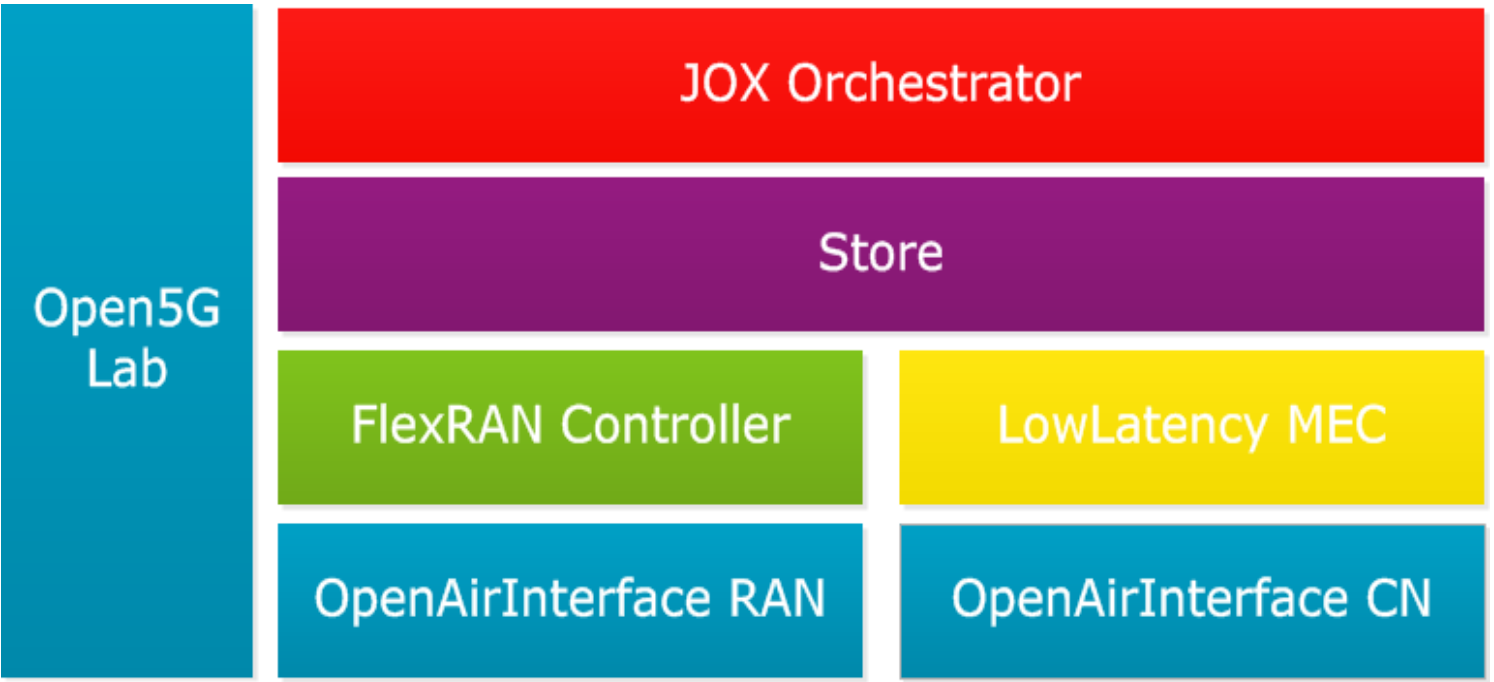
RAN slicing is an on-going research with several challenges

Isolation, **Sharing**, **Customization**

Satisfy requirements of slice owner and operator/infra. provider

Conclusion

OpenSource tools : OAI and M5G Ecosystem



MOSAIC 5G

http://mosaic-5g.io/

OPEN AIR INTERFACE

https://www.openairinterface.org/

Conclusion

Data-driven network control, orchestration, and management

Reason-Predict-Control is a generic framework

Performance is limited by the available computing resources

Outlook

5G System:

TS23.501 - System Architecture for the 5G System
TS23.502 - Procedures for 5G System
TS29.500 - 5G System, Technical Realization of Service Based Architecture
TS29.501 - 5G System, Principles and Guidelines for Services Definition
TS 33.501: "Security Architecture and Procedures for 5G System".

5GC components

AMF: - TS29.518 - Access and Mobility Management Services
NRF: TS29.510 - Network Function Repository Services
SMF: TS29.502 - Session Management Services, TS29.508 - Session Management Event Exposure Service
UDM: TS29.503 - Unified Data Management Services
AUSF: TS29.509 - Authentication Server Services, PCF: TS29.507 - Access and Mobility Policy Control Service, TS29.512 - Session Management Policy Control Service, TS29.571 - Common Data Types for Service Based Interfaces

Others:

TS 24.501: Non-Access-Stratum (NAS) protocol for 5G System (5GS)
TS 38.413: NG-RAN; NG Application Protocol (NGAP)

5G CN Specs.

RAN:

3GPP TS 38.401: "NG-RAN; Architecture description".
3GPP TS 37.340: "NR; Multi-connectivity; Overall description; Stage-2".
3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification".
3GPP TS 38.322: "NR; Radio Link Control (RLC) protocol specification".
3GPP TS 38.323: "NR; Packet Data Convergence Protocol (PDCP) specification".
3GPP TS 37.324: "NR; Service Data Protocol (SDAP) specification".
3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification".
3GPP TS 38.133: "NR; Requirements for support of radio resource management".

UE:

3GPP TS 38.304: "NR; User Equipment (UE) procedures in idle mode".
3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities".

5G RAN Specs.


Q
A

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