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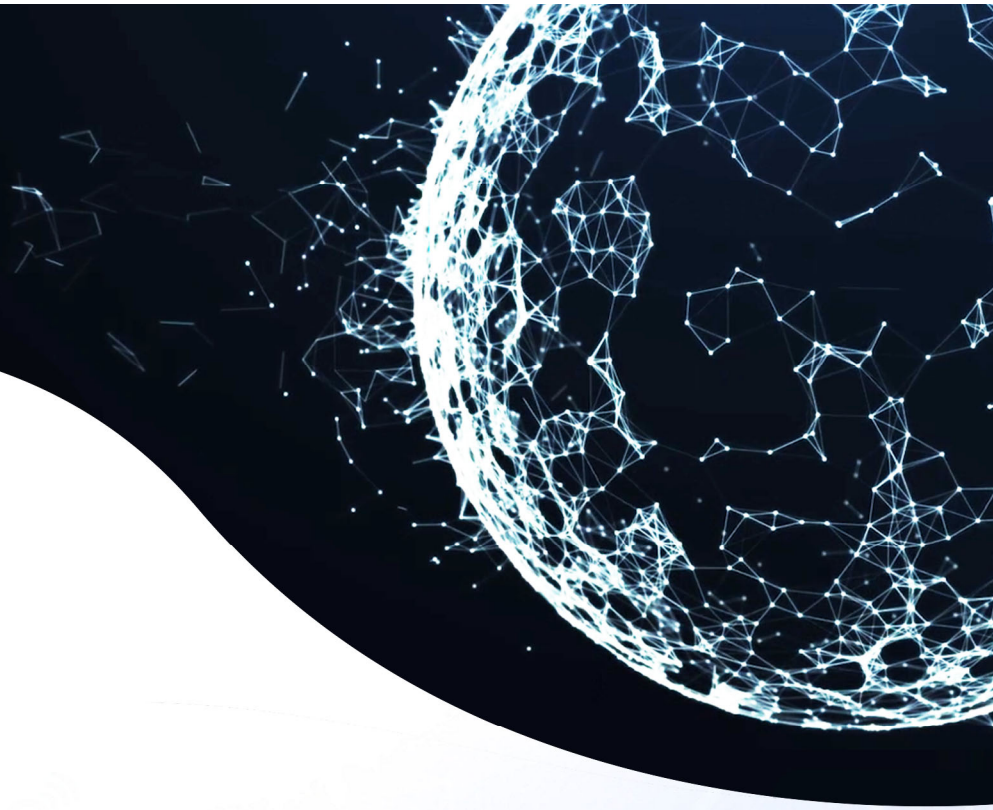

MEC Architecture

Maciej Muehleisen

Ericsson (ERI)

maciej.muehleisen@ericsson.com

31st of May / 7th of June 2021, 5GCroCo Lunchtime Web-Seminar 6 (Hosted by 5G-PPP)

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825050-5GCroCo

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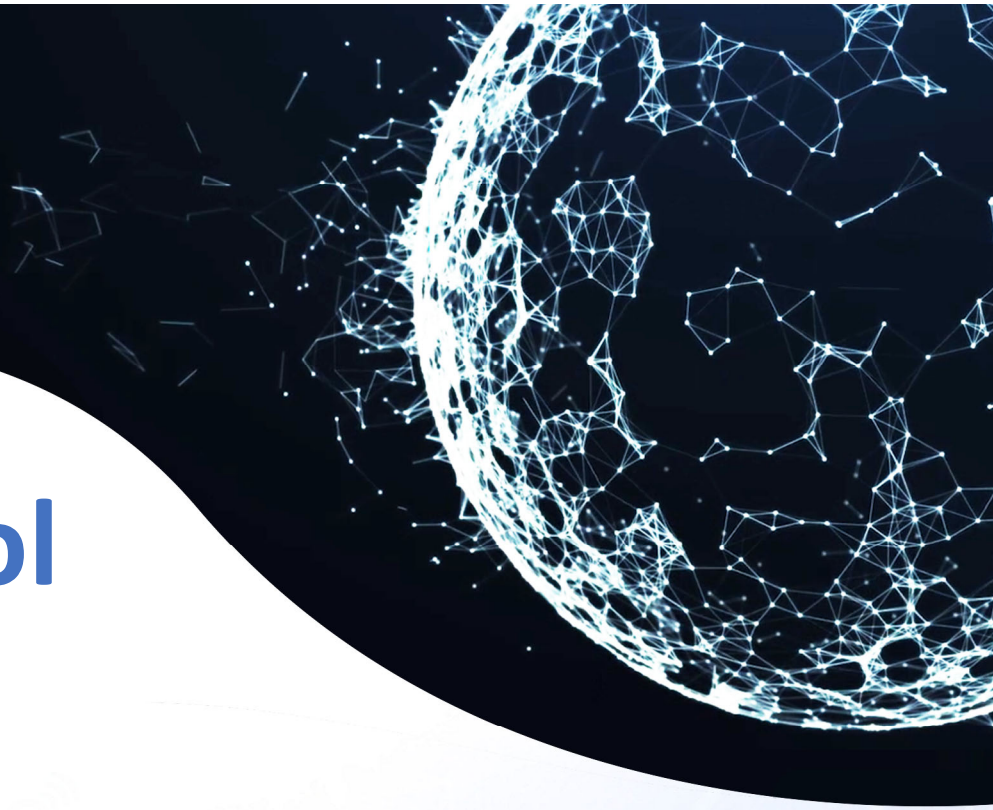

5G Cross Border Control

Innovation Action H2020-ICT-18-2018
Contract 825050

Cooperative, Connected and Autonomous Mobility (CCAM)

a 5G-PPP Phase III Project

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825050-5GCroCo

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Before we Start…

- This presentation is being recorded and recording will be shared with registered participants (password-protected link)
- Slides will be shared
- We'll continue same time next week; please watch the recording if you missed Part I

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Outline Part I

- About me
- Overview Deliverable D3.2
- Related Work
- Session Continuity: 3GPP Gateway Switching
- MEC with Cross-border / -MNO Handover
- More, if time allows

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About Me

Key research interest: Modelling, design, evaluation, and certification of highly reliable / safety critical communication systems

- 2008 – 2012 ComNets - RWTH Aachen University
  - Open Wireless Network Simulator developer
  - PhD research on “VoIP Performance of LTE Networks: VoLTE versus OTT” (2015)
- 2012 – 2016 ComNets - Hamburg University of Technology (TUHH)
  - Group leader “Mobile & Vehicular Communication” (**focus on aviation, maritime**)
  - Sometimes acting group leader for “Sensor Networks and IoT” & “Future Internet and Network Planning”
- Since 2017 Ericsson Research Germany
  - Research Area “Networks” – Master Researcher - Industry Verticals Coordination (focus on automotive)
  - Coordination of tech. work in external associations (5GAA, AECC, ETSI-ITS) and projects (5GCroCo, 5GMOBIX, 5G-ROUTES, ART-04 SHOW)
  - Deputy Technical Coordinator 5GCroCo & leader of WP3 “Architecture”
- Very eager to discuss with other “experts” who want to deep dive into this under whatever “formal roof” (5G-PPP, 5GAA, AECC, …)

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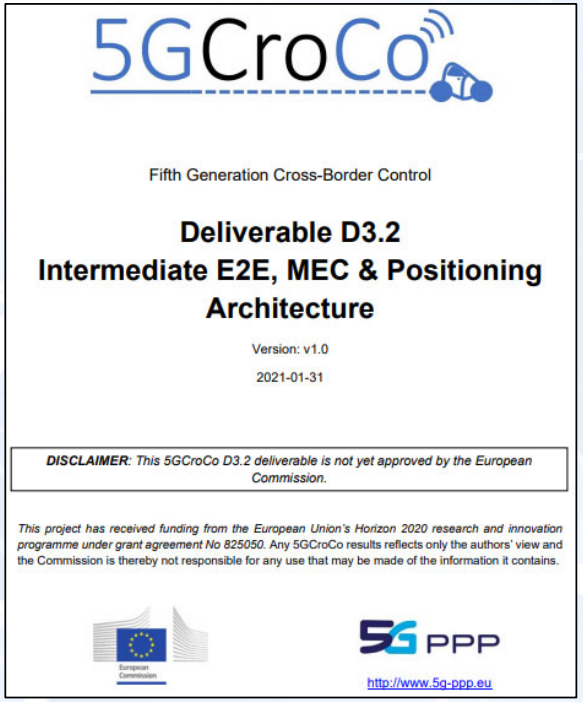
Overview Deliverable D3.2

Outline (extract):

- Related Technical Specifications and Studies and their Applicability
  - 3GPP
  - Automotive Edge Computing Consortium (AECC)
  - Cloud Native Computing Foundation (CNCF)
- Interface Between MEC and 3GPP Network
- Session Continuity when Switching Gateways
- End-to-end Service Continuity when Switching MEC-hosts and/or Gateways
- Cross-MNO Inter-MEC Communication
- Relation to other Key 5G Solutions
  - Cross-border / -MNO Handover
  - Network Orchestration and Control
- Use Case Specific Solutions
  - HD Mapping
  - Anticipated Cooperative Collision Avoidance (ACCA)



5GCroCo

Fifth Generation Cross-Border Control

Deliverable D3.2
Intermediate E2E, MEC & Positioning Architecture

Version: v1.0

2021-01-31

***DISCLAIMER**: This 5GCroCo D3.2 deliverable is not yet approved by the European Commission.*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825050. Any 5GCroCo results reflects only the authors' view and the Commission is thereby not responsible for any use that may be made of the information it contains.

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D3.2: Section 4.3 "MEC"

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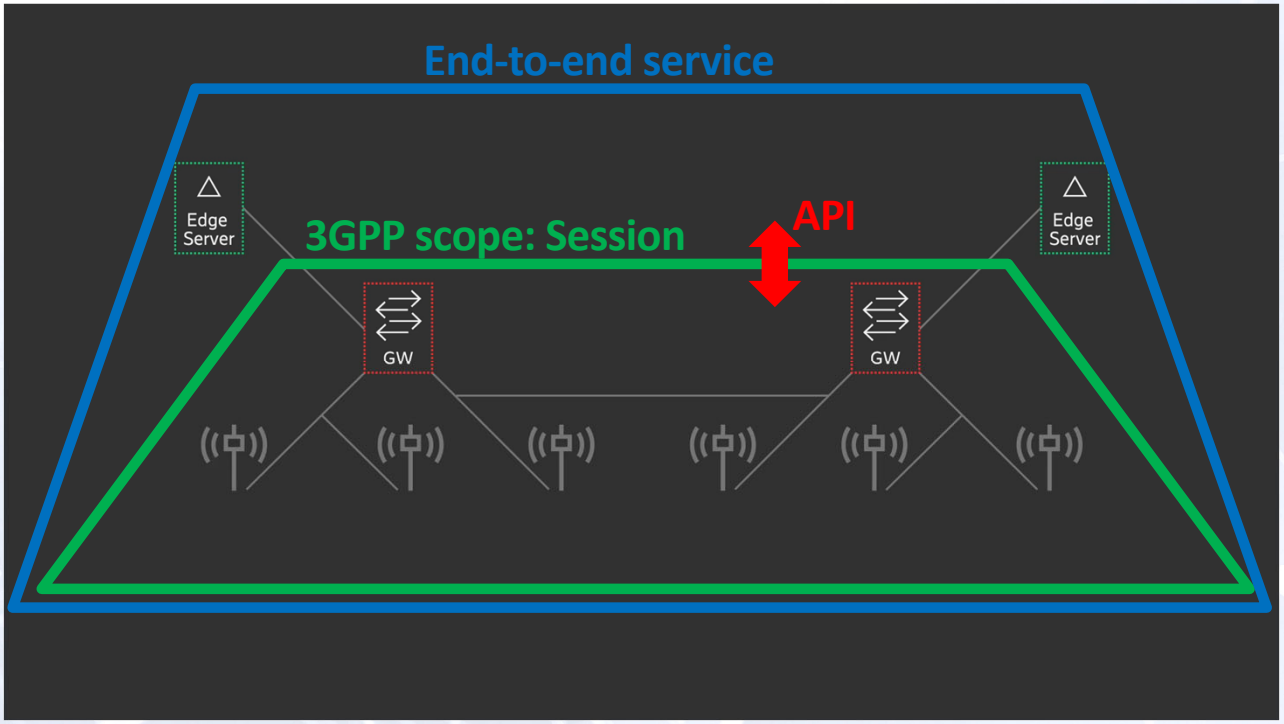
Related Technical Specifications and Studies

- 3GPP:
  - RAN: Triggers like Tracking Area Updates (TAUs) can be used for gateway/server switching
  - SA2:
    - Session & Service Continuity (SSC) mode*) 1 – 3
    - Multi-homed PDU session (combined with SSC)
    - AF influence on traffic steering API
  - SA5: Use definition of roles described there (next slide)
- End-to-end service continuity to be solved by means of IETF



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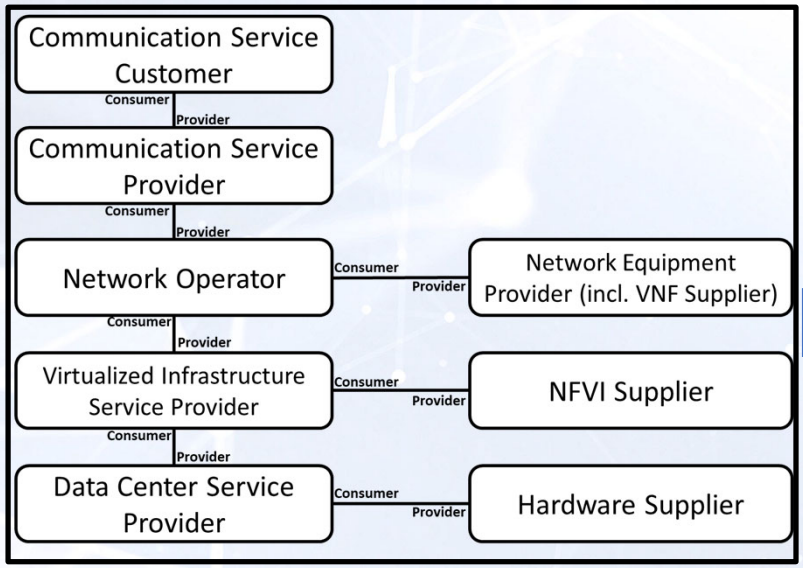
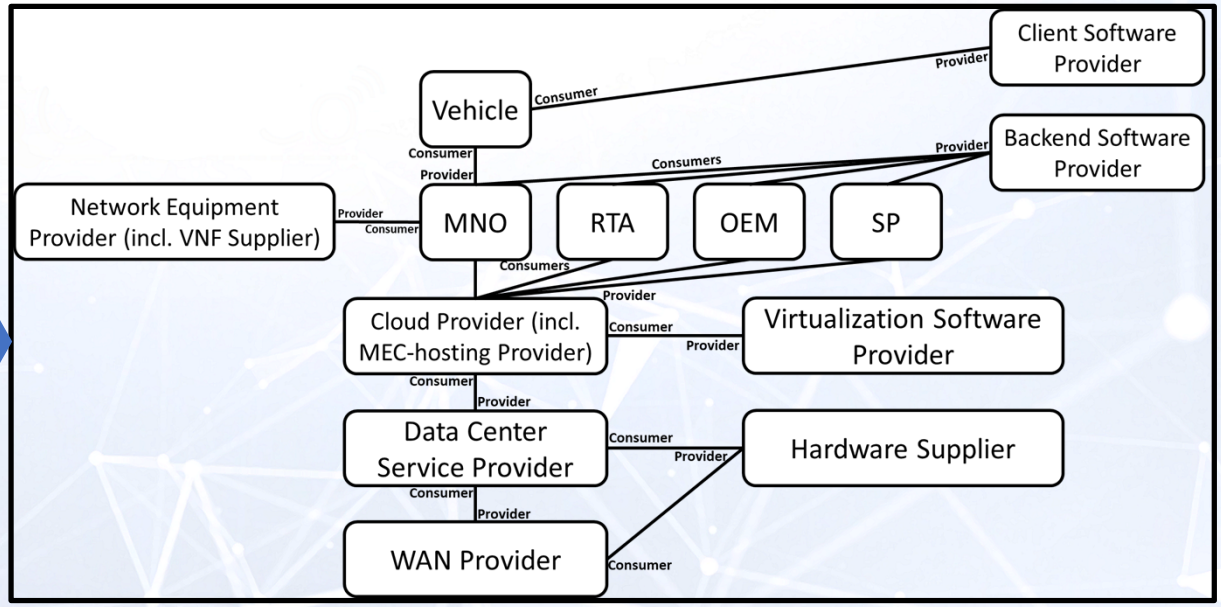
Related Technical Specifications and Studies: 3GPP SA5





Adjusted based on [5GAA V2X Application Layer Reference Architecture]
(omitted VRU as not relevant for 5GCroCo)

Adapted some terms; added “WAN Provider” and app. software providers

RTA: Road Traffic Authority
SP: Service Provider

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Related Technical Specifications and Studies: Cloud Native Computing Foundation (CNCF)

MEC is not all new but should be seen as subtopic of Cloud ecosystem incl. **common tools / APIs / principles** defined by CNCF:

- Public, private and hybrid clouds:
  - Role of MNO as “hybrid cloud” provider
  - Cooperation with Hyperscale Cloud Providers (Amazon Web Services (AWS), Microsoft Azure, …)
- Containers (Kubernetes): Lightweight virtualization instead of (Kernel) VMs ((K)VMs); **full tool chain (develop, test, deploy, …)**
- Microservices: Independent, distributed software pieces delivering the overall service
- Service meshes: Automatic discovery, interconnection and fail-over between the microservices
- Immutable infrastructure: Do not change parts of containers but deploy new ones when change is needed ➔ Seamlessly integrated through service mesh; easy rollback on failure
- Declarative APIs:
  - E.g.: “Provide me HD maps as I go”, “Assure I am always connected to the best Application Server to receive Hazard Warnings”
  - Instead of several calls (Imperative API): “Connect, initialize, select topics of interest, request change of server, …”

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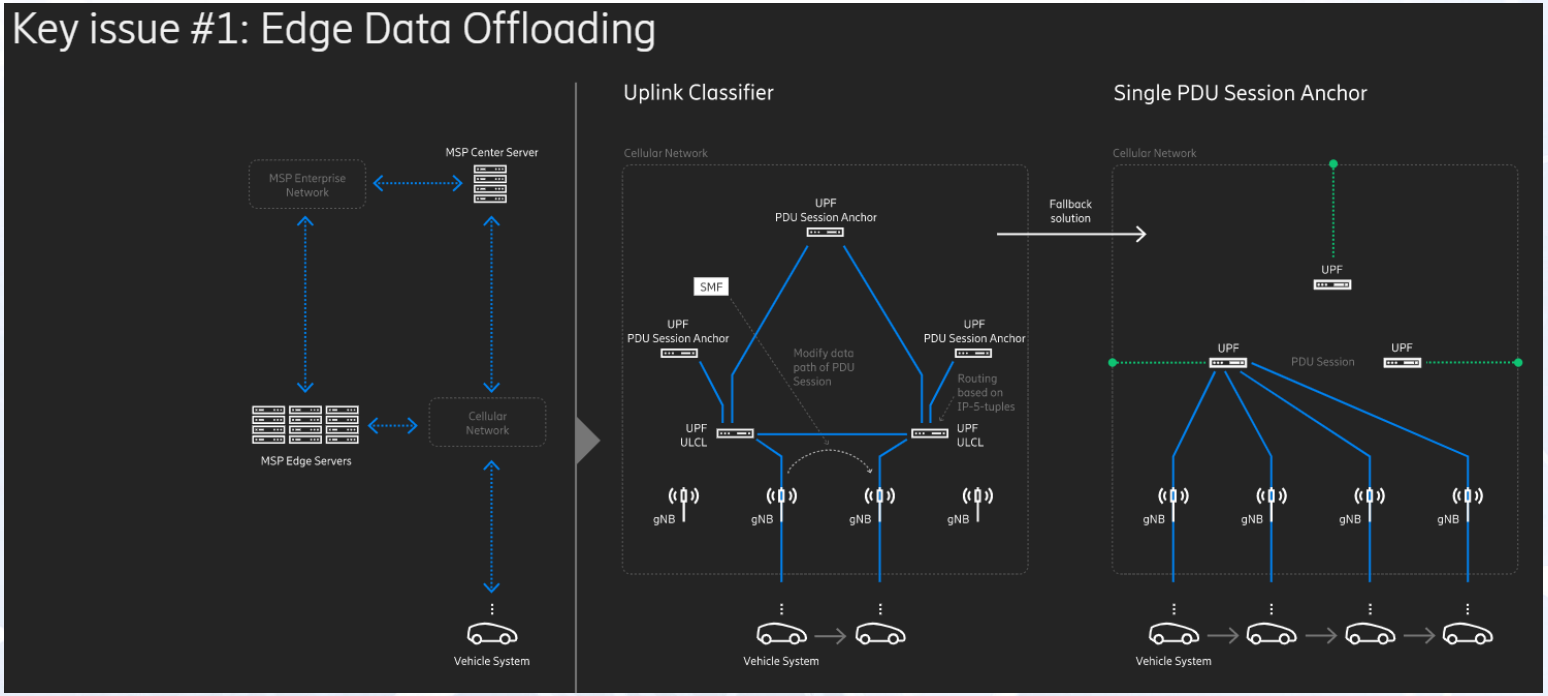
Related Technical Specifications and Studies: AECC (Technical Report 2.0)

- AECC considers 3GPP 5G NSA and SA as network architecture
- Key issue #1 solutions:
  - Connect MEC hosts through SGi (NSA) / N6 (SA) interfaces
  - Different APNs/DNNs[1)] can be used to route to MEC / central servers
  - Uplink classifier can also be used
- SSC (gateway / server switching) hardly covered in AECC



1) APN: Access Point Name (4G EPC, 5G NSA)
DNN: Data Network Name (5G SA)

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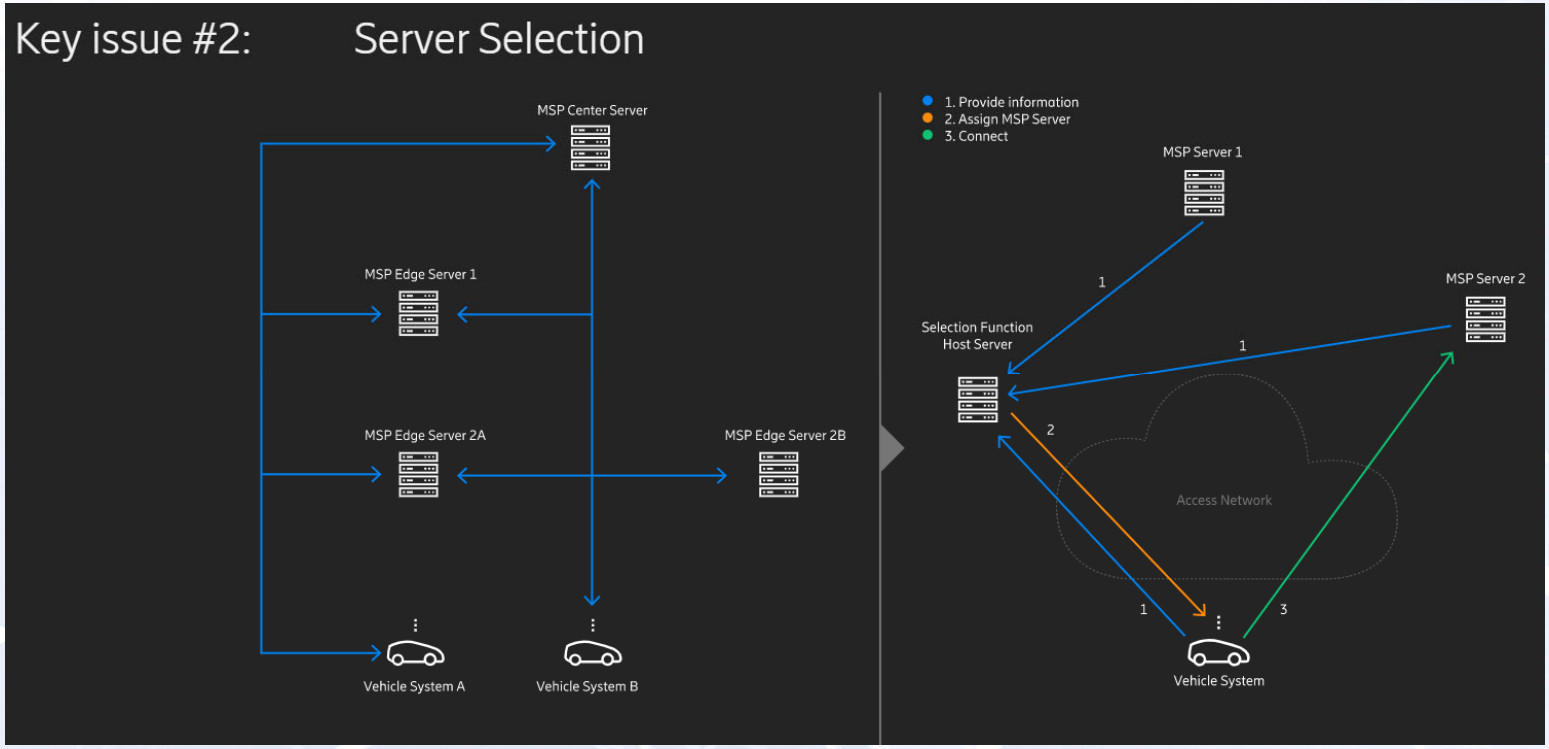
Related Technical Specifications and Studies: AECC (Technical Report 2.0)

- AECC considers 3GPP 5G NSA and SA as network architecture
- Key issue #2 solutions:
  - **DNS**, but need to define how DNS server obtains vehicle location information (later slides)
  - Lookup table in vehicle
  - IP anycast possible but not preferred (needs rarely enabled transport network support)



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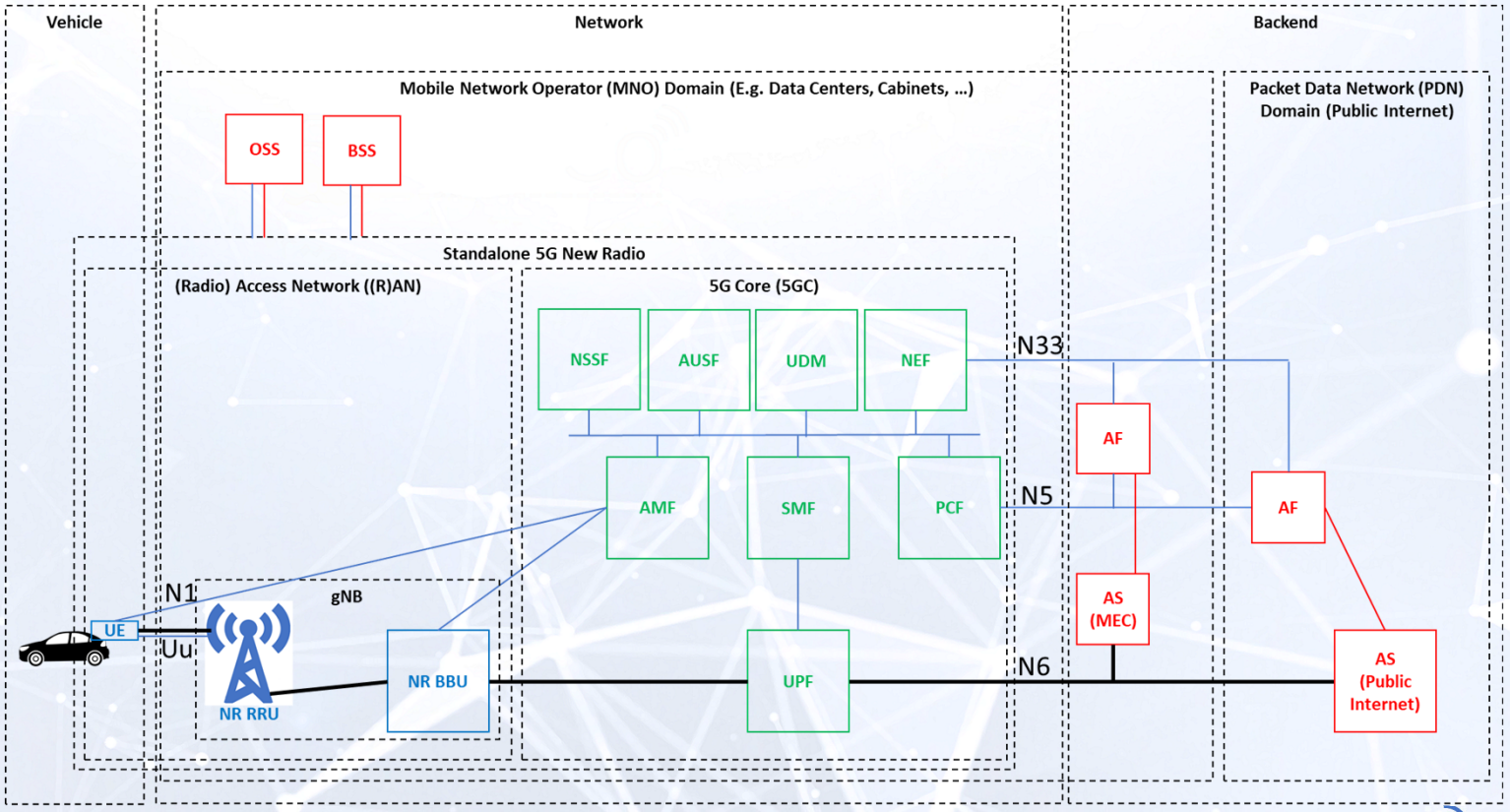
Session Continuity: 3GPP Gateway Switching

- 3GPP as basic architecture
- Similar for 5G NSA with other Network Function (NF) and interface names
- Color codes nodes:
  - Blue: Physical NF
  - Green: Virtual NF (incl. containerized (cloud native))
  - Red: Virtualized / containerized (cloud native) application
- Color codes interfaces:
  - Blue: 3GPP control / management plane
  - **Black:** 3GPP user plane
  - Red: Not (yet) defined in 3GPP



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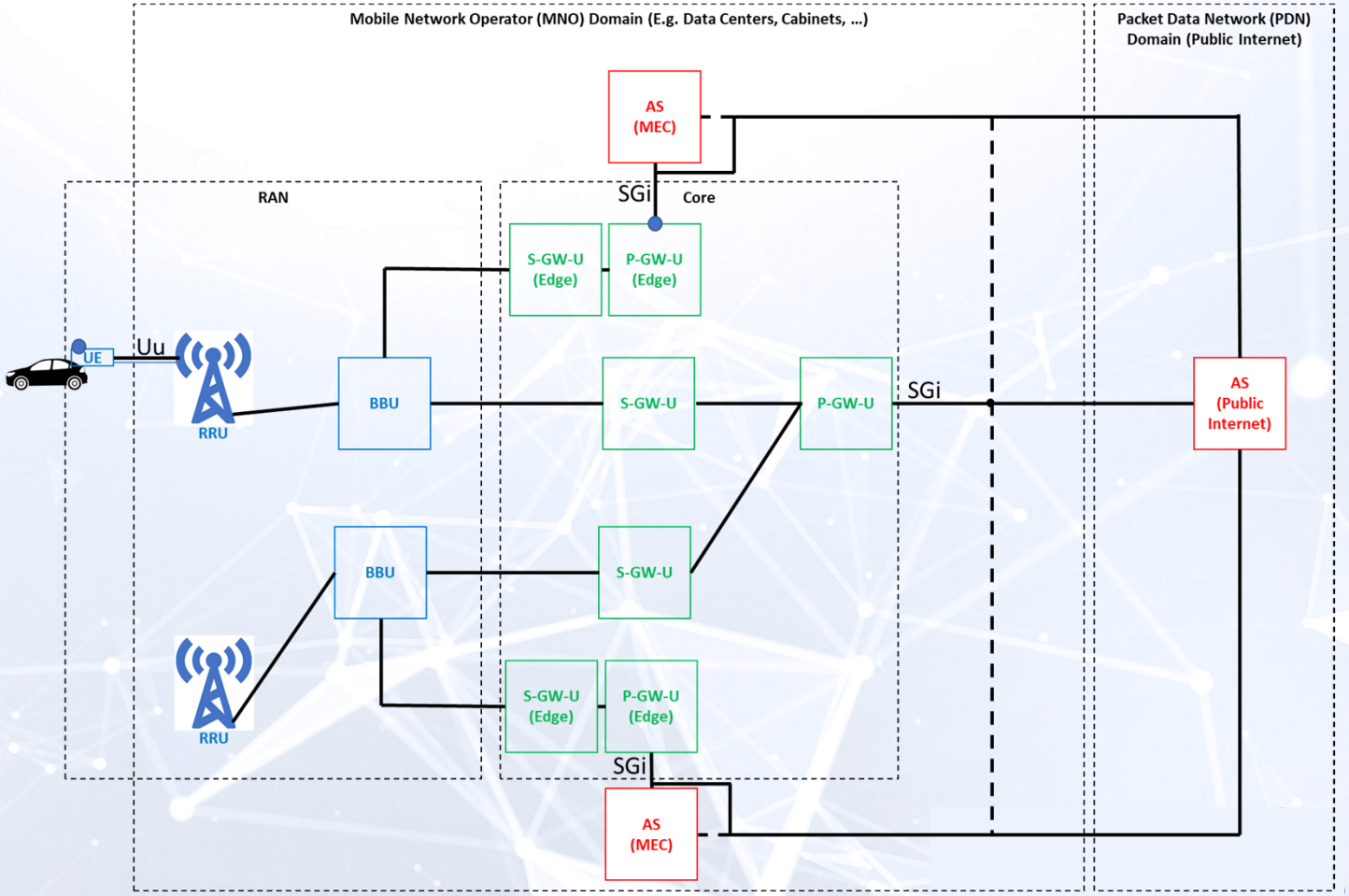
Session Continuity: 3GPP Gateway Switching

SA / NSA:

- SSC mode 1 / vehicle-triggered
- SSC mode 2 / SIPTO[1)] above RAN
- SSC mode 3 / -

- UPF / S/P-GW relations are only examples and can be different



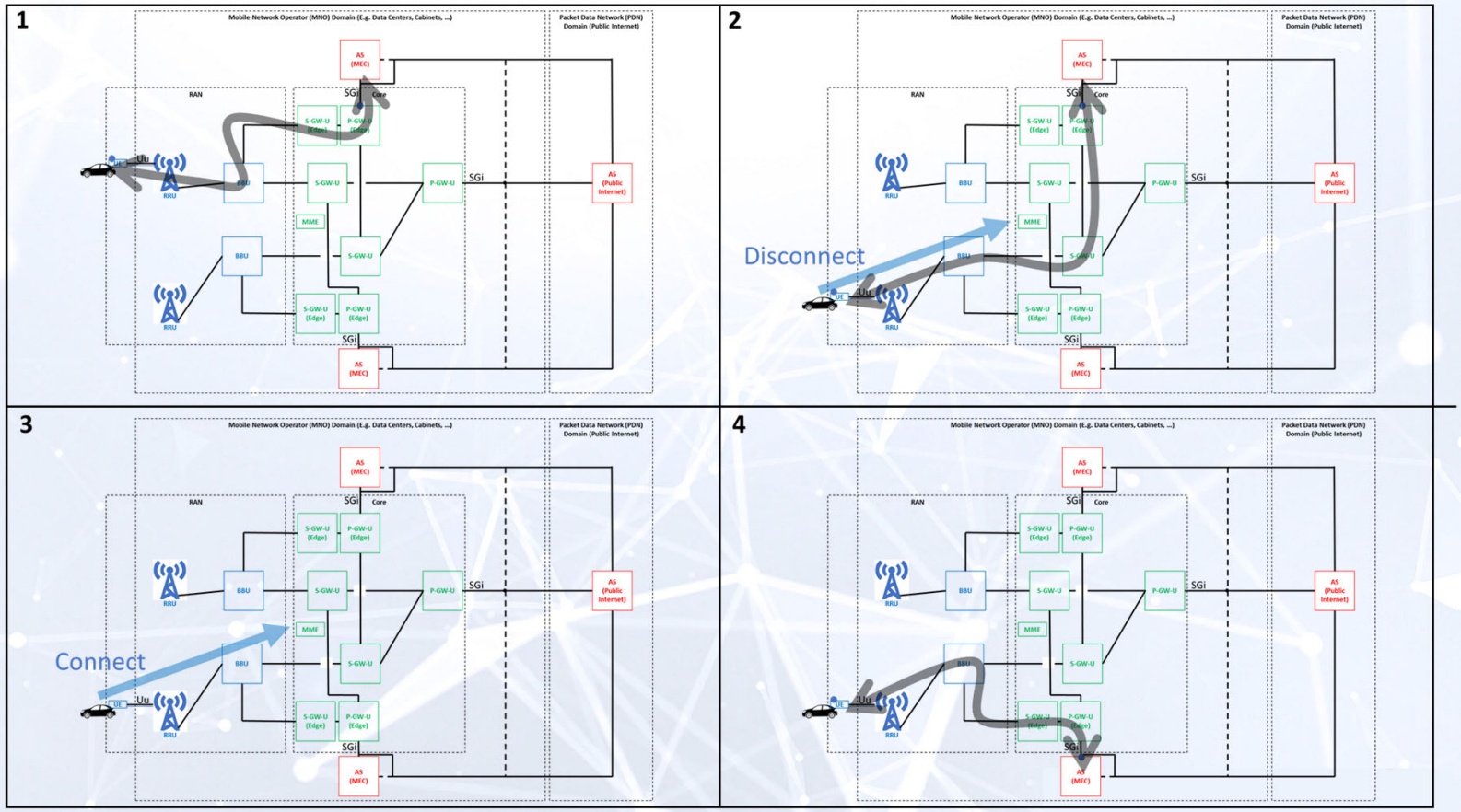
1) SIPTO: Selective IP Traffic Offload

Session Continuity: 3GPP Gateway Switching: SSC Mode 1

SA / NSA:

- **SSC mode 1 / vehicle-triggered**
- SSC mode 2 / SIPTO[1)] above RAN
- SSC mode 3 / -

➔Break-before-make, vehicle-triggered



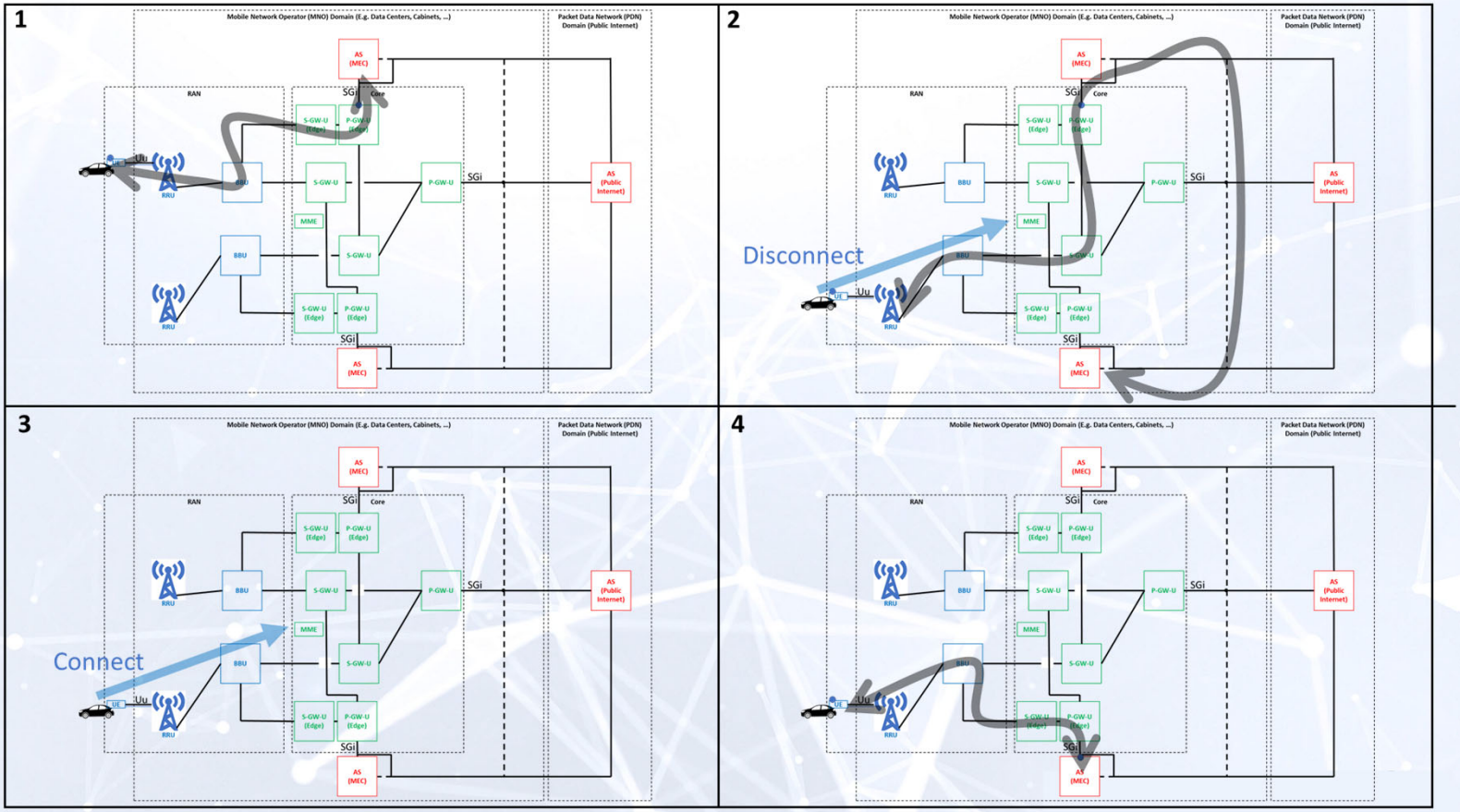
Session Continuity: 3GPP Gateway Switching: SSC mode 1

SA / NSA:

- **SSC mode 1 / vehicle-triggered**
- SSC mode 2 / SIPTO[1)] above RAN
- SSC mode 3 / -

➔Break-before-make, vehicle-triggered

Optionally, lower AS can be contacted before disconnect (any use case that can benefit?)



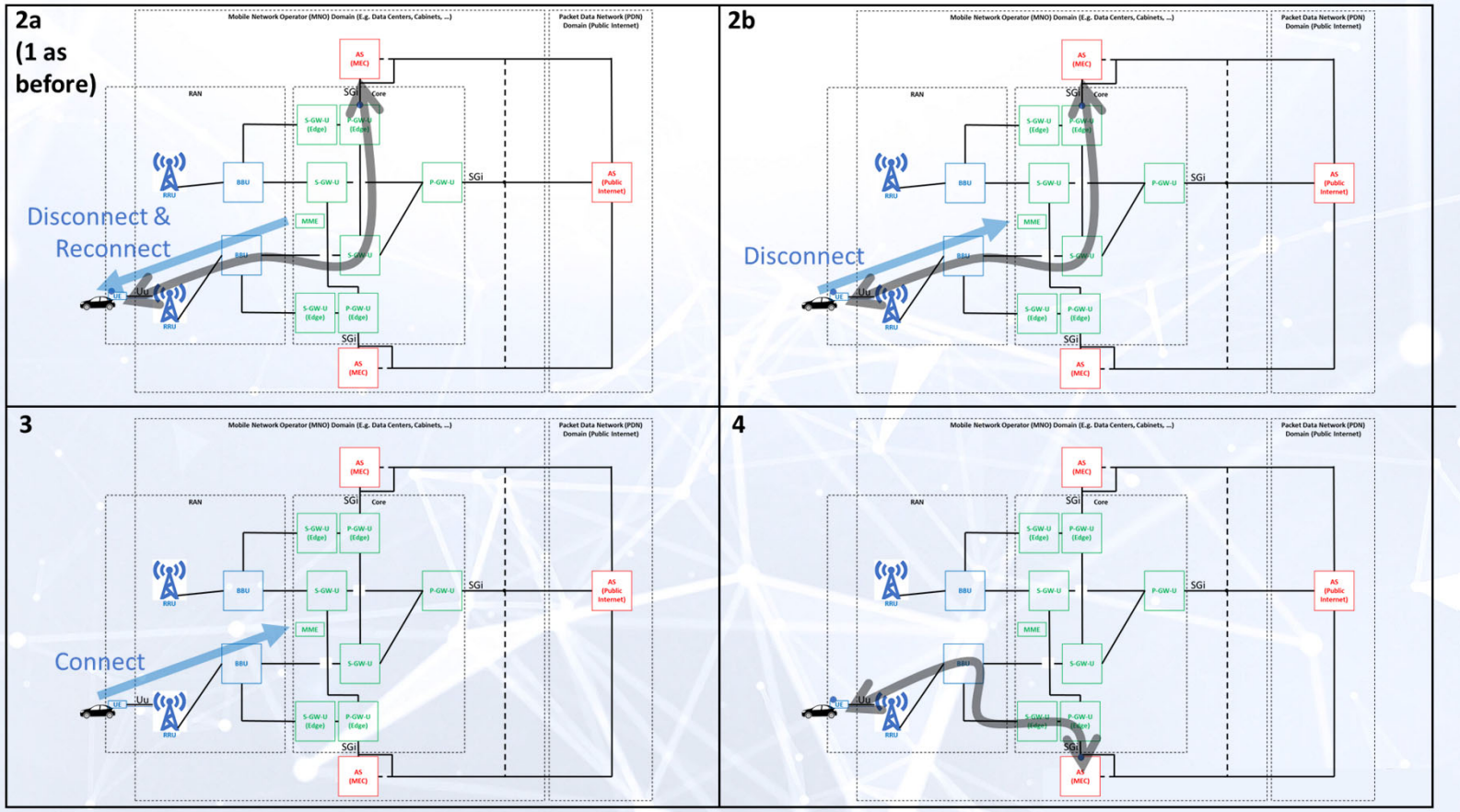
Session Continuity: 3GPP Gateway Switching: SSC mode 2

SA / NSA:

- SSC mode 1 / vehicle-triggered
- **SSC mode 2 / SIPTO[1)] above RAN**
- SSC mode 3 / -

➔Break-before-make, **network**-triggered

Also, for SSC mode 2 the new AS can be contacted before disconnect



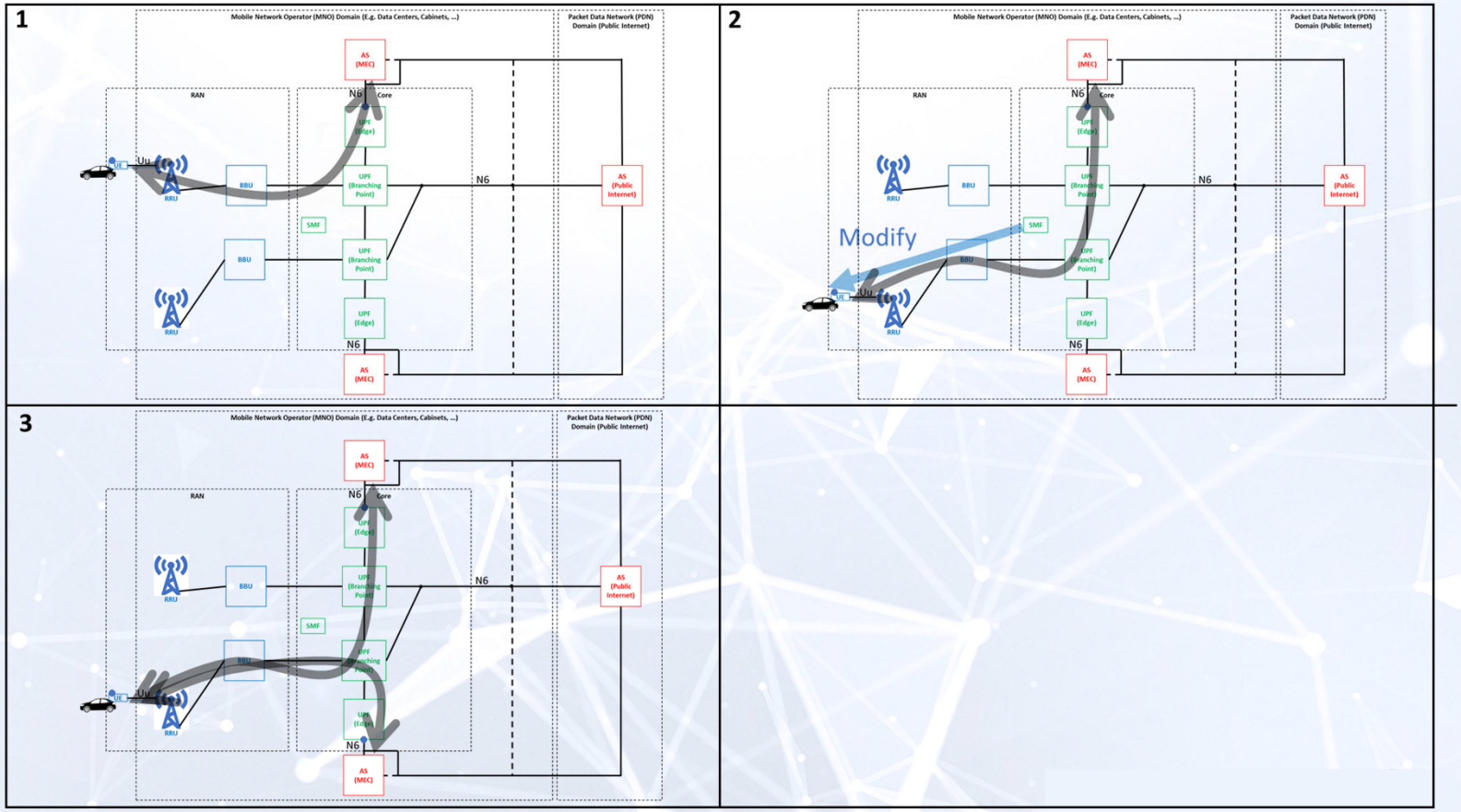
Session Continuity: 3GPP Gateway Switching: SSC mode 3

SA / NSA:

- SSC mode 1 / vehicle-triggered
- SSC mode 2 / SIPTO[1)] above RAN
- **SSC mode 3** / -

➔Make-before-break, **network**-triggered

How to decide when to disconnect from old gateway?



Session Continuity: 3GPP Gateway Switching: SSC mode 3

SA / NSA:

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- **SSC mode 3** / -

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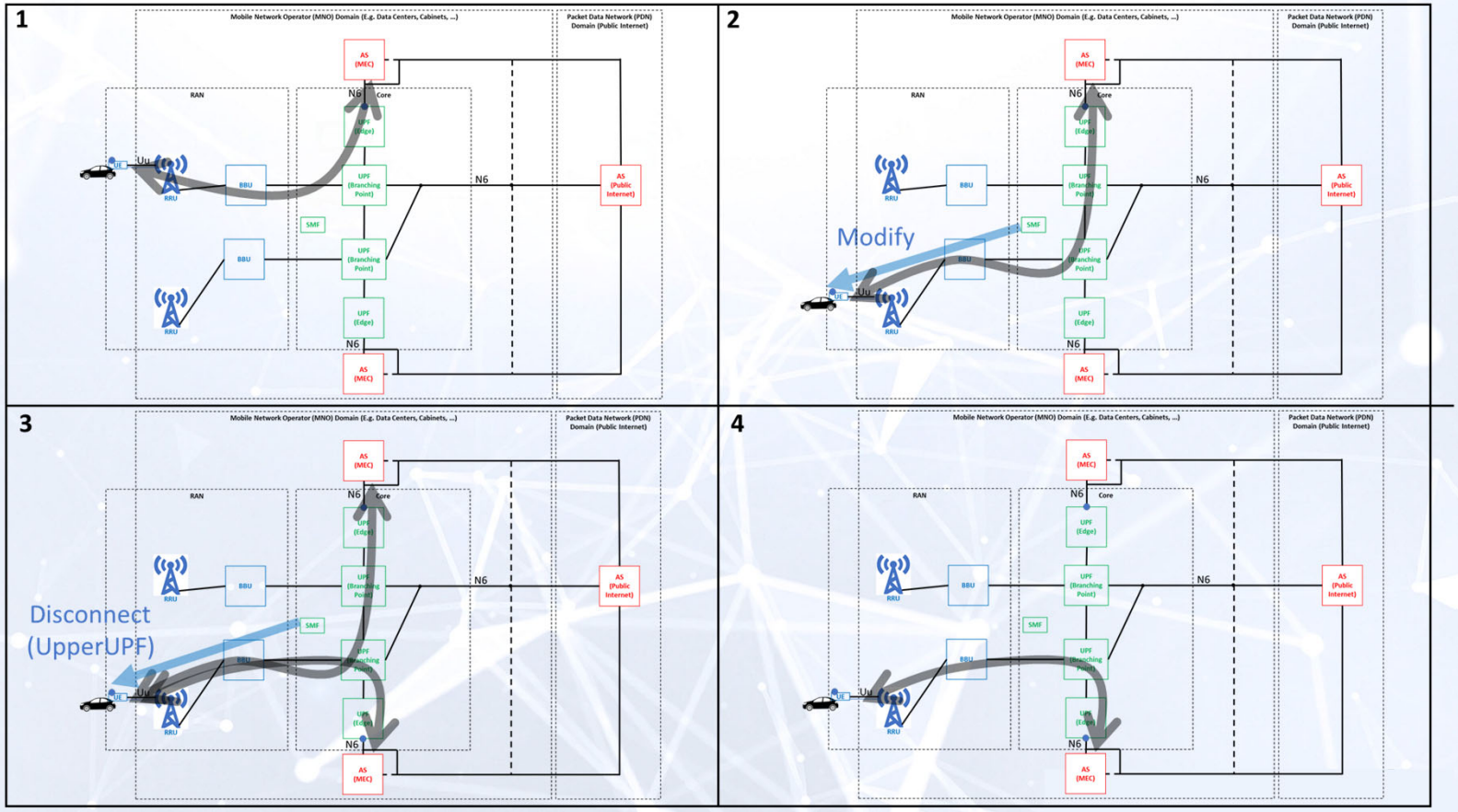

Session Continuity: 3GPP Gateway Switching

5G SA (5GC)	5G NSA, 4G (EPC)	Trigger	Drawback
SSC mode 1	Release / re-establish PDN session in vehicle CCU[1)]	Client application and/or OS e.g. based on Cell- / Tracking Area- / PLMN ID (cross-MNO) change	•Service interruption of up to one second •Triggering at wrong location will just select the same gateway again
SSC mode 2	SIPTO[2)] above RAN	Tracking Area Update from RAN but other policies possible	•Service interruption of up to one second •Needs special support in EPC
SSC mode 3	Not available (tricks with two APNs possible for our trials)	Tracking Area Update from RAN but other policies possible	•Complexity when two gateways are used •Unclear when to release the “old” gateway

1) CCU: Communication Control Unit (vehicular 3GPP network router)
2) SIPTO: Selective IP Traffic Offload

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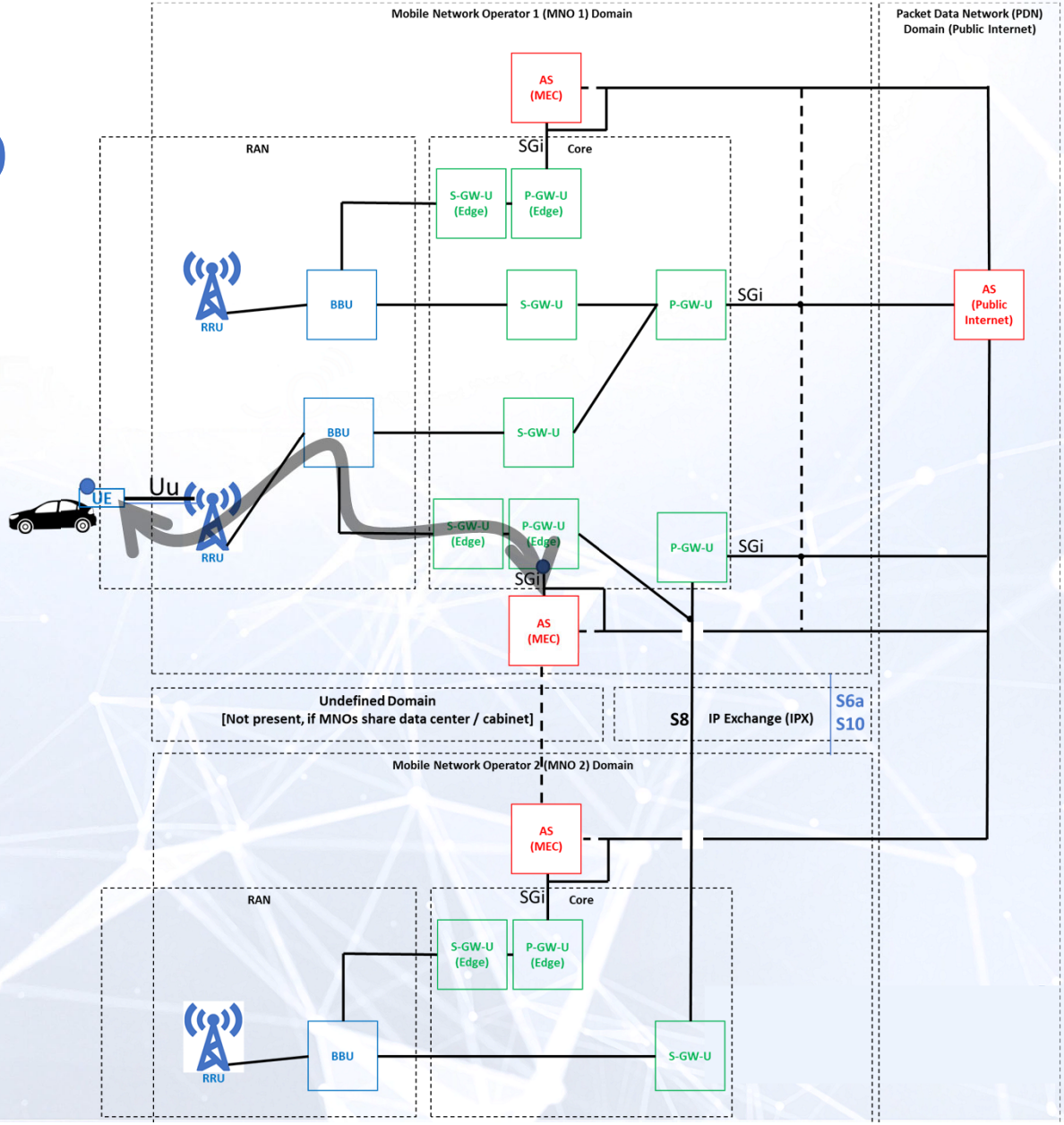
MEC in Context of Cross-border/-MNO Handover

- No cross-border/-MNO handover – no problem:
  - Just configure “Local Breakout Routing” when vehicle establishes new data network connection in visited network
- SSC mode 1 and 2 can do transition from Home to Local Breakout Roaming
  - **We now have uninterrupted cross-border/-MNO handover and do not want to “break” it due to gateway switching**
- Does SSC mode 3 work across PLMNs?
  - If not, should 3GPP Core specs be adapted for it?



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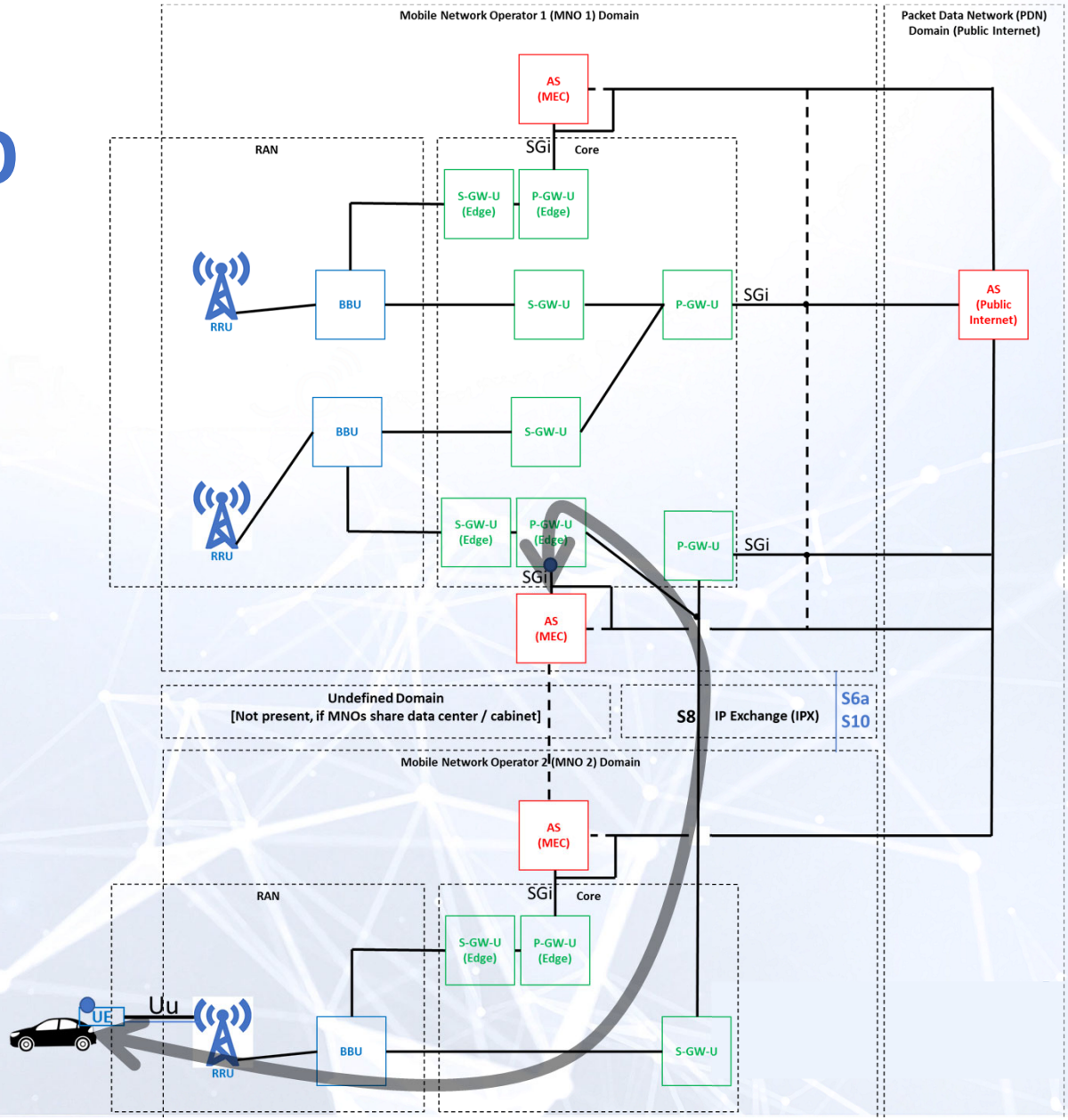

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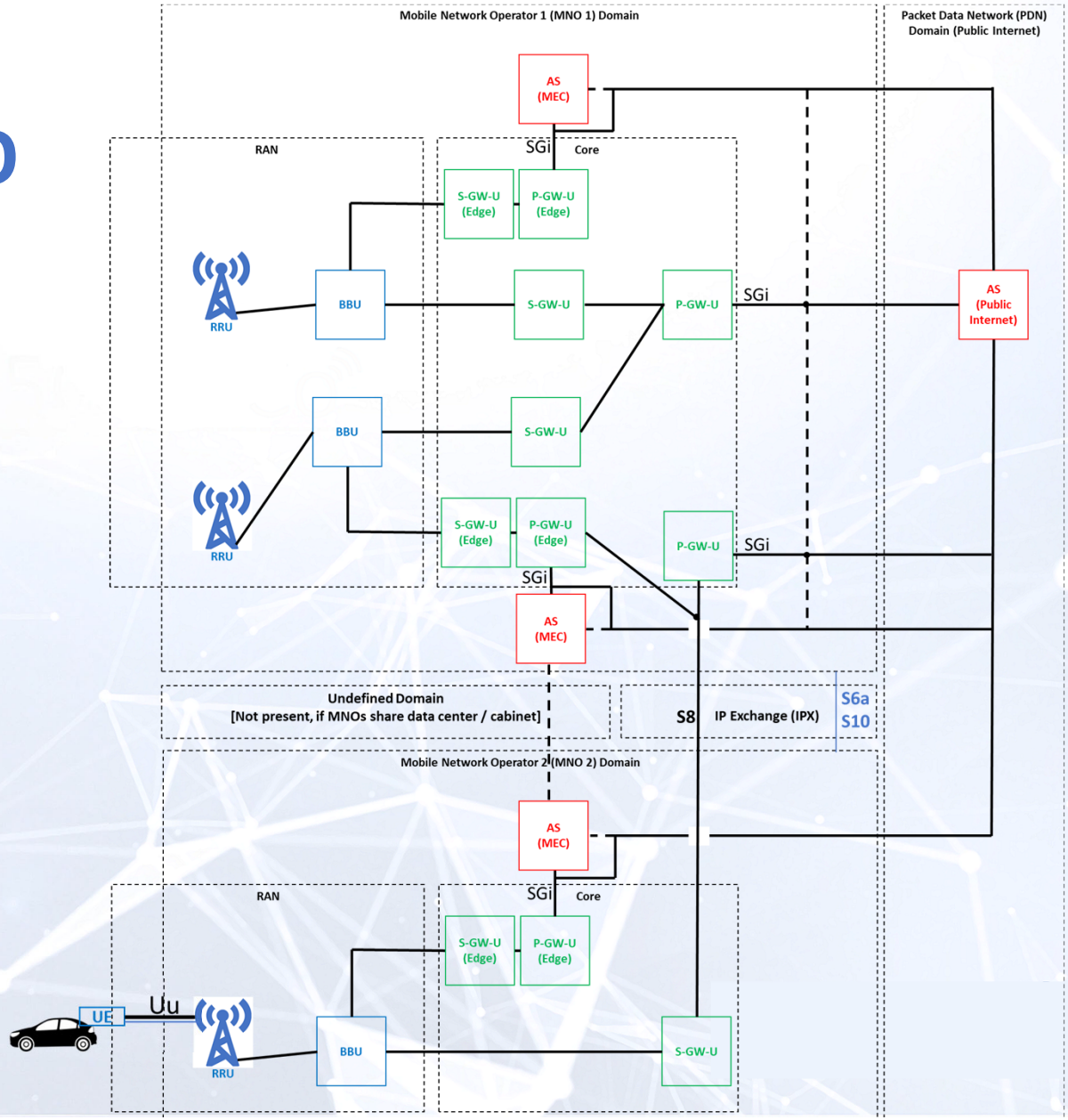

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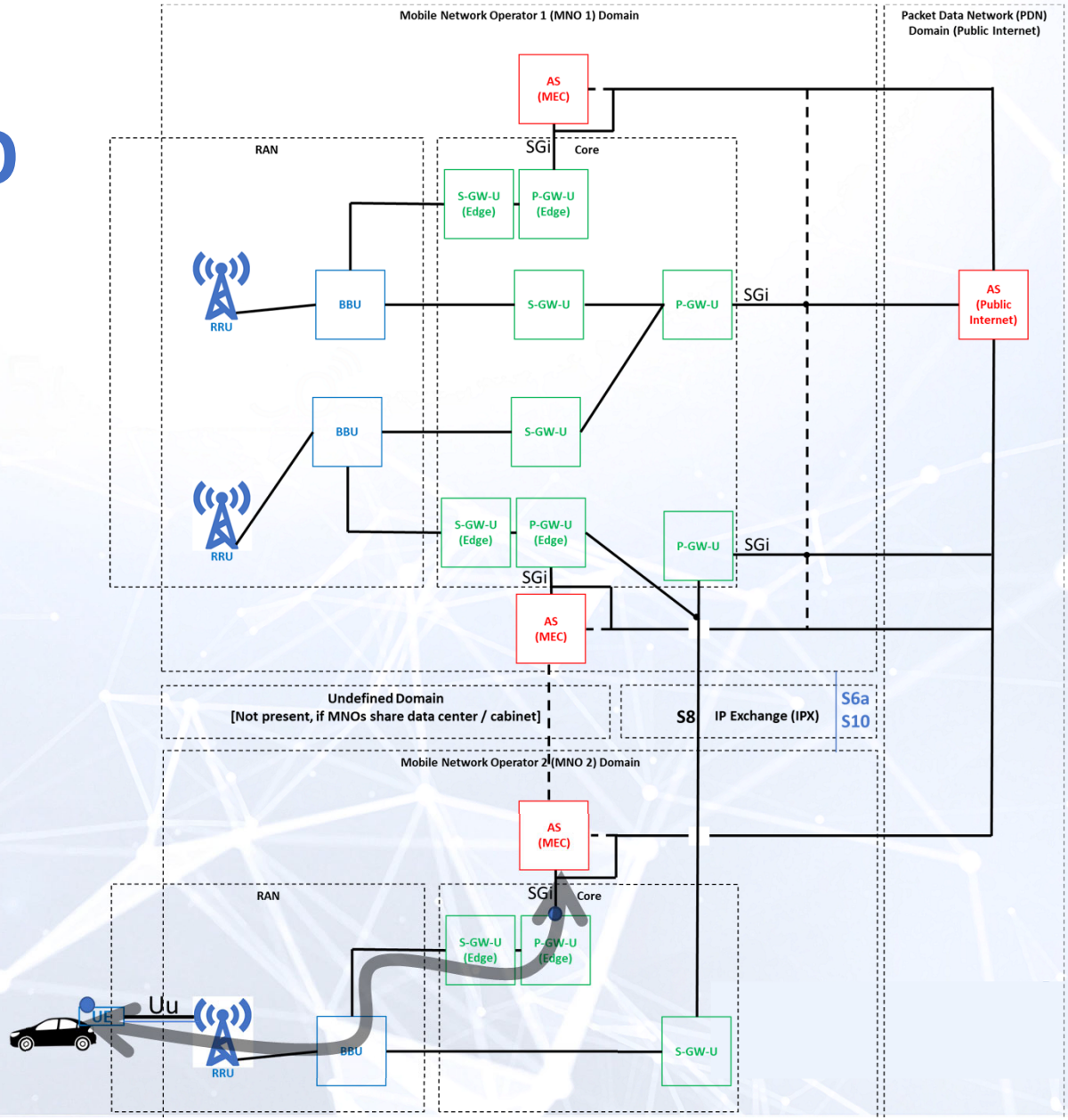

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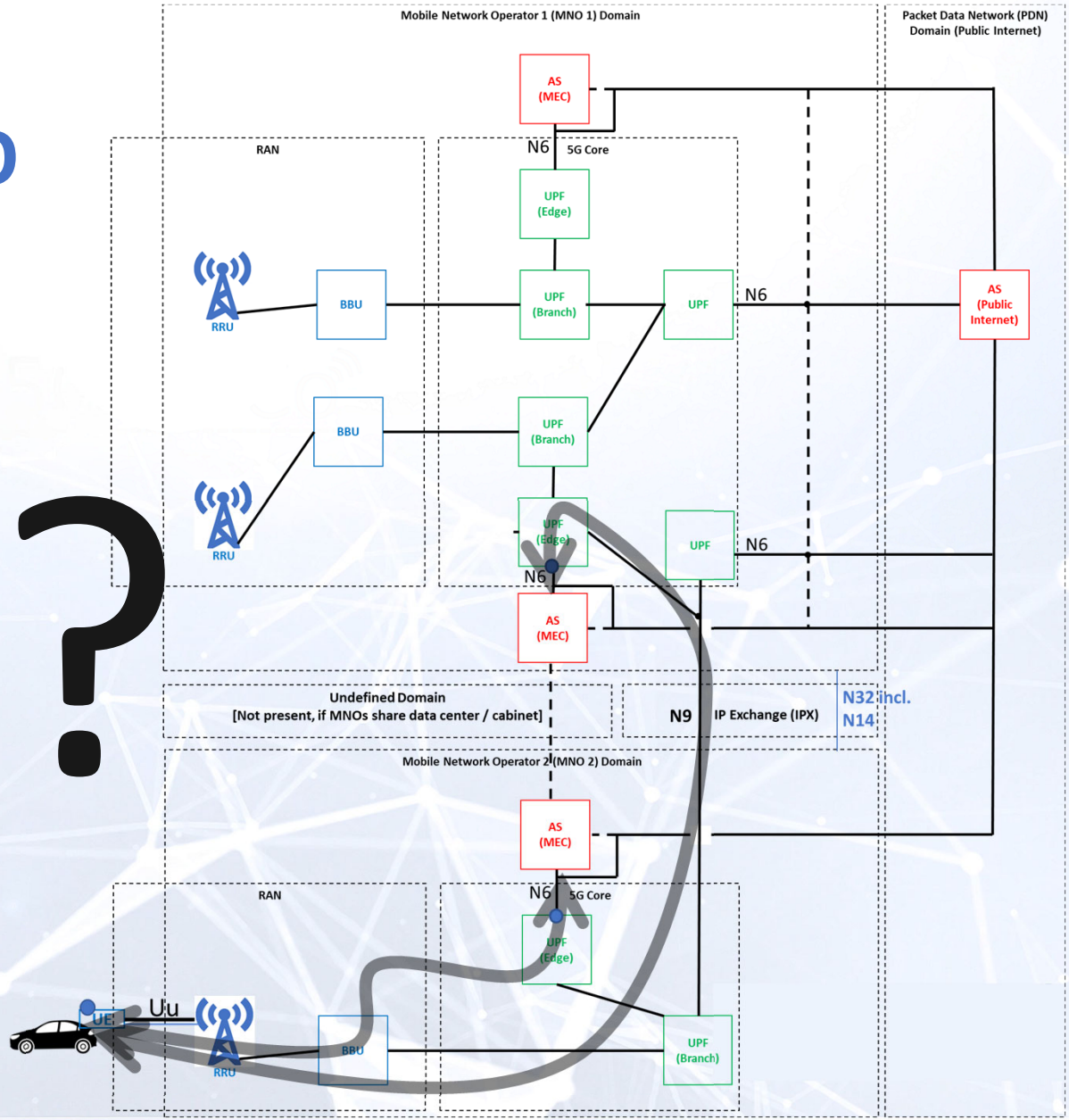

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MEC Architecture – Part II

Maciej Muehleisen

Ericsson (ERI)

maciej.muehleisen@ericsson.com

7th of June 2021, 5GCroCo Lunchtime Web-Seminar 6 (Hosted by 5G-PPP)

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825050-5GCroCo

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Outline Part II

- Service Continuity: Discovering and Switching Servers
- Use Case Examples: Triggers for Switching & Dealing with Outage
- Controlled End-to-End QoS Across Multiple MNOs
- Joined Management and Orchestration of Virtual Network Functions and MEC-hosted Application Servers
- Open Tasks for Deliverable D3.3 (March 2022)
- Completed and Planned Trials
- Summary & Conclusion

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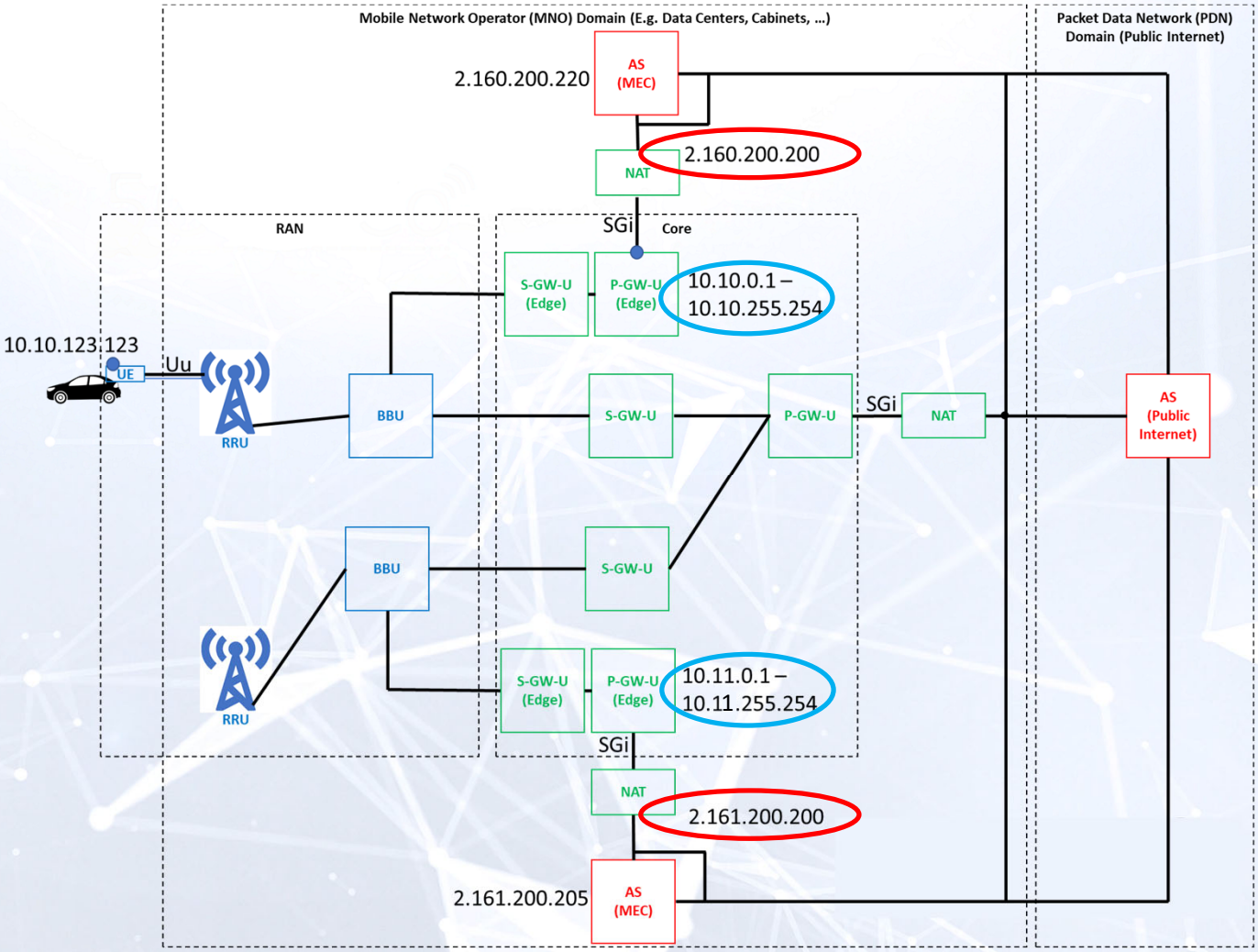
Service Continuity: Discovering and Switching Servers

- Changing the gateway usually means changing the IP address
- Usually Network Address Translation (NAT) is also used
- Normal TCP connections break when IP address changes because source IP/port are part of unique ID
- Multipath TCP and QUIC use unique IDs and survive IP address changes
  - So far, only considered to stay connected to old (upper) Application Server
- Many applications quickly recover from broken TCP connections **(demo)**



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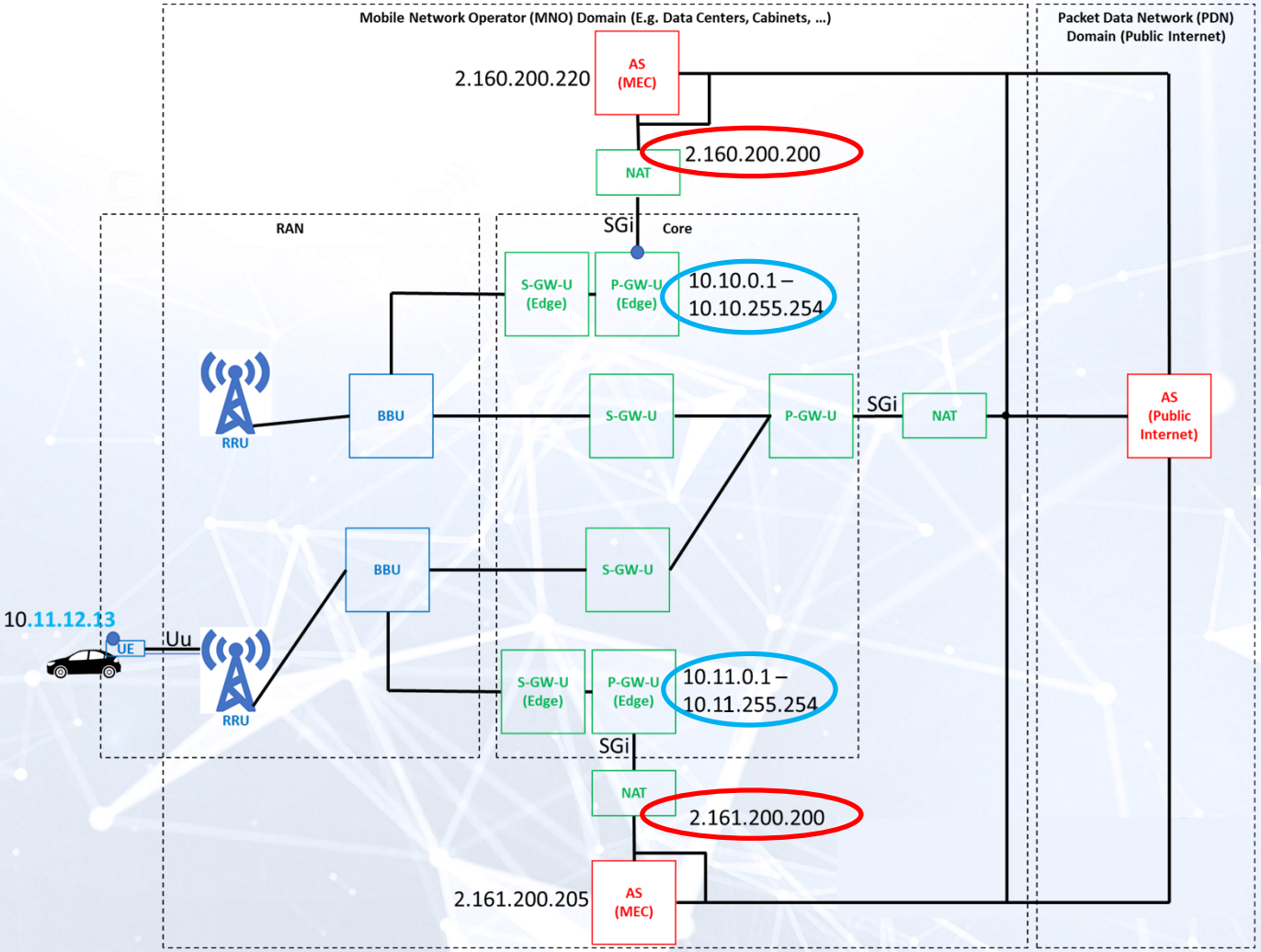

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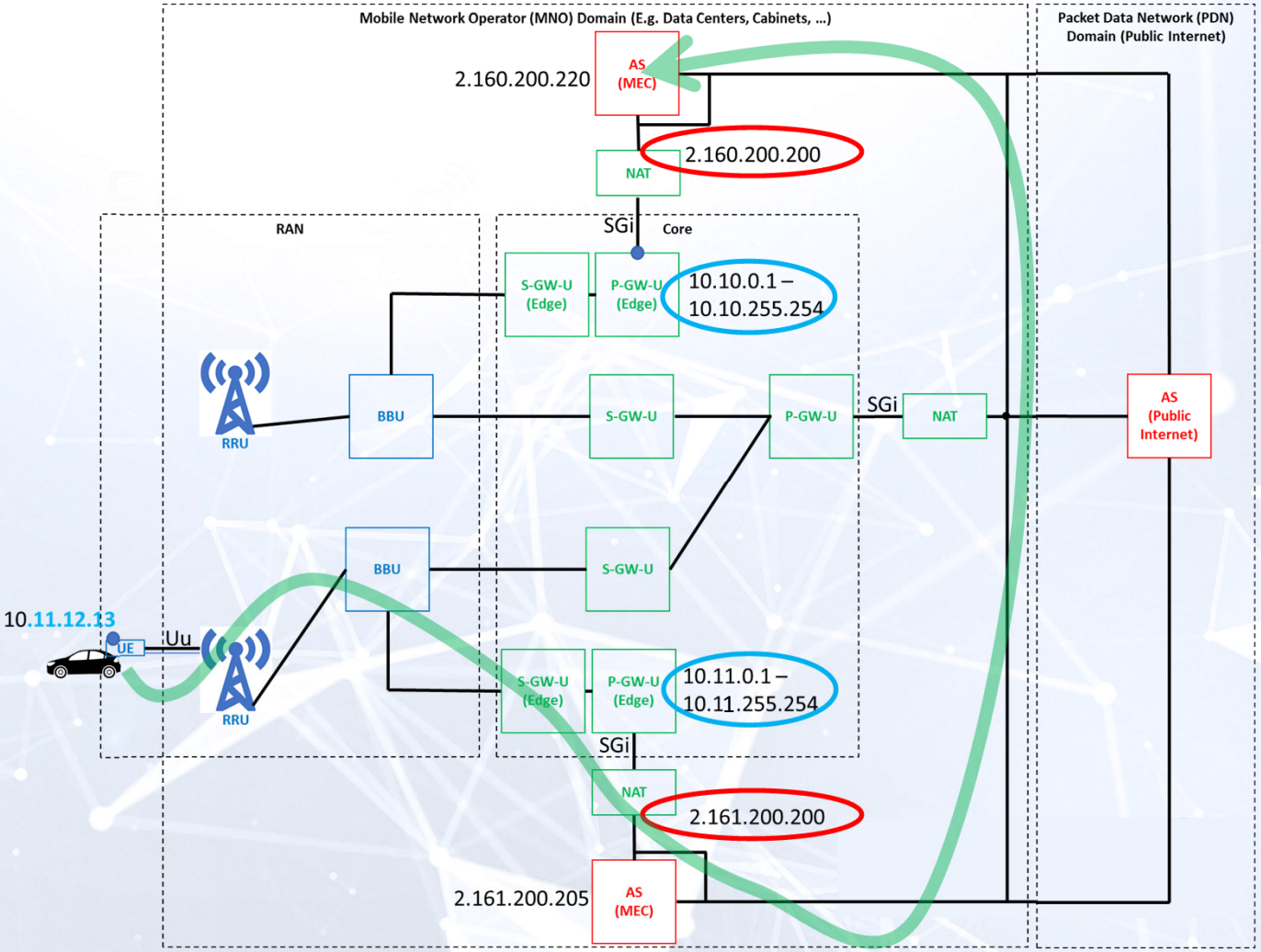
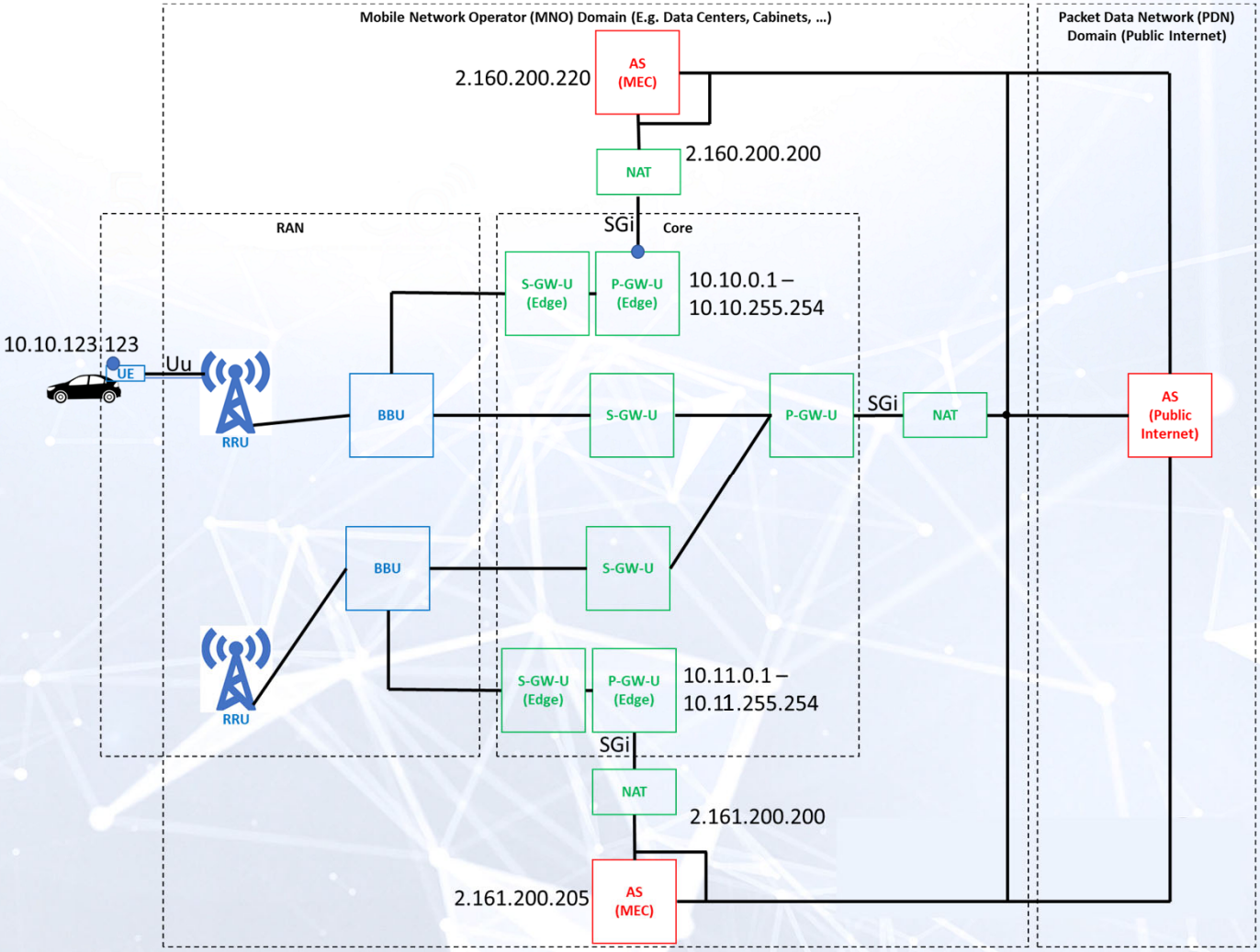


Service Continuity: Discovering and Switching Servers

- AECC describes lookup tables, IP Anycast and DNS as solutions
- Anycast not preferred as it requires network support
- Lookup table in vehicle hard to keep up to date
- DNS-based solutions:
  - Source-IP based with
  - Network information based
  - Who operates the DNS servers?



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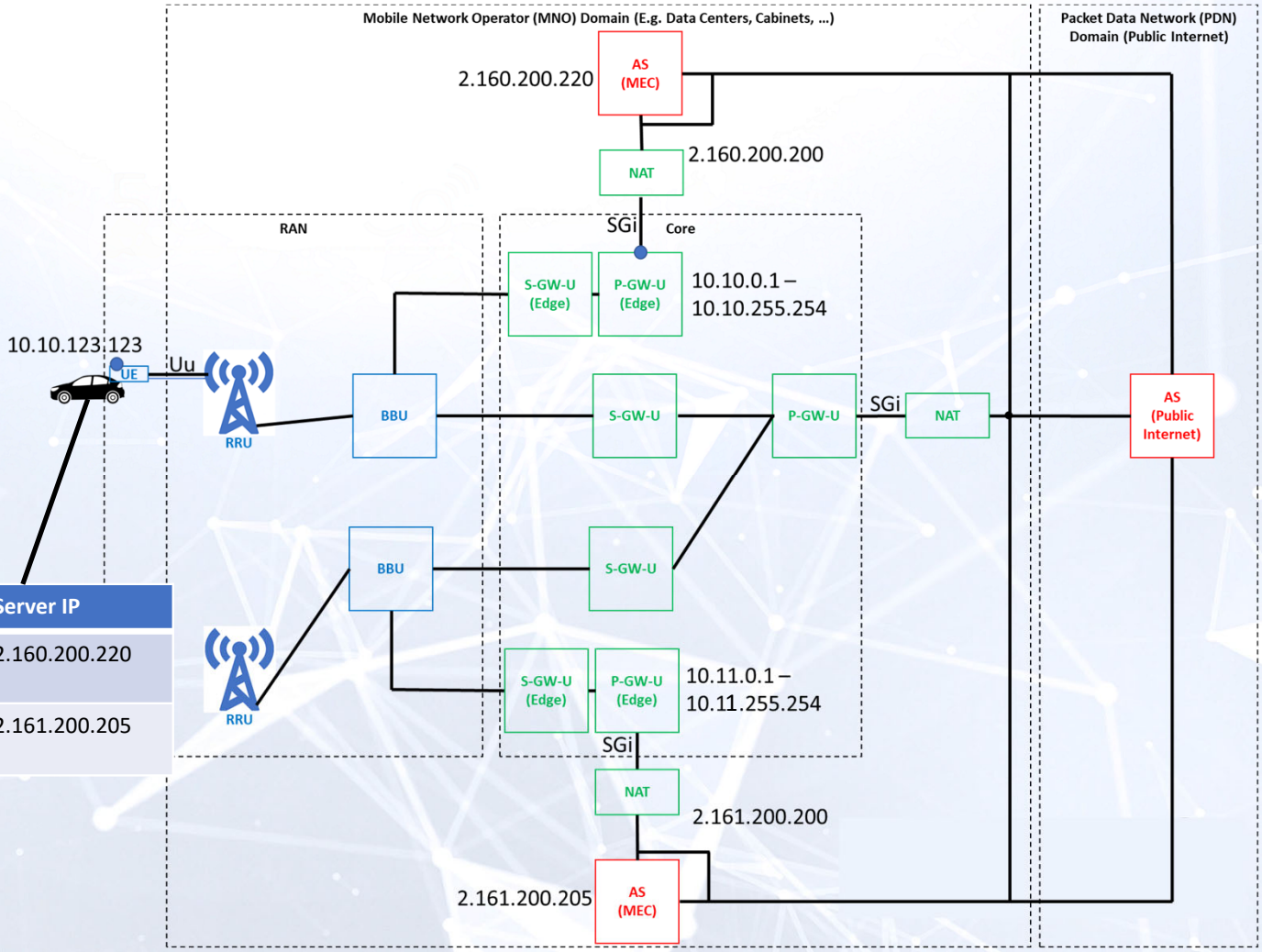
Area	Server IP
[x1, y1, x2, y2]	2.160.200.220
[x3, y3, x4, y4]	2.161.200.205



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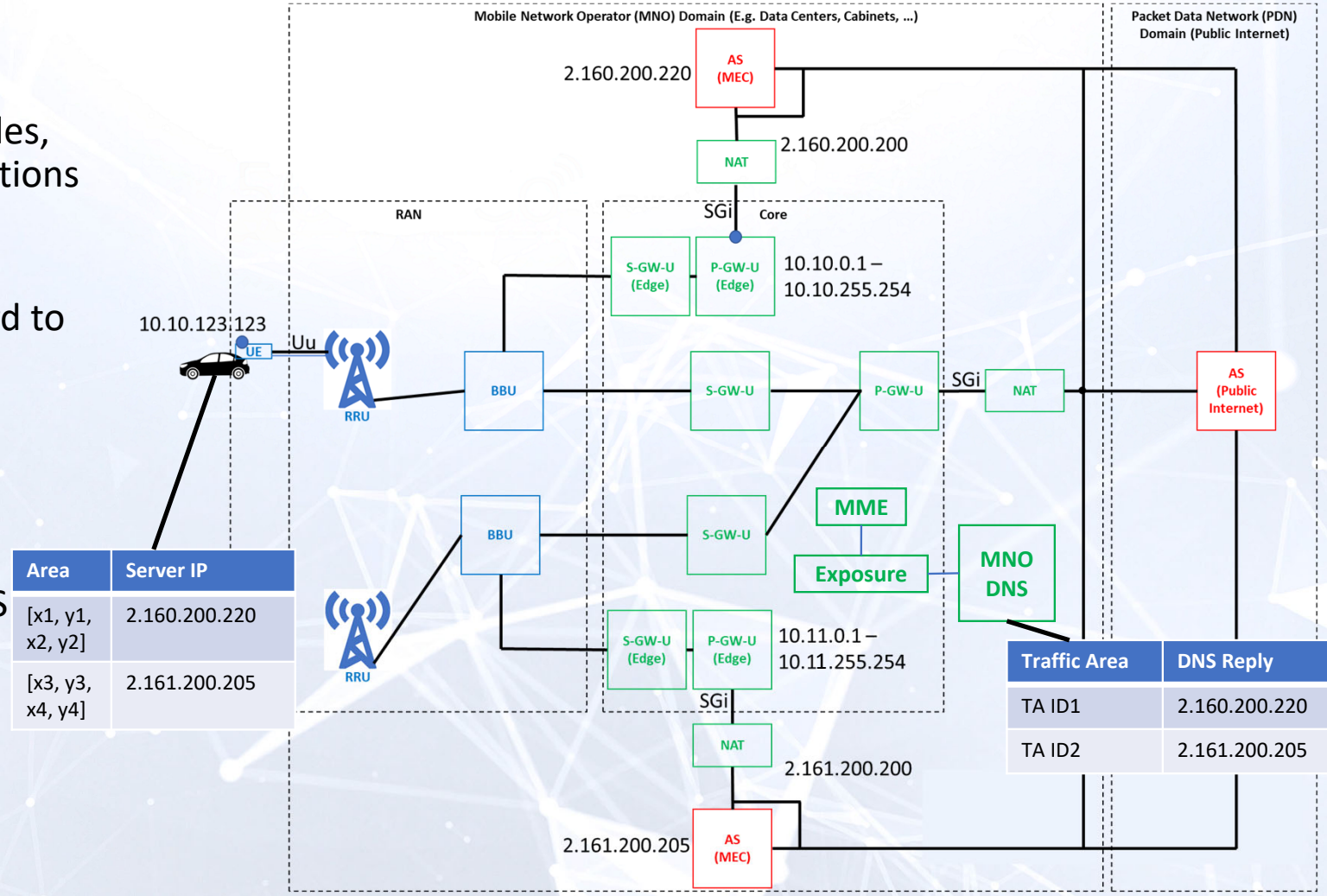

Area	Server IP
[x1, y1, x2, y2]	2.160.200.220
[x3, y3, x4, y4]	2.161.200.205

Traffic Area	DNS Reply
TA ID1	2.160.200.220
TA ID2	2.161.200.205

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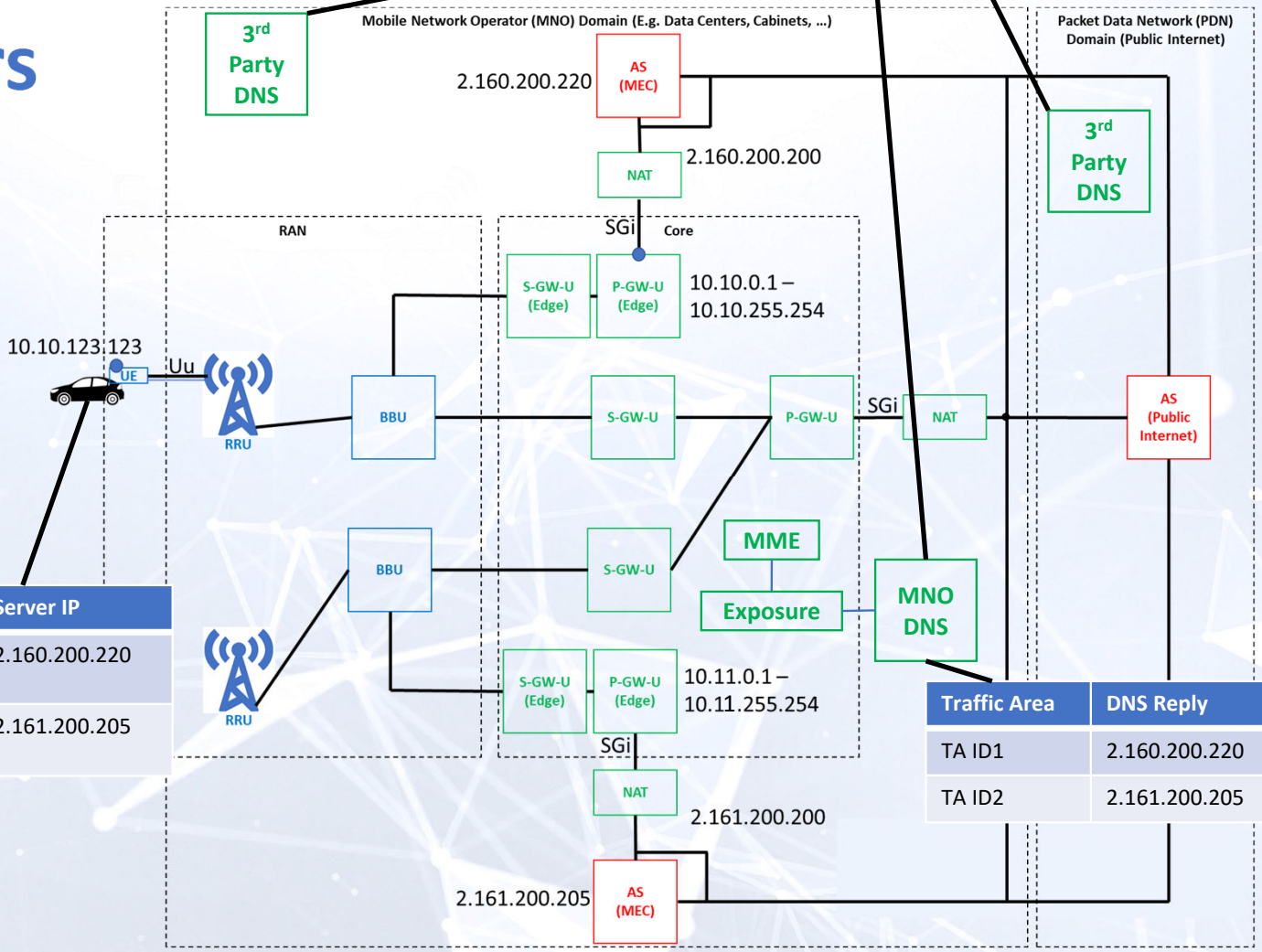
Source IP	DNS Reply
2.**160**.200.200	2.160.200.220
2.**161**.200.200	2.161.200.205



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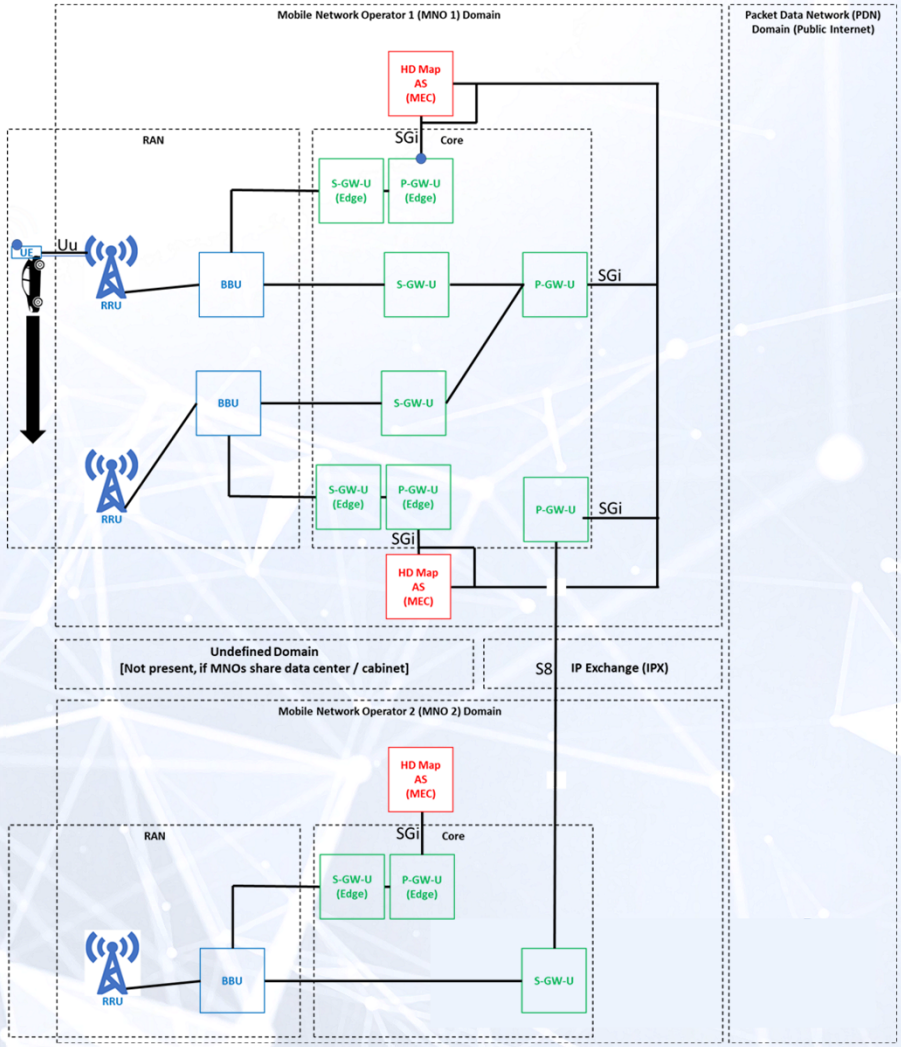
[x3, y3, x4, y4]	2.161.200.205

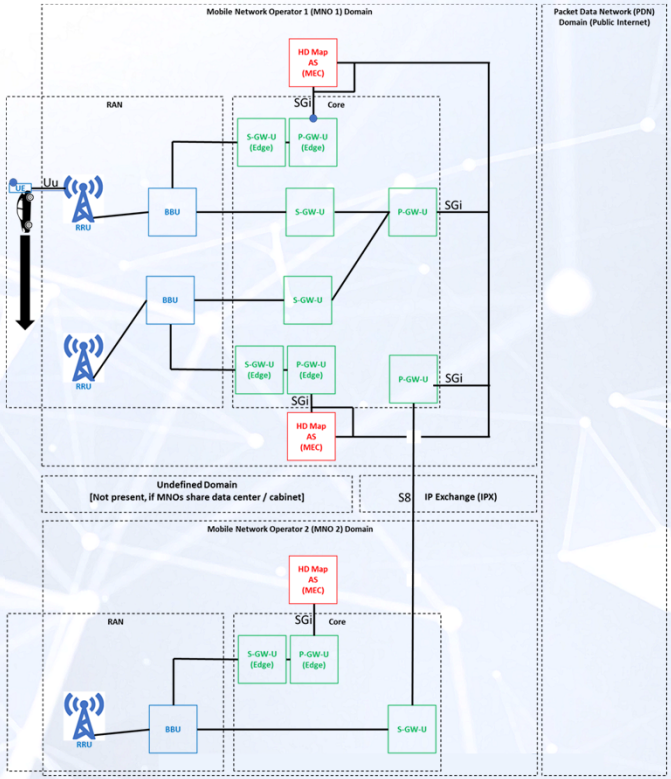
Traffic Area	DNS Reply
TA ID1	2.160.200.220
TA ID2	2.161.200.205

Use case Examples: Triggers for Switching & Dealing with Outage

Step	Event	Example Triggers	Application Server		Gateway	
			Old	New	Old	New
0	Precondition		X		X	
1	Optional: Contact new server before gateway/server switching	To be determined if possible	X	X	X	
2	Disconnect from old gateway (SSC mode 1 and 2 only)	CCU trigger (SSC mode 1); MME/SMF trigger (SSC mode 2)				
3	Connect to new gateway	CCU trigger (SSC mode 1); MME/SMF trigger (SSC mode 2 and 3)	X	X	X	X
4	Use new application server	Detecting that a new gateway is being used	X	X	X	X
5,6	Stop using old application server	To be determined; if Step “6,5” is done first, it can serve as (part of the) trigger		X	X	X
6,5	Disconnect from old gateway (SSC mode 3 only)	To be determined		X		X

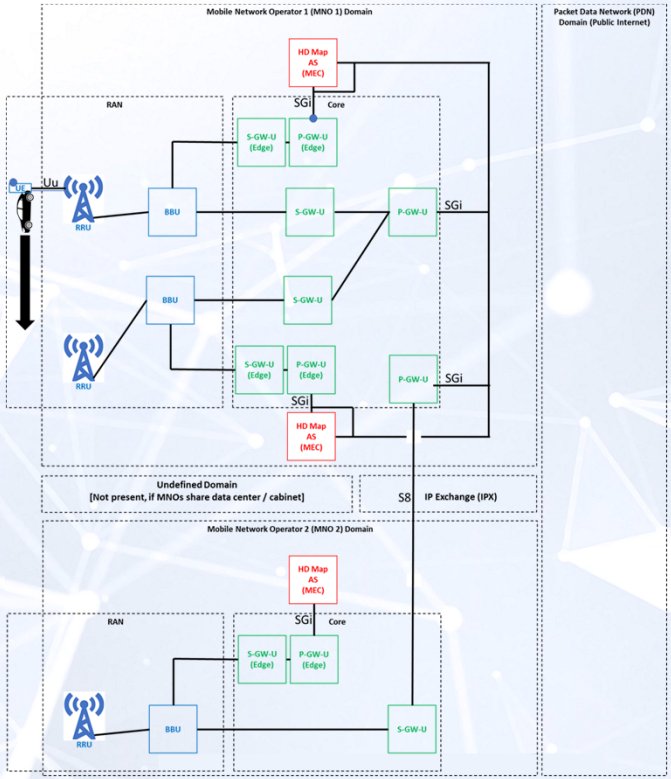


Use case Examples: Triggers for Switching & Dealing with Outage - HD Mapping SSC Mode 1



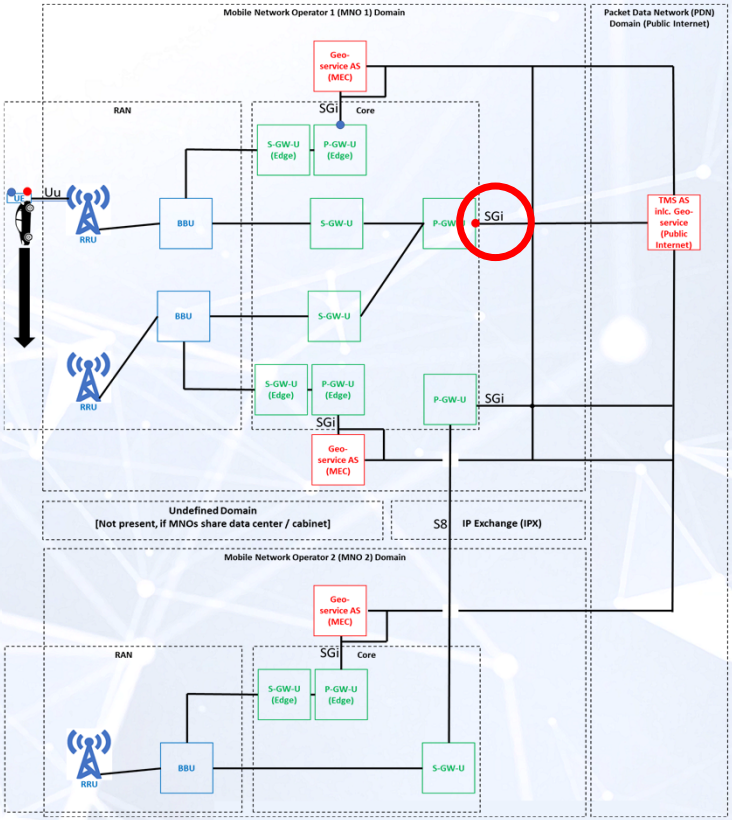
Use case Examples: Triggers for Switching & Dealing with Outage - HD Mapping SSC Mode 1

Step	Event	Trigger	Application Server			Gateway		
			MNO 1		MNO 2	MNO 1		MNO 2
			Upper	Lower		Upper	Lower	
0	Precondition		X			X		
1	Disconnect from MNO 1 upper gateway	Change of Tracking Area (vehicle triggered / SSC mode 1); wait for pending transmissions to finish and do not start new ones						
2	Connect to MNO 1 lower gateway	Disconnect completed (see row above)					X	
3	Connect to HD map application server (IP address discovered through DNS request)	Connect completed (see row above)		X			X	
4	Request pending User Story 3 downloads	Connected to HD map application server (see row above)		X			X	
Intra-MNO gateway and application server switching complete								
5-8	Same as for intra-MNO; instead of Tracking Area change, also Mobile Network Code change can be used as trigger				X			X
Cross-border / -MNO gateway and application server switching complete								



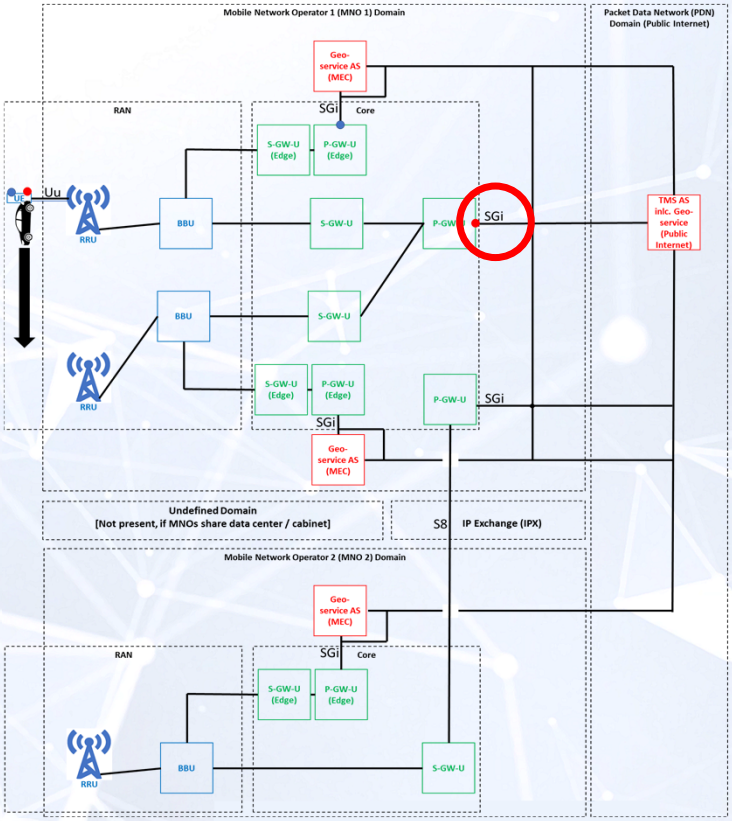
Use case Examples: Triggers for Switching & Dealing with Outage - ACCA SSC Mode 1 or 2

ANTICIPATED COOPERATIVE COLLISION AVOIDANCE (ACCA)



Use case Examples: Triggers for Switching & Dealing with Outage - ACCA SSC Mode 1 or 2

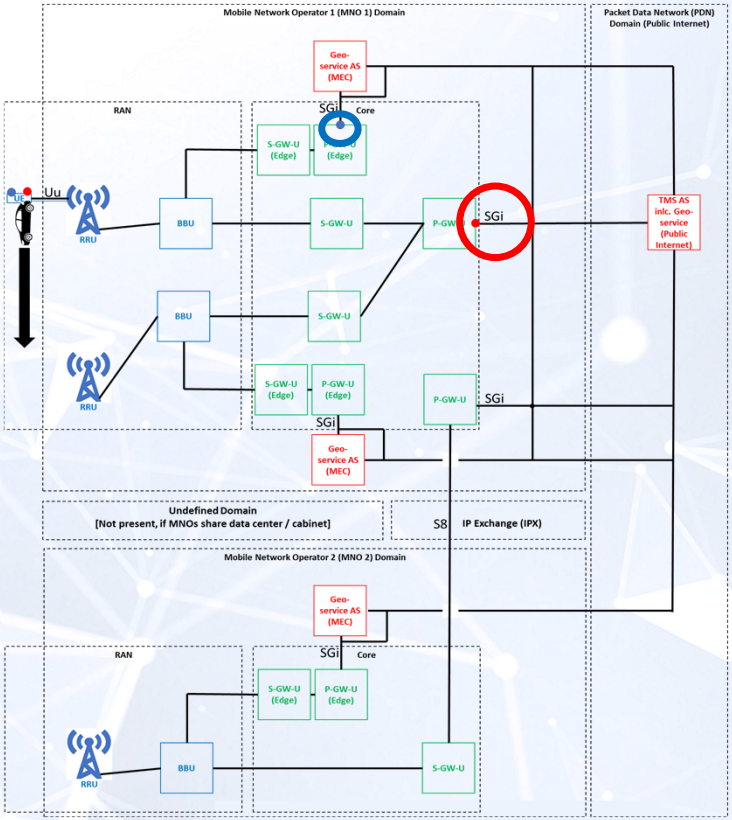
Step	Event	Trigger	Application Server			Gateway		
			MNO 1		MNO 2	MNO 1		MNO 2
			Upper	Lower		Upper	Lower	
0	Precondition		X			X		
1	Disconnect from MNO 1 upper gateway	Change of Tracking Area detected in CCU (vehicle triggered / SSC mode 1) or trigger from network (SIPTO above RAN / SSC mode 2)						
2	Connect to MNO 1 lower gateway	Disconnect completed (see row above)					X	
3	Connect to lower Geoservice (IP address discovered through DNS request)	Connect completed (see row above), to be further evaluated what triggers are possible with SIPTO above RAN / SSC mode 2		X			X	
Intra-MNO gateway and application server switching complete								
4-6	Same as for intra-MNO; instead of Tracking Area change, also Mobile Network Code change can be used as trigger; no need to change the gateway for public Internet access (keep Home Routed Roaming for public Internet access)				X			X
Cross-border / -MNO gateway and application server switching complete								



Use case Examples: Triggers for Switching & Dealing with Outage - Device-side Routing

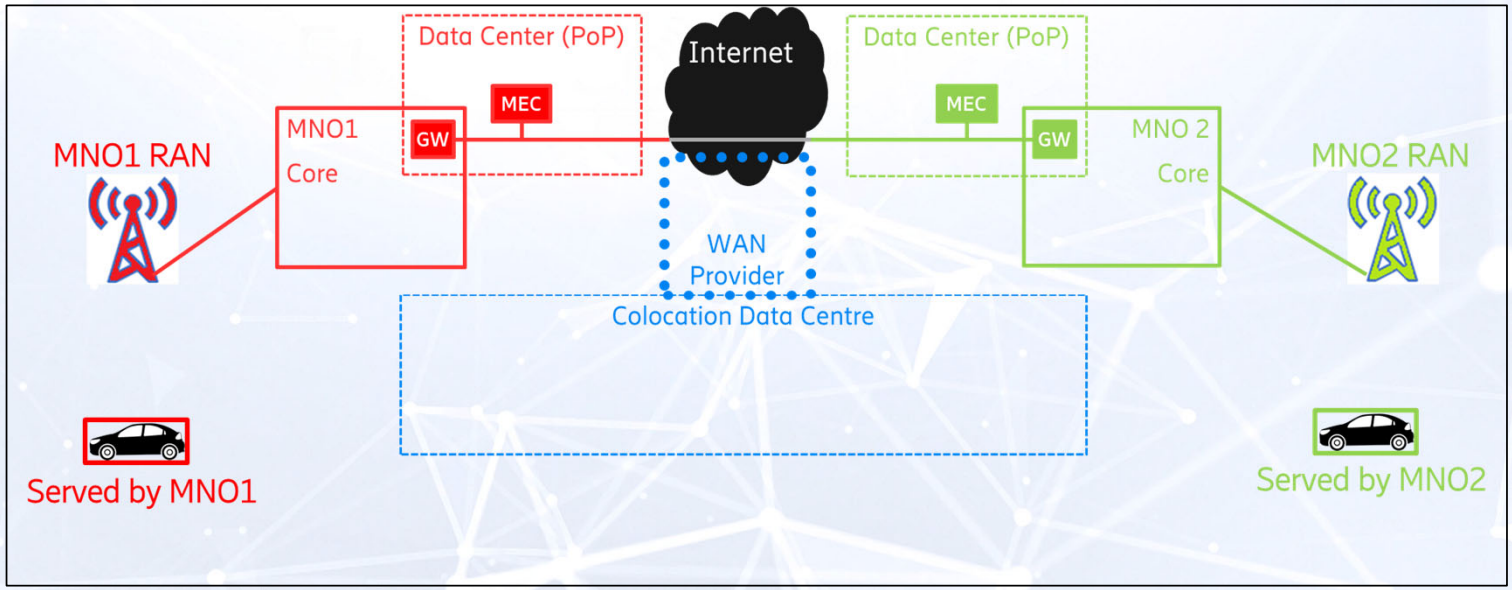
```
wwan0: flags=4305<UP,POINTOPOINT,RUNNING,NOARP,MULTICA
        inet 192.168.193.18  netmask 255.255.255.252
        inet6 fe80::d0e:ce8a:9601:a00b  prefixlen 64
        unspec 00-00-00-00-00-00-00-00-00-00-00-00-00-
        RX packets 2  bytes 612 (612.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 6  bytes 848 (848.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0

wwp0s20f0u6i10: flags=4305<UP,POINTOPOINT,RUNNING,NOAR
        inet 192.168.193.2  netmask 255.255.255.
        inet6 fe80::a2e:b89b:e4d8:e616  prefi
        unspec 00-00-00-00-00-00-00-00-
        RX packets 2  bytes 612 (612
        RX errors 0  dropped 0  ove  rame 0
        TX packets 6  bytes 848 (84
        TX errors 0  dropped 0 overruns 0  carrier 0
```

UE Route Selection Policies (URSP)?



Controlled End-to-End QoS Across Multiple MNOs

- MEC simplifies providing bounded latencies within one MNO
  - **Only if transport network for Core is "controlled", not "best effort"**
- It cannot be assumed that all vehicles are served by same MNO
- Connecting MNOs over the public Internet will not result in controlled QoS
- Solution co-created with data center provider Equinix
- Also published in [5GAA MEC whitepaper]



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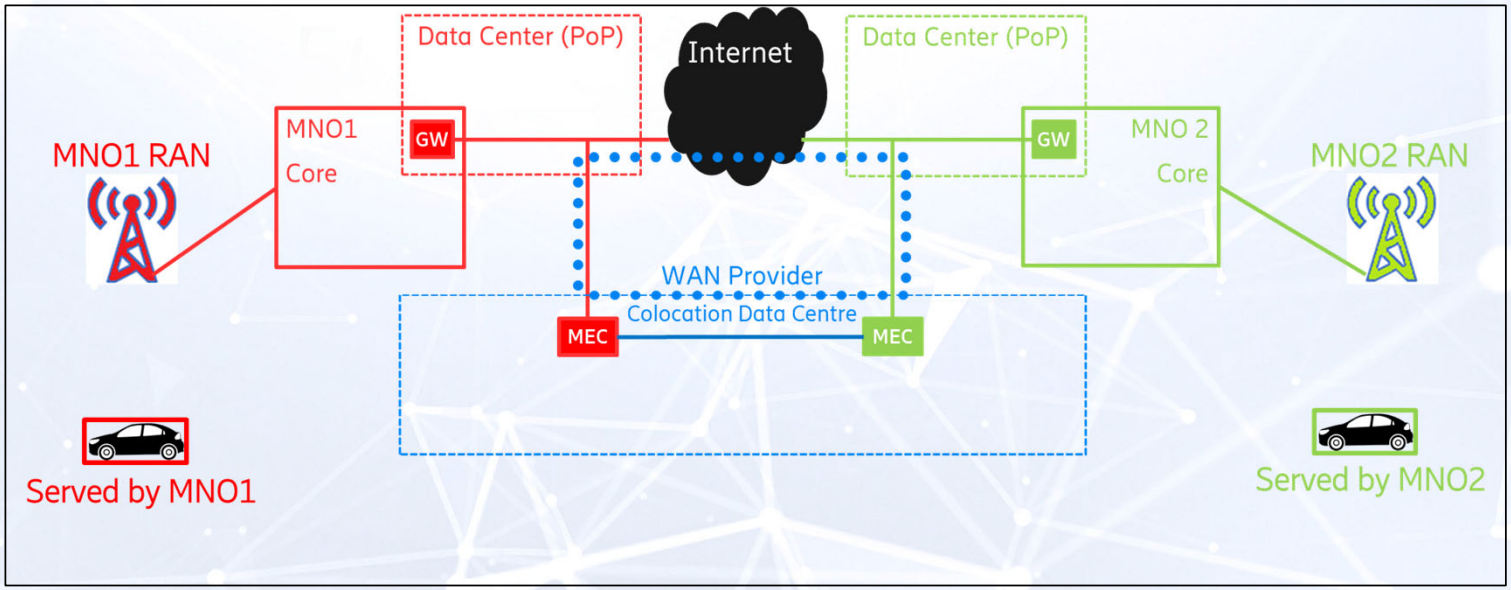
Controlled End-to-End QoS Across Multiple MNOs

- Solution 1: Move MEC hosts from MNO to collocation data centers (DCs) (aka “shared DCs”)
- Obtain controlled links from MNO to collocation DCs
- Within DC high-performance networks will not be a bottleneck
- Some MNOs are also WAN and/or DC provider



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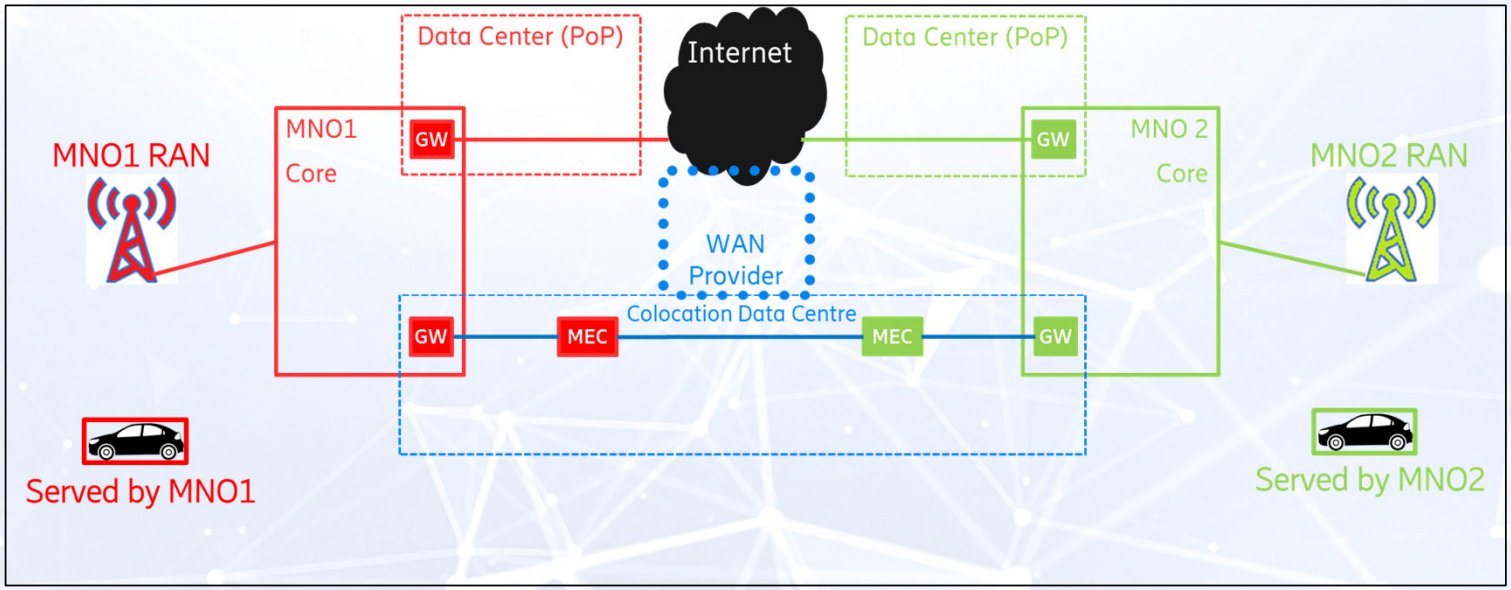
Controlled End-to-End QoS Across Multiple MNOs

- Solution 2: Move MEC hosts and gateways from MNO to collocation DCs
- Assure transport connecting Core nodes also covers the DCs (technically likely the same as for Solution 1)
- Within DC, high-performance networks will not be a bottleneck
- Some MNOs are also WAN and/or DC provider



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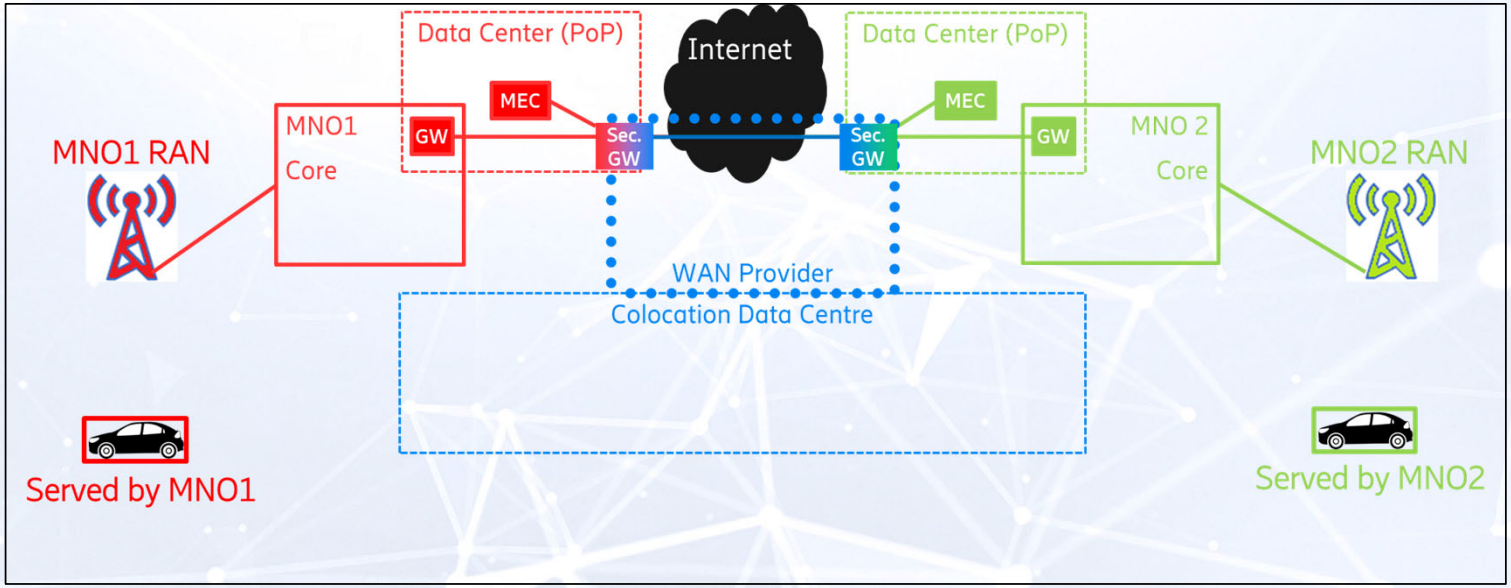
Controlled End-to-End QoS Across Multiple MNOs

- Solution 3: Controlled connection between MNOs
- Security is always an issue but here it is pointed out that MEC hosts usually do not have public IP addresses
- Some MNOs are also WAN and/or DC provider
- Sec. gateways: MEC-hosts usually do not have public IP addresses
  - Also for Sol. 1 & 2, but emphasized here



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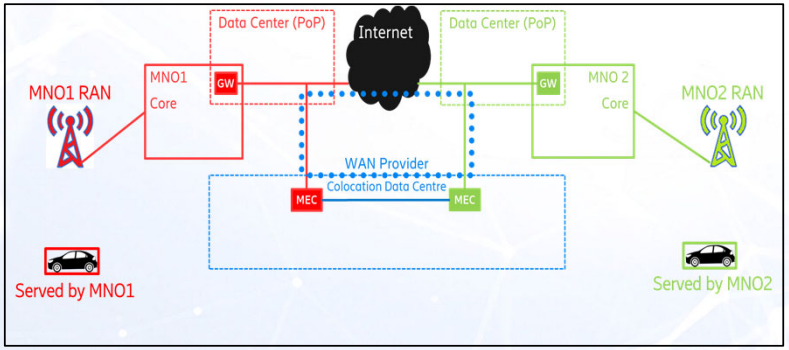
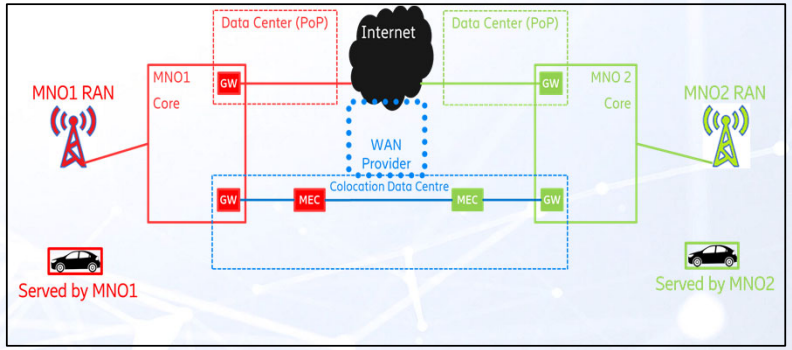
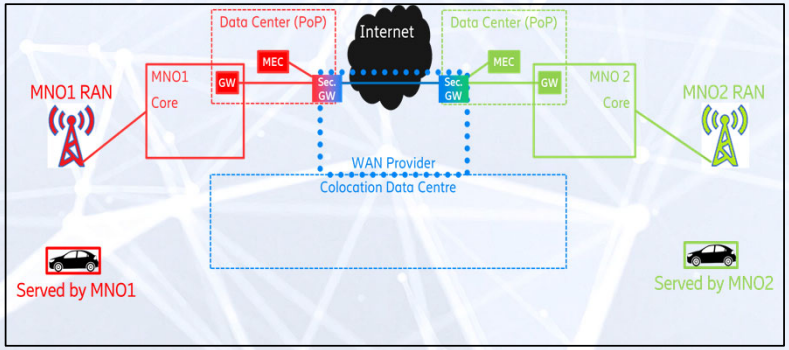
Controlled End-to-End QoS Across Multiple MNOs

- **Some MNOs are also WAN and/or DC provider**
- Technically, the solutions are equal
- Selecting one depends on
  - If MNOs are also in the WAN / DC business
  - Costs WAN / DC providers ask for their service
- **It is an economic / organizational decision**







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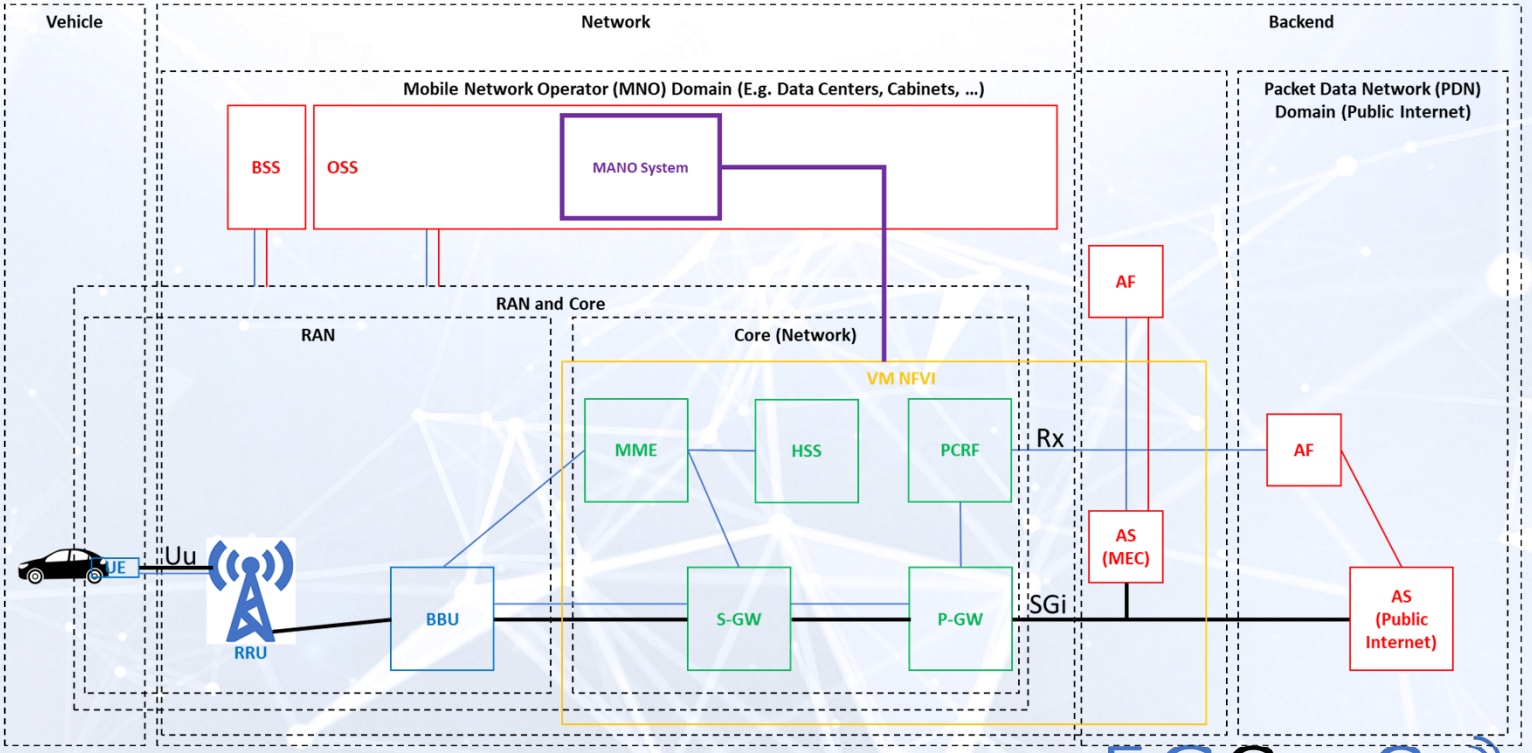
Joined Management and Orchestration of VNFs and MEC-hosted Application Servers

- Current deployments usually use full virtualization for Network Functions (NFs) forming the Core
  - E.g. OpenStack or VMWare
- It appeared logical to use the same for MEC-hosted ASs



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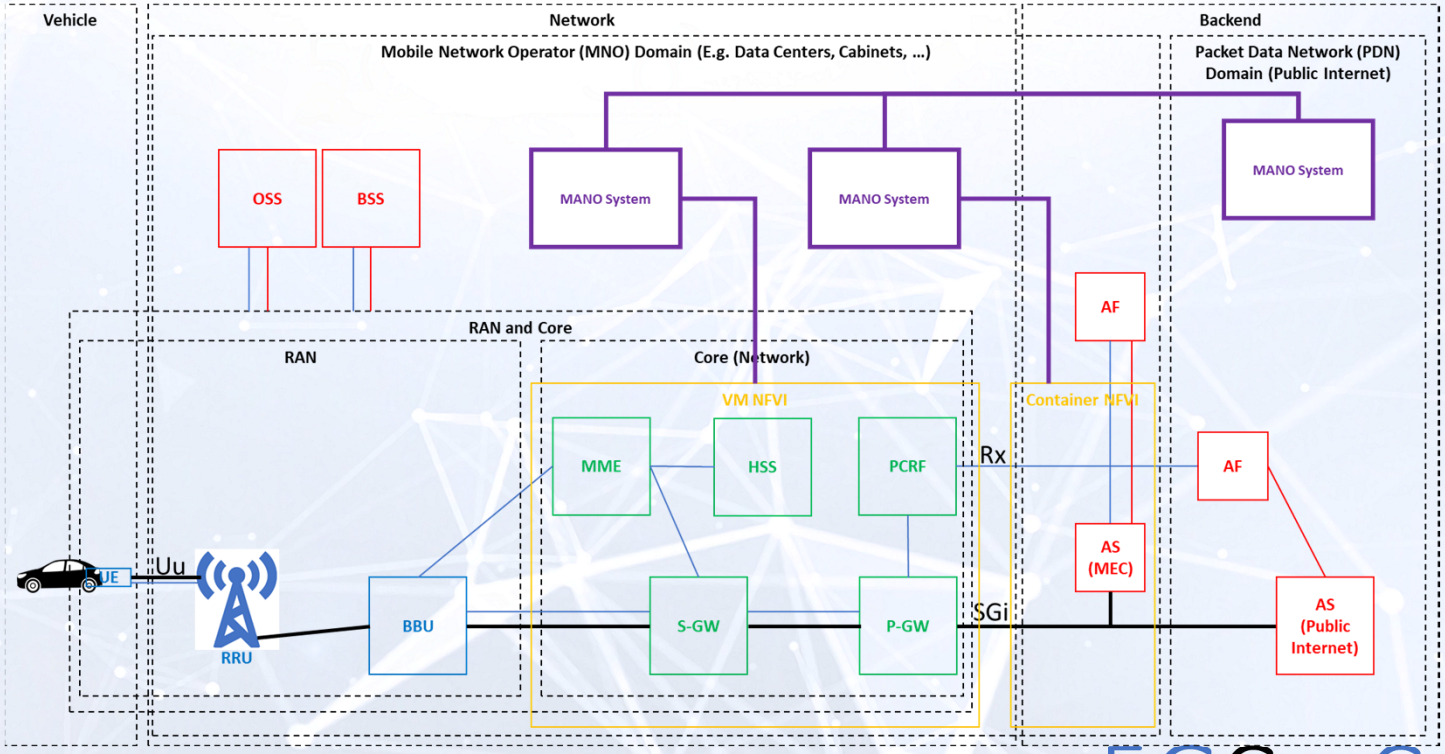
Joined Management and Orchestration of VNFs and MEC-hosted Application Servers

- Hyperscale Cloud Providers (HCPs) (e.g. AWS, MS Azure, Google) use Containerizes ASs
- They are now partnering with MNOs to also deploy to MEC hosts
- MNOs might still be using VM-based NF deployment



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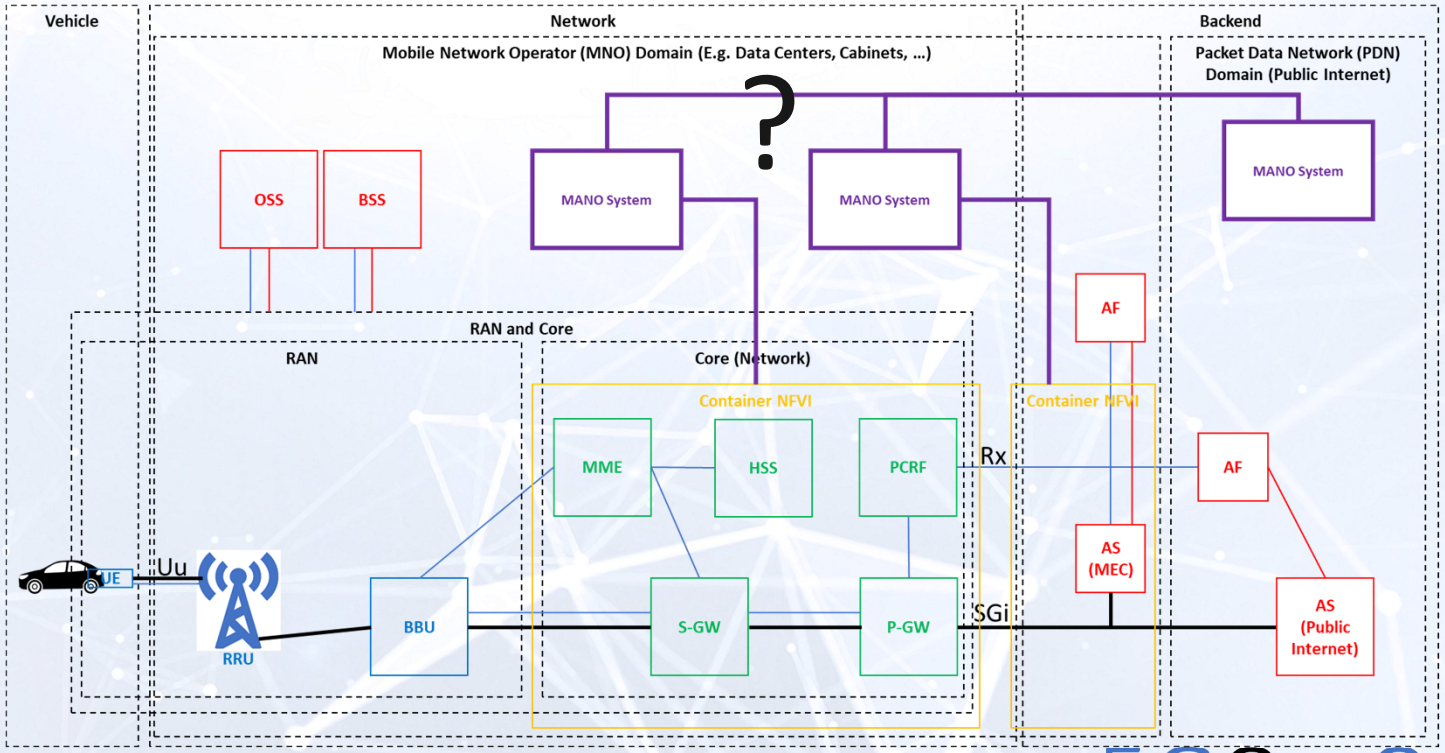
Joined Management and Orchestration of VNFs and MEC-hosted Application Servers

- Hyperscale Cloud Providers (HCPs) (e.g. AWS, MS Azure, Google) use Containerizes ASs
- Mobile network vendors are also taking this path
  ➔ **Cloud Native**
- How to coordinate the MANO systems
  - “Meta-MANO”?
  - Master-slave?
  - …
- Different HCPs have different MANO interfaces



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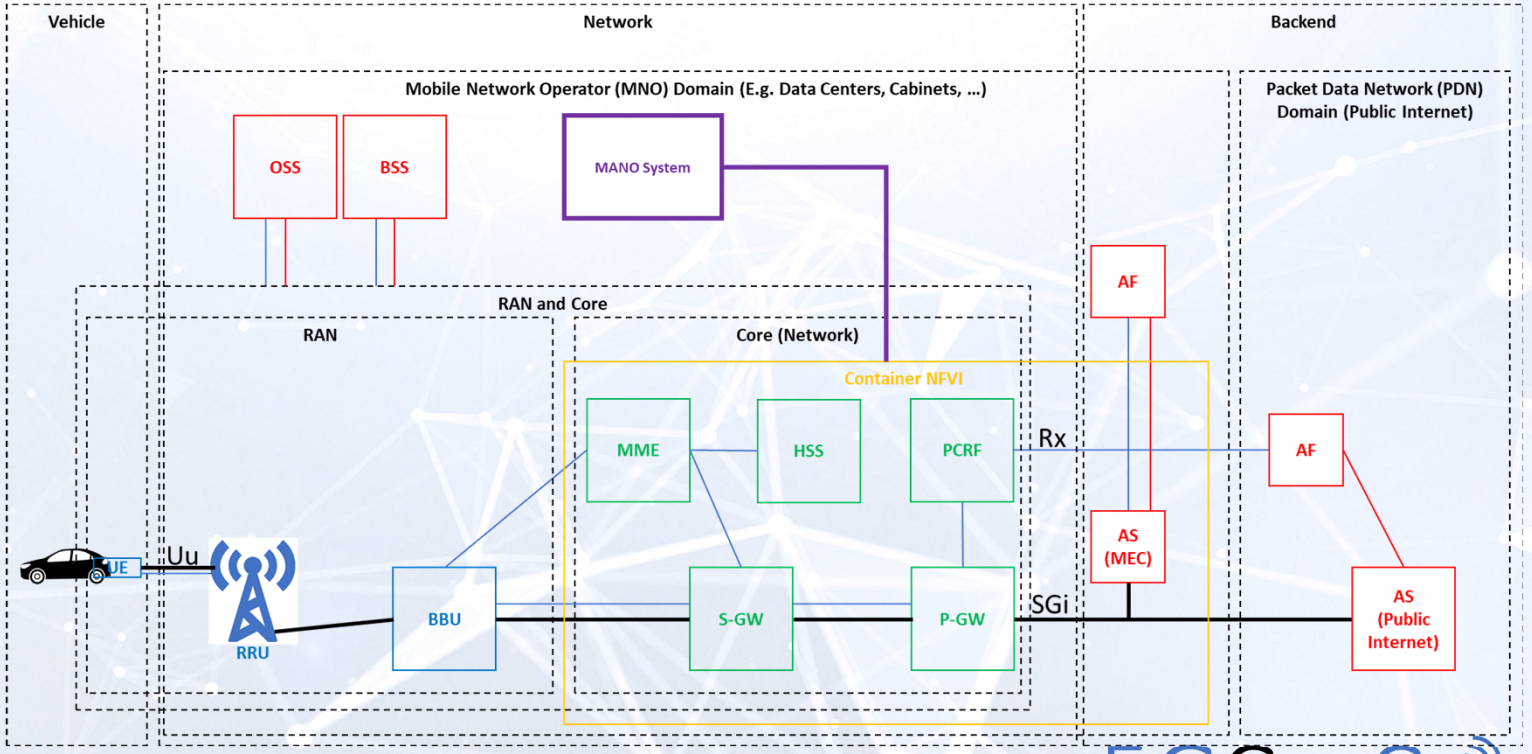
Joined Management and Orchestration of VNFs and MEC-hosted Application Servers

- Hyperscale Cloud Providers (HCPs) (e.g. AWS, MS Azure, Google) use Containerizes ASs
- Mobile network vendors are also taking this path
  ➔ **Cloud Native**
- Who provides the MANO system?



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Joined Management and Orchestration of VNFs and MEC-hosted Application Servers

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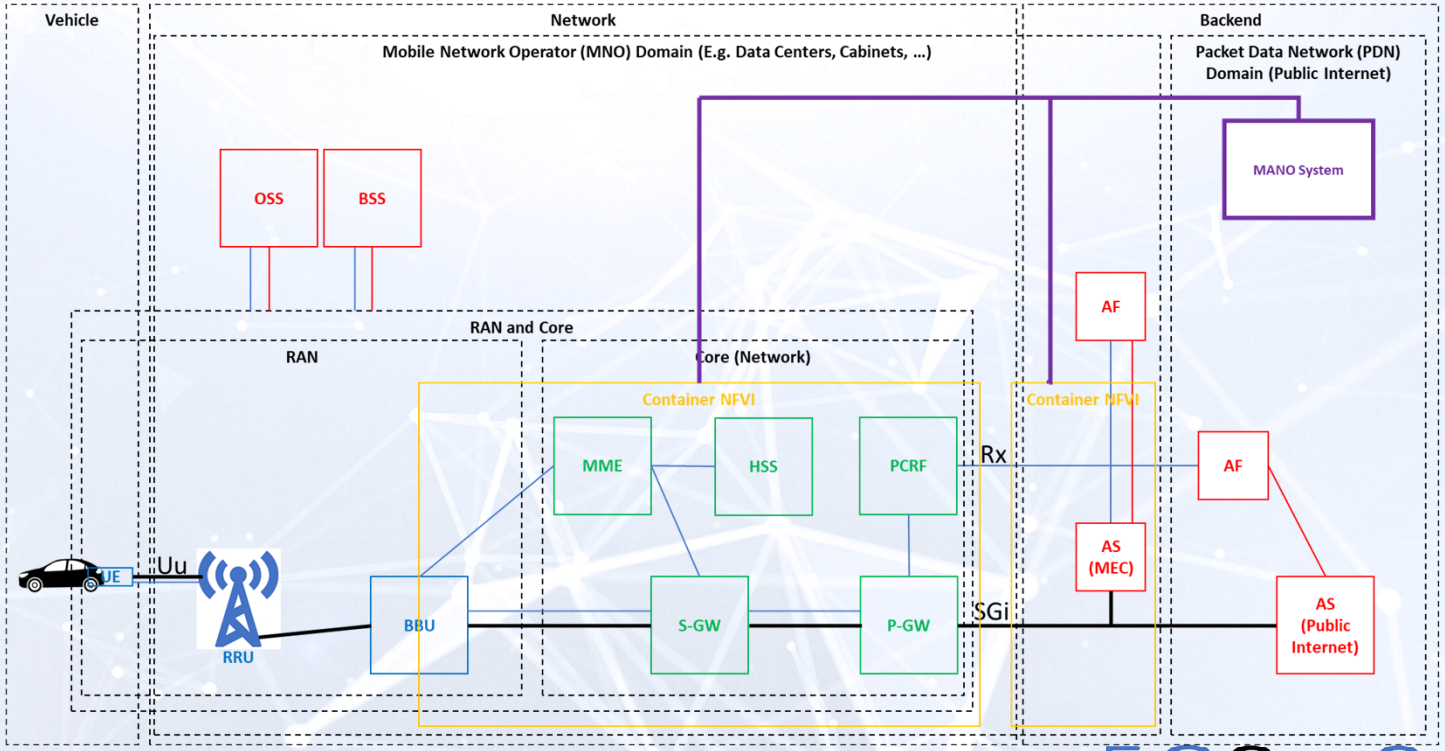

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Joined Management and Orchestration of VNFs and MEC-hosted Application Servers

- A transition from full VMs to Container-based (Cloud-native) deployment is taking place
- Using same virtualization technique does not imply using same MANO
  - Esp. applies for (Graphical) User Interface ((G)UI)
- It is for now open how different MANO systems can cooperate in context of MEC

Scenario	VNF MANO	MEC-hosted Application Server MANO
VM-based for VNFs and application servers	VM-based (e.g. OpenStack-based)	Same as for VNFs (VM-based)
VM-based for VNFs, Container-based for application servers	VM-based (e.g. OpenStack-based)	Container-based (usually Kubernetes-based)
Container-based for VNFs and application servers, separate MANO systems of same kind	Container-based (usually Kubernetes-based)	Container-based (usually Kubernetes-based)
Container-based for VNFs and application servers, common MANO system	Container-based (usually Kubernetes-based)	Same as for VNFs (Container-based)

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Open Tasks for Deliverable D3.3

- Tie all loose ends to obtain:
  - Solutions fitting all use cases (even more than the 3 5GCroCo ones)
  - An evolutionary path
    - Starting with non-standalone 5G New Radio (and 4G where yet no 5G coverage)
    - Leading to standalone 5G New Radio with SSC mode 3
- Device-side routing and reactions to “triggers”
  - Esp. UE Route Selection Policies (URSP)?
- Better point out differences / benefits of IPv6
- Realistic topologies:
  - Draft “reference” topologies for different “MNO classes” and ask MNOs if they confirm and/or how to adjust
- Capture evolution of MNO/Hyperscale Cloud Provider cooperation

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Completed and Planned Trials

Done (Round 1, HD Mapping & ACCA):

- MEC vs. public Internet performance:
  - **15% faster download of** 6.7 MByte tiles for HD Mapping
  - **5 ms shorter App. Level Latency** compared to server in Frankfurt (AWS) for ACCA

Planned (Round 2, all ACCA, selected vehicles/modems):

- MEC-to-MEC information exchange (already used in Montlhery)
- Break-before-make (SSC mode 1) gateway switching
- Make-before-break (SSC mode 3) gateway switching (emulated)
- DNS-based server discovery & switching

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Summary & Conclusion

- MEC consists of the two major challenges
  - Gateway switching (session continuity)
  - Server switching (service continuity)
- The first is covered by 3GPP SSC modes 1-3
  - Some open questions regarding SSC mode 3 in single- and multi-MNO scenario
- Many open questions on the device side (expected to clarify in 2021) prevented to have a final architecture
- Solutions are very use-case-dependent why we would like to have a general proposal:
  - Consider use case classes / communication patterns, e.g.
    - Request/reply
    - Publish/subscribe (message broker)

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Thanks!!
5GCroCo
www.5gcroco.eu
Maciej Muehleisen
Ericsson (ERI)
maciej.muehleisen@ericsson.com
To know more:
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