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5G BLUEPRINT

Next generation connectivity for enhanced, safe & efficient transport & logistics

D5.1: 5G Network Requirements and Architecture

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Abstract

One of the aims of 5G Blueprint project is to enable teleoperation and seamless cross border use with 5G technology. The use cases to demonstrate this capability are automated barge control, automated drive-in-loop docking, CACC based platooning, remote take-over operations. In this deliverable, the basic network requirements of the selected use cases and related enabling functions are first analysed. The results are then used to identify 5G network features and requirements. Finally an end-to-end 5G architecture (with a focus on network slicing and seamless cross boarder roaming) for the trial network is designed, based on the most recent standardization work and implementation tools, from user equipment, radio, transport, core network to exposed network APIs. This work will be used as guideline for further network deployment and feature implementation in test labs and project pilot area.

Keywords: seamless cross border teleoperation; 5G; network slicing.

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CI	Classified, information as referred to in Commission Decision 2001/844/EC	☐
CO	Confidential to 5G-Blueprint project and Commission Services	☐

* R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

Being the next generation of cellular network technology, 5G is considered as the mobile system that meets the stringent requirements of enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), massive Machine Type Communications (mMTC). These characteristics, together with 3GPP C-V2X (sidelink), could make 5G technology a game changer for teleoperation, CACC platooning and related enabling functions. In this deliverable, the selected piloting use cases (automated drive-in-loop docking, CACC based platooning, remote take-over operations) and enabling functions (enhance awareness dashboard, vulnerable road user warnings, slot reservation, distributed perception, active collision avoidance, container ID recognition, ETA sharing, scene analytics) are analysed to assess required properties of the 5G network architectural components and thus define the network architecture of 5G Blueprint.
In a large scale 5G deployment, the 5G network still faces challenges from cross border coverage and cross MNO service continuity. Thus the research and design of the 5G architecture focus on both end-to-end service guarantee with network slicing, and cross border roaming with two operator networks.

This deliverable is performed with three steps. First step is to perform a functional analysis of uses cases, enabling functions and corresponding application requirements. The result is presented as connectivity requirements of 5G network. At second step, a study of lasted standardization work is done to identify the features and tools to suit the connectivity requirements. At last step, an end-to-end design of 5G network architecture is done. The final result will be used as guide line for further lab and pilot area network deployment and feature implementation.

The result shows that the selected use cases and enabling functions have very specific and high requirements on latency, bandwidth, reliability and service continuity of 5G network. Simplified as three main challenges, uplink bandwidth requirement of uploading raw video or lidar data from a mobile unit to cloud servers, ecosystem readiness and the critical end-to-end service stability of URLLC & V2V services, and complexity of large-scale deployment of seamless cross border roaming features. These challenges can be partially solved by the design in this work (such as optimization of radio resource for uplink with limited bandwidth), or by coordinating with use cases and enabling functions (such as adaptively change video quality based on teleoperator's behaviour and scheduling of raw/compressed data upload circles based on movement). Some challenges require continuous further work with ecosystem partners on testing & validating the lasted equipment and features, also governance and data exchange between of cross boarder network providers.

A WORD ON THE ARCHITECTURAL DRAWINGS

The requirements to the Fifth Generation (5G) mobile network were described by the NGMN [1]. This successor of the 4G network was envisioned to maximally benefit from advancements in the IT industry. The two most influential of these advancements at that moment were Software Defined Networks (SDN) and Network Function Virtualization (NFV). The 5G standards written by the 3GPP are all assuming SDN and NFV. Therefore, almost all architectural components (the rectangular boxes) in a standardized 5G network are Virtual Machines performing a Network Function (possibly implemented in a software container or on bare metal). Each of these Network Functions is "horizontal scalable": its capacity can (within physical limits) be expanded or reduced according to momentary demand. Therefore, the reader should be aware that it is not possible to estimate the capacity of the network from these squares. They represent functions, not instances.

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ABBREVIATIONS

5GAA	5G Automotive Association
3GPP	3rd Generation Partnership Project
5GC	5G Core Network
5GS	5G System
ACA	Active Collision Avoidance
ACC	Adaptive Cruise Control
AEB	Advanced Emergency Breaking
AF	Application Function
AMF	Access and Mobility Management Function
ANPR	Automatic Number Plate Recognition
AUSF	Authentication Server Function
API	Application Programming Interface
APN	Access Point Name
BIC	Bureau of International Containers
BSS	Business Support Systems
CA	Certification Authority
CACC	Cooperative Adaptive Cruise Control
CN	Core Network
CP	Control Plane
CU	Central Unit
CUPS	Control Plane User Plane Separation
DDoS	Distributed Denial of Service
DEA	Diameter Edge Agent
DNN	Data Network Name
DNS	Domain Name System
DNSSEC	Domain Name System Security Extensions
DoS	Denial of Service
DRA	Diameter Routing Agent
DTI	Delta Time until Impact
DTP	Delta T Paths
EAD	Enhanced Awareness Dashboard
EBA	Emergency Breaking
EF	Enabling Function
EF1 EAD	Enabling Function 1: Enhanced Awareness Dashboard
EF2 VRU	Enabling Function 2: Vulnerable Road User
EF3 iTLC	Enabling Function 3: Time slot reservation at iTLC

EF4 DP	Enabling Function 4: Distributed Perception
EF5 ACA	Enabling Function 5: Active Collision Avoidance
EF6 CID	Enabling Function 6: Container ID Recognition
EF7 ETA	Enabling Function 7: ETA Sharing
EF8 SA	Enabling Function 8: Scene Analysis
ELKS	Emergency Lane Keeping System
eMBB	Enhanced Mobile Broadband
ENDC	Enhanced UTRAN New Radio Dual Connectivity
eLTE	Evolved LTE
EPC	Evolved Packet Core
EPS	Evolved Packet System (Core)
ETA	Estimated Time of Arrival
ETSI	European Telecommunications Standardisation Institute
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FCD	Floating Car Data
FOTA	Firmware over the Air
FQDN	Fully Qualified Domain Name
GFBR	Guaranteed Flow Bit Rate
GERAN	GSM/Edge Radio Access Network
GMLC	Gateway Mobile Location Center
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRX	Global Roaming Exchange
GTP	GPRS Tunnelling Protocol
HMI	Human Machine Interface
HMTC	High-Performance Machine-Type Communication (= mcMTC)
HPMN	Home Public Mobile Network
HR	Home Routed
HSS	Home Subscriber Server
HTTP	Hyper-Text Transfer Protocol
HUD	Heads-Up Display
IE	Information Element
IMEI	International Mobile Equipment Identifier
IMEISV	IMEI Software Version
IMSI	International Mobile Subscriber Identity
IKE	Internet Key Exchange
IP	Internet Protocol

IP-CAN	P Connectivity Access Network
IPUPS	Inter-PLMN User Plane Security
IPX	Internet packet Exchange
ISY	I Saw You (message)
iTLC	intelligent Traffic Light Controller
LA	Location Area
LBO	Local Break Out
LMF	Location Management Function (5G)
LTE	Long Term Evolution (Radio)
LiDAR	Light Detection and Ranging
MAP	Mobile Application Part (protocol)
MBR	Maximum Bit Rate
MME	Mobility Management Entity
mcMTC	Mission Critical Massive Machine Type Communication (= hMTC)
mMTC	Massive Machine Type Communication (= MIoT)
MIoT	Mobile Internet of Things (= mMTC)
MQTT	MQ Telemetry Transport ('MQ" is an old IBM product name)
NDW	National Dataportaal Wegverkeer
NE	Network Element
NEDC	New Radio Enhanced UTRAN Dual Connectivity
NEF	Network Exposure Function
NEST	Network Slice Type
NF	Network Function
NR	New Radio (5G)
NR CGI	New Radio (5G) Cell Global Identifier
NRDC	New Radio Dual Connectivity
NRF	Network Repository Function
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
OCS	Online Charging System
OSS	Operations Support Systems
OTA	Over the Air
PCF	Policy Control Function
PDR	Packet Detection Rule
PDU	Protocol Data Unit
PEI	Permanent Equipment Identifier
PFCP	Packet Forwarding Control Protocol
PGW	PDN (Packet Data Network) Gateway

PKI	Public Key Infrastructure
PLMN	Public Land Mobile Network
PMIP	Proxy Mobile IP
P-NEST	Private Network Slice Type
PRD	Permanent Reference Document
QCI	QoS Class Identifier
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
REST	Representational State Transfer
RfR	Ready for Review
RTK	Real Time Kinematics
RU	Remote Unit
SA NR	Standalone New Radio
SBA	Service Based Architecture
SBI	Service Based Interface (5G)
SCEF	Service Capability Exposure Function (4G)
SEPP	Security Edge Protection Proxy
SGD	Safety Gateway Device
SGW	Serving Gateway
S-NEST	Standardized Network Slice Type
SMF	Session Management Function
S-NSSAI	Single Network Slice Selection Assistance Information
SETI	Safety-Related Traffic Information
SUCI	Subscription Concealed Identifier
SUPI	Subscriber Permanent Identifier
TA	Tracking Area
TAS	Truck Assignment System
TAU	Tracking Area Update
TCP	Transmission Control Protocol
TOV	Tele Operated Vehicle
TLC	Traffic Light Controller
TLS	Transport Layer Security
UDM	Unified Data Management
UDP	User Datagram Protocol
UDR	Unified Data Repository
UE	User Equipment
UP	User Plane

UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Communication
USIM	Universal Subscriber Identity Module
V2I	Vehicle to Infrastructure
V2X	Vehicle to everything
VPN	Virtual Private Network
VPMN	Visited Public Mobile Network
VRU	Vulnerable Road User
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing
WGS 84	World Geodetic System 1984
WP	Work Package
XCAP	XML Configuration Access Protocol
XML	eXtensible Markup Language
YAML	‘YAML Ain’t Markup Language’

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1 INTRODUCTION

One of the aims of 5G Blueprint project is to enable teleoperation and seamless cross border use cases with 5G technology. 5G is the future mobile system that makes a significant improvement over 4G for industrial use cases. By providing Enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC), the architectural design of 5G network is key to the success of the project. Thus, as the first deliverable of R&D on the 5G network for the project, this document aims to provide end-to-end 5G architecture design that can be used as guidelines for further network deployment, feature implementation, testing & validation in lab and pilot area.

The architecture design covers from 5G User Equipment, Radio Access Network, Edge Computing, Transport, Core Network, to network APIs. The design has a focus on addressing network slicing parameters and design for the project use cases and seamless cross bordering roaming. The project addresses two main challenges: a) to provide guaranteed services, which differentiate from legacy (LTE) mobile network; b) to overcome service discontinuity caused by insufficient coverage and handover mechanisms in current network. The design not only provide best practise solution based on current situation, but also direction of research and improvement for future large scale deployment.

This deliverable is the first step in a multi-step empirical process. First perform a functional analysis of project uses cases, use case enabling functions and application requirements. The result is considered as basic connectivity requirements of 5G network. Then a study of relevant standardization work is done to identify the features and tools to support the connectivity requirements or address directions of further investigation during trials. Finally, an end-to-end design of 5G network architecture is proposed based on available infrastructure, ecosystem readiness, and possibilities of further research. The end result of the complete process is a recipe or “Blueprint” on how to configure a 5G based telecom network, as standardized by 3GPP, in such a manner that it optimally supports cross border teleoperated transport. This will be demonstrated by a number of “Use Cases” and “Enabling Functions”. This multi-step empirical process is visualized in Figure 1.

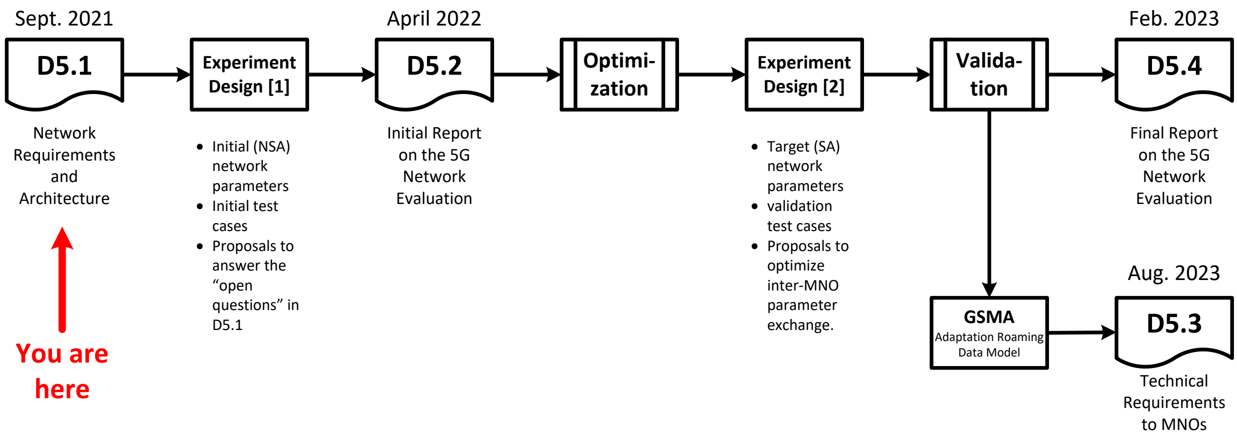

Figure 1: WP5 multi-step empirical process.

A contemporary 5G network can be “Stand Alone” (SA), meaning it doesn’t use resources from 4G, or “Non Stand Alone” (NSA), meaning is does employ resources from 4G. Given the initially small number of users equipped with true 5G User Equipment (UE), most Mobile Network Operators (MNO) will launch their 5G network in NSA mode. One of the novelties of 5G is network slicing. Slicing is meant to provide isolation between the multiple dataflows in a 5G Radio Network. As 4G doesn’t support network slicing a 5G NSA network can only use the Quality of Service (QoS) mechanism of LTE. Therefore the target architecture of the 5G Blueprint project is a 5G SA implementation. Many of the use cases of the 5G Blueprint project can also be demonstrated in a 5G NSA network. This could be an advantage for the adaptation of the results of the project as it doesn't force MNOs to implement a 5G SA network. The aggregation of 4G and 5G is vitally important to the project as in the foreseeable future all know European 5G networks will be integrating existing 4G network.

As depicted in Figure 1 not all parameters to fulfil the Use Case (UC) and Enabling Functions (EF) Requirements are known at this moment in time. The questions which are to be answered by field trials are marked in the text as shown below.

1.1 Document Structure

In total there are five chapters in this document. After the introduction in this chapter, chapter 2 provides a review and analysis of use cases and functions to be implemented in the project, based on deliverables from other work packages. In Chapter 3 all technical components of 5G network are described, either as network design output, based on Chapter 2, or as an individual research item that can impact or improve network performance. Chapter 4 provides an overview of the relation between network requirement and the final network architecture, which can be used as guideline for overall design changes. This can be used to assess the consequences of a change in use case requirement which stem from (observed) user behaviour in practical experiments or from further studies.

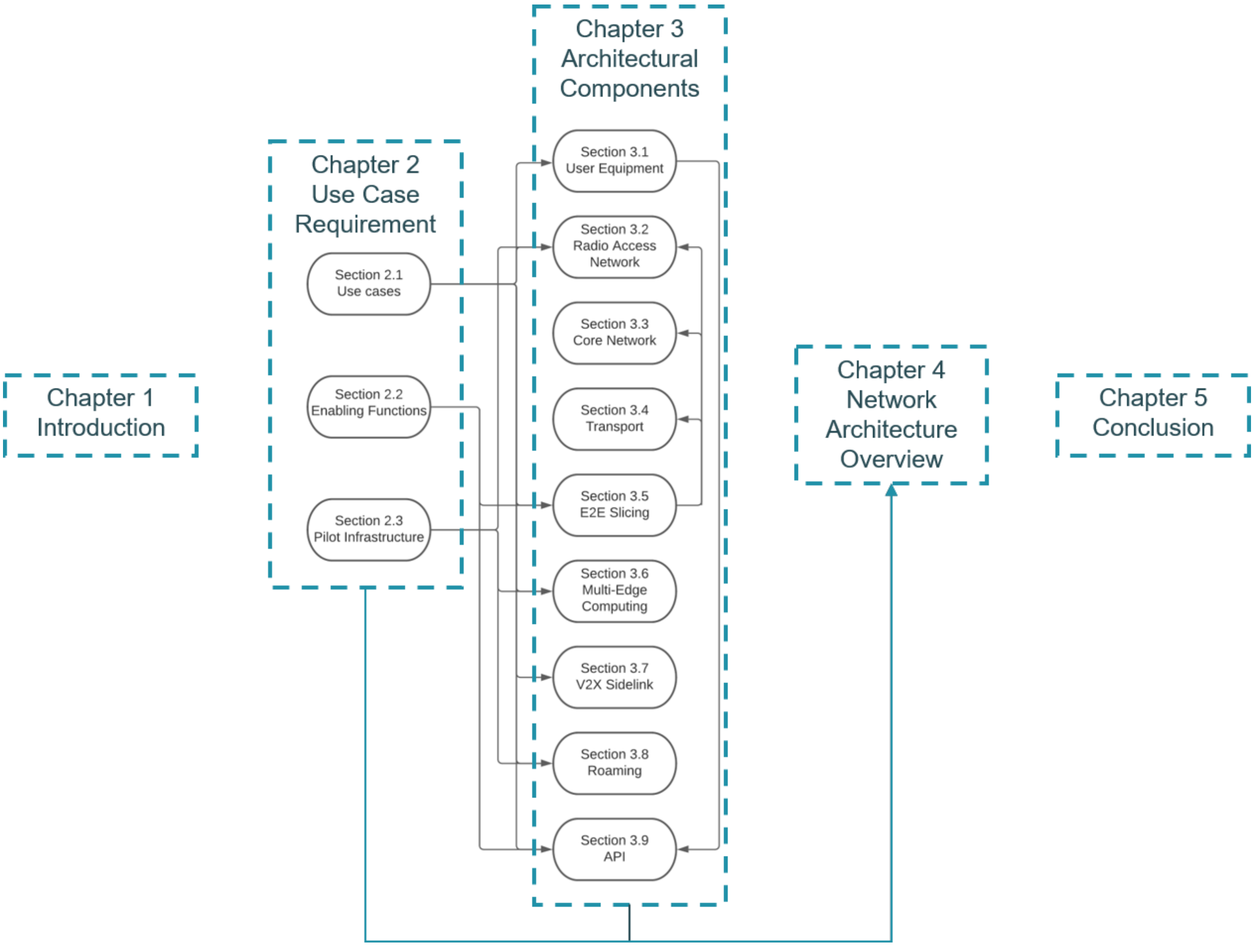

Figure 2: Document structure of D5.1

2 USE CASES REQUIREMENT

The purpose of the 5G Blueprint project is to deliver a blueprint for a 5G based infrastructure which enables seamless Tele Operated transport across Europe.

The seamless cross border teleoperation in 5G Blueprint project is demonstrated & piloted with four selected Use Cases (UC). Next to the UCs there are seven Enable Functions (EF) defined to further enhance or supplement the UCs. In this chapter these UCs and EFs will be described.

An analysis of UCs and EFs is done to generalize and categorize the connectivity requirements. In the 5G network. The “Flow” is the unit representing an individual data stream through the network. Characteristics of Flows can be tuned by network parameters or on the application layer for individual end users. Flows are accommodated by network Slices. The mapping of requirements to Slice Types is taken from Deliverable 7.1 “*D7.1: Initial Defined Architecture*” [2].

2.1.1 Automated Barge Control

The functional requirements for this Use Case is described in Deliverable 4.2. Chapter 2. From these requirements the technical requirements to the telecom infrastructure are derived in Deliverable 7.1 chapter 2.3. In turn from these requirements the practical values to parameters in the GSMA defined Network Slice Template (NG 116) [3] are derived.

ID	UC1-CAM	UC1-SCI	UC1-DDS
Description	HD Camera stream	Ship control interface	Distance/depth sensor on ship
Service Type	Uplink	E2E	Uplink
5G Network Latency	One way <22ms	Round trip <35ms	One way <100ms
Network Service Interruption	<30s	<200ms	<1s
Bandwidth Requirement	>5Mbps <25Mbps	<2Mbps	<1Mbps
Slice Type	eMBB	URLLC/ hMTC	V2X
No. Flow	6 per ship	1 per ship	1 per ship

Table 1: Requirements for Automated Barge Control

"Service Type" only describes the main radio service involved for the data flow.

"5G Network Latency" describes the network latency threshold defined by use case owners. Latency for use case traffic is always the lower the better, but the value described here is sufficient to unlock the full potential of the service based on existing use case hardware and software. Note that the value needs to be considered together with "Service Type". For example, the "<35ms" latency of UC1-SC1 refers to E2E latency with both uplink and downlink. While "<22ms" of UC1-CAM and UC1-VID refers to uplink and downlink separately, resulting in E2E latency of <45ms.

"Network Service Interruption" describes the allowed network interruption time of one single traffic stream, NOT the complete traffic type. This is a strong use case dependent value. For example, the allow interruption time of one camera stream is "<30s", which is very relaxed for tele-operation. There are 10 cameras capable of generating 10 camera streams on one vessel, while the tele-operator only supervises 6 camera views on screen simultaneously, some redundancy is already considered by camera setup on vessels. Such redundancy is not only in place for network interruptions, but also considering the rough environment that camera operates on vessels and the multi axis movement of vessels.

"Bandwidth Requirement" is the range of required 5G bandwidth of one data flow. Details can be found in D4.2.

"Slice Type" is a general identification of the type of network slice according to 3GPP standard. The detailed slice design is described in Chapter 3.

"No.Flow" refers to the number of data flows of the described data flow type of the use case, which leads to the maximum number of flows supported by one 5G device.

Note that the analysis of use cases does not include the Package Error Rate requirement of 5G network. From use case perspective, if a package error or package loss from network cannot be corrected on application level, it will result in a service interruption and service delay caused by data retransmission. The general data error rate of use case is defined very relaxed (<1%) considering all error sources (network, use case hardware/software) if service latency and interruption requirements are fulfilled. Thus, the 5G network availability, Package Error Rate, and network latency is considered together in network design to fulfil the latency and interruption of use cases.

2.1.2 Automated Driver-in-Loop Docking

The functional requirements for this Use Case is described in Deliverable 4.2. Chapter 3. From these requirements the technical requirements to the telecom infrastructure are derived in Deliverable 7.1 chapter 2.3. In turn from these requirements the practical values to parameters in the GSMA defined Network Slice Template (NG 116) [3] are derived

The result of the use case analysis is described in following table.

ID	UC2a-CAM	UC2a-VCI	UC2a-TEL
Description	HD Camera stream	Vehicle control interface	Telemetry sources
Service Type	Uplink	E2E	Uplink
5G Network Latency	<50ms	<35ms	<100ms
Network Service Interruption	<150ms	<150ms	<1s
Bandwidth Requirement	>5Mbps <25Mbps	<2Mbps	<1Mbps
Slice Type	eMBB	URLLC/ hMTC	V2X
No. Flow	3 per vehicle	1 per vehicle	1 per vehicle

Table 2: Requirements for Automated Driver-in-Loop Docking

Please note the “Service Interruption” of UC2a-CAM is much lower than UC1-CAM, as all three camera streams are required simultaneously by tele-operator. For 5G device installed on vehicle indoor coverage is considered as the vehicle could be in an indoor parking location.

2.1.3 Teleoperated Mobile Harbour Crane

The functional requirements for this Use Case is described in Deliverable 4.2. Chapter 4. From these requirements the technical requirements to the telecom infrastructure are derived in Deliverable 7.1 chapter 2.3. In turn from these requirements the practical values to parameters in the GSMA defined Network Slice Template (NG 116) [3] are derived

The result of the use case analysis is described in following table.

ID	UC2b-CAM	UC2b-CCI	UC2b-CSI
Description	HD Camera stream	Crane control interface	Crane sensor information
Service Type	Uplink	E2E	Uplink
5G Network Latency	<50ms	<35ms	<100ms
Network Service Interruption	<150ms	<150ms	<1s
Bandwidth Requirement	>5Mbps <25Mbps	<2Mbps	<1Mbps
Slice Type	eMBB	URLLC/ hMTC	V2X
No. Flow	5 per crane	1 per crane	1 per crane

Table 3: Requirements for Teleoperated mobile harbour crane

2.1.4 CACC Based Platooning

The functional requirements for this Use Case is described in Deliverable 4.2. Chapter 5. From these requirements the technical requirements to the telecom infrastructure are derived in Deliverable 7.1 chapter 2.3. In turn from these requirements the practical values to parameters in the GSMA defined Network Slice Template (NG 116) [3] are derived

The result of the use case analysis is described in following table.

ID	UC3-CAM	UC3-VCI	UC3-TEL	UC3-LID
Description	HD Camera stream	Vehicle control interface	Telemetry sources	LiDAR data stream
Service Type	Uplink	E2E	Uplink	V2V
Ideal latency	<50ms	<35ms	<100ms	<100ms
Service Interruption	<150ms	<150ms	<1s	<1s
Bandwidth Requirement	>5Mbps <25Mbps	<2Mbps	<1Mbps	>20Mbps <100Mbps
Slice Type	eMBB	URLLC/ hMTC	V2N	V2V
No. Flow	3 per vehicle	1 per vehicle	1 per vehicle	2 per vehicle

Table 4: Requirements for CACC Based Platooning

Please note LiDAR data considered here is the raw data input from LiDAR sensor before processing. Transferring raw data before processing is not preferred in this project.

2.1.5 Remote Take Over Operation

The functional requirements for this Use Case is described in Deliverable 4.2. Chapter 6. From these requirements the technical requirements to the telecom infrastructure are derived in Deliverable 7.1 chapter 2.3. In turn from these requirements the practical values to parameters in the GSMA defined Network Slice Template (NG 116) [3] are derived.
As mentioned in Section 2.2.4, the remote take over operation shares the same hardware setup as UC3. Thus, the analysis result of UC4 is combined with UC3 and described in Section 2.2.4.

Following topics will be further explored and validated during field trial.

2.2 Enabling Functions

The EFs as described by Work package 6 (WP6) [4], that are used to enhance or supplement UCs are analysed in this section. The relationship between UCs, EFs and pilot areas, where these Use Cases are demonstrated, can be found in D4.2.

2.2.1 Enhanced Awareness Dashboard

An Enhanced Awareness Dashboard (EAD) provides three types of information to a teleoperator:

1. Speed Advise.
2. Warnings.

3. Navigation and Routing features.

This information is presented to the teleoperator by means of a Heads-Up-Display (HUD), a small widget directly in the line of sight of the teleoperator. On a second screen a dynamic map is presented. On this map the route is shown, as well as long distance obstacles, Vulnerable Road Users (VRUs) and logistical optimization data. The update frequency of the EAD is 1 sec.

When the second screen shows Camera Images of a hazard location, a temporary HD video connection (1080p) is required.

Noted that this enabling function is implemented at the Tele Operations Center. All data input are available from defined use cases. Thus, no additional network requirement is defined for this enabling function.

2.2.2 Vulnerable Road User Warnings

The Vulnerable Road User Warning function is meant to provide both the participating Vulnerable Road User (VRU) and the teleoperator with alerts regarding potential colliding trajectories. To this end it has two objectives:

1. Calculate the likely path of all participating VRUs and makes this data available to interested parties.
2. Provides early warnings to both relevant VRUs and teleoperators when the anticipated path of the VRU and that of the Tele-Operated Vehicle (TOV) potentially cross (collide).

Participating VRUs are equipped with a handset which provides location, speed, acceleration and heading information to a centrally located datacentre or cloud, with an update frequency of one update per second. The TOV's provide location, speed, acceleration and heading information with an update frequency of one update per second to the same centrally located datacentre.

The Datacentre will alert the relevant VRUs and teleoperator. For the VRU this alert will presented on the handset. For the teleoperators the alert will be shown on the EAD.

Note that data from VRU is not included in use cases, which is analysed as following:

ID	**EF2-VRU**
Description	Movement data from VRU
Service Type	Uplink
Ideal latency	<500ms
Service Interruption	<1s
Bandwidth Requirement	<1Mbps
Slice Type	eMBB
No. Flow	1 per VRU

Table 5: Requirement for Vulnerable Road user Warnings

2.2.3 Time slot reservation from Intelligent Traffic Light Controllers

Th Time slot reservation from Intelligent Traffic Light Controllers (iTLCs) ensures conflict-less crossings for tele-operated transport at intersections with iTLCs. To use this function a teleoperator can request a timeslot during which the TOV (and possibly all TOV's which are part of a platoon) is/are guaranteed a green-light passage over an intersection. This EF will:

1. Receive continuous the intermitted updates regarding location, speed, acceleration and heading of the TOVs.
2. Receive the calculated Estimated Time of Arrival (ETA) at an intersection with an iTLC.
3. Request a timeslot at the relevant iTLC and renew these requests when appropriate.
    a. The reservation can be made by the EF or
    b. The reservation can be made using V2X from the TOV to the iTLC, where the TOV itself provides an ETA to the iTLS.
4. Provide confirmation to the TO in the EAD about the reserved timeslot and an advice of speed to be at the intersection at the reserved time.

Note that data from iTLC is not included in use cases, which is analysed as following:

ID	EF3-iTLC
Description	Control of iTLC
Service Type	Downlink
Ideal latency	<200ms
Service Interruption	<1s
Bandwidth Requirement	<1Mbps
Slice Type	IoT
No. Flow	1 per iTLC

Table 6: Requirements for Time slot reservation from iTLCs

2.2.4 Distributed perception

Distributed Perception (DP) will extend the perceptive range of the remote teleoperator for making the appropriate decisions. To this end this function collects sensory information of a diverse range of vehicles. Not only the Tele Operated Vehicle itself, but also data from nearby vehicles and road-side sensors. All data is used and presented to the EAD. Related sensors are:

1. Camera images from Vehicles
2. LiDAR point-clouds from Vehicles
3. Road-Side sensory data (stationary)
4. Location information from Vehicles

Note that in UC3 the LiDAR data is already passing by between TOVs but not yet shared towards the TOC. So both LiDAR point-clouds and RSU data are analysed as following:

ID	EF4-LiDAR	EF4-RSU
Description	LiDAR point-clouds	Info from RSU
Service Type	Uplink	Uplink
Ideal latency	<100ms	<200ms
Service Interruption	<1s	<1s
Bandwidth Requirement	>20Mbps, <100Mbps	<1Mbps
Slice Type	eMBB	IoT
No. Flow	1 per vehicle	1 per RSU

Table 7: Requirements for Distributed perception

2.2.5 Active Collision Avoidance

The Active Collision Avoidance (ACA) function is meant to mitigate the hazardous situations associated with a loss of connection and impaired perception of the environment by the teleoperator. This is achieved by the supervision of the Quality of Service (QoS) of the wireless connection and numerous local sensors in the TOV, such as LiDAR, RADAR, GNSS-INS and cameras. The ACA function is performed locally in the TOV. It needs a heartbeat connection to the telecom infrastructure for the supervision of connectivity, to notify the interventions to the teleoperator.

Data flow for EF5 is analysed as following

ID	EF5-ACA
Description	Heartbeat message
Service Type	E2E
Ideal latency	<100ms
Service Interruption	<150ms
Bandwidth Requirement	<1Mbps
Slice Type	V2N
No. Flow	1 per vehicle

Table 8: Requirements for Active Collision Avoidance

2.2.6 Container ID recognition

This function offers the capability to identify shipping containers on video streams. This is done by means of image recognition using Artificial Intelligence (AI). This consumes a considerable amount of processing power. Therefore, the computing is done in a cloud. The video data is obtained by a camera on a crane or on a reach-stacker. The analysed information will be available to the EAD.

Noted that this enabling function is implemented at the Tele Operations Center. All data input are available from defined use cases. Thus, no additional network requirement is defined for this enabling function.

2.2.7 Estimated Time of Arrival Sharing

Estimated Time of Arrival (ETA) Sharing provides two basic functionalities which allow planners to dynamically schedule in teleoperators:

1. An ETA at the destination and intermediate Points of Interest (PoIs) of tele-operated transport, which will be continuously calculated using numerous data-points provided by the TOV and its surroundings. This ETA will be made available to other Enabling functions such as VRU Warning and iTLC timeslot reservation.
2. Support (automated) logistical planning systems with ETA information. Examples of these functions are
    a. providing a truck assignment system with ETA data to assign a pick-up/ drop-off timeslot
    b. assigning a teleoperator to an arriving vehicle by a logistic planner.

Noted that this enabling function is implemented at the Tele Operations Center. All data input are available from defined use cases. Thus, no additional network requirement is defined for this enabling function.

2.2.8 Scene Analytics

The scene analysis function monitors numerous data-feeds, as provided by TOVs and stationary sensors. It provides pattern recognition functions (implemented as Machine Learning Algorithms). The purpose is to provide early warning when it recognises anomalies and patterns which, in the past, turned out to lead to dangerous or undesirable situations. The function enhances the EAD and ETA function. The function is expected to use additional speakers or other methods of interaction to communicate with the teleoperator with available data.

Noted that this enabling function is implemented at the Tele Operations Center. All data input are available from defined use cases. Thus, no additional network requirement is defined for this enabling function.

2.3 Pilot Area

There are in total three pilot areas in the 5G-BP project: Port of Antwerp in Belgium, Vlissingen in Netherlands and Zelzate where border crossing area. For detailed description of use cases and location mapping please refer to “R4.2_UC Requirements”.

In Port of Antwerp, there are two main locations for use case trails. The Zandvlies/Berendrecht lock in the north and the Deurganckdock docking on the left bank in the south. Totally two terminals, one parking area, one industrial area and connecting road are included in the Deurganckdock docking. An helicopter view of the pilot area is as following:

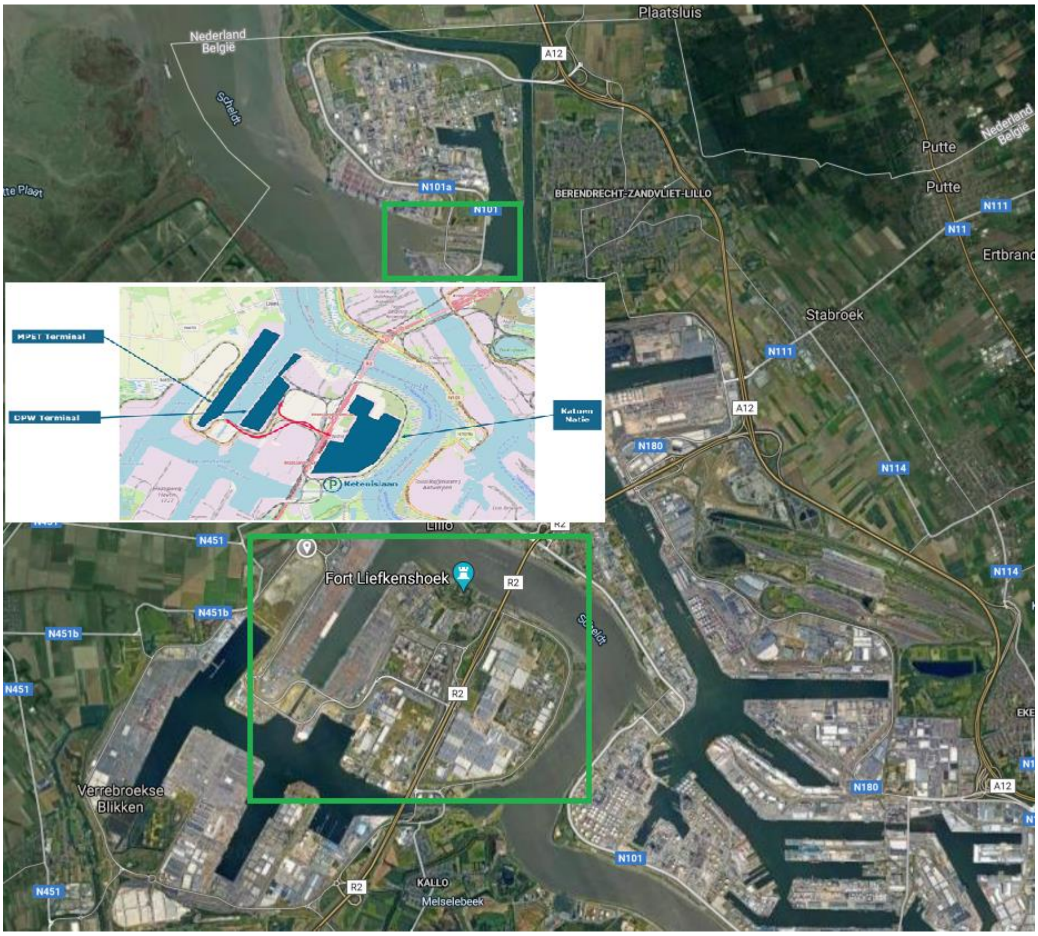

Figure 3: Helicopter view of Antwerp pilot area

The Zelzate pilot area has a focus on cross-border trails. As illustrated in figure below, both water way and highway go across the border between Netherlands and Belgium within a focused area. The pilot area and land route for use case trials are indicated in Green and Red lines respectively.

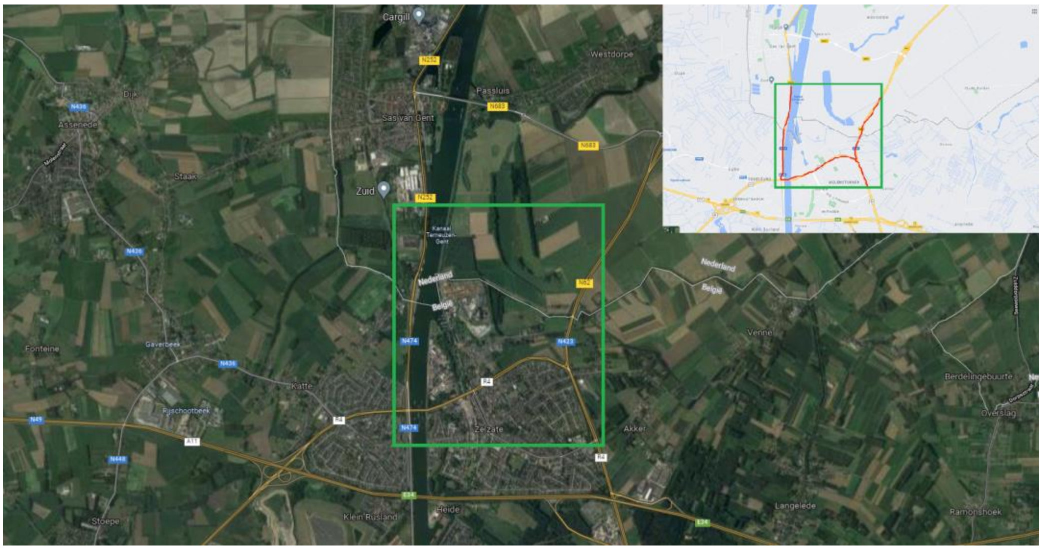

Figure 4: Helicopter view of Zelzate pilot area

The Vlissingen pilot area consist of MSP Onion industrial zone and a route from parking to docking as indicated below.

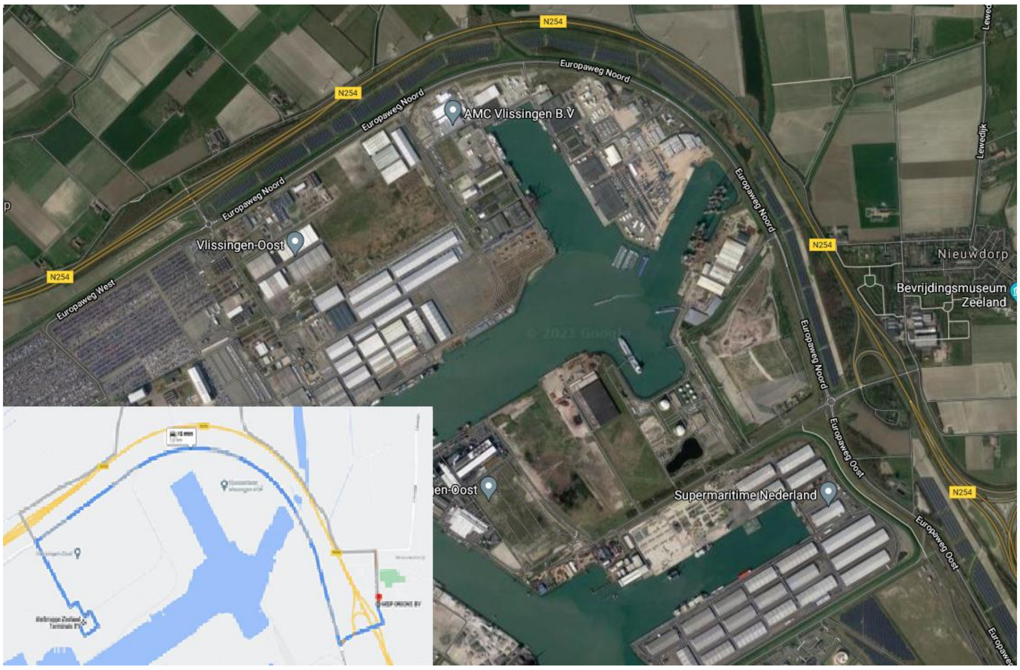

Figure 5: Helicopter view of Vlissingen pilot area

In all three areas connectivity are required for devices that are on mobile or stationary on both waterway and land. The areas have environmental challenges such as stacks of metal containers, towers of high voltage power lines, wind turbines and tunnels & interchanges of road infrastructure. All these challenges must be considered when designing and optimizing 5G coverage as discussed in Section 3.2.2.

On top of connecting use case equipment, 5G is also considered as abundant connectivity for existing infrastructure. For example, the onshore operation center for vessel control. These requirements have an impact on network resource allocation and network slicing design as discussed in Chapter 3.

3 ARCHITECTURAL COMPONENTS

This chapter provides discussion and definition of each 5G network element or key technology that has an impact on 5G Blueprint use cases. Both technologies that are currently evaluated by KPN & Telenet, and upcoming technologies that are under development by ecosystem or studied by standardization. The results of selected and defined technology feature and configuration parameter are a combination of the ideal design for use cases, the realistic evaluation of ecosystem development, the geographical and regulatory status of pilot regions and the preference of KPN and Telenet based on previous network evolution and deployment experience.

The discussion starts from fundamental elements of mobile network: user equipment, radio access network, core network and transport network. Then focus on key technology to answer challenges of the project, such as end to end slicing design in Section 3.5, edge computing in Section 3.6, V2X technologies in Section 3.7, roaming in Section 3.8 and network APIs in Section 3.9. An overview of 5G network architecture is shown in figure below. The discussed elements in following sections of the architecture will be highlighted at the start of the section.

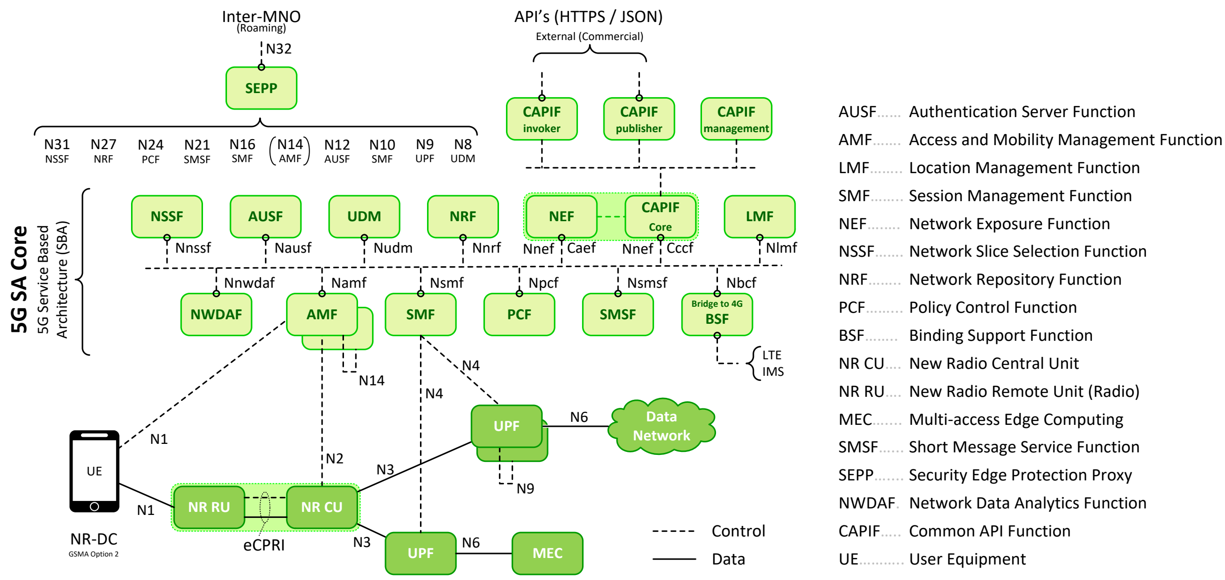

Figure 6: Generic 5G 'Stand Alone' Architecture

3.1 User Equipment

In order to satisfy the availability requirement independently from the implementation of Packet Duplication, a dual 5G modem / 5G SIM solution is designed. Such solution can also be used as an "over the top" means for session continuity at border crossings. In the 5G Blueprint project MNO bases solutions will be explored S10 based inter-MNO roaming for NSA and N14 based roaming for SA Networks, while also considering user equipment maturity to use dual modem/SIM as a starting point and finally "over the top" option for 5G device. This can also lead to higher availability while device is not roaming, by combining 5G links in a managed manner. In this section the design of the device solution as well as technical requirement of each 5G modem will be explained.

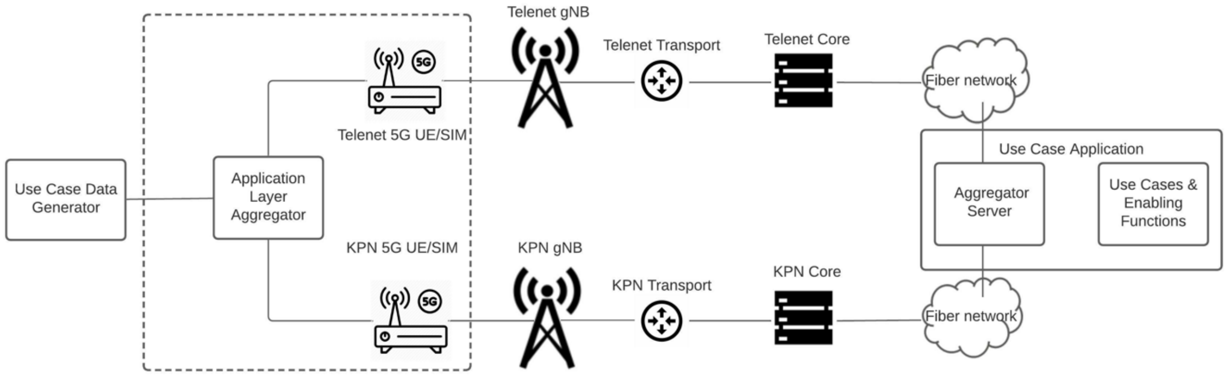

Figure 7: UE Dual Connectivity Aggregator

As illustrated above, the use case device(s) that generates or consumes data is connected to an application layer aggregator, which is connected to two 5G modems with KPN and Telenet SIM card respectively. The aggregator should be able to aggregator the bandwidth of both 5G devices and distribute/priorities/switch traffic between them. The aggregator should also provide switching functionality to provide all IP requirements of use case device(s). If the ecosystem allows to source an all-in-one 5G device, which integrates two 5G modems, two 5G SIMs, aggregation functionality and configurable distribute /priorities /switching functionality, then it is a considerable alternative which provides more system robustness on device side while sacrifices some configuration flexibility.

The two 5G modems shall always scan for its home network and roaming network, to provide best effort connectivity to the aggregator. The aggregator then decides how both 5G connectivity shall be used based on network parameters and network slicing information.

3.1.1 5G Modem Capabilities

The 5G modems used must support both 5G non-standalone mode and standalone mode. 5G SA is requirement to provide network slicing (NS) functionality for use case traffic flows that requires guaranteed connectivity. Each 5G modems should also support 5G dual connectivity mode to utilize all available spectrum.

In [5] [6] [7] the GSMA proposed several Dual Connectivity modes, each with a different “Anchor Point” for the UE. The three most relevant are shown in Figure 8. In ‘EN – DC’ the UE is anchored on an enhanced UTRAN site (LTE) and uses a New Radio (NR) site as additional channel. In ‘NE – DC’ the anchoring is in NR and the secondary channel is from LTE, Finally, in ‘NR DC’ both the anchor site and the secondary site are 5G NR. Each of these bring different requirements on the UE and the RAN features is supports.

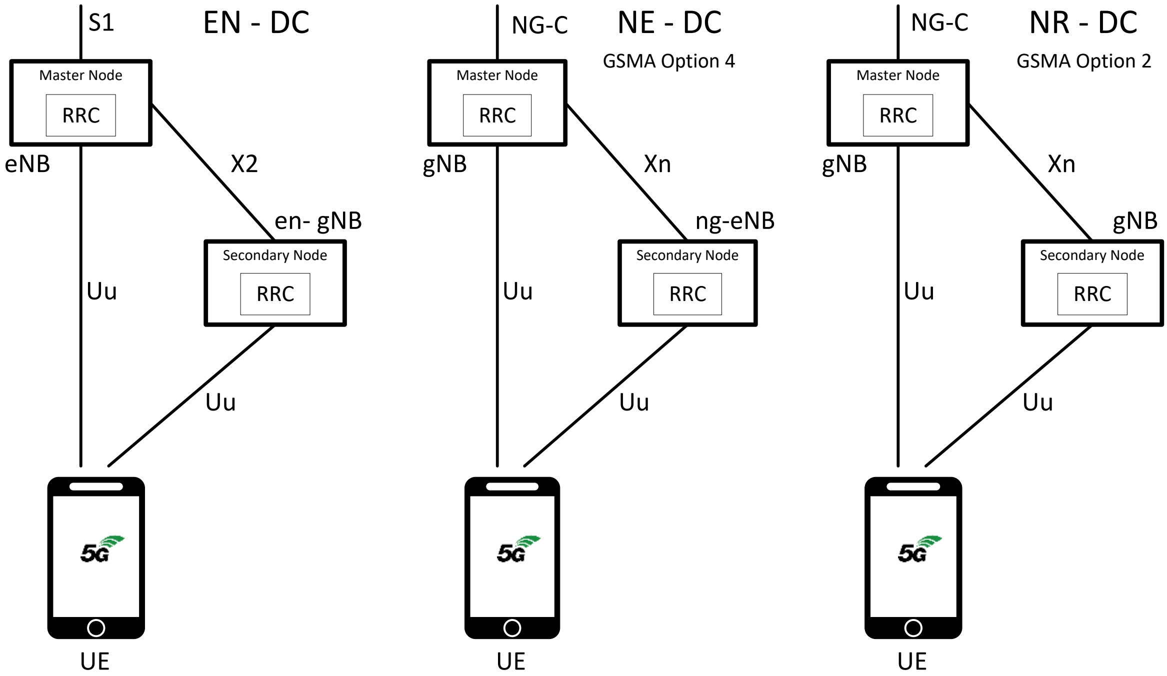

Figure 8: Dual Connectivity options in RAN

For 5G NSA mode the selected dual connectivity mode for both KPN and Telenet is EN-DC. If license allows NR-DC are also consider for 5G SA. The design dual connectivity and carrier aggregation combination requirements is described as following:

NR Band	Frequency	5G CA	4G CA	EN-DC Comb	No. streams
N78	3500 MHz	N/A	N/A	DC_3_n78	B3:4x4
N78	3500 MHz	N/A	N/A	DC_7_n78	B7:4x4
N78	3500 MHz	N/A	N/A	DC_20_n78	B20:2x2
N78	3500 MHz	N/A	N/A	DC_1_n78	B1:4x4
N78	3500 MHz	N/A	2CA	DC_1-3_n78	B1:4x4, B3:4x4
N78	3500 MHz	N/A	2CA	DC_1-7_n78	B1:4x4, B7:4x4
N78	3500 MHz	N/A	2CA	DC_1-20_n78	B1:4x4, B20:2x2
N78	3500 MHz	N/A	2CA	DC_3-7_n78	B3:4x4, B7:4x4
N78	3500 MHz	N/A	2CA	DC_3-20_n78	B3:4x4, B20:2x2
N78	3500 MHz	N/A	2CA	DC_7-20_n78	B7:4x4, B20:2x2
N78	3500 MHz	N/A	3CA	DC_1-3-7_n78	B1:4x4, B3:4x4, B7:4x4
N78	3500 MHz	N/A	3CA	DC_1-3-20_n78	B1:4x4, B3:4x4, B20:2x2
N78	3500 MHz	N/A	3CA	DC_1-7-20_n78	B1:4x4, B7:4x4, B20:2x2
N78	3500 MHz	N/A	3CA	DC_3-7-20_n78	B3:4x4, B7:4x4, B20:2x2
N78	3500 MHz	N/A	4CA	DC_1-3-7-20_n78	Not support
N1	2100 MHz	N/A	No CA	DC_3_n1	B3:4x4
N1	2100 MHz	N/A	No CA	DC_7_n1	B7:4x4

N1	2100 MHz	N/A	No CA	DC_20_n1	B20:2x2
N1	2100 MHz	N/A	2CA	DC_3-7_n1	B3:4x4, B7:4x4
N1	2100 MHz	N/A	2CA	DC_3-20_n1	B3:4x4, B20:2x2
N1	2100 MHz	N/A	2CA	DC_7-20_n1	B7:4x4, B20:2x2
N1	2100 MHz	N/A	3CA	DC_3-7-20_n1	B3:4x4, B7:4x4, B20:2x2
N1-N78	2100&3500 MHz	2CC	No CA	DC_3_n1-n78	N/A
N1-N78	2100&3500 MHz	2CC	No CA	DC_7_n1-n78	N/A
N1-N78	2100&3500 MHz	2CC	No CA	DC_20_n1-n78	N/A
N1-N78	2100&3500 MHz	2CC	2CA	DC_3-7_n1-n78	N/A
N1-N78	2100&3500 MHz	2CC	2CA	DC_3-20_n1-n78	N/A
N1-N78	2100&3500 MHz	2CC	2CA	DC_7-20_n1-n78	N/A
N1-N78	2100&3500 MHz	2CC	3CA	DC_3-7-20_n1-n78	N/A
N28	700 MHz	N/A	N/A	DC_3_n28	B3:4x4
N28	700 MHz	N/A	N/A	DC_20_n28	B20:2x2
N28	700 MHz	N/A	N/A	DC_7_n28	B7:4x4
N28	700 MHz	N/A	2CA	DC_3-7_n28	B3:4x4, B7:4x4
N28	700 MHz	N/A	2CA	DC_3-20_n28	B3:4x4, B20:2x2
N28	700 MHz	N/A	2CA	DC_7-20_n28	B7:4x4, B20:2x2
N28	700 MHz	N/A	3CA	DC_3-7-20_n28	B3:4x4, B7:4x4, B20:2x2
N1-N28	700&2100 MHz	2CC	No CA	DC_3_n1-n28	N/A
N1-N28	700&2100 MHz	2CC	No CA	DC_7_n1-n28	N/A
N1-N28	700&2100 MHz	2CC	No CA	DC_20_n1-n28	N/A
N1-N28	700&2100 MHz	2CC	2CA	DC_3-7_n1-n28	N/A
N1-N28	700&2100 MHz	2CC	2CA	DC_3-20_n1-n28	N/A
N1-N28	700&2100 MHz	2CC	2CA	DC_7-20_n1-n28	N/A
N1-N28	700&2100 MHz	2CC	3CA	DC_3-7-20_n1-n28	N/A

Table 9: Dual connectivity and carrier aggregation support of 5G UE

For device working 5G SA network, different 5G chipset/modem could be selected to support different type of network slices, while ideally one type of 5G chipset/modem could support multiple network slices. should be able support at least 5 different type of network slices, which are:

- eMBB (uplink focus): a network slice with guaranteed uplink bandwidth, stability and latency for camera streaming of UC 4.1 automated barge control, UC 4.2 automated driver-in-loop docking, UC 4.3 CACC based platooning, UC 4.4 remote takeover operation.
- eMBB (downlink focus): a network slice with guaranteed downlink & uplink bandwidth, stability and latency for fixed wireless access towards one or multiple teleoperation

center of use cases. This is an optional slice which is defined as fixed wireless at Tele-operation Center to provide fallback for fixed line or fiber.
- URLLC/hMTC: a network slice with ultra-low latency and high reliability connectivity for mission critical data.
- IoT: a network slice for any IoT sensor or UE that carries non-essential data for use cases.

Note that downlink or uplink focused eMBB slices could result in selection of different 5G modems or firmware versions, supporting different network features, such as UL MIMO, 256QAM etc. This depends on 5G modem ecosystem readiness in the coming years. At this moment 5G eMBB modem with focus on downlink is generally available from the market and has been tested by MNOs.

3.1.2 5G Use Case Device Capabilities

The 5G device should be able to determine how both 5G connectivity should be used on application layer and collaborate with user traffic aggregator on the use case server side. The decision is made by application layer aggregator and informed to the traffic aggregator server before establishing or switching traffic on a new connectivity link. In principle with correct 5G network planned and implemented, the use cases should be satisfied by one of the 5G links and does not requires the second one to serve at the same time.

If both 5G connectivity are in 5G SA mode with network slicing enabled, the device can decide which 5G link to use based on user preference (e.g., pricing) or current link used (to avoid link switching). Any change of connection mode or link needs to be informed to traffic aggregator on the server.

If one of the 5G connectivity is in 5G SA mode with network slicing enabled, the 5G device should request or define the correct slice to use via exposed network API. The 5G link with required network slices should always be prioritized, leaving the other link in duplication or standby. Any change of connection mode or link needs to be informed to traffic aggregator on the server side.

If both 5G connectivity are in 5G NSA mode, the decision is made by measuring the latency, signal strength, bandwidth, acquired cell info and network quality expectancy (based on geolocation and neighbouring cell info). If both connectivity link satisfies the use case requirement then traffic can be distributed in load balancing mode, duplicated to further improve reliability, or prioritized in one link depending on user preference or current link used. If one of the connectivity has better measured results, then traffic can be prioritized into one 5G network and leaving the other 5G link in duplication or standby. Any change of connection mode or link needs to be informed to traffic aggregator on the server.

If the device is on mobile and close to a boarding region, the device should always make one of 5G chipset/modem in standby mode to establish new connection during board crossing. Once the new connection is ready, the device should inform traffic aggregator on server and perform the link switch once current connection is lost or network quality reaches the designed threshold.

3.2 Radio Access Network

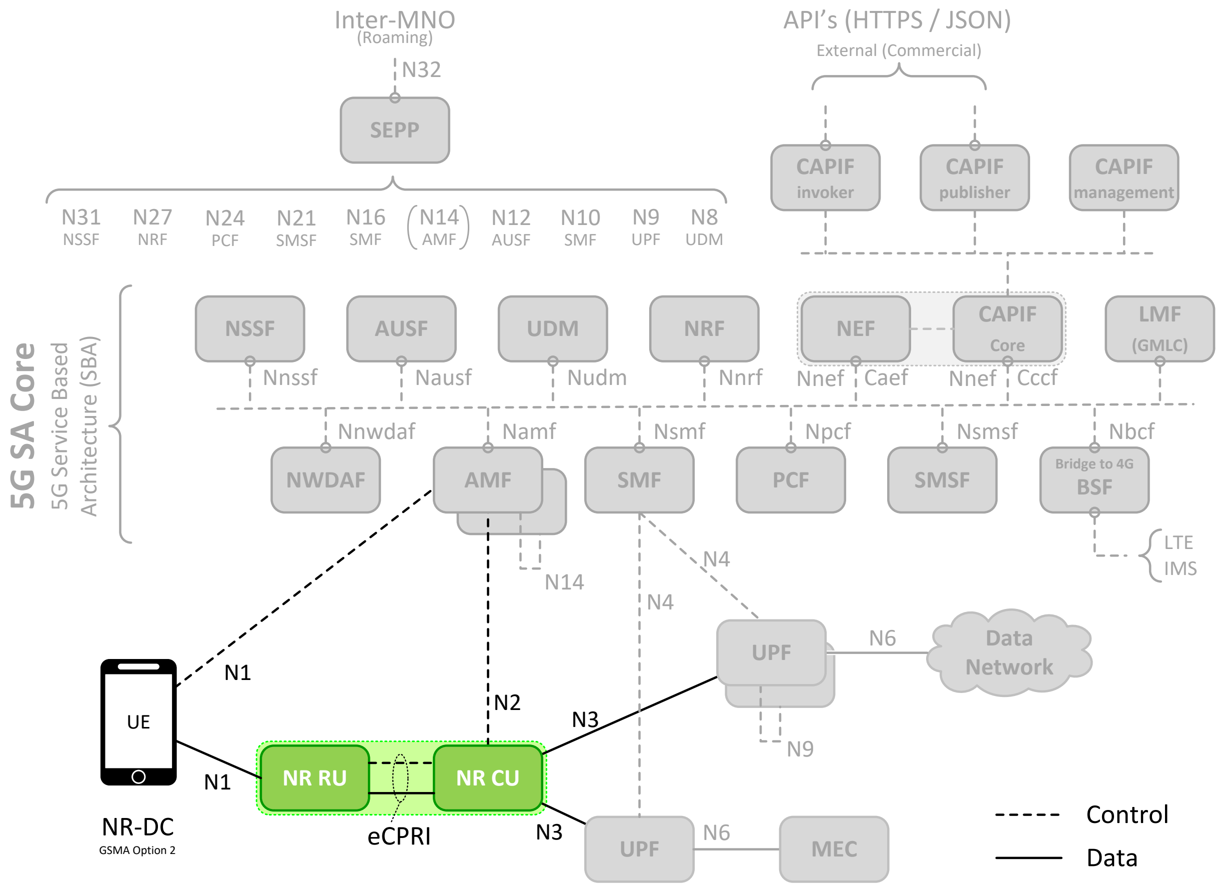

Figure 9: 5G Radio Access Network

This section focuses on design of hardware, software and functions of the radio access network. As highlighted above, NR RU manages the air interface and part of the PHY layers, which is related to radio frequencies usage, coverage of the test zone, signal exchange with 5G UE, bandwidth of air interface. NR CU manages the PHY, MAC, RLC, PDCP and RRC layer, which is related to UE access, baseband capacity and transfer user data into transport network. N3IWF is for managing traffic from non-3GPP connectivity.

3.2.1 Frequencies

Current available spectrum resource and deployment scenario of two MNOs are as following:

Band	Frequency	Technology	MNO	Bandwidth	Comment
N28	713-723 / 768-778	FDD NR	KPN	2x 10MHz	Macro
N1	1960-1980 / 2150-2170	FDD NR	KPN	2x 20MHz	Indoor small cell
N1	1935-1950 / 2125-2140	FDD NR	TLN	2x 15MHz	Macro
N78	3600-3650	TDD NR	TLN	50MHz	Macro/small cell
B20	811-821 / 768-778	FDD LTE	KPN	2x 10MHz	Macro
B20	791-801 / 832-842	FDD LTE	TLN	2x 10MHz	Macro

B3	1710-1730 / 1805-1825	FDD LTE	KPN	2x 20MHz	Macro/small cell anchor
B3	1760-1780 / 1855-1875	FDD LTE	TLN	2x 20MHz	Macro/small cell anchor
B7	2535-2545 / 2590-2620	FDD LTE	KPN	2x 10MHz	Macro
B7	2535-2550 / 2655-2670	FDD LTE	TLN	2x 15MHz	Macro

Table 10: Spectrum resource of KPN & Telenet

Note that availability of 3500MHz spectrum for KPN depending on auction in H2 2021, and availability of 700MHz spectrum for Telenet depending on auction in H1 2022. In Belgium test licenses are also applicable prior to field trials with a limitation and time flame and radiation area.

3.2.2 Coverage

The radio coverage planning is based on the radio Link Budget. This is the “budget” of losses of signal strength between the transmitter and the receiver which still allows for proper reception of the sent signal. This is closely related to the Maximum Coupling Loss (Figure 10) used by the 3GPP.

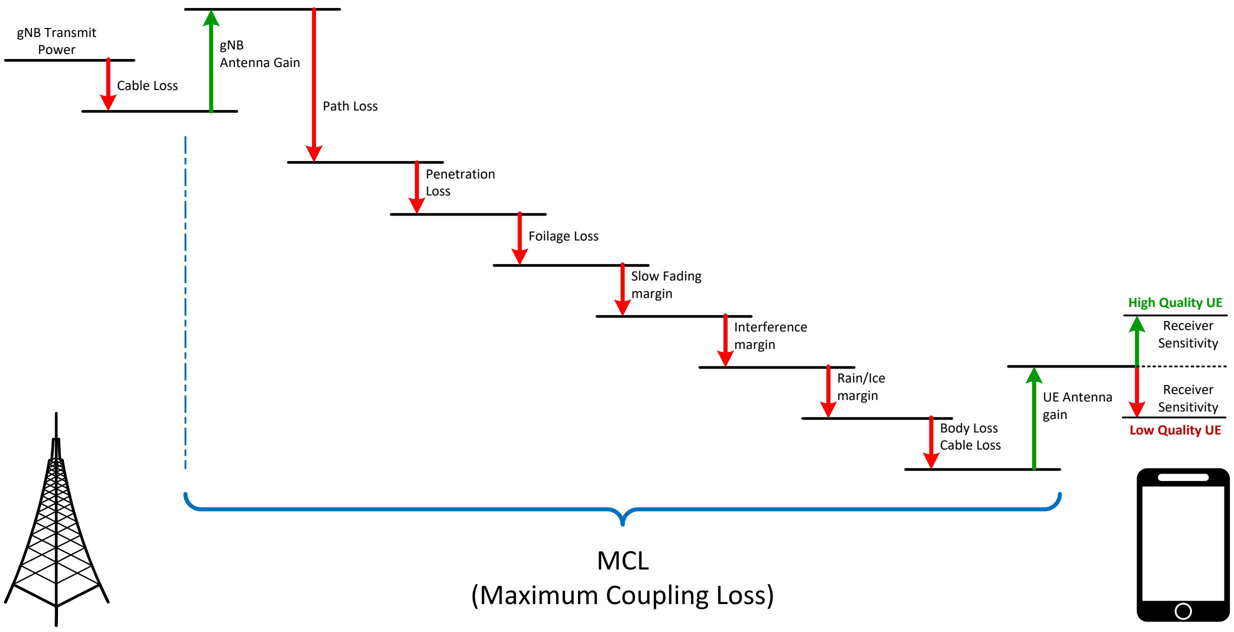

Figure 10: Radio planning: Maximum Coupling Loss (MCL)

The coverage of 5G network is greatly affected by NR spectrum, NR mode, transmit power and actual propagation path in the coverage arrea. As higher spectrum has higher propagation loss comparing with lower spectrum, thus using lower bands can improve 5G coverage and field strength.

The influence of the frequency on the path-loss, which is a significant part of the MCL, can be calculated using the Friis transmission formula:

$$\frac{P_r}{P_t} = \frac{G_t \cdot G_r \cdot C^2}{(4 \cdot \pi \cdot R \cdot f)^2}$$

P_t: transmitted Power
P_r: received Power
G_t: transmitter Antenna Gain
G_r: receiver Antenna Gain
C: speed of Light
f: Frequency
R: Distance Transmitter / Receiver

The network bandwidth of lower bands is normally lower due to limited spectrum bandwidth. As NR on 3500MHz is in TDD mode, the frame structure with different DL/UL time slot allocation can impact the DL/UL bandwidth. The transmit power allowed by regulation in different regions also impact the 5G MCL. Currently the regulations are still being refined by regulatory.

In case network is configured in NSA mode with anchoring on LTE 1800MHz and NR on 3500MHz, the uplink traffic can be allocated on LTE bands to increase uplink link budget. As uplink is the limiting factor of 5G coverage, this can also increase the coverage of 5G NSA. In case network is configured in SA mode with NR on 3500MHz only, the limiting factor of network coverage is the uplink link budget due to limited transmit power of 5G UE.

Regarding NR frame structure, both KPN and Telenet decided to use DDDSU TDD pattern with 2.5ms repetition period and 10:2:2 for downlink, gap and uplink symbols in the special slot. The choice is made based on KPN and Telenet's experience of operating legacy TDD system and maturity of ecosystem. Resource allocation in one sub-frame is concluded as following:

Transmission period	DL slots	DL symbols	UL slots	UL symbols
2.5ms	3	10	1	2

Table 11: TDD NR resource allocation per sub-frame

The frame structure is illustrated as following:

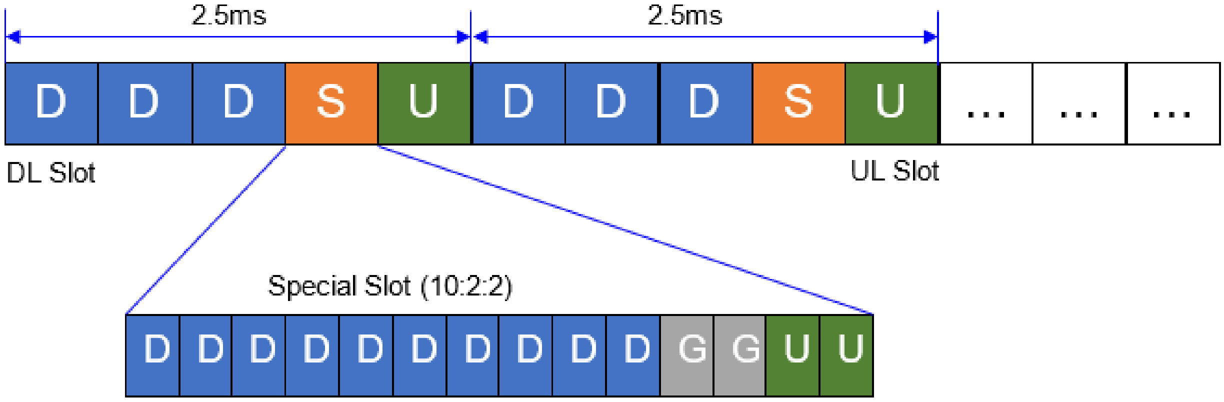

Figure 11: Selected TDD NR frame structure

Summarizing both factors mentioned above, together with current granted radiation license and geographical data of pilot area, the simulation of 5G coverage in pilot are presented as below.

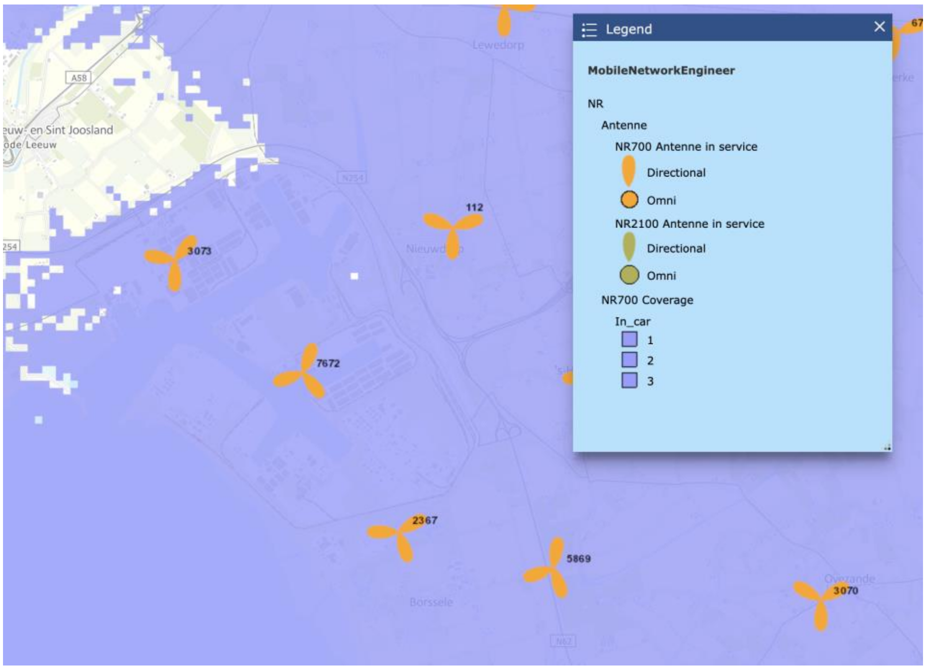

Figure 12: KPN 700MHz 5G coverage in Vlissingen 2021-2022

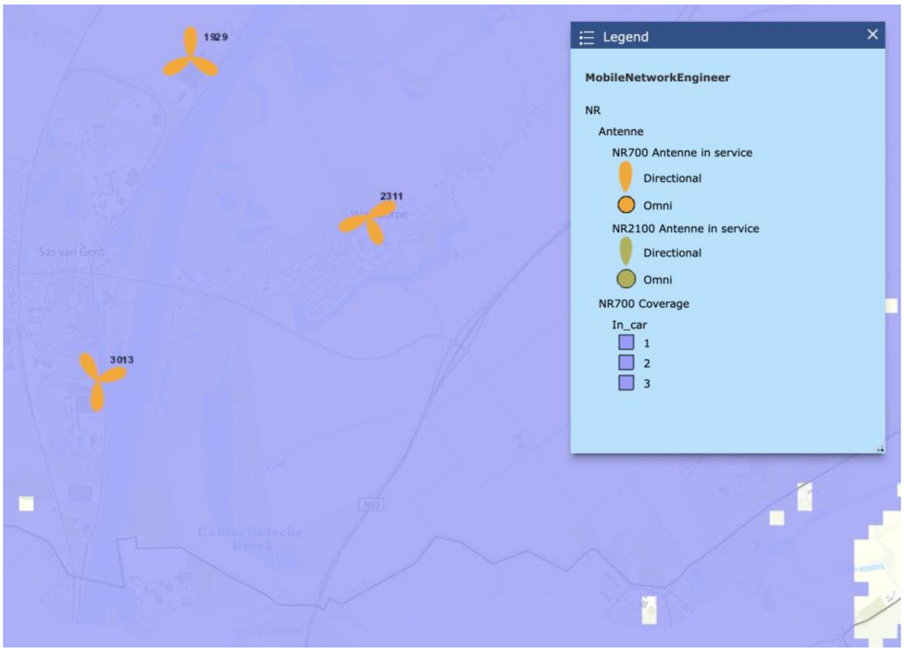

Figure 13: KPN 700MHz 5G coverage in Sas van Gent (Zelzate) 2021-2022

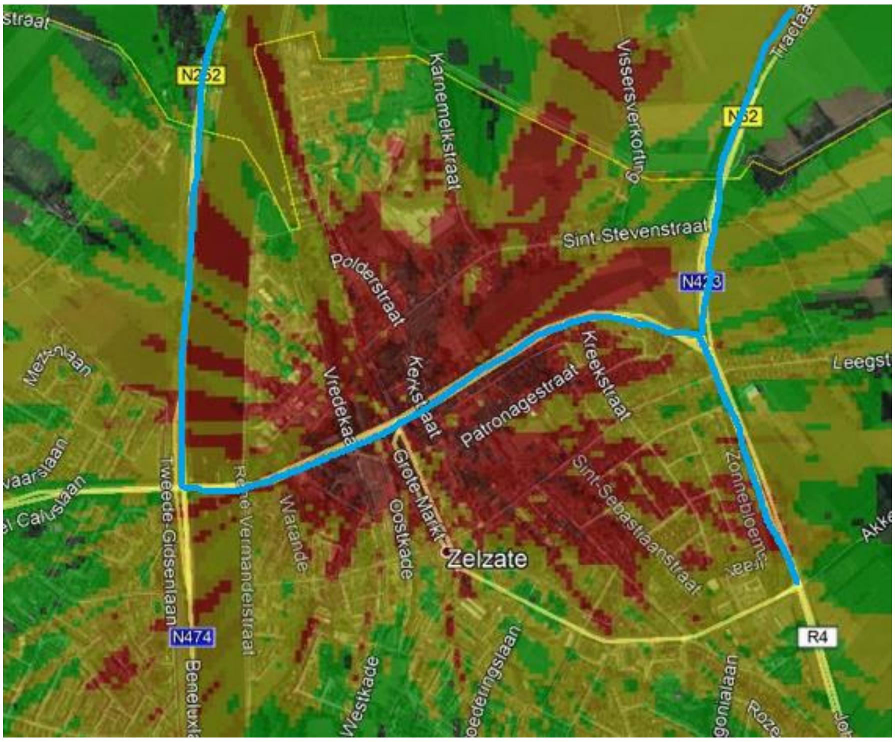

Figure 14: Telenet 3.5GHz coverage in Zelzate

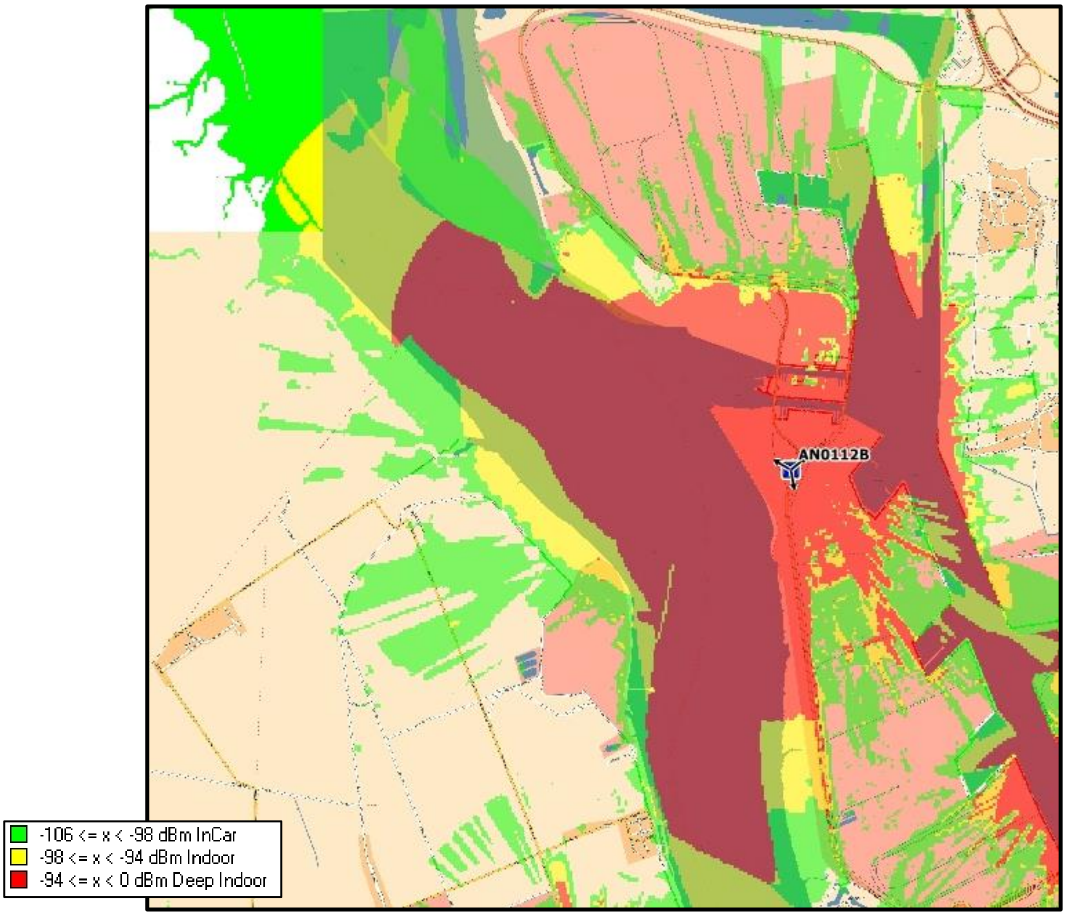

Figure 15: Telenet 3.5GHz coverage in Port of Antwerp (north lock)

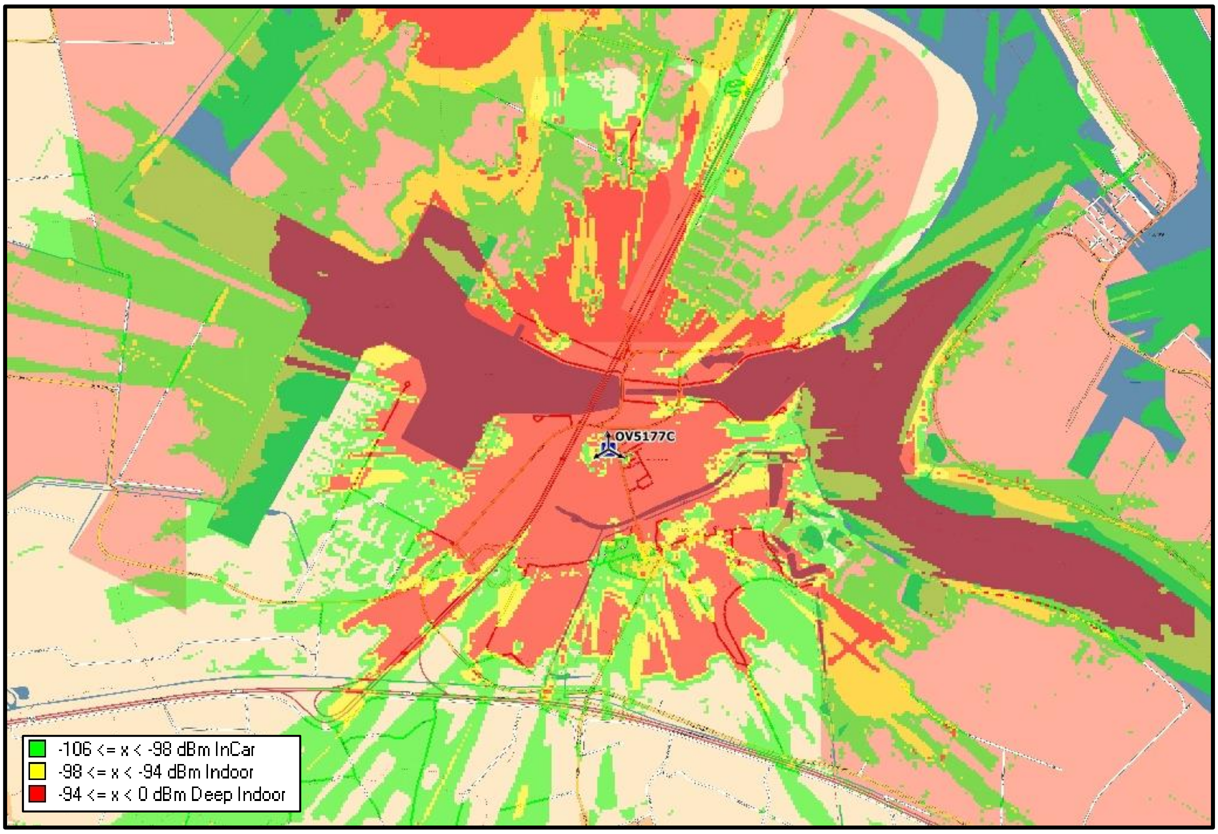

Figure 16: Telenet 3.5GHz coverage in Port of Antwerp (over Roosens)

3.2.3 RAN Configuration & Behaviour

The RAN configuration and resulted UE behaviour is different for 5G network in NSA and SA mode.

In SA mode, two deployment options from GSMA standard are selected. In Option 2, both user plane and control plane go through NR directly and NR only, which means 5G UE can only attach to NR in SA mode on different NR spectrums as described in Section 3.2.1. This is the preferred SA deployment strategy of Telenet. The preference of network slice deployment are as following:

Band	mMTC/MIoT	eMBB	V2N	hMTC/URLLC
Frequency	No preference	3500/2100/700MHz	3500/2100/700MHz	700/3500MHz

Table 12: Network slice deployment preference of Telenet

For eMBB and V2N slices preference are from high spectrum to lower spectrum to allocate more bandwidth. For hMTC or URLLC slices lower bands are preferred for better coverage and signal penetration, while high band is considered as optional. On IoT slices there is no preference.

In Option 4, the control plane goes through NR only while user plane goes through both NR and LTE. In this case 5G UE can attach to NR in SA mode, or both NR and LTE in NSA mode. The benefit of this strategy is to allow 5G user to utilize 4G bandwidth in case necessary. This is the preferred deployment strategy of KPN. KPN has no prioritization on network slice to spectrum allocation. Option 2 and Option 4 are illustrated in figure below.

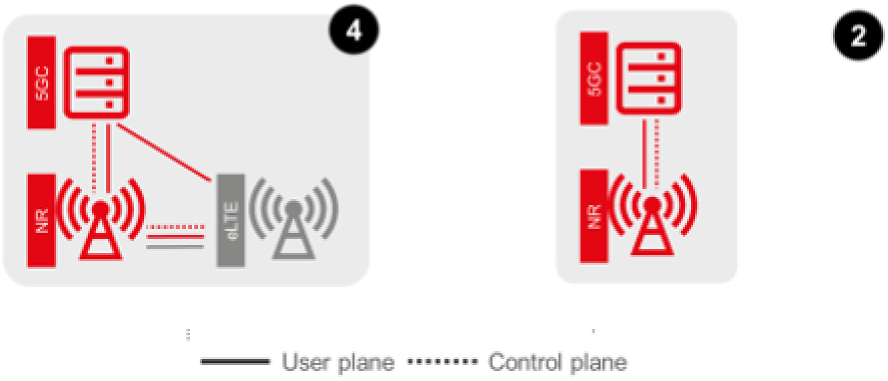

Figure 17: 5G SA Option 2 and Option 4 [6]

When RAN is configured in 5G NSA mode, 5G network supports carrier aggregation and EN-DC combination of all spectrum described in Section 3.2.1. Depending on UE location and coverage scenario described in Section 3.2.2, the UE then select carriers according to capabilities described in Section 3.1.1. The UE will lose 5G NSA connection and fall back to LTE, once 5G link budget exceeds or 1800MHz LTE anchoring band is unreachable.

3.2.4 RAN Slicing

5G RAN supports priority management with 5G QoS Flow input, UE TCP session, and 5G QoS Flow to data radio bearer (DRB) mapping. The network first map different IP flows with same QoS requirements into the same QoS Flow, as illustrated in figure below. For non-guaranteed bit rate flows (Non-GBR) the total bandwidth is limited by aggregated maximum bit rate (AMBR) which is similar as 4G network. The gNB maps QoS Flows into different DRB parameter as defined in 3GPP TS 23.501.

5G QoS Identifier (5GQI)

5QI is the indicator of a 5G QoS characteristics, which is preconfigured in gNB.

Allocation and Retention Priority

ARP configures the priority level, the pre-emption capability and the pre-emption vulnerability of service. ARP value range from 1-15 where 1 refers to the highest priority. Value 1-8 is configured by the serving network and value 9-15 is configured by the home network.

Reflective QoS Attribute

Optional parameter indicates that part of UP traffic on this QoS Flow flows the QoS Flow.

Notification Control

Indicates whether notifications are requested from the NG-RAN when the GFBR can/cannot be guaranteed for a QoS Flow during the lifetime of the QoS Flow

Flow Bit Rate

Additional QoS parameter contains guaranteed flow bit rate (GFBR) for bit rate over a time window and maximum flow bit rate (MFBR) for highest bit rate. Applies only to GBR Flows.

Aggregated Bit Rate

Contains both per session aggregated maximum bit rate and per UE aggregated maximum. Only applies to Non-GBR Flows.

Default Value

The default value SMF receive from UDM for every PUD session.

Maximum Pack Loss Rate

Indicates the maximum tolerated lost packets rate of the QoS flow, which only applies to GBR flows.

There is also a relationship between latency and the target Error Rate within the same RAN slice, as illustrated below.

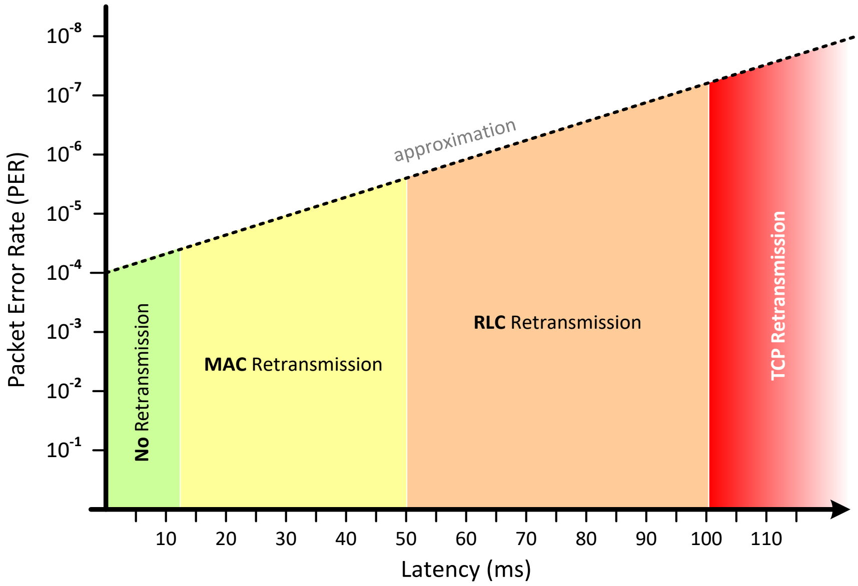

Figure 18: Reducing PER leads to increased latency

The quality of the radio channel will influence latency. Considering, for example, the use of packet duplication [8, p. 118]. When for a radio channel the probability of a packet error is 1% (0.01) and the packet is transferred using two independent channels, each with this probability, the total probability of a lost packet is 0.01 * 0.01 = 0.0001. As a result of this packet duplication the reliability is increased from 99% to 99.99% [9] at the expense of channel capacity in the RAN. The balance between the advantages of packet duplication (reliability, latency) and the costs (use of radio resources) needs to be explored. For local (on campus) usage, where dedicated coverage is available with good field strength, the benefits of using packet duplication to improve latency are probably limited. Although Figure 18 suggests a linear relationship, in practise for individual occurrences this will be a set of staircase-functions (since a retransmission requires a complete package to be retransmitted).

The 3GPP defined 5GQI values [10, p. 204] with the default parameters and example of application is listed in Table 14.

In 5G-Blueprint project, both MNOs made their 5QI design based on standard and configured RAN parameters mapped to these 5QI values. For example:

logicalChannelGroupId

packetDelayBudget

packetDelayBudgetOffset

priorityLevel

are configured differently per 5QI, completing the RAN slicing design. The E2E slicing is described in Section 3.5.

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2	GBR	40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3	GBR	30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages, Electricity distribution – medium voltage, Process automation monitoring
4	GBR	50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65	GBR	7	75 ms	10^{-2}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g. MCPTT)
66	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67	GBR	15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
75	GBR	25	50 ms	10^{-2}	N/A	2000 ms	V2X messages
71	GBR	56	150 ms	10^{-6}	N/A	2000 ms	"Live" Uplink Streaming
72	GBR	56	300 ms	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming
73	GBR	56	300 ms	10^{-8}	N/A	2000 ms	"Live" Uplink Streaming
74	GBR	56	500 ms	10^{-8}	N/A	2000 ms	"Live" Uplink Streaming
76	GBR	56	500 ms	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming
5	Non-GBR	10	100 ms	10^{-6}	N/A	N/A	IMS Signalling
6	Non-GBR	60	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7	Non-GBR	70	100 ms	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming

8		80	300 ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		90					
69		5	60 ms	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g. MC-PTT signalling)
70		55	200 ms	10^{-6}	N/A	N/A	Mission Critical Data (e.g. example services are the same as 5QI 6/8/9)
79		65	50 ms	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality
10		90	832ms	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.) and any service that can be used over satellite access type with these characteristics
82	Delay-critical GBR	19	10 ms	10^{-4}	255 bytes	2000 ms	Discrete Automation
83		22	10 ms	10^{-4}	1354 bytes	2000 ms	Discrete Automation V2X messages (UE - RSU Platooning, Advanced Driving: Cooperative Lane Change with low LoA)
84		24	30 ms	10^{-5}	1354 bytes	2000 ms	Intelligent transport systems
85		21	5 ms	10^{-5}	255 bytes	2000 ms	Electricity Distribution- high voltage V2X messages
86		18	5 ms	10^{-4}	1354 bytes	2000 ms	V2X messages (Advanced Driving: Collision Avoidance, Platooning with high LoA.)

Table 13: 3GPP defined 5QI and parameters

3.3 Core Network

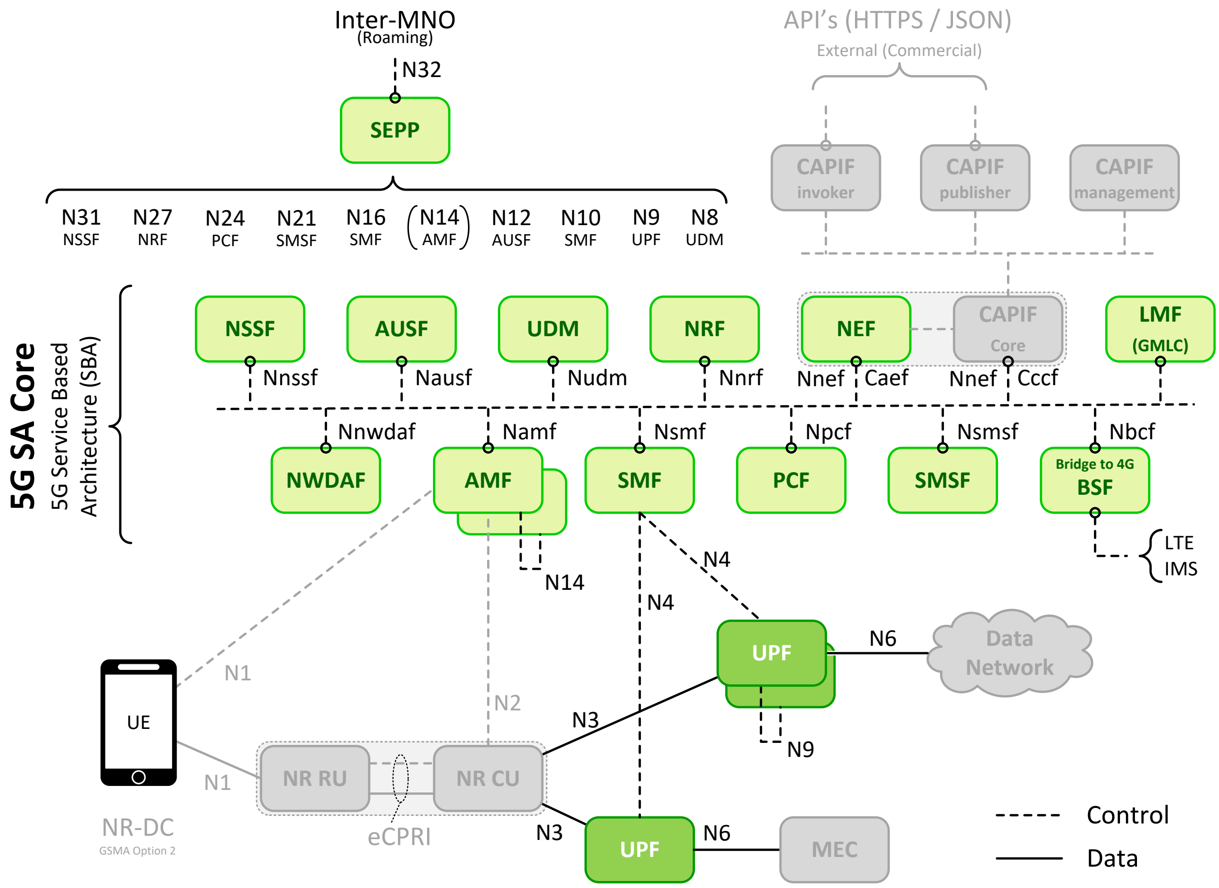

Figure 19: 5G Core Network

3.3.1 Service Based Architecture

The 5G architecture is an evolution of the 4G architecture that introduces however major changes such as the Service Based Architecture. In a Service Based Architecture, as defined in 3GPP, the primary architectural components that are put forward are services, which are used to execute different sets of functions with authorization to access each other's services. These interconnected network functions (NFs) foresee the control plane functionality and common data repositories of a 5G network. The transition to SBA separates the end-user service from the underlying network. The Service Based Architecture for core 5G networks is defined in 3GPP TS23.501.

5GC includes the separation of User Plane (UP) and Control Plane (CP) functions of the gateway, which was an evolution of the gateway CP/UP separation (CUPS) introduced in EPC Release 14. It separated the packet gateways into control and user planes allowing for more flexible deployment and independent scaling achieving benefits in both, CapEx and OpEx. The next step in the evolution to 5G was to rename core network entities and either split or merge them depending on the functions that fall within the user or control plane in the 5G architecture.

CUPS is essential to 5G networks because it allows operators to separate the evolved packet core (EPC) and 5GC into control and user plane. The use of CUPS can increase the flexibility of the network as it provides several deployment options including:

- Co-located control plane and user plane functions (e.g., in the same data center)
- Control plane functions and user-plane functions in a distributed way, across multiple locations

- Control plane function in a centralized location and user-plane functions in multiple locations (e.g., closer to the applications)

Such flexibility enables the network operators to deploy UP and/or CP functions in one or more locations to meet the throughput and latency requirements of 5G services and applications, increasing the QoS and Quality of Experience (QoE) for the users. Especially for latency-critical 5G use cases. The use of CUPS can bring the user plane closer to the user application reducing the latency significantly, as illustrated in Figure 20.

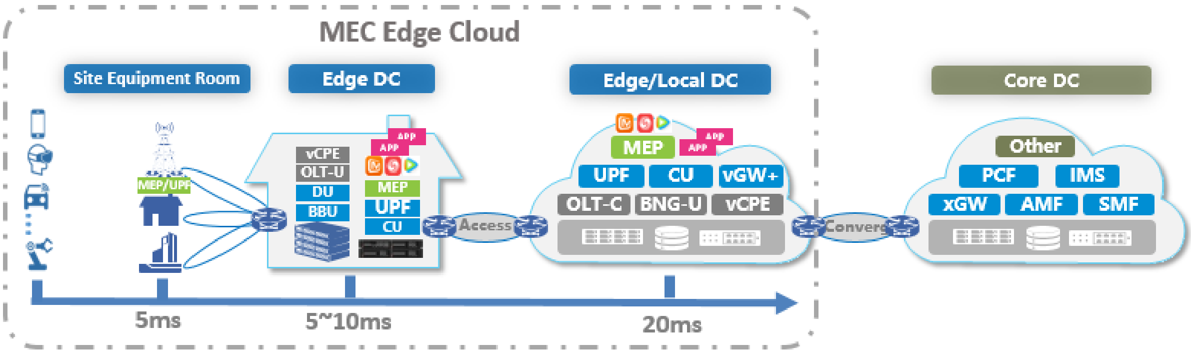

Figure 20: CUPS distributed deployment of NFs

In summary, CUPS can significantly assist in increasing the performance and the flexibility of a 5G network as it allows for:

- Reducing the latency on application service, by selecting user plane nodes which are closer to the RAN without increasing the number of control plane nodes.
- Increasing the throughput, by enabling to increase the user plane nodes without changing the number of control plane nodes.
- Locating and scaling the CP and UP resources of the 5GC functions independently.
- Independent evolution of the CP and UP functions.
- Enabling Software Defined Networking to deliver user plane data more efficiently.

3.3.2 Core Slicing

The 3GPP defined what in context of 5G is meant with “a Network Slice” and an instance [10]:

Network Slice: A logical network that provides specific network capabilities and network characteristics.

Network Slice instance: A set of Network Function instances and the required resources (e.g. compute, storage and networking resources) which form a deployed Network Slice.

In the document NG.116 [3] the GSMA developed a set of minimum attributes with their industry accepted values for the standardized slice types as defined by 3GPP in TS.23.501 [10, p. 204], i.e., eMBB, URLLC, MIoT/mMTC, V2X and hMTC. However, these slice types are so generic that the respective attributes will likely be defined with still rather broad ranges and options, given operators the room to define one or more flavours per standardized slice type based on the needs of their market.

For the specific situation of roaming, GSMA is further attempting to define a minimum set of attributes that would need to be supported by respective slice types in a roaming situation for use cases that require cross-border support. The GSMA document proposes standardized S-NESTs with industry accepted characteristics which can be a basis of roaming agreements. In addition, operators can have bilateral agreements on individual slices (P-NESTs) where needed.

The attributes describing the characteristics of a network slice are related to performance, isolation level, functional support, as well as operational possibilities. Each attribute is classified as either mandatory, optional, or conditional based on the presence and/or value of other attributes. The following list is intended to give an overview of the different attributes only, including an attempted classification into groups. The list is not complete. For a complete and up-to-date list and detailed definition of the attributes please always refer to the newest version of the GSMA document defining the GST (NG.116 [3])

Area of service

- e.g., country(s), region(s), cell(s)

Network

- Radio spectrum
- Simultaneous use of the slice

Capacity/Throughput

- DL/UL throughput per slice/per UE (guaranteed and maximum)
- Number of connections or terminals
- Terminal density

QoS, Availability, Reliability

- QoS parameters (standard 5QI / customized 5QI)
  - If customized: delay budget, packet error rate, jitter, max packet loss rate, …
- Availability – not yet defined in v2 of NG.116
- Reliability – not yet defined in v2 of NG.116

Traffic characteristics

- deterministic/periodicity
- packet size
- delay tolerance

Service support

- IMS support
- NB-IoT support
- Positioning support
- Session and service continuity support
- Non-IP traffic support (Ethernet)
- Supported device velocity
- Synchronicity (for TSN?)
- V2X communication mode (No, EUTRA, NR, NR & EUTRA)

Isolation

- no / physical / logical
- Per network part (RAN, TN, CN)
- User data access
  - Internet
  - Private network termination (tunnel: L2TP, GRE, VPN, Label based routing)
  - Local traffic

Management

- User management openness
- Performance monitoring

The introduction of ‘Slicing’ distinguishes 5G from earlier generations of mobile networks. Slicing allows the optimization of the network behaviour to the need of specific use cases and individual customers. All preceding networks where focused on one uniform performance for all users.

3.4 Transport

The launch of 5G, creates an opportunity to create an open digital infrastructure to support a multitenant mobile infrastructure that delivers the performance and economics required to support the future digital society. By providing a smooth evolution from 4G LTE to 5G the architecture should deliver the future advanced features that 5G promises, building a foundation for enhanced digitization of industry and the wider society alike.

The additional 5G spectrum can be used for a variety of applications, largely grouped together Fas eMBB and URLLC as well as mMTC. eMBB services provide significantly higher network capacities than traditional 4G LTE services. The capacity increase enables mobile operators to provide fixed wireless access (FWA) services, allowing direct access to residential and small and medium enterprise (SME) markets without the cost of last mile access and in many cases removal of dependency on costly wholesale access to local loop unbundling (LLU). URLLC and mMTC services are expected to become available in the second phase of 5G and promise to create new revenue streams for mobile operators. But questions remain whether these additional use cases will be delivered ubiquitously across the network or whether they will be provided on a case-by-case basis, growing organically through a push-pull mechanism between demand and supply between an industry demand and applications availability.

The emerging transport architectures for 5G need to address the commercial benefits associated with network convergence, weighed against the operational complexity of collapsing network layers and functions. Overcoming these challenges is necessary to satisfy the insatiable subscriber demand for more bandwidth.

3.4.1 Architectural Component

With radio densification and new radio functions such as massive multiple input multiple output (mMIMO) and new advanced URLLC services, there is an option to split the base band processing into DU and CU function. Starting in the dense urban areas, the RAN evolves to a C-RAN (Centralized RAN) architecture, allowing the DU and CU functions to be more centralized, as detailed in 3.6.5.

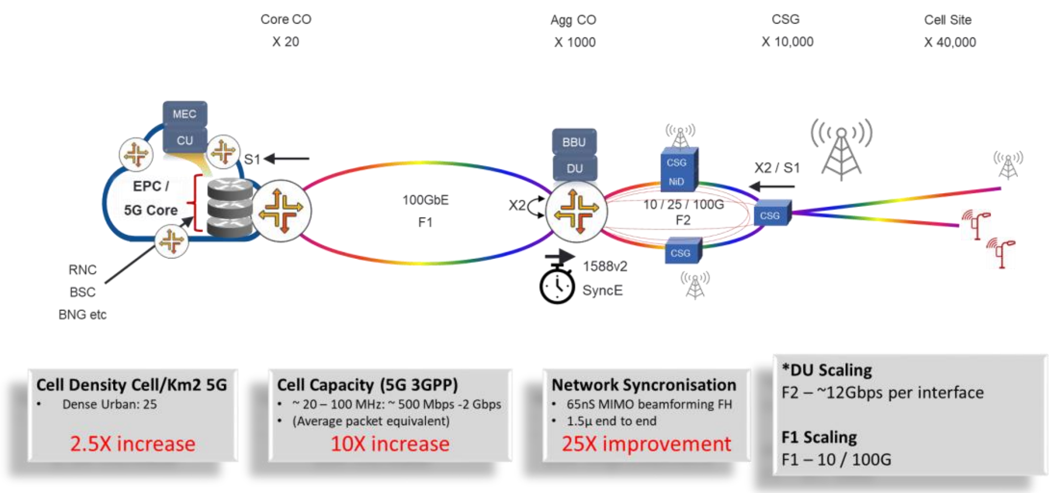

Figure 21: Generic CRAN Fronthaul Architecture

The radio functional splits between radio unit (RU), DU and CU have been largely analysed across the industry. The CU operates the RRC and PDCP functions which are relatively lower bandwidth and with relatively relaxed sync and latency requirements. The DU-CU communication across the midhaul network can adhere to similar network transport requirements to traditional backhaul. The DU function operates the RLC, MAC and High PHY radio functions. With the lower-PHY at the RU, the DU-RU communication is associated with strict bandwidth, synchronisation, and latency requirements. In 5G, this traffic is carried over packet infrastructure using the eCPRI protocol.

In 5G, radio antennae need to be synchronized to allow seamless handover, radio beamforming, spectrum sharing and reuse. The transport requirements are dependent on which radio applications are enabled, the CRAN architecture and radio split points between radio functions. The maximum acceptable time error from CU to RU = <1.5µS, similar to 4G LTE; however, in 5G the radio function will also need to be synchronized in phase as well as in frequency, which was not generally the case in LTE. In the fronthaul segment, the DU to RU transport UNI has stricter synchronization requirements, driven by applications such as inter- and intra-band carrier aggregation and the use of MIMO antennas requiring relative time error below 190ns. This significant increase in capacity, coupled with ultra-low latency and demanding phase synchronization environment requires a shift in the way transport networks are built to cater for new 5G radio applications.

The design in the following sections are based on the O-RAN Open Xhaul Transport Working Group 9 “Xhaul Transport Requirements” (O-RAN.WG9.XTRP-REQ) specifications. The open transport requirements define the solutions and test specifications for fronthaul, midhaul or backhaul, collectively known as Xhaul transport networks. The Xhaul Transport Requirement document states requirements for an Open Xhaul transport infrastructure. The Wavelength Division Multiplexing (WDM) based fronthaul transport document describes best practices for O-RAN fronthaul transport based on WDM technologies. The Xhaul Packet Switched Architectures and Solutions Work Item delivers best practices for deployment of end-to-end packet switching technologies. The Synchronization Architecture and Solutions Specification provides the architecture and solutions for Open Xhaul timing and synchronization and recommends best practices for relevant use cases in Xhaul.

3.4.2 Fronthaul

Requirements and characteristics of the network connectivity between the radio antenna or radio unit (RU) and the baseband unit (BBU) in 4G or distributed unit (DU) in 5G are referred to as the fronthaul network. 4G fronthaul uses the CPRI protocol which is typically proprietary and 5G uses the enhanced CPRI (eCPRI) protocol which is based on standardized Ethernet framing.

The key to open fronthaul is to create a tiered fronthaul transport network. The underlaying transport infrastructure shall provide the transport infrastructure and allow multiple Mobile Network Operators (MNOs) to operate over the network. The O-RAN 7.2x Control and User planes run between the O-RUs and their serving O-DU. Ethernet encapsulation is a mandatory requirement. The latency requirements associated with 7.2x control plane and user plane traffic are very low, and the bandwidth requirements are high.

However, the initial traffic requirements may be modest but reach and coverage requirements are high. This means that the transport network, providing the reach and coverage must be versatile and scalable in order to allow for pay-as-you-grow architectures. The only technology that allows both flexible and independent transport combined with the high requirements on latency, slicing and transport characteristics is WDM technology. There are various WDM network architectures that can be used, such as passive WDM, active WDM, and semi-active WDM. Auto-tuneable transceiver technology enables a pluggable optic directly hosted in a non-DWDM system, such as a cell site gateway router, to autonomously tune to the correct wavelength (10G, 25G or 100G) for the DWDM port it has been connected to. This technology is software that is integrated into a transceiver generally available from the industry supply chain and leverages the current tunability of a transceiver but through intelligent automation moves the point of tuning from the host system to the transceiver itself.

3.4.3 Backhaul

Backhaul and midhaul requirements for 5G networks are largely very similar to those required in current 4G networks. Traffic requirements will ultimately be higher in 5G networks and new management and control functionality to support network slicing will be required but the underlying transport mechanisms operate in a similar manner to 4G networks today.

DWDM provides the most common mechanism for mobile transport in midhaul and backhaul networks connecting IP routing, DU and CU nodes and MEC locations. In multitenant networks DWDM provides an economic mechanism of separation with separation of traffic either at the wavelength level for full separation or with dedicated lower-level bandwidth.

3.4.4 Synchronization

The key applications in Teleoperated Transport and Logistics such as high-quality positioning, the high availability requirements that mandates efficient and reliable transport. Traditionally positioning and navigation have been using GNSS infrastructure to deliver the services. Due to the importance of the resilience and robustness of network synchronization for teleoperated transport and logistics these factors are leading to requirements to security and resiliency handle the high-performance synchronization delivery inside the transport network as part of the transport service.

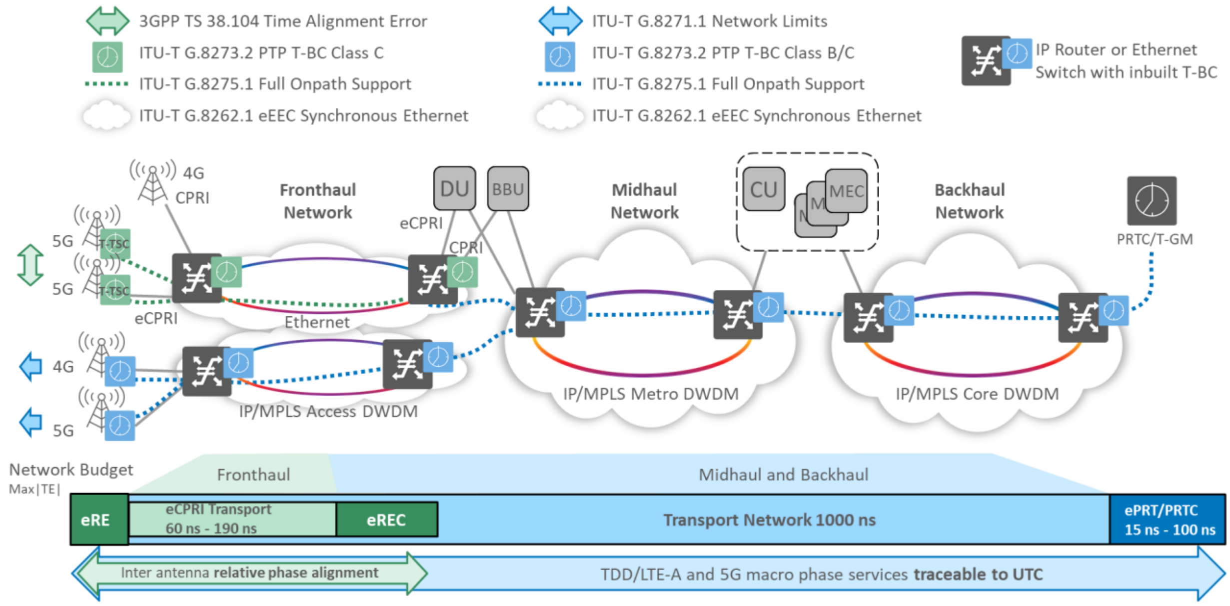

Figure 22: Synchronization and Timing Specifications for 5G Transport

3.4.4.1 Backhaul timing requirements

Backhaul networks must be built to allow for transparent transport of PTP phase and time information to the MEC locations on the edge of the backhaul network. Most often this is called a timing cloud. Alternatively, there could be complete out-of-band requirement to connect to the timing cloud at MEC locations in the end of the backhaul network.

3.4.4.2 Midhaul timing requirements

The midhaul network Backhaul networks must be built to allow for transparent transport of PTP phase and time information to the MEC locations on the edge of the backhaul network. Since each MNO may provide its own time and phase domain, the transport infrastructure for the midhaul network must be able to allow for multiple timing domains over the same transport infrastructure.

The midhaul transport requires G.8275.1 full on-path support so all nodes in the timing service chain must be timing aware. Transparent transport of PTP phase and time information to the MEC locations and the requirement for multiple timing domains over the same transport infrastructure means that there cannot be shared T-BC function inside the transport network. All nodes in the transport network must either provide inline transport of timing while maintaining phase synchronization properties such as constant time error (cTE) and dynamic time error (dTE). Alternatively, optical timing channels (OTC) may be used, and the included nodes in the OTC can only perform 3R ("3R" means re-shaping, re-amplifying and re-timing so the last R, "re-timing" must be made in a transparent and 5G compliant manner) or apply a high-performance Telecom Transparent Clock (T-TC) function.

All time and phase synchronization in 5G networks as well as in Teleoperated Transport and Logistics networks are supported by a physical layer frequency. This frequency is delivered by Synchronous Ethernet (SyncE) specified by G.8262.1 enhanced Ethernet equipment clock (eEEC). There are however no requirement to supply multiple frequency domains, the MNOs all use the same supporting frequency, traceable to ePRTC reference, for support of their time and phase domains.

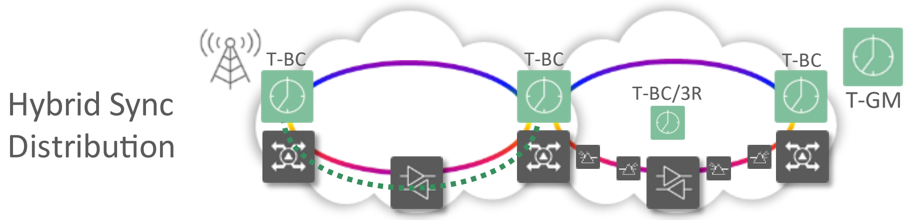

Figure 23: Hybrid Synchronization Distribution

3.4.4.3 Fronthaul timing requirements

Fronthaul networks have the same requirements for transparent timing delivery, but the requirements for timing accuracy are much higher.

Fronthaul network, with requirements on eCPRI delivery of inter- and intra-band carrier aggregation and the use of MIMO antennas, have very demanding relative phase error budgets in 5G networks. The measurement at the UNI of the O-RU of as low as 190 ns to just 60 ns. The corresponding time alignment error (TAE) specifications, which is defined as the largest timing difference between any two signals, of 260 ns to just 130 ns which is measured at the antenna. The 1.5 µs absolute phase error requirement which is still required at every cell site, this is an additional requirement to control the relative phase error between all the cell sites within a 4G BBU or 5G O-DU cluster.

3.4.5 Inter-MNO Transmission

In the majority of the use-cases the transmission between components of the Service Based Architecture (SBA) of the 5GC is local in the building in which the instance of the 5GC is situated. The in-venue delay is in the sub-ms range and can be neglected.

For the use case of Seamless Roaming based on the N14 interface, the 5GC can be distributed. In this case two AMFs from different MNOs are connected via this N14 interface and a Security End Point Proxy (SEPP) in the domain of the two MNO's. The transmission path of the Control Plane is sketched out in Figure 24. The routing of S10 signalling for the equivalent function in LTE uses a comparable trajectory.

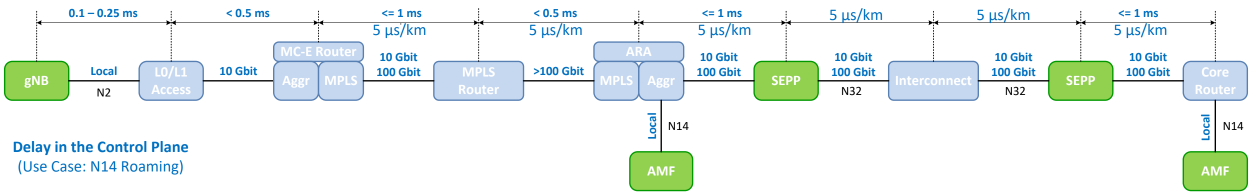

Figure 24: Transmission path Control Plane (example: N14)

This (one-way) transmission delay between MNO's needs to be factored in when evaluating the time it takes to perform a cross border seamless handover (based on the N14 or S10 interface).

For Further Study:
A method to do precise measurements of the delay in the transmission path between MNO's needs to be developed. Synchronization between the different measurement points and equipment is (probably) necessary.

Further Study 1: Measurement of inter-MNO transmission delay

3.4.6 Transport Layer Slicing

The complete transport network should be ultimately capable of supporting 5G network slicing once the ongoing work within the relevant standardization bodies has completed. The transport network has a vital role to play as part of wider end-to-end network slicing strategy that covers all aspects of the network from the RAN through the transport network to the core. In order to achieve this, the orchestration and control functions of the transport network will need to support open APIs to a higher-level end-to-end service/slicing orchestrator as shown in Figure 25.

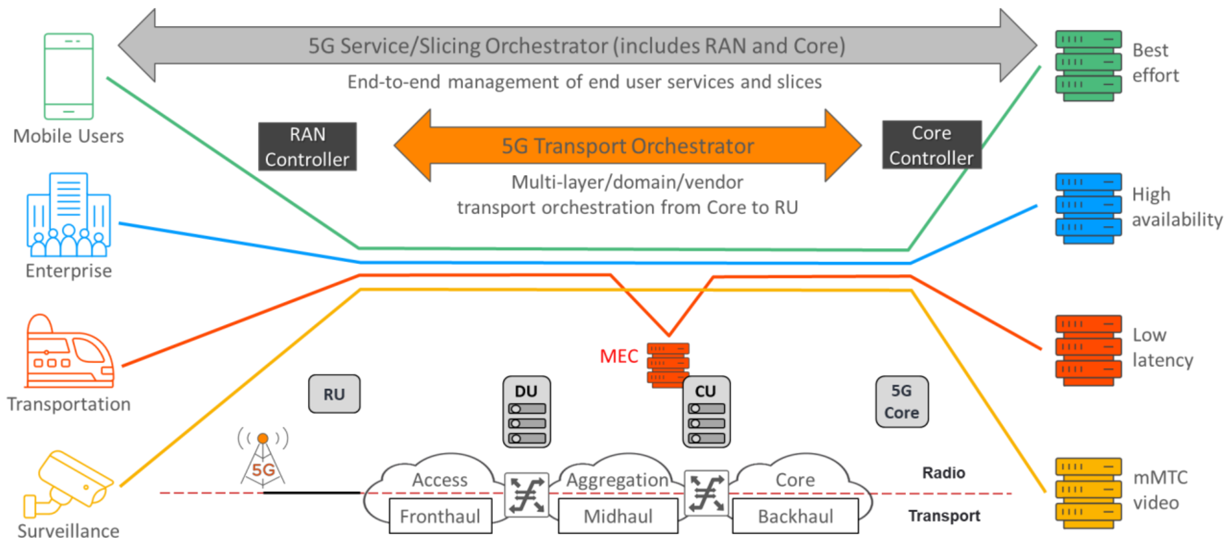

Figure 25: 5G Transport Network Slicing Architecture

5G slicing within mobile transport networks will need to deliver both "hard" and "soft" slicing capabilities in order to support multiple service types within the network. Hard slices will be dedicated bandwidth allocated to a specific slice using existing fixed bandwidth mechanisms such as DWDM wavelengths or layer 1 bandwidth mechanisms. Soft slices will be variable bandwidth allocated to a specific slice using existing variable bandwidth mechanisms such as existing Ethernet or IP bandwidth mechanisms. Hybrid slices will use a combination of these mechanisms to provide a combination of fixed and variable bandwidth to a slice.

The 5G transport orchestrator will need to manage slices across the transport network and their interaction with RAN equipment located within the network such as the DU, CU or MEC capabilities. The 5G transport orchestrator will need to manage all transport equipment from layer 0 (WDM) through layers 1 and 2 (OTN and Ethernet) through to layer 3 (IP) end-to-end across the transport domain. This capability may involve sub controllers to manage specific layers, vendors or geographic domains.

3.5 End-to-End Network Slicing

As discussed in Section 3.1.1 regarding 5G UE capabilities, Section 3.2.4 RAN slicing, Section 3.3.2 core slicing and Section 3.4.7 transmission slicing, a combined E2E slicing design is presented in this section. As a result, and end to end soft slicing with logical separation between RAN, transmission and core resources is designed. Such design based on public network and no hard server and hardware resource represents the most feasible way for mass roll out. Each IP flow from use case applications can be identified and secured in QoS flow and resulted in different DRB mappings as shown in figure below.

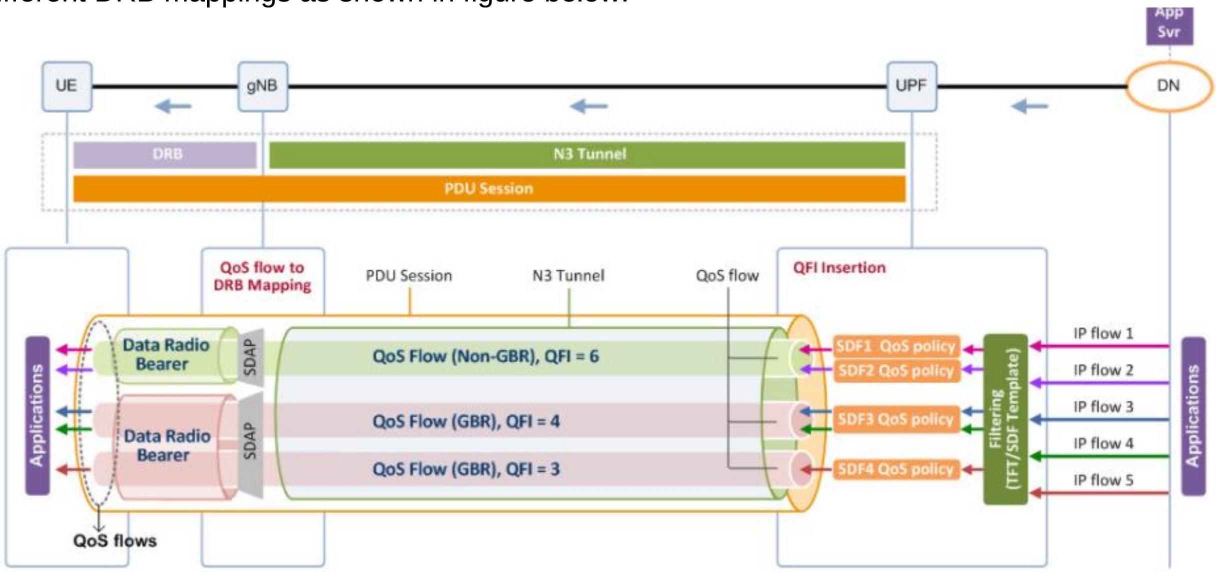

Figure 26: 5G IP flow, QoS flow and DRB mapping [11].

This E2E soft slicing will be implemented in KPN and Telenet network by using GSMA generic network slicing template NG.166. The advantage of using such slicing tool from standardization is to provide the best means of inter-MNO coordination. The process flow of translating use case input to parameters in slicing template is shown in figure below. Please note that the initial network analysis is based on input of WP4 where industrial partners have their network requirements to fulfil their vertical needs. MNOs can take consideration of special requirement and able to customize new additional slices if necessary.

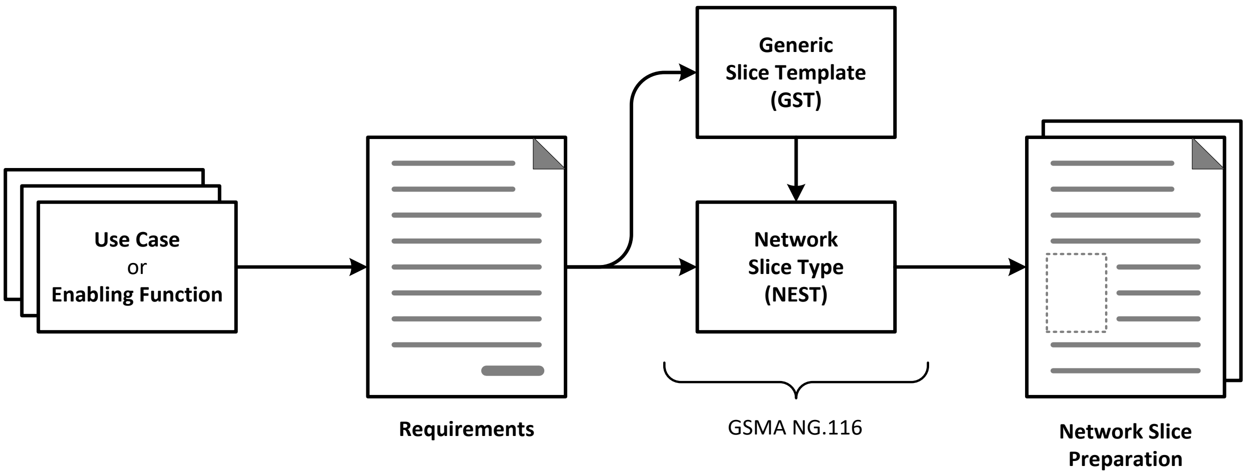

Figure 27: From Use Case to Requirement

In the 5G standard five basic Slices are defined [10]. Those are:

- **eMBB**
  This slice type is best suited for Voice and Video services.
- **URLLC**
  This slice type is best suited for mission critical services with low latency tolerance and high long term reliability.
- **MIoT/mMTC**
  This slice type is best suited for infrequent and small messages and potentially a high geographical density of devices.
- **V2X**
  This slice type is best suited for machine to machine communication whilst at least one of the parties is mobile.
- **HMTC**
  This slice type was introduced in 3GPP release 17 as a precursor to full URLLC (which is not yet achievable with current technologies in the Radio Access Network).

In 5G-BP these aforementioned basic slices are further elaborated by tailoring them towards the vertical needs of our industrial partners. The slices we are considering in 5G-BP are as following:

- **eMBB (UL)**
  An eMBB slice prioritized in uplink traffic, based on analysis of UC1, UC2, UC3, UC4 and EF4. This eMBB slice has the highest priority among all eMBB slices.
- **eMBB (regular)**
  An eMBB slice defined for regular 5G consumer device users, based on analysis of EF2. This eMBB slice has the lowest priority among all eMBB slices. It can be pushed to legacy technologies is network resource limits.
- **eMBB (DL)**
  An eMBB slice prioritized in download traffic, based on analysis of UC1, UC2, UC3, UC4. This eMBB slice has the lower priority than eMBB (UL) slices, as it is defined to provide abundant connectivity towards teleoperation centers.
- **LTE-M**
  An IoT slice defined for machine communication with small message and infrequent connection, based on analysis of EF3 and EF4.
- **HMTC/URLLC**
  A high reliable slice defined for critical control signals based on analysis of UC1, UC2, UC3, UC4.
- **V2N**

A performance slice defined for 5G UE that are on mobile, based on analysis of UC1, UC2, UC3, UC4.

3.6 Multi-Edge Computing (MEC)

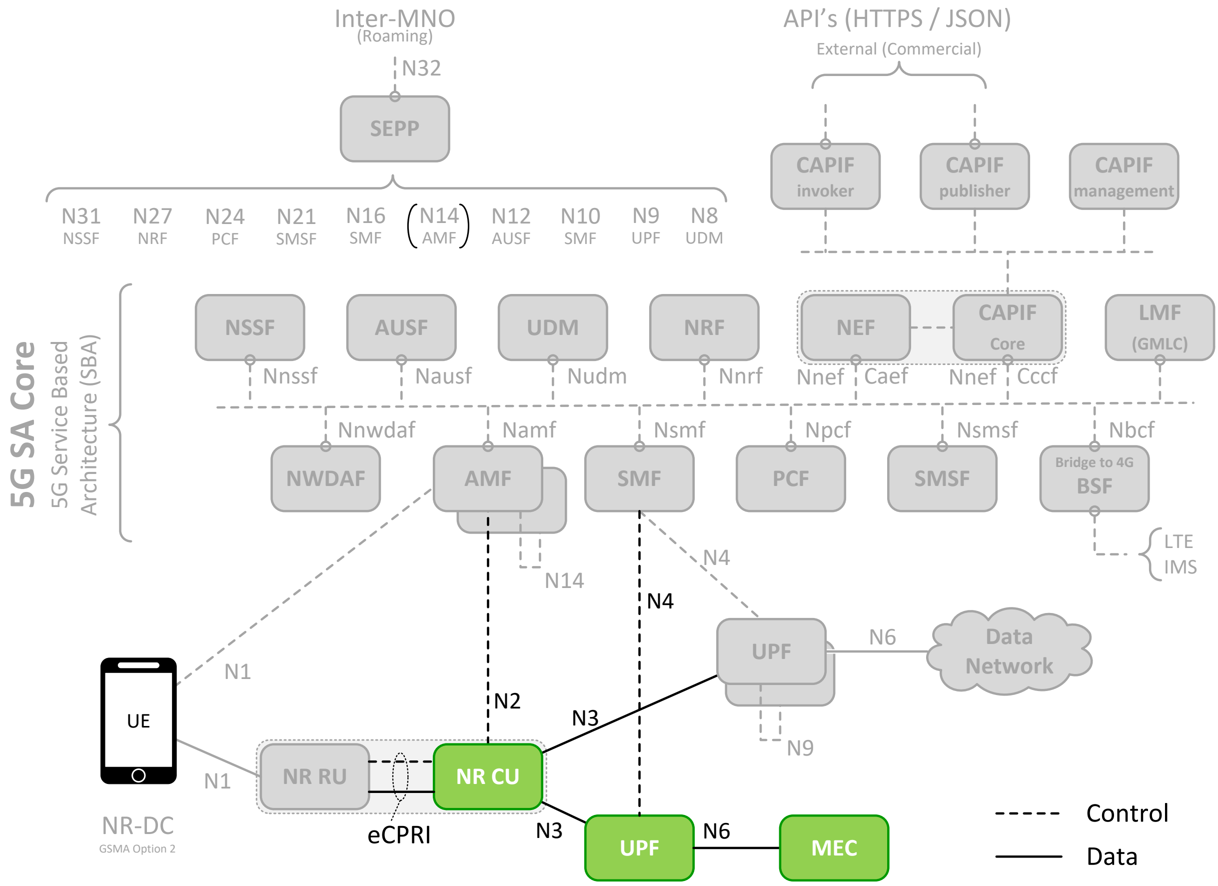

Figure 28: Multi-Edge Computing

Edge computing is a generic term that refers to the use of decentralized processing power for processing data closer to the user, rather than transmitting it to a far-away data centre. There are several possible “edge” locations, depending on the use case considered. The general advantages include a lower latency, relieving network load in the core networks, and potentially keeping data locally for security/privacy reasons (isolation).

While ETSI is standardizing a Multi-access Edge Computing (MEC) framework [12], 3GPP is providing support for edge computing within the 5G system architecture [10, p. 5.13], including UPF (re)selection procedures, network capability exposure, and support of local area data networks. The combination of Edge Computing and Network Slicing will allow an application dependent routing of user data to either a specific edge location or to the general service endpoints of the MNO (e.g. for IMS or Internet), thereby providing high flexibility and ensuring application dependent requirements such as latency, user data flow isolation, etc.

There are several possible edge locations as shortly introduced in the following.

3.6.1 Edge Computing at a local operator data centre

The UPF for the user plane termination is located in MNO's local data centre such as an Metro-Core (MC) location, and the respective application platform is located at the same local data centre. The advantages are:

- MNOs can offer processing power with a cloud installation at the local data centre, thereby providing the service provider the possibility to offer low delay services to our customers without having to provide own infrastructure.
- The user data can either be processed in a local cloud installation at MNO's local data centre or be routed via private VPN connections to the customer's data centre to be processed there, with potential mixed scenarios.
- Use cases get the advantages of a lower latency and/or a certain amount of data isolation.
- V2X service platforms located at a local data centre can potentially provide lower latency services.
- In this case, however, mobility and session service continuity will be important, such that sessions will need to be transferred from one local data centre to a neighbouring local data centre when the 5G user moves to a new coverage area.
-

3.6.2 Edge Computing at Cell Tower

Theoretically, local processing equipment could be provided at the cell tower itself, leading to even lower latencies and keeping user data extremely localized. This equipment would still be completely part of the operator network/management and hence can potentially be used for several customers at the same time.

Considering the high costs of dedicated computing resource, the complexity in management, limitation of onsite power and space, and limited latency gain as 5G transport network can deliver data to centre nodes via fibre network, we currently do not consider this solution as economical and realistic.

3.6.3 Edge Computing at Use Case Owner's Premises

Business customers such as large enterprises, production industries such as refineries and smart factories, etc., have raised increasing interest in either very low latency applications or to keep their data on site for security/privacy reasons. To support such demands, the UPF can be placed at the customer premises itself and directly be connected to the local customer data centre.

From 5G architecture perspective, this concept is only realistic when combined with a local radio network installation, e.g., an indoor radio network. Such a concept is often referred to as a "Campus Network". This can be realized either with the operator's radio spectrum, or via a private radio spectrum from the enterprise itself. The latter one is further discussed in Section 3.6.7.

From use case input, there are existing computing resource on any use case owner's premises (e.g., tele-operation centre in trail area) for the 5G enabled UCs and EFs. Thus, this solution is both beneficial and feasible. It will be further evaluated in planning and deployment phase.

3.6.4 Distributed computing over Device, Edge, and Cloud

Certain use cases might benefit from a smart distribution of the computation load between the public cloud, the edge cloud and the device itself. One exemplary use case would be around machine learning, where the main training of the model would run in the public cloud or edge cloud, and the actual application of the model is done on the device itself.

An advantage of data processing in the device is extremely low latency (e.g. for quick reaction times such as sensors in a car or other IoT devices). Further, pre-processing in the device itself (e.g., compression, data transformation, aggregation) can limit the eventual amount of data that is sent towards the network and thereby save network resources.

However, any considerable data processing in a device requires higher processing power and consumes more energy. This usually means higher device complexity and therefore higher device costs. Especially in massive IoT use cases that is not always economically feasible. Here, may be of advantage to deploy simple devices and run data processing in the cloud or a local edge computing instance.

3.6.5 Edge Computing and RAN split in Central and Decentral Units (CU/DU)

An Edge Computing platform at one of the locations in the network as explained above will be reached via UPF of the 5G mobile core network (5GC). In many cases, this UPF will be placed at the same location as the Edge platform. The UPF itself is reached via the Data Plane (DP) part of the RAN Central Unit (CU). In MNO's contemporary RAN, the DU and CU are still collocated on the actual cell site. This allows for placement of UPF and Edge Platforms either close to the RAN site, e.g., at enterprise customer premises, or at local data centres of the operator.

In case of a potential move to distributed RAN concepts in the future, the relation to Edge Computing needs to be considered as well. Figure 29 from the NGMN [1, p. 11] shows the different options for a distributed RAN, some of which include a MEC option. Estimates on the latency of the different MEC implementations is discussed on [1, p. 12]. Use cases requiring URLLC can only be realized using MEC or Local Break-Out (at the gNB) close to the RAN site. For example, either with the CU at the Cell Site RAN in case of a Monolithic scenario, or via a remote User Plane part of the CU (CU-UP) at the RAN site in case of a distributed RAN scenario, where the main CU is located at an operator's data centre.

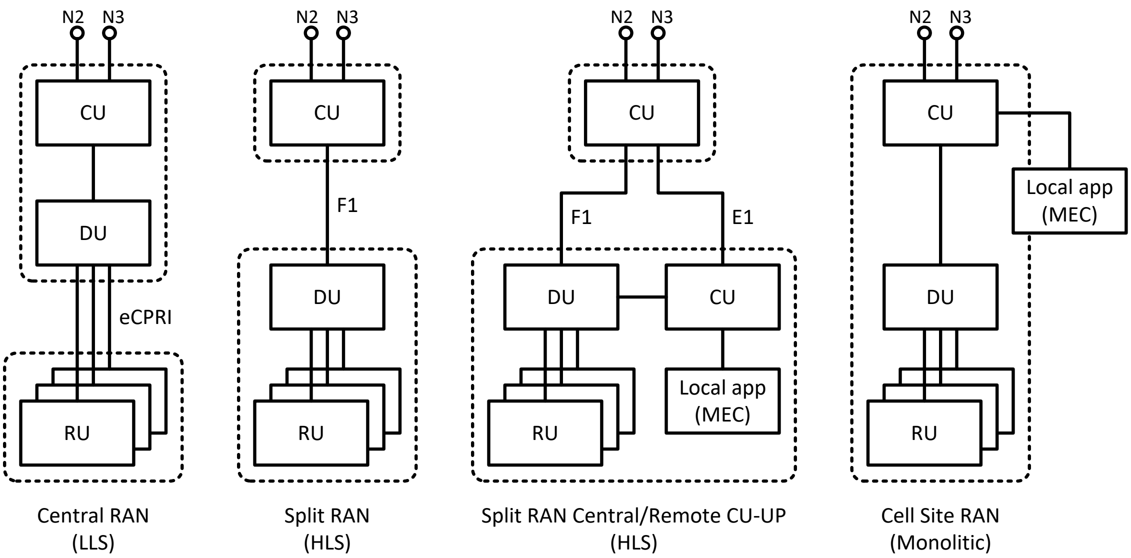

Figure 29: Possibilities to Split the RAN (in Central and Decentral units)

3.6.6 Edge Deployment Strategy

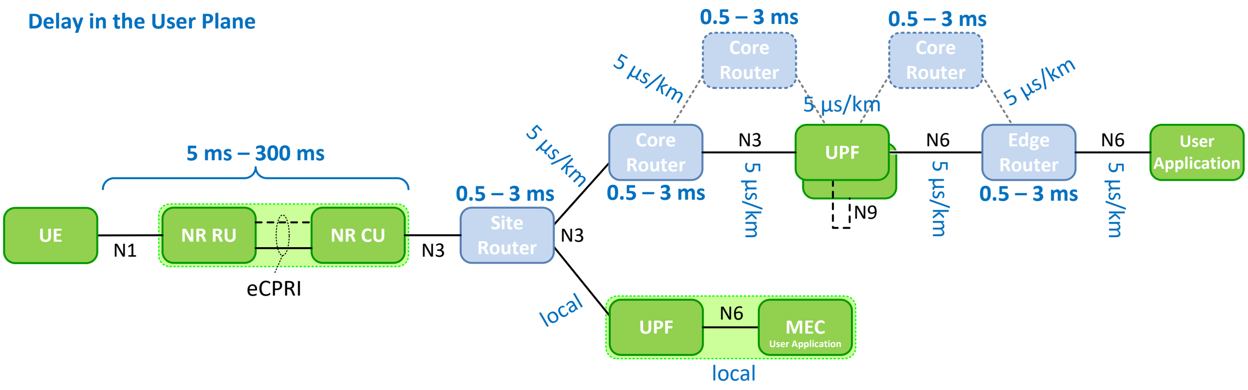

Figure 30: Sources of delay in the E2E chain

As a rule of thumb network elements which contain a memory (e.g. a buffer or queue) add delay. In Figure 30 the typical delay contributions of the different components in two Edge computing scenarios are shown:

- the top route is Edge Computing at a MC location
- the bottom branch encompasses a local break-out of the User Plane traffic to a local instance of the UPF at the site router.

As illustrated above, there are more possible paths and thus possible values of the delay in the top branch. This causes the variance in delay to be larger than in the bottom branch.

Considering also the latency vs packet error rate relationship discussed in Section 3.2.4, the two provisional conclusions regarding Edge Computing in a mobile network are:

- On short term no Edge on MC locations for customers (latency gain compared to central core locations in a country of the size of Belgium or the Netherlands is below 5ms)
- Local Edge on customer premises (e.g. industry terrains) is however an option. See more detailed discussion in the section on “Campus Networks” or “Non Public Networks”.

In this project no centralized MEC solution is considered as necessary given the lack of gain and no need for private networks.

3.6.7 Non-Public Networks

This section describes the potential requirements of enterprises that could be fulfilled with concepts of local “campus” networks, which in 3GPP standards are referred to as Non-Public Networks (NPN).

A description of what private 5G networks are and how they can be used in an industrial context is provided by the GSMA [13].

3.6.7.1 Enterprise requirements for local networks and edge computing

Across all sectors including the production and process industries, industry parties are working on the further digitization and automatization of their work processes, including the work process of the employees, the production processes, maintenance procedures, etc. The connectivity between people, machines, devices and sensors is an important base for this development, and 5G mobile network technologies are promising new possibilities (such as low latency as well as eMBB applications in the production process, video communication incl. added information via AR, training via VR, video based sensors, etc).

Industrial sites differ in setup and structure. In the process industry (such as refineries) there are large terrains with mainly outdoor areas, while the production industry usually has one or several indoor production halls plus potentially an outdoor area in between the buildings. A further example are warehouses and delivery centres, where again large indoor areas are predominant. Exemplary application areas of 5G technology in the factory of the future, as well as the respective requirements, are for example identified in [14].

KPN has and is continuing to investigate and evaluate various industrial use cases in our field labs in Rotterdam (with Shell) and at the Brainport Industries Campus (BIC) in Eindhoven, e.g., AGVs machine control via local edge cloud, etc. Potential needs of such industry parties:

- Sufficient indoor/outdoor coverage on the industrial terrain
- Sufficient network capacity
- Guarantees in (low) latency and/or available capacity
- Keeping the user data on site (in case of very stringent data privacy/security requirements)
- Network isolation
- High availability and reliability

Depending on the given scenario and requirements, various technical solutions are able to deliver the required capacity, latency, as well as reliability. These solutions can consist of dedicated local coverage, network slicing, edge computing, up to a complete local non-public network.

3.6.7.2 Deployment Scenarios

The mobile network standardization has taken these requirements and developed various options to support such industries with 5G networks. These options differ in the level of separation between the public network and the local network at the industry. In the 3GPP standards (see [10, p. 5.30], NPN are differentiated between SNPN (Standalone Non-Public Networks) and Public Network Integrated Non-Public Networks (PNI-NPN).

The GSMA white paper [15] summarizes the different deployment options with respect to the core network integration as depicted in Figure 31

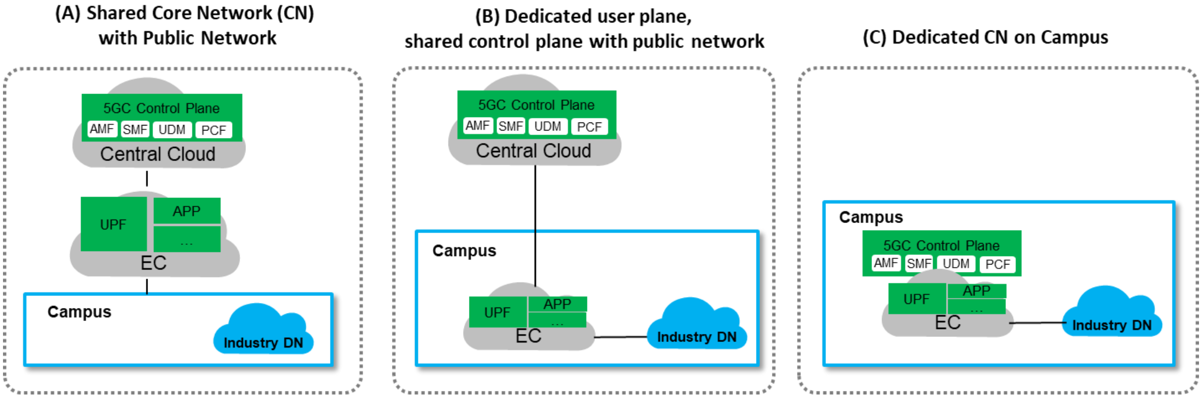

Figure 31: NPN deployment - Core network options

(A) Core Network shared with public network; potentially realizing User Plane and applications in an Edge Cloud of an operator's data centre closer to the customer; isolation and QoS can further be achieved by network slicing

(B) Control plane shared with public network, user plane dedicated locally in an Edge Cloud on premise; isolation and QoS can further be achieved by network slicing

(C) Dedicated local core network, i.e., independent from operator's public network; this is in fact a private network, which however might still be operated by an operator, although not necessarily. Interconnection with a public network, e.g., for using certain services, is possible, but requires special setup.

Models (A) and (B) are PNI-NPNs, model (C) is a SNPN. The deployment models differ in the level of network separation and supported services from the public network. All three options can either be realized with a dedicated local RAN, or via RAN sharing with the public network RAN. In case of factories and warehouses it can be expected that rather dedicated RAN sites will be utilized.

3.6.8 User Plane Functions on Location

The SBA is an enabler for local break out of a Slice. As shown in Figure 30 local break out for Edge Computing requires the separation of the UP and CP in the N3 interface at the Site Router. When this router supports Slicing it is possible to do this local break out selectively for specific Slices (or specific User Groups). The UP data is routed to a local instance of the UPF. The CP using the N4 interface to the Session Management Function (SMF) is processed in the 5GC of the MNO. The N3 and N4 interface is well standardized. In principle this allows for an UPF implementation from another vendor than that of other components in the 5GC (e.g. the SMF). Choosing different vendors requires Multi-Vendor Integration (MVI) efforts both in the 5GC and at the dedicated UPF location. MVI implies synchronized testing of software updates and upgrades every time one of the vendors releases such update/upgrade. This also applies to the testing of gNB software (on the N3 interface to the local instance of UPF).

3.7 Roaming

This is section, the high-level architecture and critical elements for network steered roaming are discussed. The final 5G NSA. 5G SA and dual SIM solutions that will be implemented and tested are described in D5.3, including detailed design, deployment description, testing methodologies and results.

It is a common issue amount MNOs that a large number of interruptions during border crossing. The UE intents o stay connected to the network it currently has a connection with, independent of whether this is the Home PLMN (HPLMN) or a visited PLMN (VPLMN). The UE only starts to perform a full network scan after the current connection is completely lost. After the scan will try to connect to a network that: 1) is not blacklisted by the HPLMN or UE; 2) has a sufficient signal strength.

3.7.1 Seamless Roaming

There are two potential solutions to solve this problem: proactive measures taken by the UE, and proactive measures & steering from the current network.

In case of measures taken by the UE to lower the disconnect time or keep a redundant connection:

- **Fast registration**
  The goal is to have the UE register in the new network within the allowable interruption time. To speed up the registration, the UE receives a hint on the new network to register on before it is disconnected from the current network. The hint can be provided by an application running on the device/SIM or, in a later phase of roaming functionality deployment, from the network. Furthermore, to benefit from this hint, the UE is prevented from doing a complete scan for candidate networks. This can already be achieved by manually disabling automatic network scan on the UE. The application will trigger a network search before the connection is lost and steer the UE to a new network. Initial tests at the Dutch-Belgium border show that the reconnect time can become as low as 1 or 2 seconds (depending on the PLMN chosen).
- **Dual modem**

In this solution a connection to the new network is set up before the current connection is lost (e.g., make before break). In current implementations, this would require two SIM cards and two 5G modems to temporarily have parallel connections to the two networks. Also, an application layer aggregator is needed as discussed in Section 3.1.

In case of measures from the network to the steering of roaming and providing a handover between bordering networks:

- **Optimization of roaming steering**
  Aims at selecting the best network for the UE and its services. The HPLMN is responsible to set up the roaming agreements with the VPLMNs and allows the UE to make use of them. The UE should always be steered to the most optimal network, be it to utilize the specific services it requires or to benefit from the best (wholesale) roaming business model and rates. Therefore, current technologies need to evolve from denying services on non-preferred networks to steering the UE toward the preferred network.
- **Inter-PLMN handover**
  The well-known intra-PLMN handover is extended to work across PLMN borders. In 4G, this involves introducing an S10 interface between MMEs of the two bordering network operators. In 5G SA architectures, this translates to an N14 interface between the AMFs (potentially absorbed in the overall N32 interface between the two operators' SBA architectures in the control plane). As pointed out by earlier measurements in trials by Ericsson [16], there is no noticeable interruption because of the handover and the latency keeps well below 100ms during such inter-PLMN handovers. Currently the N14 interface has not yet been earmarked to be used as a roaming interface. Although the inter-PLMN handover has been described since 2006 in 3GPP release 8, it has as of yet not been adopted by operators. This is probably due to the lack of demand and the complex integration that is required. The current technology for seamless roaming has some serious drawbacks, such that it is almost impossible to implement across multiple countries in Europe.

3.7.2 Data routing

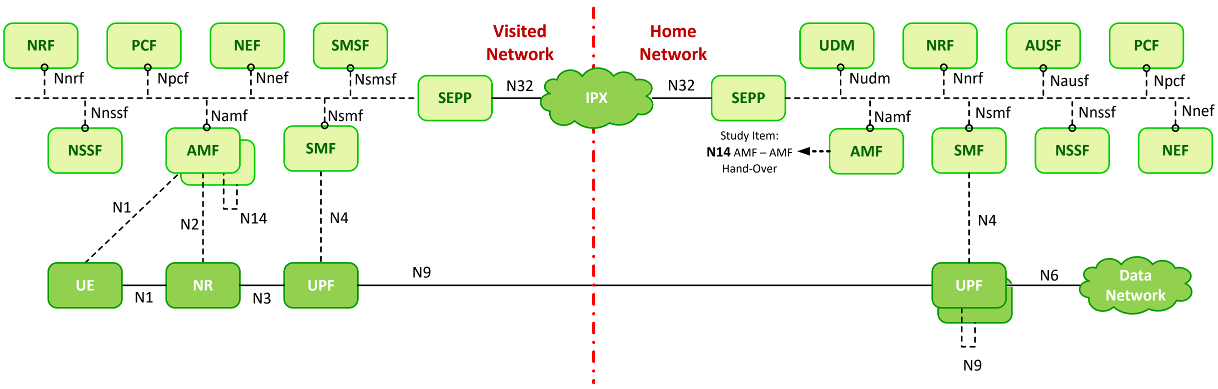

Figure 32: Roaming, Home Routing

As illustrated in Figure 32, It is expected that keeping the home-routed connection when roaming will result in an unacceptable increase in latency because of traffic routed over the GRX/IPX network between the Current(C)-VPLMN and Next(N)-VPLMN. Given the strict latency requirements for project use cases, a local breakout becomes necessary by keeping the traffic in the Next-PLMN as illustrated in Figure 33.

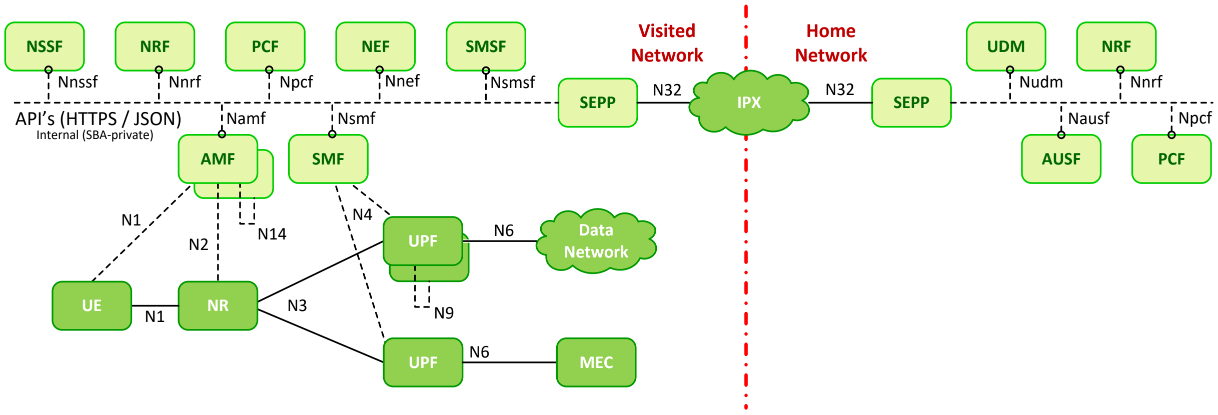

Figure 33: Roaming, Local Break Out

However, setting up a session to the new data network will take extra time. The UE will need to be registered in the new network after which a PDU session can be setup to the closest UPF. By keeping the connection to the C-VPLMN before the connection to the N-VPLMN is active an interruption is prevented, following a make before break scheme. Although the connection is uninterrupted by keeping the connection to the C-VPLMN, this will result in a temporary increase in latency. The make before break scheme is part of current standardization on session and service continuity mode 3 [10]. It is however unclear if this will be possible during inter-PLMN handovers. In addition, it is unclear how the application can work together with SSC mode 3 since most applications have some form of state. Even a simple in-vehicle MQTT application for message exchange builds up a TCP/IP session with a central hosted MQTT host and subscribes over this connection toward one or more topics. This in-vehicle application would need to be notified of a connection change such that it can build up a connection to the new MQTT system on the new edge before disconnecting from the previous edge. As an alternative, it is also possible to introduce a central control system, acting as an application function toward the mobile network and coordinating the discovery of the closest data network and edges that serve the necessary CCAM services. The central control system receives updates on the changing position of the UE in the network and based on that instructs the UE and application running on the UE to connected to the new closest data network offering the services needed. Potentially this central service can also contain information of the services offered in the N-VPLMN.

3.7.3 Scalability of Seamless Roaming

When designing a roaming architecture, the consideration should go beyond the HPLMN and VPLMN, but also the current PLMN. With such approach the design becomes more scalable across multiple borders. Figure 34 illustrates a vehicle that is already roaming on a VPLMN and crossing a border into a new VPLMN. In this document, those will be referred as Current-VPLMN and Next-VPLMN respectively.

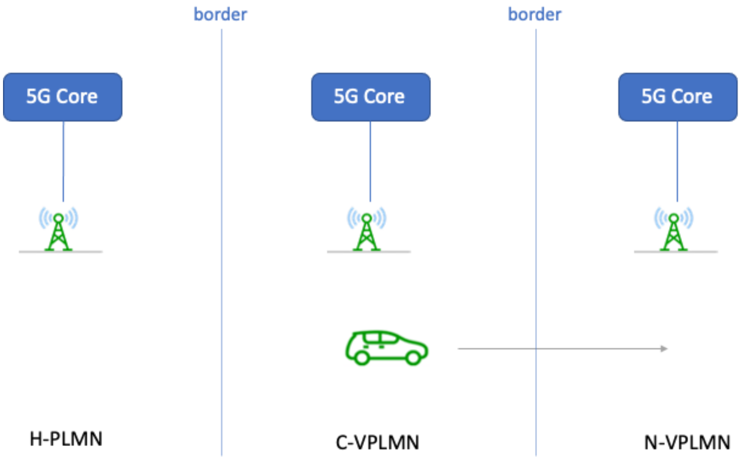

Figure 34 Example of roaming relations

When considering the bordering networks of the HPLMN, it is possible to create an optimized seamless roaming solution with the VPLMN. Most MNOs have roaming agreements in place, with specific preferences of certain operators. For instance, due to certain contractual agreements that exists, it should be possible to select the N-VPLMN when coming from the C-VPLMN based on the H-PLMN preferences. Currently standards do NOT support a selection mechanism based on preferences of the HPLMN. It is up to the RAN configuration at the border to hand-over to the base-station of the VPLMN, ignoring user specific subscriptions or roaming agreements.

To configure seamless roaming, configuration on RAN at the border are needed so that base-stations are aware of the bordering base-stations in the other PLMN. More specifically a base-station need to have the list of frequencies and cell-ids of the neighbouring base-station from the other network across boarder. The base-station can request the UE to also measure those frequencies proactively. It is worth researching if an extension of the Automatic Neighbour Relation function can be used to build this list automatically. For instance, requesting the UE to do a full search and update the list based on the searched frequencies and cell-id's. This is however not possible with current UE's and network technology. As a start we would start with manual configuration conder trust and data governance between KPN and Telenet.

When seamless roaming from a certain network at a certain border, the UE will need to take preventive measures such that it does not lose the connection longer than necessary. A fast reconnect scheme or a dual modem setup can be used as discussed in Section 3.6.3.1.. But currently such implementation requires specific design based on 5G-Blueprint pilot area and applications. Thus, the solution is not scalable until such functionality is standardized in future 5G modems.

To conclude, following developments are considered for scalable seamless roaming:

- Implement RAN data sharing solution at borders
- Share info regarding in which network at what location seamless roaming is supported toward application and use case device. So that 5G UE can be steered.
- Share info regarding available application, network slice used and data network
- Share how to connect to closest service
- Share roaming options per subscription to the current VPLMN, or refer to specific services at the HPLMN to select the N-VPLMN
- Make PLMN selection possible from Current-VPLMN
- Enable N14 as roaming interface
- Research possible extension of ANR cross border
- Standardize network reselection at the UE with support from the network

3.8 Application Programming Interfaces (APIs)

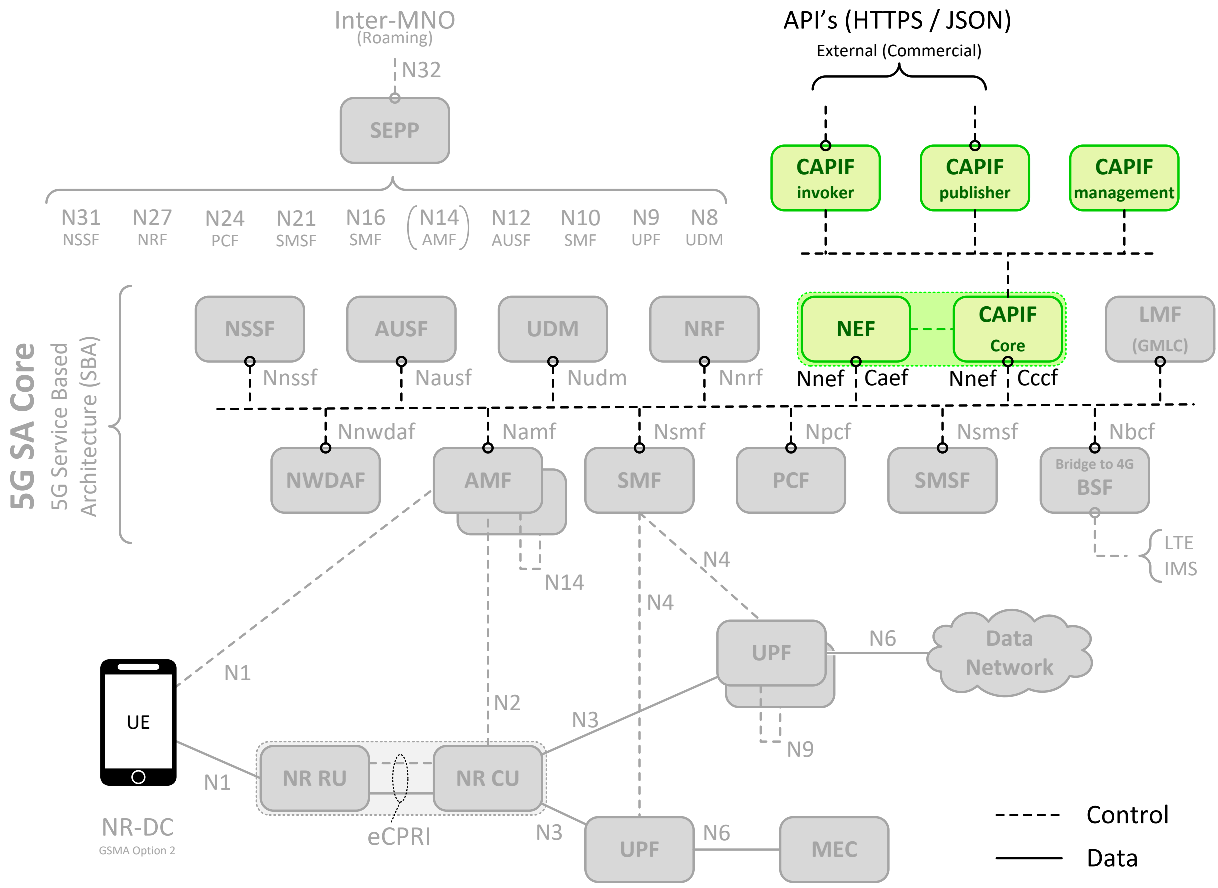

Figure 35: Application Programming Interfaces

3.8.1 3GPP specified APIs

The 5G network provides a number of standardized Application Programming Interfaces (APIs). These APIs provide to external systems the means to compose an End-to-End service, in which the potential of the 5G infrastructure is used optimally (as seen from the perspective of the End-to-End application). Another property of 5G, Slicing, is meant to provide the isolation between different, otherwise conflicting, End-to-End services. A detailed overview of these APIs can be found in the Annex.

An example of the possible use of such API is to allow an external application to receive information on the status of the 5G network in a specific geographical area. The application then can adjust its behaviour on the actual performance of the 5G network. This information is exposed using the Network Exposure Function (NEF) [17] by the "*ReportNetworkStatus*" API. The 3GPP specified APIs for both for internal use in the 5G Service Based Architecture (SBA) and for exposure to parties external to the Network Operator (Figure 36).

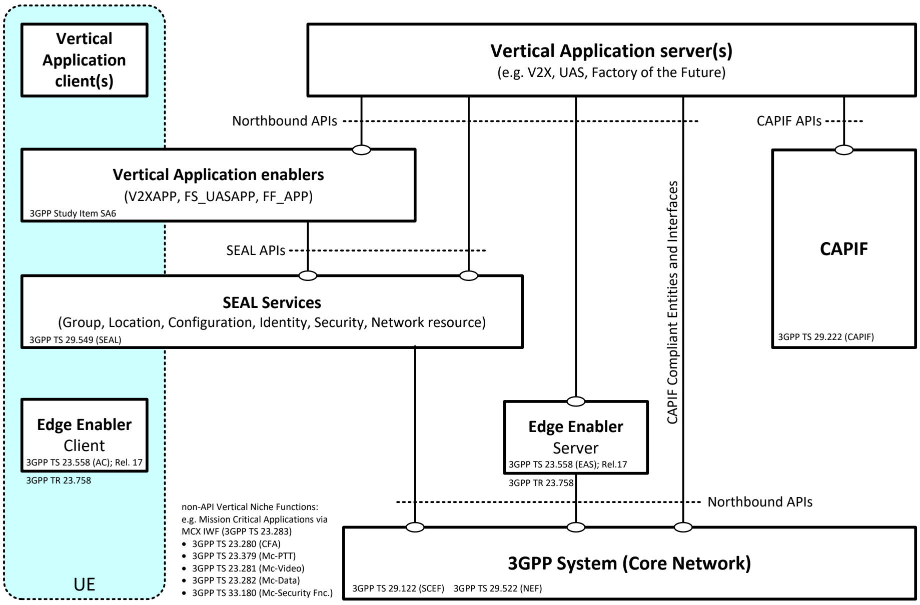

Figure 36: 3GPP defined APIs

In the 5G standard a Network Data Analytics Function [18] [19] (NWDAF) is specified which may be used to predict upcoming changes in network performance. These predictions are envisioned to be based on the recognition of patterns sensed by the NWDAF on the SBA. The NWDAF uses Artificial Intelligence (AI) for this pattern recognition. In the specification of the APIs on the NEF an API is provided to expose analytics data to external applications subscribing to this information (the '*AnalyticsExposure*' API).

The Open API Specification (OAS) is also relevant for Application Developers. It defines a standard, programming language-agnostic interface to RESTful APIs which allows both humans and computers to discover and understand the capabilities of the service without access to source code, documentation, or through network traffic inspection. Swagger [20] is the tool currently chosen to write "OpenAPI Specification" (OAS) compliant documentation on in-house developed APIs. The OAS does not specify individual APIs. Contemporary 3GPP specified APIs can be (and are) documented in OAS format. 5G APIs always include .yaml files containing the formal interface. YAML [21] is one of the standards specified in the OAS (the other OAS endorsed format is JSON [22]).

In this section APIs on three layers of abstraction, as documented by the 3GPP, are presented:

- Service Enabler Architecture Layer (SEAL)
- Common API Framework (CAPIF)
- Service Capability Exposure Function (SCEF) and Network Exposure Function (NEF)

Additionally the 3GPP envisions Edge functions and interfaces to Vertical Applications. These are the subject of studies and future specifications. The latter encompass the Mission Critical Applications (MCX). Contemporary Mission Critical applications are not exposed to the developer community by APIs. In this document the 3GPP specifications of SEAL, CAPIF, SCEF and NEF provides the primary index, the official technical names of the APIs, as used in these 3GPP standards, are used as secondary index. The brief description of their function is derived from this specification. When in doubt: the specifications prevail over these derivates.

3.8.2 BSS APIs

From a business perspective, a slice includes a combination of all relevant network resources, functions, and assets required to fulfill a specific business case or service, including OSS, BSS and DevOps processes.

According to the analysis of the industry and standardization resources, the requirements for an E2E management and orchestration in 5G network slicing include: flexibility, customization, simplification, exposure, elasticity, cloudification, legacy support, lifecycle management, automation, isolation and multi-domain and multi-tenant support. The identified requirements illustrate the need for centralized management and orchestration of network slice instances. This is so because the current management elements, network managers and OSS/BSS have no such capabilities.

There exist a number of research works on network slicing management (e.g. [23] and [24]) focusing on orchestrating resources from either a single type of network infrastructure resource domain (e.g., NFV), a single network domain type (e.g., RAN) , or using a single type of resource domain manager (e.g., SDN controller).

Figure 37 [23] shows the generic slice architecture. The Global OSS/BSS is responsible for managing the behavior of the entire system. As it is shown, a slice consists of three groups of functions, namely the Slice Manager (SM), the Sliced Network (SN) and the Slice Operations Support (SOS).

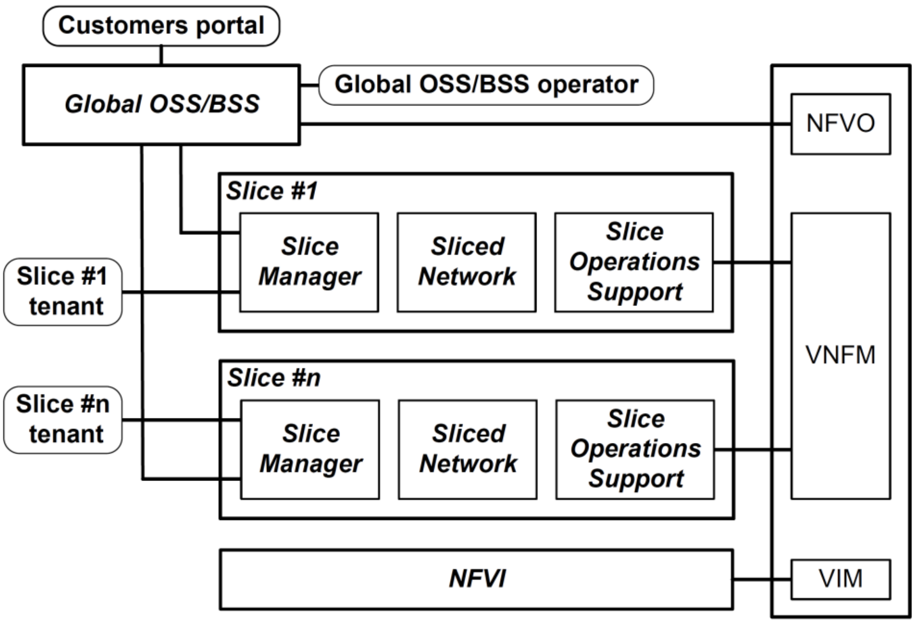

Figure 37: Generic slice architecture

The SM is an entity that handles faults and performance of a slice or sub-slice. In cooperation with the Global OSS/BSS, which plays the master role in the overall management and orchestration, the SM is also responsible for managing the sliced network. It is important to mention that all requests regarding slice creation and termination as well as access to current and historical data related to a particular slice from tenants are made through the Global OSS Tenants Portal. The role of the SM into a slice is twofold. Firstly, it increases the scalability as the management of multiple functionally isolated slices by a single management system is not scalable and raises problems related to the separation of management operations between slices. Secondly, it allows tenants to have some management capabilities to operate their slices efficiently. Tenants request creation of a slice via the Global OSS Tenants Portal, but then they use SM for most slice-oriented operations, except those that are related to slice life-cycle management and accounting.

The SN consists of the same set of functions as in the non-sliced networks, namely data, control, and application planes. That allows for sharing of functions of a specific plane by several slices whereas other planes can be fully based on slice-dedicated functions.

The SOS block consists of functions that are responsible for network slice discovery, selection, subscription, and authentication. In addition, it includes functionality for creating E2E slices by horizontally stitching single domain slices. Such functionality includes the exposure of an abstracted view of single domain slices to other domains and the support of inter-slice operations using protocols that enable information exchange between different domains.

3.8.2.1 Single Domain Management and Orchestration

Figure 38 [24] shows a high-level overview of the Global OSS/BSS functional components for single-domain management and orchestration. The Global OSS/BSS is a logically centralized master block that manages the behavior of the entire system, following the NFV MANO compliant orchestration.

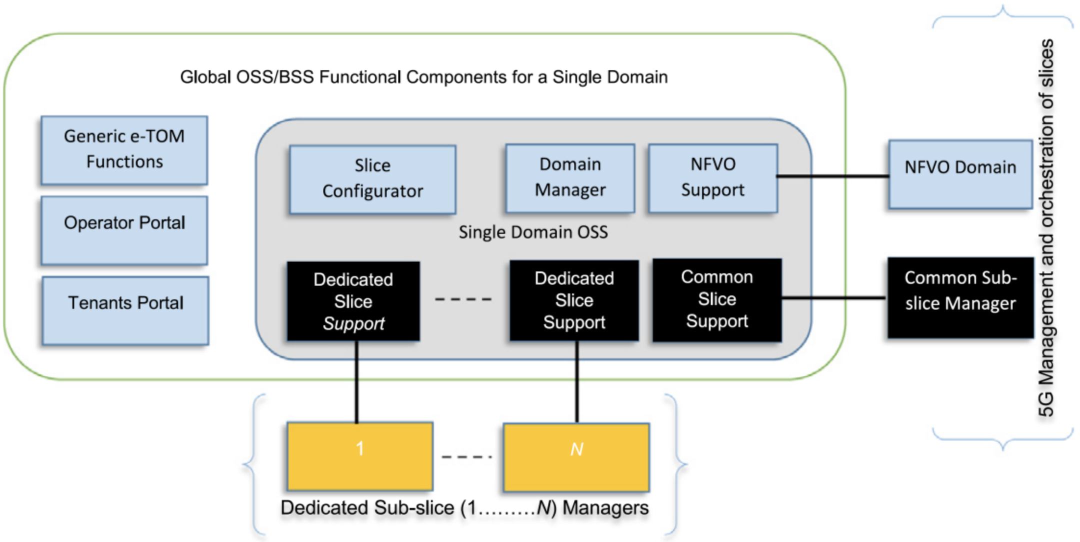

Figure 38: Single-domain management and orchestration architecture

The first group of the Global OSS/BSS components includes the portals for the operators and the tenants as well as the generic enhanced Telecom Operations Map (e-TOM) functions. E-TOM is a process model framework that aims to provide a common language and catalogue of the business processes that a service provider will use. The target of the second group is to enable single-domain slice management and orchestration. The Slice Configurator is responsible to analyze the policies of users and operators as soon as a slice is requested. The Domain Manager among others handles information about the resource availability within the domain, resource use, resource allocation to slices based on their demands and priorities. The Network Function Virtualization Orchestrator (NFVO) Support keeps a catalogue of the network slices and is responsible to create the Network Slice Description (NSD) that is used by the NFVO for slice deployment. It also keeps the catalogue of network slices.

One main disadvantage of single-domain management and orchestration in 5G network slicing is the limited scalability, as it only focuses on a single network domain. The multi-domain orchestration and management aims to solve this problem by providing E2E slice management and orchestration in 5G networks.

3.8.2.2 Multi-domain Orchestration and Management

Multi-domain provides a realization of E2E management and orchestration of resources in 5G sliced networks, where single-domain slices can be horizontally stitched to form an E2E slice. That horizontal stitching of multiple slices has an impact on two functions of SOS, namely the slice selection operations and the Inter-Domain Operations Support (IDOS) entities. The slice selection capabilities should be implemented at the edge sub-slices. The IDOS entities act as inter-slice gateways that target the exchange of relevant information between neighboring domains towards their efficient cooperation. In that direction, IDOS should expose an abstracted view of its domain and enable inter-domain communication.

As shown in Figure 39 [23], in the context of the multi-domain management and orchestration, the global OSS/BSS includes several single-domain OSS/BSS and two new entities, namely the Multi-Domain Slice Configurator (MDSC) and the Multi-Domain Manager (MDM).

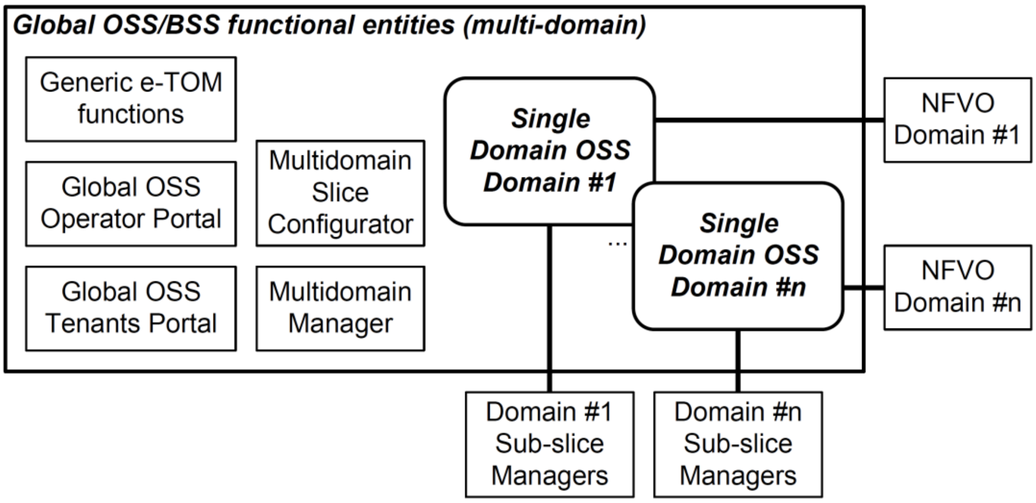

Figure 39: Multi-domain management and orchestration architecture

The MDSC translates the business requirements into technology-specific requirements. Then, in cooperation with Slice Configurator entity of each domain, it configures each domain's SOS entity for proper interdomain operations.

The MDM interacts with each Domain Manager to solve multi-domain management issues. Such information exchange could be beneficial for E2E optimization. According to the "domain-oriented philosophy", though, exchanging management information between domains should be minimized.

4 NETWORK ARCHITECTURE OVERVIEW

This chapter provide a high level summary and overview of the design 5G network architecture and its relation with other work items in the 5G Blueprint project.

4.1 Hybrid 4G/5G Network Evolution

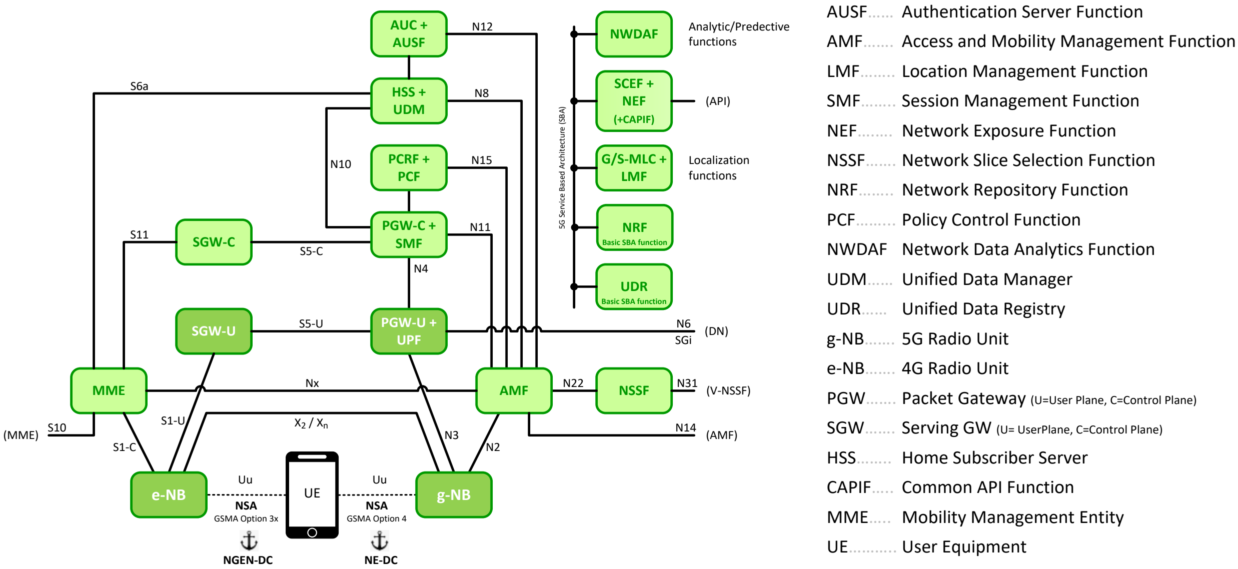

Figure 40: Initial hybrid 4G/5G Network

In the foreseeable future all known European 5G networks will be integrated with existing 4G (LTE) networks. As described in Section 3.2.3, on top of 5G SA Option 2, the SA also be a hybrid 4G/5G network where session control is done via 5G. An existing 4G e-NB needs new software to be able to support 5G control. The term 5G NSA, refers to a hybrid 4G/5G network where session control initially is done via 4G. The GSMA also defined an NSA option in which session control is done via 5G, this is known as “NSA Option 4” [6]. The aggregation of 4G and 5G is vitally important to the project. As a result of European wide choices on (5G) spectrum usage, the uplink capacity of 5G is 20% of the total 5G capacity. Since teleoperations requires primarily uplink capacity, the capacity of the LTE network can’t be missed.

As discussed in both Chapter 2 and Chapter 3, one of the novelties of 5G is network slicing. Slicing is meant to provide isolation between the multiple dataflows in a 5G Radio Network. As 4G doesn’t support network slicing a 5G NSA network can only use the QoS mechanism of LTE. The target architecture of the 5G Blueprint project is a 5G SA implementation. Many of the use cases of the 5G Blueprint project can also be demonstrated in a 5G NSA network. This could be an advantage for the adaptation of the results of the project as it doesn’t force MNOs to implement a 5G SA network from the start. But instead allow smooth 5G NSA to 5G SA evolution via options discussed in Section 3.2.

From use case point of view, some characteristics of hybrid 4G/5G network are also beneficial. For example, as discussed in Section 3.1, in case the UE can support dual connectivity between 4G/5G links, the maximum bandwidth is reached by combining 4G and 5G bandwidth. For some use case traffic that are generated for redundance or backup, such advantage is beneficial even though the traffic is non-GBR data. Another example is for some non-critical sensor data or legacy machine type communications, the existing LTE-M / NB-IoT or other 4G technologies are already sufficient. In this case, keeping legacy 4G UEs can avoid unnecessary cost as long as legacy network prioritized correctly comparing with 5G traffic.

As conclusion, KPN and Telenet will deploy both 5G NSA and 5G SA network in pilot area for use cases to trial and study the differences and validate the most suitable network service.

Note that comparing with the 5G core network architecture defined in Section 3.3, there are two optional network functions in Figure 41: Network Data Analytics Function (NWDAF) and Location Management Function (LMF). These functions are not compulsory for use cases and enabling functions defined in Chapter 2.

4.2 5G Blueprint Architecture Overview

The overall network architecture of 5G Blueprint is illustrated in figure below, showing the interaction between various use case/enabling function components and 5G network.

The end-to-end network architecture encompasses User Equipment (UE) that depends on the use case, radio network built upon 5G gNodeBs deployed in three pilot sites, transport, and core network. Concerning the UEs, the project leverages either prototype or commercial cars, trucks, barges, and skid steers, which depends on a use case and a testing teleoperation scenario. To be able to connect to use case applications and enabling functions that serve as support for all use cases (either running on the cloud or on the network edge), UEs are equipped with 5G communication capabilities, i.e., 5G modems (NSA/SA) and necessary antennas, including various sensors, and Central Control Unit (CCU) that executes the commands sent by the teleoperator.

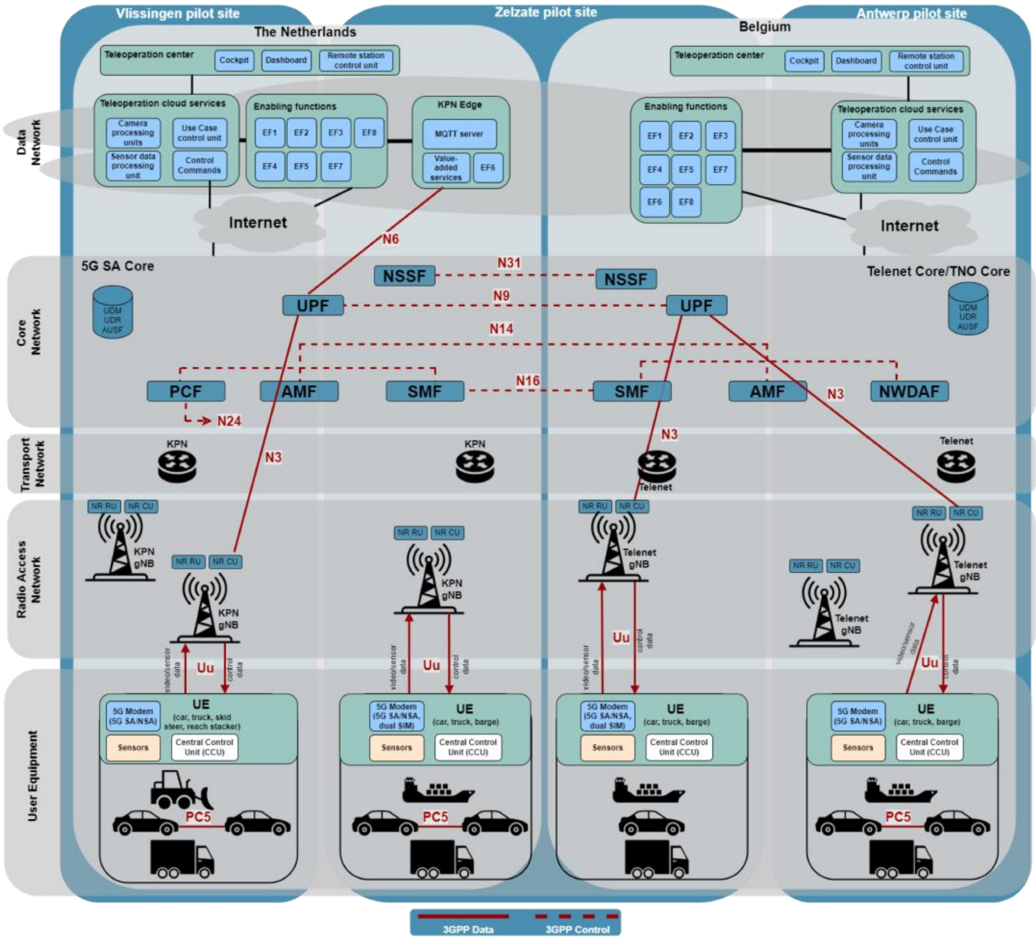

Figure 41 The overall 5G-Blueprint network architecture encompassing three pilot sites

The data generated by UEs (barges, cars, trucks, skid steers), which are mobile and have a specific service continuity requirement when crossing the border, should be collected via specific use case device. As discussed in Section 3.1.1, if one 5G modem (hardware or software version) does not fulfil the requirement of all network slices simultaneously, 5G device can be separated according to service type. Taking UC4.1 (Automated barge control) as an example, there could be one use case device installed on the barge for the purpose of gathering all traffic from cameras, sensors, and CCUs. At the same time, this use case device can contain three 5G modems in total, to support three or more network slices on the current network, while other three 5G UEs can be used as redundancy or for roaming. If the use case device deployment scenario does not allow full aggregation of all data needed for the use case, then multiple 5G device are mandatory. Therefore, the device solution will be further updated and refined during field trails, based on the learnings we collect during the trialing activities.

This brings to the following segments of the overall 5G network, i.e., 5G Radio Access Network (RAN) through which all the aforementioned data traffic is then transferred to the transport network, and finally to the core network (leveraging the standardized 3GPP N3 reference point). The traffic is propagated through the defined network slices, which are created based on the end-to-end network slicing concepts deployed in both Telenet and KPN.

Finally, the HD video traffic, as well as the sensor data, are collected and processed by services running in the cloud or edge. After the data is processed, it can be retrieved from the teleoperation center for the purpose of reliable remote monitoring, and for steering the UEs by sending the control commands to the cars/barges, i.e., their CCUs (downlink communication).

In case of Zelzate pilot site, which is specific due to the border and necessity for performing seamless roaming, we are taking various approaches to extend the existing roaming mechanisms, including the standardized 5G core components and their mutual interactions between MNOs. In particular, N14 interface is considered as a key feature (as discussed in Section 3.8.1, with the methodology explained in 3.8.3).

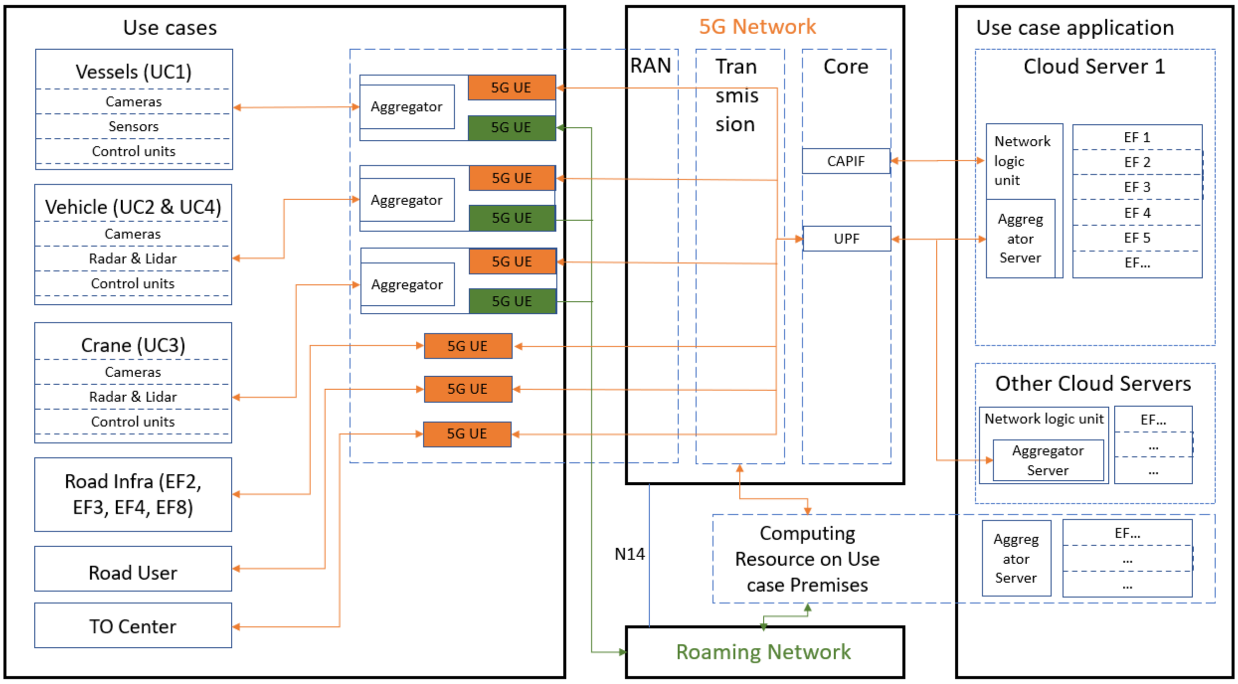

Figure 42: 5G Blueprint network elements overview

5 CONCLUSIONS

In this deliverable, all input from use cases, enabling functions and trial environment are analysed and processed together with standardization work, MNO resource, regulatory and ecosystem info to provide the architecture design of 5G Blueprint. During this process each network function & component (user equipment, radio network, transport network, core network, E2E slicing, multi-edge solution, V2X, roaming and network API) is discussed in detail individually with listed further study for field trails.

Despite the grand technical result shows very capable 5G network design to answer the main challenges of seamless, high reliable and high-performance network services, the deployment of such complicated network comes the new challenge. Also methodologies and designs defined in this deliverable needs to be further tested and validated in later works of WP5.

APPENDIX A APIS ON 3GPP PART OF 5G NETWORK

The 3GPP published numerous APIs to the 5G network. These specifications contain both text and a formal interface description in YAML format. This annex gives an detailed overview over the available APIs. Applications external to the 3GPP network, but part of the service chain are meant to use these APIs

1. Service Enabler Architecture Layer (SEAL)

In TS 23.434 [25] and TS 29.549 [26] the 3GPP has considered the development of Service enabler architecture layer (SEAL) for verticals over 3GPP networks to support vertical applications (e.g. V2X applications). It specifies the functional architecture for SEAL and the procedures, information flows and APIs for each service within SEAL in order to support vertical applications over the 3GPP systems. To ensure efficient use and deployment of vertical applications over 3GPP systems, SEAL services includes: group management, configuration management, location management, identity management, key management and network resource management. Vertical Applications are consumed in the “Vertical Application Layer” (VAL) which, to this end, uses the Service Enabler Architecture Layer (SEAL). The Application Exposure Function (AEF), which is part of SEAL, can be implemented by the SCEF and/or NEF. SEAL Core Functions add a “wrapper” to the API’s provided by the SCEF and NEF. Below the SEAL functions as part of the 5G Service Based Architecture (SBA) are shown (Figure 43). The AFs are abstracted instances of 5G SBA entities e.g. the GMLC or the UDR.

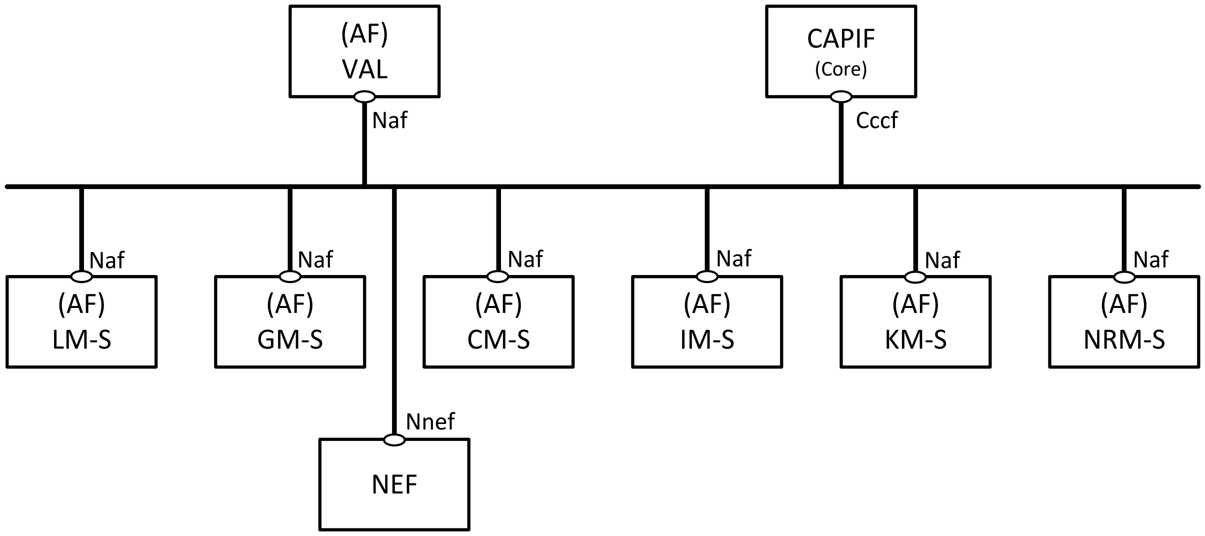

Figure 43: SEAL as part of the SBA

SEAL API includes:

- **SS_LocationReporting**
  Allows a Vertical Application Layer (VAL) server to configure a reporting trigger for location information in the Location Management Server (LM-S) in the telecom infrastructure.
- **SS_LocationInfoEvent**
  Allows a VAL server to subscribe for and receive notifications of location information from the location management server. The SS_LocationInfoEvent API supports this via the event "LM_LOCATION_INFO_CHANGE" of the SS_Events API.
- **SS_LocationInfoRetrieval**
  Enables the VAL server to obtain location information from the Location Management Server. This can be once or repeated during a configurable period of time.
- **SS_GroupManagement**

Allows VAL server to create, fetch, update and delete VAL group membership and configuration information in a Group Management Server (GM-S).

- **SS_GroupManagementEvent**
  Allows a VAL server to subscribe for and receive notifications from Group Management Server on new VAL group creations and on modifications to VAL Group membership and configuration information. The SS_GroupManagementEvent API supports this via the SS_Events API. The VAL Servers need to be known an authorized for these operations.
- **SS_UserProfileRetrieval**
  Allows VAL server to obtain a user profile from the Configuration Management Server (CM-S).
- **SS_UserProfileEvent**
  Allows a VAL server to subscribe for and receive notifications from the Configuration Management Server on profile updates to VAL User or VAL UE. The SS_UserProfileEvent API supports this via the CM_USER_PROFILE_CHANGE event in SS_Events API.
- **SS_NetworkResourceAdaptation**
  Allows VAL server to communicate with the Network Resource Management Server (NRM-S) for network resource adaptation including reserving network resource, requesting and subscribing for unicast and multicast resources.
- **SS_Events**
  Allows a VAL server via interfaces on the LM-S, GM-S and CM-S to subscribe and unsubscribe from SEAL events and to receive notifications from the Location Management Server, Group Management Server and Configuration Management Server respectively.
- **SS_KeyInfoRetrieval**
  As specified in [25], the SS_KeyInfoRetrieval API, allows the VAL server to obtain the VAL service specific key management information from the Key Management Server (KM-S).

2. Common API Framework (CAPIF)

The 3GPP specification TS 29.222 [27] describes an Common API Framework (CAPIF) for 3GPP Northbound APIs and the associated API Registry. An API registry is a registry maintained by the CAPIF Core Function to store information about the service APIs based on the data models defined in this TS 29.222 specification. According the specification this API Registry is part of the CAPIF Core Function. It is explicitly stated that the NRF on the SBA shall not be used to this end.
The functionality and Business Roles supported by this CAPIF are specified in 3GPP TS 23.222. This document also provides an overview of the relationship of CAPIF with the OMA Network APIs and the ETSI MEC API framework.

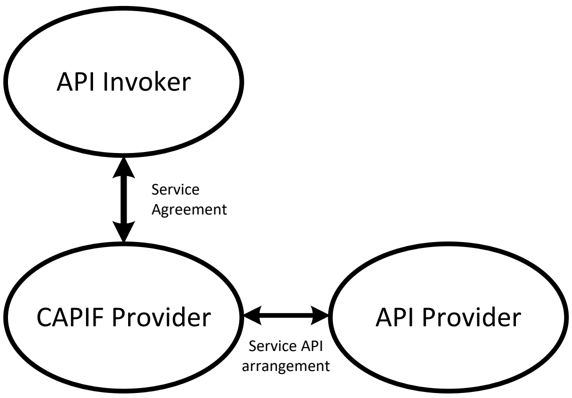

Figure 44: CAPIF Roles

The Common API Framework is applicable to both internally used- as well as externally exposed APIs.

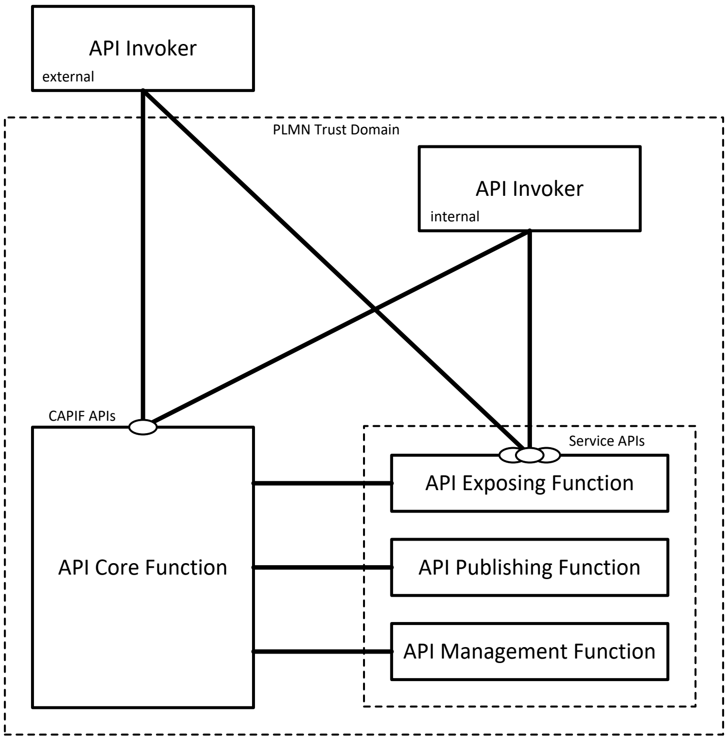

Figure 45: CAPIF Functions

The Common API Framework related functions can be fitted in the 5G SBA.

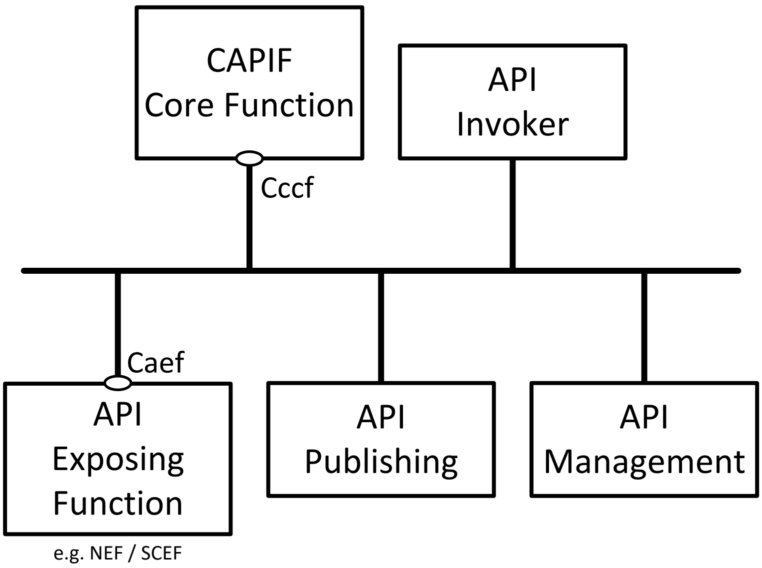

Figure 46: CAPIF as part of the SBA

The CAPIF relations and communication patterns:

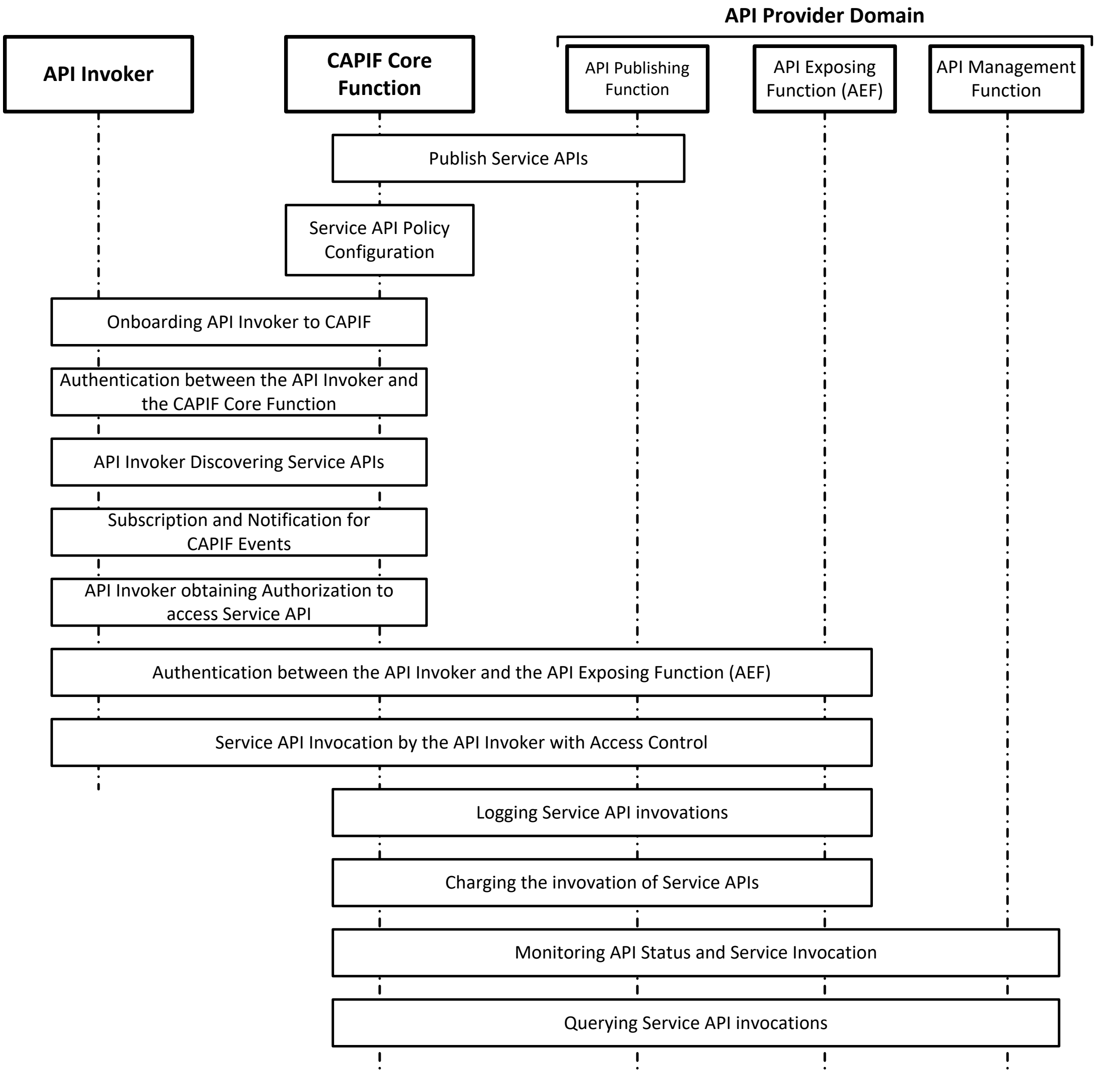

Figure 47: CAPIF Relations

CAPIF core function APIs includes:

- **AEF Security API**
  - Allows an API invoker to request API exposing function to ensure that authentication parameters necessary for authentication of the API invoker are available with the API exposing function. If the necessary authentication parameters are not available, the API exposing function fetches necessary authentication parameters from CAPIF Core Function to authenticate the API invoker.
  - Allows the CAPIF core function to request an API exposing function to revoke the authorization of service APIs for an API invoker.
- **CAPIF_Discover_Service_API**
  Allows API invokers to discover service API available at the CAPIF core function, and allow CAPIF core function to discover service API available at other CAPIF core functions.
- **CAPIF_API_Invoker_Management_API**
  Allows API invokers to on-board and off-board itself as a recognized user of the CAPIF or update the API invoker’s details on the CAPIF core function.
- **CAPIF_Events_API**

Allows an API invoker API exposure function, API publishing function and API management function to subscribe to and unsubscribe from CAPIF events and to receive notifications from CAPIF core function.

- **CAPIF_Security_API**
  - Allows API invokers to (re-)negotiate the service security method and obtain authorization for invoking service APIs; and
  - Allows API exposing function to obtain authentication information of the API invoker and revoke the authorization for service APIs.

API Exposing Functions includes:

- **CAPIF_Logging_API_Invocation_API**
  Allows API exposing functions to log the information related to service API invocations on the CAPIF core function.
- **CAPIF_Access_Control_Policy_API**
  Allows API exposing function to obtain the service API access policy from the CAPIF core function.
- **CAPIF_Routing_Info_API**
  Allows an API exposing function to obtain the API routing information from the CAPIF core function.

API Publishing Functions includes:

- **CAPIF_Publish_Service_API**
  Allow API publishing function to publish and manage published service APIs at the CAPIF core function, and allow CAPIF core function to publish and manage published service APIs at other CAPIF core function.

API Management Functions includes:

- **CAPIF_Monitoring_API**
  Allow the API management function to monitor service API invocations and receive such monitoring events from the CAPIF core function. The CAPIF_Monitoring_API utilizes the CAPIF_Events_API as described above.
- **CAPIF_Auditing_API**
  Allows API management functions to query the log information stored on the CAPIF core function.
- **CAPIF_API_Provider_Management_API**
  Allow API management functions to register, deregister and update registration information of API provider domain functions (API Exposing Function, API Publishing Function, API management Function) as a recognized API provider domain of the CAPIF domain.

3. Service Capability Exposure Function (SCEF)

The 3GPP specification TS 29.122 [28] describes the interface between the Services Capability Server (SCS) / Application Server (AS) and the Service Capability Exposure Function (SCEF). This interface is also known as the “T8” reference point. It specifies APIs that allow the SCS/AS to access the services and capabilities provided by 3GPP network entities and securely exposed by the SCEF. The SCEF itself is specified in 3GPP TS 23.682 [29]. Each of the APIs in 3GPP TS 29.122 describes the data models, resources and the related procedures for the creation and management of the API.

- **MonitoringEvent API**
  Allows the SCS/AS to subscribe to notifications about specific events in 3GPP networks. It also allows the SCEF to report the event by sending notifications to the

authorised users when the corresponding event is detected. The API also allows the SCEF to indicate the removal of a previously configured monitoring request.

- **ResourceManagementOfBdt API**
  Allows the SCS/AS to request background data transfer (BDT) related conditions for a set of UEs.
- **ChargeableParty API**
  Allows the SCS/AS to either request to sponsor the traffic from the beginning or to request becoming the chargeable party at a later point in time via the T8 interface.
- **NIDD API**
  The Non IP Data Delivery (NIDD) API allows the SCS/AS to send non-IP data to the UE or receive non-IP data from the UE.
- **DeviceTriggering API**
  Allows the SCS/AS to deliver specific device triggers to the SCEF; it allows the SCS/AS to replace or recall the pending device trigger via the SCEF. If the corresponding device trigger delivery report is received by the SCEF, it also allows the SCEF to indicate the trigger delivery result to the SCS/AS.
- **GMD via MBMS related APIs**
  Both APIs allow the SCS/AS to deliver the group message to the SCEF. Two interface specific API variants are defined:
    - GMDviaMBMSbyMB2 API
      For use via the MB2 interface as specified in 3GPP TS 29.468 [30]
    - GMDviaMBMSbyxMB API
      For use via the xMB interface as specified in 3GPP TS 26.348 [31]
- **ReportingNetworkStatus API**
  Allows the SCS/AS to be one-time or continuous notified of the network status in a geographic area.
- **CpProvisioning API**
  Allows the SCS/AS to add, change or delete the communication pattern parameter sets of the UE.
- **PfdManagement API**
  Allows the SCS/AS to manage the Packet Flow Descriptions (PFD) via the SCEF.
- **ECRControl API**
  A custom API (RPC interaction) that allows the SCS/AS to query or configure the Enhanced Coverage Restriction (ECR) over 3GPP networks. The Enhanced Coverage feature is an integral characteristic of NB-IoT, as it increases the depth of radio coverage to enable IoT devices to operate in locations that would otherwise not be possible. The 3GPP Enhanced Coverage feature increases the power levels of signalling channels together with the ability to repeat transmissions. Repeated transmission improves the ability of receivers to correctly resolve the message sent. The trade-off is that repeating signal transmissions consumes additional power and the time between battery recharge or replacement may be reduced.
- **NpConfiguration API**
  Allows the SCS/AS to send suggested Network Parameters to influence certain aspects of UE/network behaviour such as the UE's Power Save Mode (PSM), extended idle mode Discontinuous Reception (DRX), and extended buffering configurations.
- **AsSessionWithQoS API**
  Allows the SCS/AS to set up a session with SCEF with required Quality of Service (QoS) based on the application and service requirement.
- **MsisdnLessMoSms API**
  Allows the delivery of MSISDN-less mobile originated SMSs from the SCEF to the SCS/AS.
- **RacsParameterProvisioning API**
  Allows the SCS/AS to provision manufacturer specific UE Radio Capability parameters.

4. Network Exposure Function (NEF)

The Network Exposure Function (NEF) Northbound interface is between the NEF and the AF. In the 5G Architecture it is also referred to as the N33 reference point and the Nnef service interface in the Service Based Architecture (SBA). This AF is the equivalence of the SCS/AS as described in context of the SCEF.

The TS 29.522 [32] standard specifies RESTful APIs that allow the AF to access the services and capabilities provided by 3GPP network entities and securely exposed by the NEF.

The NEF reuses some of the functions provided by the APIs specified for the SCEF. These SCEF API functions of which an equivalent instance is available on the NEF are:

- MonitoringEvent
- ResourceManagementOfBdt
- ChargeableParty
- NIDD (Non IP Data Delivery)
- DeviceTriggering
- CpProvisioning
- PfdManagement
- ECRControl
- NpConfiguration
- AsSessionWithQoS
- RacsParameterProvisioning

The NEF adds new APIs which are available as a gateway to 5G SBA based Network Functions.

- **5GLANParameterProvision**
  Considerations regarding a 5G LAN are the subject of 3GPP TR 22.821 [33] (use cases) and 3GPP TR 23.734 [34] (technical aspects). The procedures in the 5GLANParameterProvision API are used by the AF to provision 5G LAN type service related parameters to the NEF. The following procedures support:
    - Management of 5G Virtual Network group membership; and/or
    - Management of 5G Virtual Network group data.
- **ACSParameterProvision**
  The procedures are used by the AF to provide ACS (Auto-Configuration Server) configuration information to 5G system via NEF. The ACS is described in 3GPP TS 32.593 [35] and 3GPP TS 23.316 [36] and is used to configure a HeNB via the TR-069 [37] or its successor the TR-369 [38] interface.
- **AnalyticsExposure**
  The procedures are used by the AF to subscribe/unsubscribe to retrieve analytics information via NEF, and are used by the NEF to notify the AF about the requested analytics information by the NWDAF as described in 3GPP TS 23.288 [39]. Via the NEF an (authorized) AF can subscribe to events as analysed in the NWDAF on the SBA.
- **ApplyingBdtPolicy**
  Background Data Transfer (BDT) is described in 3GPP TS 29.554 [40]. This API enables the AF to negotiate policy for a future background data transfer and offers the following functionalities:
    - get background data transfer policies based on the request via the NEF.
    - update background data transfer policies based on the selection provided by the NEF.
    - provide background data transfer warning notification to trigger renegotiation of background data transfer policy.
- **IPTVConfiguration**
  The IP TV Multicast functions for distribution of linear TV over a 5GCN are described in 3GPP TR 26.891 [41]. The IPTVConfiguration API enables the configuration of 5G

mobile broadband Media Distribution parameters in the UDR and UDF on the SBA. These parameters include (non-exhausting):
    - address of a streaming server
    - routing parameters to a CDN
    - QoS related parameters
- **LpiParameterProvision**
  The API's are used by the AF to provision Location Privacy Indication parameters to the NEF. The procedures are applicable for an individual UE or a group of UEs. The parameters are specified in 3GPP TS 23.503 [42] and encompass:
    - If location of the UE (or Group of UEs) is allowed of disallowed
    - Time period during which the Location Privacy Indication is valid.
- **MoLcsNotify**
  This Mobile Originated Location Request Notify API is used by NEF to notify the AF of updated UE location information from the GMLC as described in paragraph 6.2 of 3GPP TS 23.273 [43].
- **NIDDConfigurationTrigger**
  This API is an extension of the NIDD API as provided by the SCEF. It is used by the NEF to send/receive the non-IP data to/from the AF. It comprises NIDD configuration and NIDD delivery. In 5G the NIDD configuration may be triggered by the NEF or the AF.
- **ServiceParameter**
  This API is used by the AF to provide service specific parameters to 5G system via NEF. The NEF interacts with the UDM and UDR.
- **TrafficInfluence**
  In order to create a rule for the Traffic Influence, the AF shall send a message to the NEF to the resource "Traffic Influence Subscription", the message may include:
- **AF request identified by UE address**
  Upon receipt of the above AF request which is for an individual UE identified by IP or Ethernet address, the NEF may interact with the BSF to retrieve the related PCF information by invoking the Nbsf_Management_Discovery service operation as described in 3GPP TS 29.521 [44]
- **AF request not identified by UE address**
  For AF request not identified by UE address, it may target an individual UE, a group of UEs or any UE. For an individual UE identified by GPSI, or a group of UEs identified by External Group Identifier, the NEF shall interact with the UDM by invoking the Nudm_SubscriberDataManagement service as described in 3GPP TS 29.503 [45] to retrieve the SUPI or Internal Group Identifier. The NEF shall interact with the UDR by invoking the Nudr_DataRepository service as described in 3GPP TS 29.504 [46]
- **Handling of UP path management event notification**
  If the NEF receives a UP path management event notification from the SMF indicating that the subscribed event has been detected, then the NEF shall provide a notification by sending a message that shall include the EventNotification data type at least with the subscribed event (e.g. UP Path has changed) to the AF identified by the notification destination received during creation of the Individual Traffic Influence Subscription. If a URI for AF acknowledgement within the "ackUri" attribute is provided by the SMF in the event notification as defined in 3GPP TS 29.508 [47].

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