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

D5.2: Initial Report on 5G Network Deployment

Covers the 5G NSA implementation and experimental SA lab-system.

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Abstract

In this document the detailed design of the 5G test network is presented. The implementation of these designs at the three designated pilot areas is presented. The initial performance of the individual realization is assessed. The methods to establish the performance of this network is described as well as the measurements results obtained.

During the design phase of the project it turned out none of the vendors is able to deliver a 5G SA capable core network which implements 5G Roaming. Vendors justified this by pointing out the immature state of the relevant standards and the need to prioritize other functions which have shown more market demand. To circumvent this issue the project organization invited TNO, an organization which can contribute to achieve the project objectives with their open source 5G SA core on which they can implement the sought after 5G SA Roaming functions.

Many of the really interesting 5G features, such as URLLC and dynamic Slicing are not available yet with current 5G SA network technology (neither the commercially available networks nor the open source variant by TNO). Nevertheless the contemporary commercial implementation of a 5G SA network has a noticeable better performance than a 5G NSA network.

For the vast majority of the teleoperations use cases chosen by the 5G-Blueprint project the performance of a NSA network or even a contemporary LTE network was shown to be sufficient. Thus, the development of the market for teleoperations is not dependent on the availability of 5G SA networks. The deployment of 5G SA is still “struggling” with postponed spectrum auctions, sparce spectrum in the 3500 MHz because of maritime and military use and immature standards.

Keywords: Initial Network Performance, Slice Characteristics, Detailed design.

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* 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

CONTENTS

FIGURES

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TABLES

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ABBREVIATIONS (USED IN WP5)

In this overview all abbreviations used within WP5 documents are shown.

5GAA	5G Automotive Association
3GPP	3rd Generation Partnership Project
5GC	5G Core Network
5GS	5G System
5QI	5G QoS Identifier; a pointer to a set of QoS characteristics
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
AT	Agentschap Telecom
AUSF	Authentication Server Function
API	Application Programming Interface
APN	Access Point Name
BIC	Bureau of International Containers
BIPT	Belgisch Instituut voor Postdiensten en Telecommunicatie
BSS	Business Support Systems
CA	Certification Authority
CACC	Cooperative Adaptive Cruise Control
C/I	Carrier to Interference (Ratio)
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

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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)
e-PLMN	Equivalent PLMN (other formats: ePLMN and E-PLMN)
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
GBR	Guaranteed Bitrate
GFBR	Guaranteed Flow Bit Rate
GERAN	GSM/Edge Radio Access Network
GMLC	Gateway Mobile Location Centre
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

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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
KPN	Koninklijke PTT Nederland (Incumbent telecom operator in the Netherlands)
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
MiMo	Multiple Input / Multiple Output; an Antenna technology
MME	Mobility Management Entity
mcMTC	Mission Critical Massive Machine Type Communication (= hMTC)
mMiMo	Massive MiMo (usually a raster of more than 8 x 8 antenna elements)
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
NRI	Network Reselection Improvement (a.k.a. Seamless Roaming)

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
PDN	Packet Data Network
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
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RTK	Real Time Kinematics
RTT	Round Trip Time
RU	Remote Unit
SA NR	Standalone New Radio
SBA	Service Based Architecture
SBI	Service Based Interface (5G)
SCEF	Service Capability Exposure Function (4G)
SD	Slice Differentiator (8 bit field in S-NSSAI)
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
SST	Slice/Service type (24 bit field in S-NSSAI)
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
UICC	Universal Integrated Circuit Card (a SIM-Card)
UP	User Plane
UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Communication
USIM	Universal Subscriber Identity Module
v…	when used in front of another acronym: virtualized…
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 EXECUTIVE SUMMARY

The charter of the 5G-Blueprint project is to provide a blueprint architecture to allow seamless 5G service continuity whilst crossing the border between the coverage areas of two MNOs. To this end a seamless handover between KPN in the Netherlands and Telenet in Belgium is to be created. Teleoperated vehicles (cars, barges) are used to assess the practical usability of this network feature.

At the start of the project 5G was fairly new to MNOs. Essential resources such as 5G designated radio spectrum were not available. Therefore the first practical step in the 5G-Blueprint project was to create a 5G network in the target areas, often using temporary spectrum licenses.

In the 5G-Blueprint project both of the two standardized types of 5G Network deployments are utilized; the “Non Stand Alone” (NSA) and the “Stand Alone” (SA) variant. All incumbent European Mobile Network Operators (MNOs) start using 5G NSA and will, in time, migrate to SA. Telecom Equipment vendors follow the same path. Thus, commercial SA implementations are sparsely available and, at the moment of this writing, partly experimental.

After the initial 5G coverage is realized the performance of the 5G network at the designated sites is established. The purpose of these tests is to validate that the practical 5G network can support the use cases which are thereafter meant to demonstrate the usability of seamless inter-MNO border crossing.

The initial measurement reports and how the measurements were done can be found in section 4.2

Preceding H2020 projects such as 5G-CroCo, 5G-Carmen and 5G-Mobix demonstrated seamless roaming between countries using the same NSA vendor on both sides of the border. Although this proved that seamless roaming in an NSA network is possible, MNOs consider the used technology to be “unfinished”. Some of the open issues as seen by MNOs are steering of roaming in accordance with roaming agreements, chaining of seamless handovers whilst crossing multiple successive borders and the reduction of network configuration data which is required to be exchanged between MNOs. These issues are equally important in 5G NSA and 5G SA. The 5G-Blueprint intends to bring these open issues a step further.

At the border crossing between Belgium and the Netherlands the network reselection between Telenet and KPN will be improved to a level which can reliably support the tele-operations of vehicles and barges. In the NSA network this will be configured as a VPLMN – VPLMN handover between the core networks from two vendors (in B: Nokia, in NL: Ericsson). This will address some of the issues the MNOs see and advance the technology which was provided by earlier H2020 projects. Since both KPN and Telenet can’t acquire a commercial implementation of a roaming capable SA Core in the timeframe of the 5G-Blueprint project both of those 5GC’s will be an experimental (open source) SA core provided by TNO in the Netherlands. Since the 3GPP and GSMA standard for SA roaming is not yet finalized, this 5G core provided by TNO needs to be easily adaptable. Relevant findings can be reported back to 3GPP and GSMA as both TNO and KPN are active contributors to these organizations.

The architecture and design of both the 5G NSA network and the 5G SA network are discussed in section 3 and in more detail in the sections on the individual pilot sites.

Although network tests at the pilot sites are planned to continue to gain sufficient statistical power the methods meant to achieve this are discussed in section 4.4.1.1 and section 4.4.2

2 INTRODUCTION

In Deliverable 5.1 the architecture of the 5G network for the 5G-Blueprint project in Belgium and the Netherlands was presented. The document you are reading now (deliverable 5.2) describes the design of the practical networks which implement this architecture. This encompasses three physical locations where specific tests are conducted. In Antwerp and Vlissingen the 5G SA network can be tested in the harsh industrial environment of a harbor. At Zelzate the border crossing between Belgium and the Netherlands both NSA and SA based Network Reselection Improvements (NRI) between the coverage areas of two MNOs can be tested.

The 5G-Blueprint project is the youngest member of a “family” European projects focused on cross border tele-operations. Preceding projects, such as 5G CroCo and 5G Mobix, primarily used 5G NSA to improve on Network Reselection (NRI, also known as “Seamless Handover”). The 5G-Blueprint project builds upon the achievements of these earlier projects and expands the scope to 5G SA. This is reflected in the network designs presented in this document.

The reader will find a description of a 5G NSA network in which some of the scalability issues found in earlier NRI projects are brought further towards a solution which can actually be deployed by a commercial MNO. Furthermore a 5G SA network is presented in which the principles found in 5G NSA networks are applied.

The initial NSA architecture for the advancement of the Seamless Roaming results obtained in preceding project (such as 5G Mobix) is shown in Figure 1.

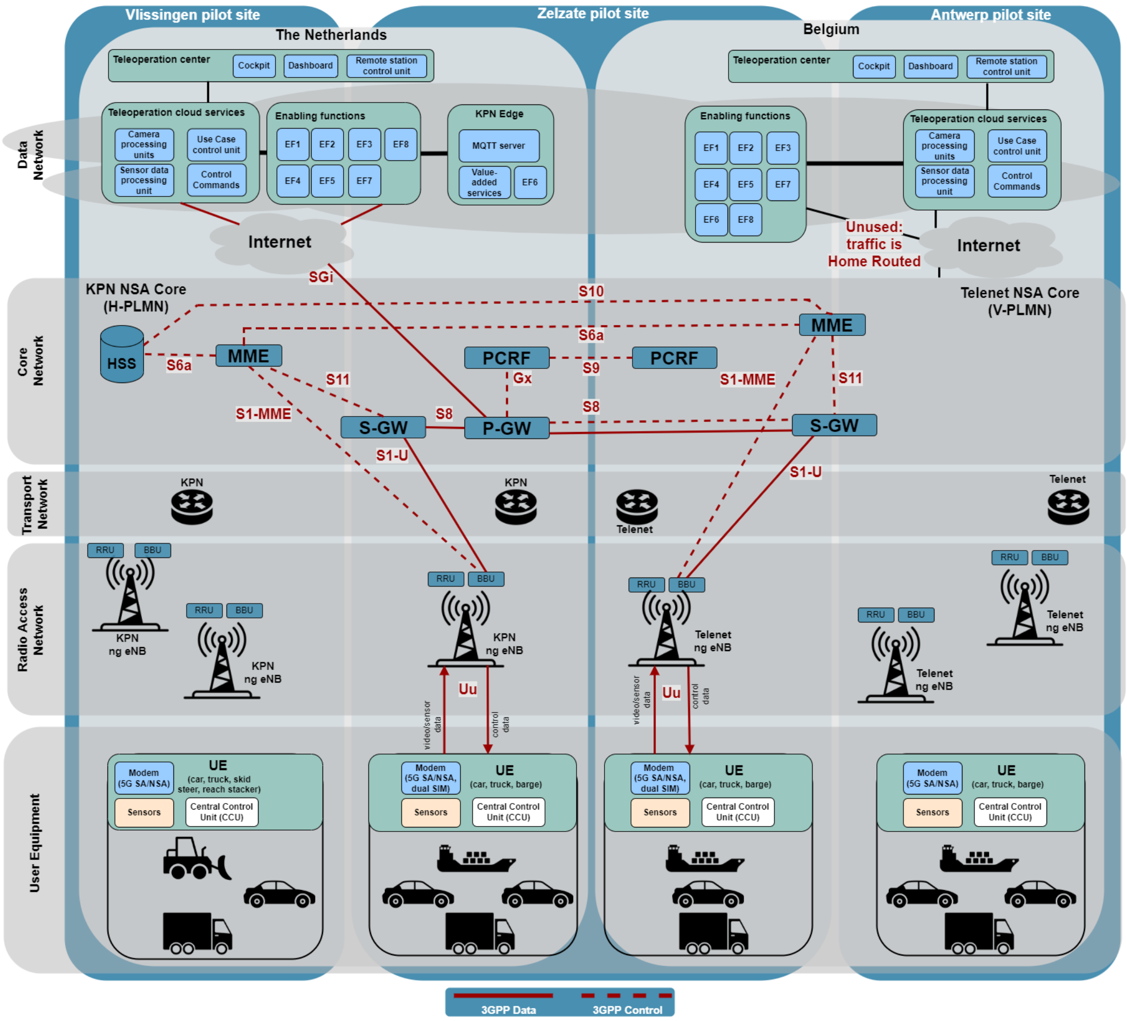

Figure 1: 5G NSA Architecture for Seamless Roaming

5G SA Roaming is still in its infancy. Standards are not finalized. Not all commercial suppliers of 5G networks are ready to deliver SA Roaming. TNO turned out to be able to provide an inhouse built experimental 5G SA core on which they can make changes where needed. Therefore TNO was invited to contribute their expertise the 5G-Blueprint project consortium.

The content of this document is structured as follows: First the performance of a selection of User Equipment is established in a lab environment. This provides a baseline for the next two sections. In these sections the SA network at the pilot sites in Antwerp and Vlissingen is described. Next the two network designs for the border crossing are presented. These will be both an NSA network and an SA network. The NSA network is meant to bring scalability issues found in earlier project a step further. The SA network has an experimental character and is meant to develop SA Seamless Roaming.

The target architecture of the 5G SA network is shown in Figure 2. In the next section the implementation at each pilot site is discussed.

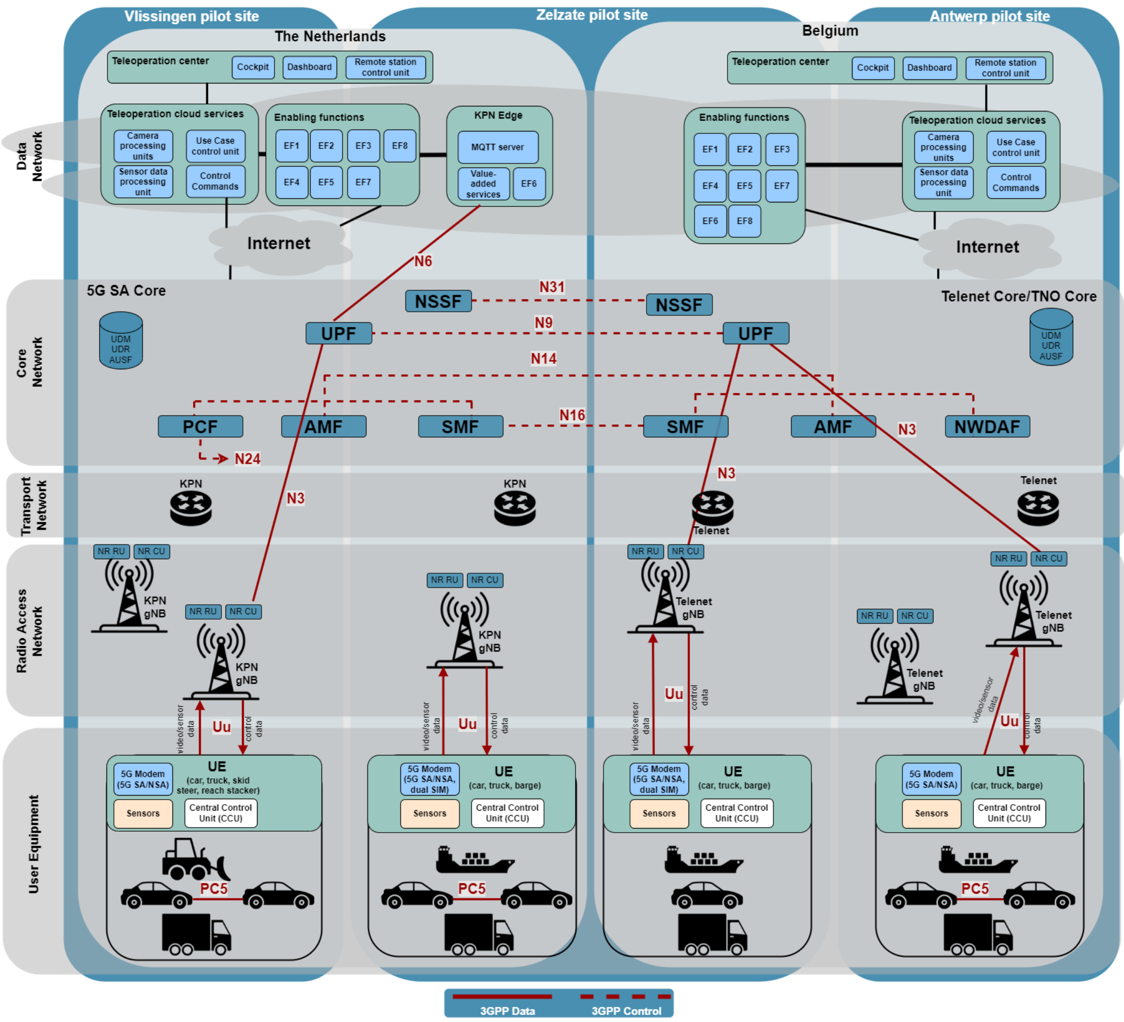

Figure 2: 5G SA Target Architecture

The above figure (Figure 2) relates the Use Cases (bottom part of the diagram) to the access networks at the pilot sites and then, via a routing and transmission layer, to the two instances of the 5G SA Core network. In this layer the essential interfaces for Seamless Handover are shown (N8, N9, N14 and N16). Finally, on the top layer the functions required to the Use Cases and Enabling Functions are shown. Not all of these functions are implemented in both networks.

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3 THE 5G NETWORK DESIGN

3.1 The Netherlands

3.1.1 5G SA RAN Node in the Netherlands

At the pilot site in the harbour of Vlissingen a dedicated (Huawei) gNB connected to the (Ericsson) 5G SA Core was built. This network is abstracted in Figure 5. This gNB consists of a BBU and a 64 elements (16 beam) MiMo antenna. The equipment is shown in Figure 3 and Figure 4. Similar equipment is foreseen at the Dutch side of the Zelzate border crossing, at the Sas van Gent site.

Figure 3: 5G SA RAN BBU Vlissingen

Figure 4: 5G SA MiMo Antenna Vlissingen

In the Netherlands the swap of the RAN towards 5G capable equipment is in progress. KPN at this moment only has a 700 MHz license for 5G. The operational 5G core is only NSA capable. This NSA network is accessible to all commercial customers of KPN.

3.1.2 5G SA Core in the Netherlands

For the 5G-Blueprint project a dedicated network is constructed. This network uses temporary 3500 MHz licenses and an SA Core exclusively accessible for designated UICC's. In Vlissingen a dedicated gNB with a mMiMo antenna is used. Operations & Maintenance is done remotely.

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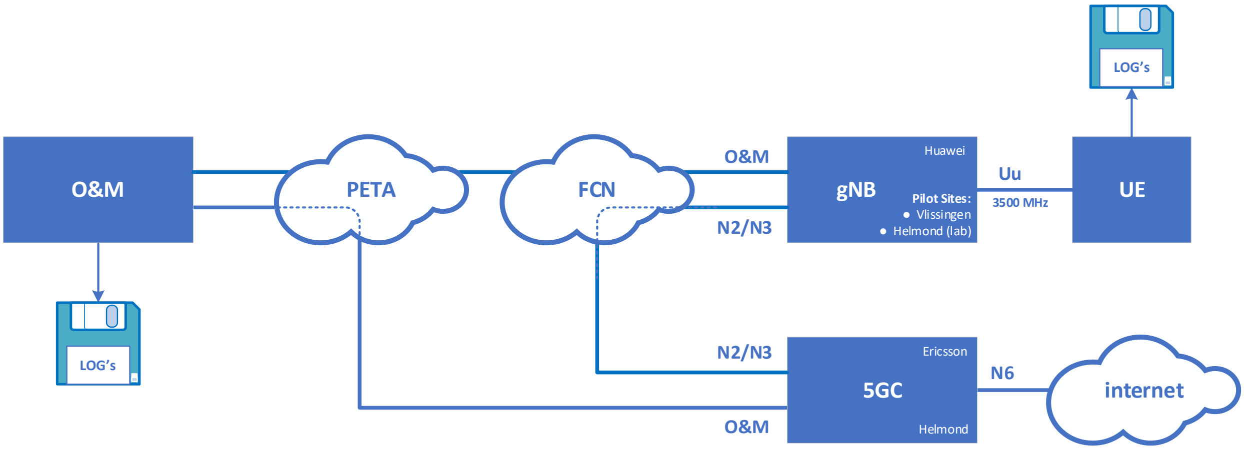


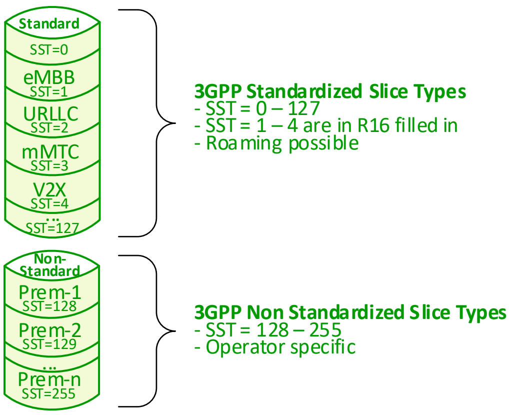
Figure 5: 5G SA Pilot network in Vlissingen

In the Ericsson 5G SA network three slices are configured next to the default slice (which is using 5QI 8). Some values for SST are defined in 3GPP TS 23.501 section 5.15: SST=1 (eMBB), SST=2 (URLLC), SST=3 (mMTC/MIoT) and SST=4 (V2X). The GSMA provides parameter values for these pre-defined Slices. As it turns out the GSMA proposed parameter-values for these standardized slices do not fulfil the Use-Case requirements. Thus, the 5G-Blueprint project had to specify their own slice parameters, using the standardized structure.

The Single Network Slice Selection Assistance Information (S-NSSAI) identifies a Slice. It is an 8- or 32-bit variable which consists of two fields:

- The Slice/Service Type (SST), an 8-bit field
- The Slice Differentiator (SD), an optional 24-bit field

SST values 0 to 127 belong to the standardized range. Values 128 to 255 belong to the Operator-specific range.



When an undefined S-NSSAI is indicated by the UE the GSMA recommends to map this to SST=1, no SD. In certain protocols, the SD field is not included to indicate that no SD value is associated with the SST. According to 3GPP TS 23.003 section 28.4.2 the SD field has a reserved value "no SD value associated with the SST" defined as hexadecimal FFFFFF.

In the Ericsson SA Core the slices as shown in Table 1 are configured to fulfil the requirements from the Use Cases (and Enabling Functions).

In 3GPP Release 15 SST numbers are limited to 8 Slices (only 3 of 8 bits used).

In 3GPP Release 16 SST numbers are limited to 256 Slices (8 bit).

3GPP and GSMA did not specify how to use SD in Roaming situations (24 bit).

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UE receives a dynamic private range IP.

Home Routing is assumed in all use cases.

Attribute	TeleOperations Slice (≈ URLLC)	Telemetry Slice (≈ V2X)	RemoteVision Slice (≈ eMBB)
SST (no SD → used: SD=FFFFFF)	124	125	126
Availability	99,999 %	99,99 %	99,99 %
GBR	25 MB/s	6 MB/s	15 MB/s (UL) 250 MB/s DL
Session and Service Continuity support	SSC mode 1	SSC mode 1	SSC mode 1
Slice quality of service	5QI 86	5QI 3	5QI 67
pre-emption capability or pre-emption vulnerability	Capable	Capable	Capable
Latency from UPF to AS	< 50 ms	< 50 ms	< 50 ms
Supported device velocity	120 km/h	120 km/h	120 km/h
APN / DNN / PDN / IP	teleops	telemetry	remotevision

Table 1: 5G-Blueprint specific Slice Parameters in Ericsson SA Core

5QI 3: GBR, Priority level 30, Delay budget 50 ms, 10^{-3} Packet Error Rate, Averaging window 2000 ms

5QI 67: GBR, Priority level 15, Delay budget 100 ms, 10^{-3} Packet Error Rate, Averaging window 2000 ms.

5QI 86: Delay Critical GBR, Priority level 18, Delay budget 5 ms, 10^{-4} Packet Error Rate, maximum data burst 1354 Bytes, Averaging window 2000 ms.

The TeleOperations Slice (≈URLLC) in meant to be used in UC1: Automated Barge Control, UC2: Driver in loop Docking, UC3: Teleoperated Harbour Crane and UC4: CACC Platooning.

The Telemetry Slice (≈V2X) in meant to be used in UC1: Automated Barge Control, UC2: Driver in loop Docking, UC3: Teleoperated Harbour Crane and UC4: CACC Platooning.

The Remote Vision (≈eMBB) Slice is meant to be used in UC1: Automated Barge Control, UC2: Driver in loop Docking, UC3: Teleoperated Harbour Crane and UC4: CACC Platooning.

As can be seen all slices are in use in all Use Cases. The essence of the Slicing experiments is that these streams exist in parallel and that they independently can produce the target values for the mentioned parameters. At this moment not all vendors can actually provide the exact values stated in the tables. This will be corrected in future releases. To the 5G-Blueprint it is only important that these streams exist in parallel and that they independently can produce the set values. Thus momentarily differences in parameter values between Belgium and the Netherlands can be ignored (for the moment).

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3.2 Belgium

5G NSA technology was gradually introduced to Telenet production network as from 2020. As described in D5.1, the default NR spectrum for wide 5G coverage is N1, on which DSS is configured on 15MHz bandwidth. For the 5G-Blueprint project, additional NR equipment for N78 was deployed at the desired coverage areas to meet the capacity requirements of the use cases and enabling functions. Until Q3 2022, only 50MHz bandwidth is activated on N78, due to delayed spectrum auction in Belgium. BIPT has confirmed in June 2022, that Telenet will get new 100MHz spectrum from 3480-3580MHz, which is expected later this year. Once the full spectrum is available Telenet will adapt the NR configuration. Please note that this also means that the exact frequency range could also change (the currently used 50MHz may not be overlapping with the final granted 100MHz spectrum). This should not introduce performance exceptions. The anchoring band for 5G NSA deployment always remains B3, which is the same for N1 only or N1/N78 dual band sites. Current used 5G NSA N1 is 1935-1950MHz/2125-2140MHz FDD NR. 5G NSA/SA N78 is 3600-3650MHz TDD NR. For more details, please refer to Table 12 and Figure 12 of D5.1.

For having dedicated user management and slicing management enabling 5G research, Telenet decided to introduce a dedicated 5G core, located in the Aartselaar data center. The 5G SA cells are collocated with 5G NSA cells, but are only accessible by trial users provisioned on the Aarselaar core. Such hybrid deployment provides the following advantages:

1. The most realistic network slicing design and deployment. The setup reflects the future proof methodology of SA network rollout, which shares radio infrastructure and keep SA network with network slicing as a private network layer on top of the production network. With real life network load on NSA layer, the network slicing services can be further studied and optimized.
2. Flexibility of network parameter changes without major impact on the production network service.
3. Provide flexibility of network monitoring and exposure.

This approach also introduces additional operational complexity, for example, alarm management. Necessary network security assessment and operational guidance has been designed for this setup.

3.2.1 Network Design Belgium

The overview of 5G RAN design is illustrated as figure below:

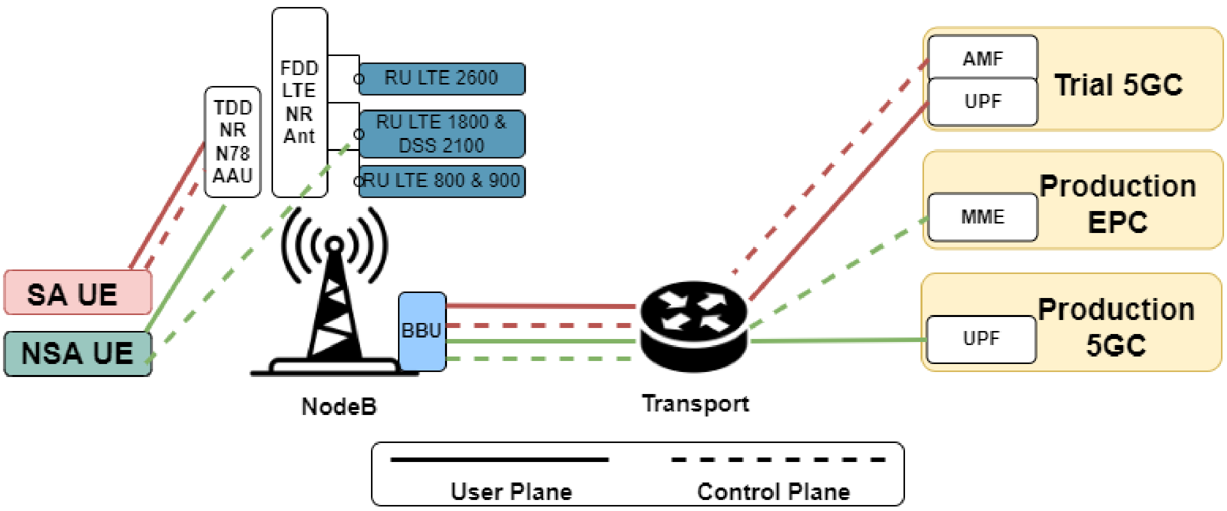

Figure 6: Telenet 5G RAN design for 5G NSA/SA environment

As illustrated in Figure 6, the 5G SA cell is radiated by only N78 TDD RU. The 5G SA UE is equipped with a dedicated SIM which is previsioned on Trial 5G core. Both user plane data and control plane data of the UE are routed through SA cell to reach Trial 5G core. Meanwhile 5G NSA network is radiated by both N78 TDD RU and N1 FDD RU. The NR N1 is configured as DSS with LTE B1 to share the total 15MHz bandwidth. At the LTE side, LTE 1800MHz (20MHz bandwidth) is used as anchoring band, while LTE 800MHz, LTE 2100MHz, LTE 2600MHz can be aggregated by LTE CA for maximum bandwidth. The 5G NSA UEs with production SIMs are connected with both LTE & NR cells with ENDC. The production network users are managed by the production operational flow and have access to the two production cores (NSA: EPC & SA: 5GC). The existing EPC is a legacy vEPC which will be phased out in 2023. The production 5GC is currently used as 5G core only but will merge to 2/3/4/5G common core. Until migration to the common 5G core is finished, the control plane data of 5G NSA user will reach the MME of the production vEPC and user plane data will reach the UPF on the production 5G core.

3.2.1.1 RAN Hardware

The main equipment deployed for N78 TDD is Ericsson Air 3227 B78T, which is a 32T32R AAU supporting high gain adaptive beamforming (vertical and horizontal), high order spatial multiplexing and multi-user MIMO. Maximum power of 200W is configured. In some cases where the overall cell capacity is low, the N78 TDD is deployed by 8T8R RU together with passive 3.5GHz antenna. In this case beamforming is no longer available and output power is limited to 160W total.

On the baseband side, all hardware is shared between LTE & NR. A typical configuration is using 6150 outdoor cabinet for baseband and transmission equipment, together with B154 cabinet for battery. The transmission network is share for both production & trial traffic, while the prioritization is configured differently.

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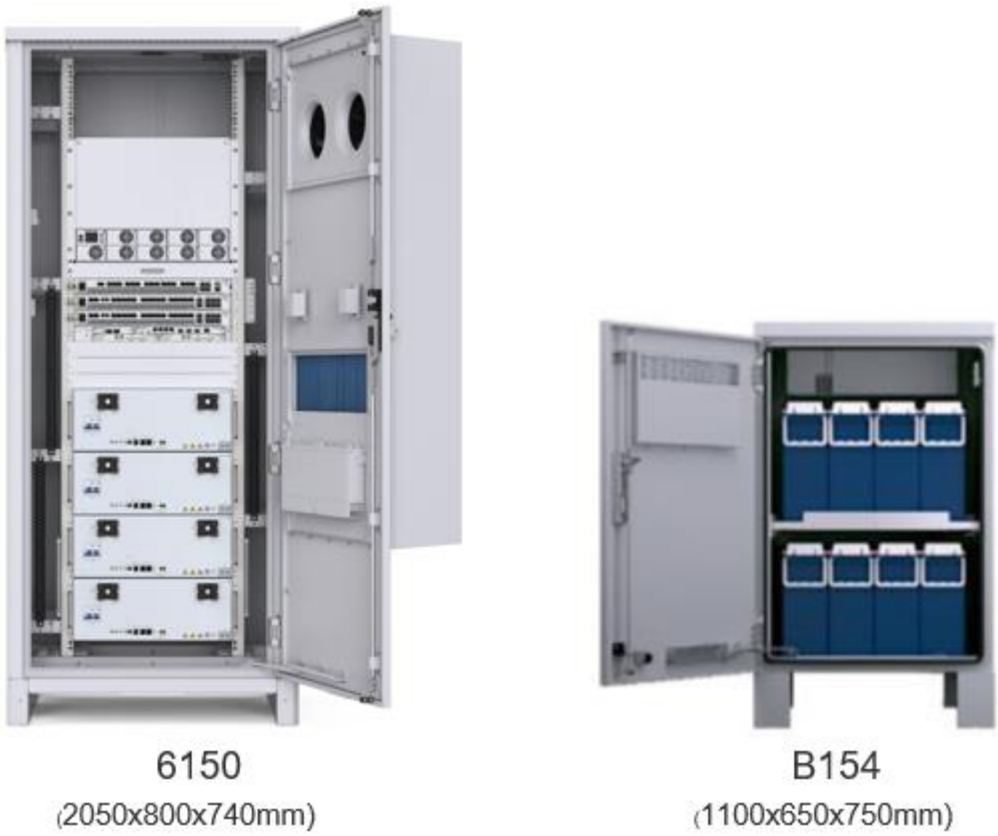

Figure 7: Telenet RAN cabinet

3.2.1.2 Core Hardware

The 5G trial core is a virtualized setup with HP servers. On the first implementation only the essential part of 5G NEs are configured, as shown in figure below:

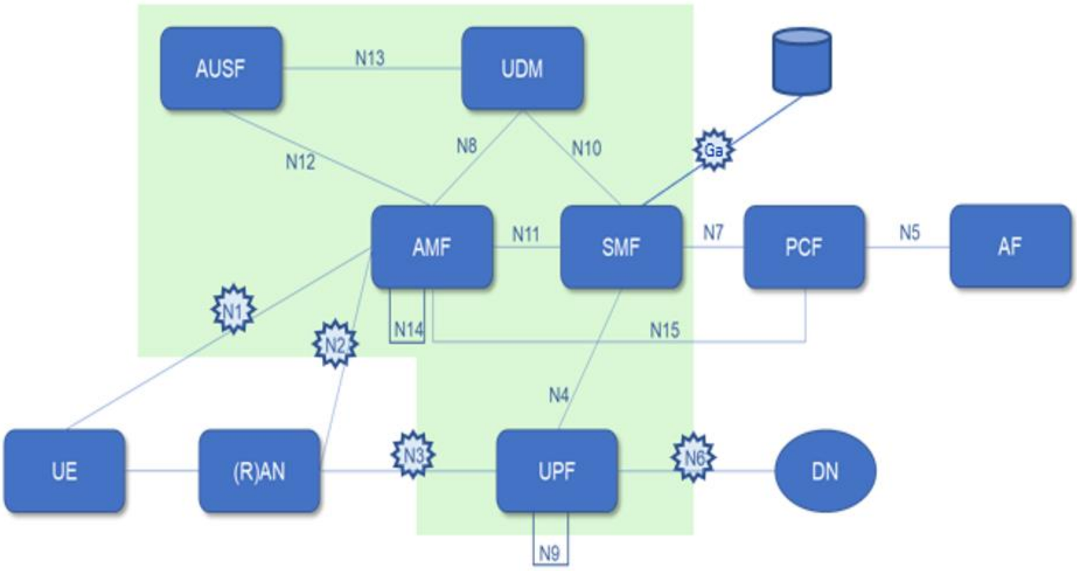

Figure 8: Telenet 5G trial core first implementation

In Figure 8, the NEs covered in green are tested and validated for the first phase of network trials. Other NEs of the 5G core architecture design will be configured and implemented in later upgrades. On top of new NE configuration and implementation, the 5G core is upgraded every three months for standard functionality upgrades. The core is deployed in redundant mode thus, the setup contains two servers, and all network elements are duplicated.

The physical cabling of the 5G trial core toward Telenet lab environment is illustrated below:

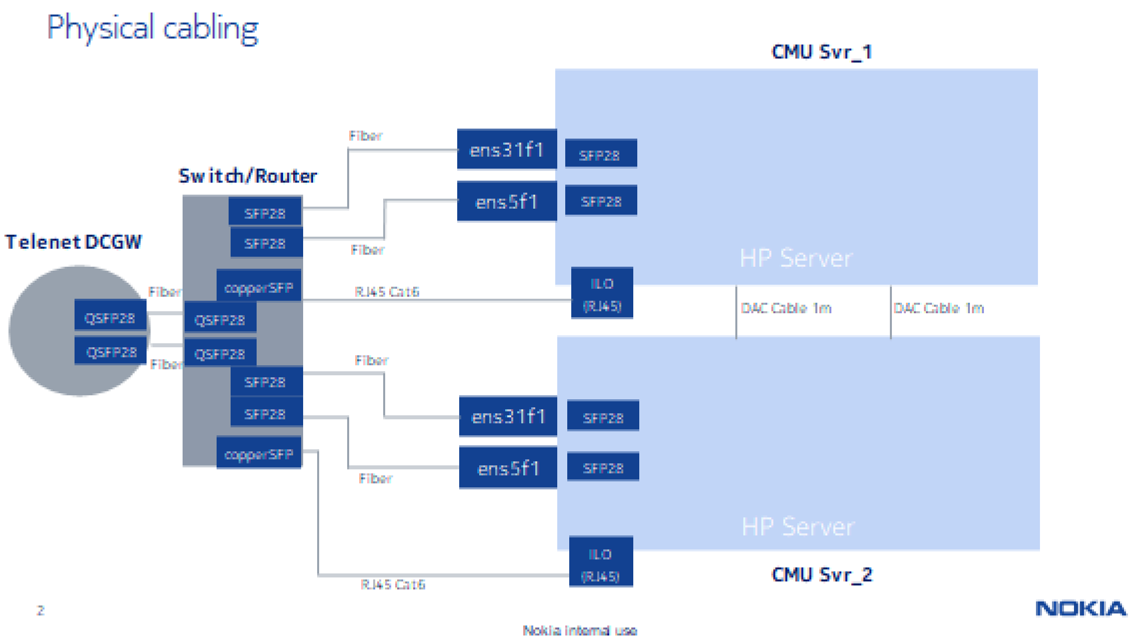

Figure 9: Telenet 5G trail core physical cabling

3.2.1.2.1 End to end slicing implementation

The end-to-end slicing implementation includes three parts: slicing profile configuration on core, 5QI value to DSCP mapping on transmission network, and 5QI configuration on 5G SA RAN. As mentioned before, the 5G trial core has a schedule software upgrade every 3 months and more 5QI values will be available in later releases. On 5G trial core, the following 5QI values are supported in the current software release:

5QI	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Averaging Window	GBR/non-GBR
1	20	100 ms	10^{-2}	2000 ms	GBR
2	40	150 ms	10^{-3}	2000 ms	
3	30	50 ms	10^{-3}	2000 ms	
4	50	300 ms	10^{-6}	2000 ms	
65	7	75 ms	10^{-2}	2000 ms	
72	56	300 ms	10^{-4}	2000 ms	
5	10	100 ms	10^{-6}	N/A	Non-GBR
6	60	300 ms	10^{-6}	N/A	
7	70	100 ms	10-3	N/A	
8	80	300 ms	10^{-6}	N/A	
9	90	300 ms	10^{-6}	N/A	
69	5	60 ms	10^{-6}	N/A	
79	65	50 ms	10^{-2}	N/A	
80	68	10 ms	10^{-6}	N/A	

Table 2: Telenet 5G trail core UPF 5QI table

As shown above, from the current supported 5QI, the network slices are defined in the first implementation according to the use case analysis and architecture design in D5.1:

Attribute	Telemetry “S-NSSAI-1”	RemoteVision “S-NSSAI-2”	TeleOperations “S-NSSAI-3”
SST, SD	SST = 1, SD = 1	SST = 1, SD = 2	SST = 2, SD = 1
Availability	99,99 %	99,99 %	99,999 %
GBR	N.A.	15 MB/s (UL) 250 MB/s DL	25 MB/s
Session and Service Continuity support	SSC mode 1	SSC mode 1	SSC mode 1
Slice quality of service	5QI 8	5QI 8 / 4	5QI 8 / 65
pre-emption capability or pre-emption vulnerability	Capable	Capable	Capable
Latency from UPF to AS	< 50 ms	< 50 ms	< 50 ms
Supported device velocity	120 km/h	120 km/h	120 km/h
APN / DNN / PDN / IP	5G-internet	live-stream	mission-critical

Table 3: Telenet 5G trial core NSSAI definition

Network slice “S-NSSAI-1” is defined as the basic 5G data service slice, with only 5QI value 8

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configured on the default DNN. The default 5QI for any DNN/network slice must be non-GBR.

Network slice “S-NSSAI-2” is the network slice defined for camera streams. Both 5QI value 8 and 4 are supported. The default 5QI value is 8. Once the network detects the UDP traffic towards predefined IP destinations, which are camera stream servers, it means that the camera streams are initiated. In this case new PDU sessions are created with 5QI value 4 just for the camera streams, while other traffic type from the same 5G UE or SIM remains on default 5QI 8. Note that the 5QI 4 is different from the discussed 5QI 67 in D5.1.

Network slice “S-NSSAI-3” is the simulated network slice for mission critical servers. In 5G BP use cases, it is meant to be mission-critical slice. The desired end-to-end URLLC service is not available in the first phase of network deployment, but this network slice will be reconfigured as soon as the vendor fully supports this (in the upcoming release). The target 5QI in an upcoming release for this network slice is 5QI 86. The default 5QI is also 8. Once the network detects traffic towards predefined IP destinations, which are mission critical sensor servers, the new PDU session will activate the 5QI 65.

As mentioned above both network slices with GBR service are configured with multiple 5QI flows and the secondary 5QI flow/PDU session is only triggered when predefined traffic recognized by the core. This by using the 5G UE Route Selection Policy (USRP) [ETSI TS 124 526]. In the network evaluation phase, the identifier is configured to be traffic type (e.g., TCP/UDP traffic used by Iperf tests). In use case trial phase and E2E evaluation, the identifier is configured to be the IP address of use case server (or the VPN tunnel). Note that 5G UEs must be compatible with USRP to use this feature, otherwise only default 5QI is used.

Totally 150 SIMs are provisioned on the 5G trial core to access network slicing. The SIM profiles are defined in three catalogs as shown below:

SIM Group	Subscribed NSSAI	Configured NSSAI
1	S-NSSAI-1	S-NSSAI-1, S-NSSAI-2, S-NSSAI-3
2	S-NSSAI-2	S-NSSAI-2
3	S-NSSAI-3	S-NSSAI-3

Table 4: Telenet SIM group configuration on 5G trial core

The Subscribed NSSAI is the default NSSAI the SIM is configured upon its attachment to the network. Thus, in default scenario, SIM cards belong to different SIM groups are distributed and used according to the use case. But in SIM Group 1, the SIMs are also configurated to be able to attach on all three network slices. This requires the 5G UE to be able to request the desired NSSAI to the network during the attach procedure. For the moment, 5G UEs are not capable of exchanging such information with the network. Thus, for current implementation and trials, the SIM cards are mapped with network slices and use cases.

End-to-end slicing also includes DSCP mapping with 5QI. With current available 5QI values, the end-to-end QoS mapping is configured as below:

Type	5QI	DSCP value	DSCP	Prec	SR
Synchronization	NA	56	CS7	7	EF
Radio Signaling	NA	34	AF41	4	AF
O&M	NA	16	CS2	2	AF
Conversational voice	1	46	EF	5	EF
Conversational living stream	2	36	AF42	4	AF
Realtime gaming	3	38	AF43	4	AF

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Non-conversational Buffered Streaming	4	34	AF41	4	AF
Mission-Critical	65	46	EF	5	EF
Live uplink streaming	72	34	AF41	4	AF
Control Plane Signaling	5	34	AF41	4	AF
Undefined 1	6	26	AF31	3	AF
Undefined 2	7	18	AF21	2	AF
Data services	8	10	AF11	1	BE
Undefined 3	9	0	BE	0	BE
Mission-Critical Signaling	69	34	AF41	4	AF
Undefined 4	79	34	AF41	4	AF
Undefined 5	80	34	AF41	4	AF

Table 5: Telenet E2E QoS mapping

The “undefined” E2E slices have 3GPP suggested services for them. But they are not currently defined in the 5G BP use cases. Thus, those E2E QoS flows are currently only configured, but not used or tested. Those undefined slices can be configured for specific services in later stage of this project. The recommended services for those 5QI values are:

5QI value 6 for: video (buffered streaming) TCP-based (e.g., www, e-mail, chat, FTP, p2p file sharing, progressive video etc.).

5QI value 7 for: voice, video (Live Streaming), interactive Gaming.

5QI value 9 for: Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, FTP, p2p file sharing, progressive video etc.).

5QI value 79 for: V2X messages

5QI value 80 for: low latency eMBB applications augmented reality.

3.2.1.3 5G Environment

The 5G trial environment for 5G BP in Belgium has four parts: 5G lab in Telenet Mechelen, 5G POC site in Telenet Mechelen, Port of Antwerp trial site, Zelzate trial site.

The 5G lab in Mechelen is used for basic network validation and integration tests. The testing following Telenet procedure of new software & hardware introduction. All components mentioned in Section 4.1 are tested first in the lab environment to verify the functionality and integrality of product description. Note that as the lab environment does not have the same network setup as in Figure 23, performance testing is not the focus of lab testing phase.

The 5G POC site in Telenet Mechelen is a dedicated test site which has existing production network setup. All software & hardware much be tested following Telenet operational and network management procedure before making any change to production network. The focus of this environment is to manage the impact of 5G SA network configuration change on production network.

The Port of Antwerp testbed is the focus of this project, where most services and coverage area are required. The network performance is also key for this test area.

The Zelzate testbed is the specific testbed for 5G roaming functionality. After the latest discussions about introducing a new partner for 5G SA roaming (TNO), the network design of Zelzate testbed will further change and will be separated into 5G NSA & SA for maximizing the testing flexibility.

4 5G NETWORK DEPLOYMENT

4.1 Modem Performance

Prior to the tests in the pilot areas the performance of the 5G modems used in these tests was assessed in the KPN 5G testlab in Helmond/Eindhoven and at Nuenen near the Automotive Campus in Helmond. Nuenen is, seen from a radio coverage perspective, a well-known 5G outdoor test area in the Netherlands, which also was used in preceding H2020 mobility tests.

All outdoor measurements described in this paragraph are done during initial Use Case testing on the 5G NSA and SA network in Helmond using two brands of 5G modem (the Digi TX64 and the Sierra Wireless XR80). Those modems are not yet capable of slicing, thus the 5QI parameters which would have been in a slice have been applied directly to the subscriptions/UICCs used in this test.

Bandwidth is primarily dependent on the available radio spectrum. The bandwidth of 5G SA is bound to the limitations of the temporary licenses. In contrast NSA can access all spectrum in the KPN license. Therefore the user bandwidth of NSA and SA can't be compared and therefore are not explicitly measured/reported in the (field-)lab test.

4.1.1 Measurements in the laboratory in the Netherlands

In the KPN testlab in Helmond/Eindhoven the effect of RAN parameters for low latency were explored. These tests were conducted under a number of (concurrent) load conditions. This load was generated using regular eMBB settings (5QI-8). The Device Under Test was using the Fibocom FG150 modem and 5QI-80 for Low Latency. The protocol used for these tests was UDP with a 160 Byte mean packet size. The Fibocom modem supports many 5G features (e.g. a limited form of slicing) but it is unfit for outdoor usage.

4.1.1.1 Uplink lab-tests

Uplink Latency (N = 19668)	No concurrent traffic	Concurrent **up**load 48000 kbps	Concurrent **down**load 62000 kbps
In graph:	Blue line	Orange line	Green line
Min	2.5	3.0	2.3
Mean	4.8	19.3	6.1
95th Percentile	8.928	30.315	10.698
99th Percentile	10.196	35.884	12.836
Max	17.5	44.5	20.9
Std. Dev.	1.7	6.7	2.4

Table 6: Uplink Latency, lab test (values in ms)

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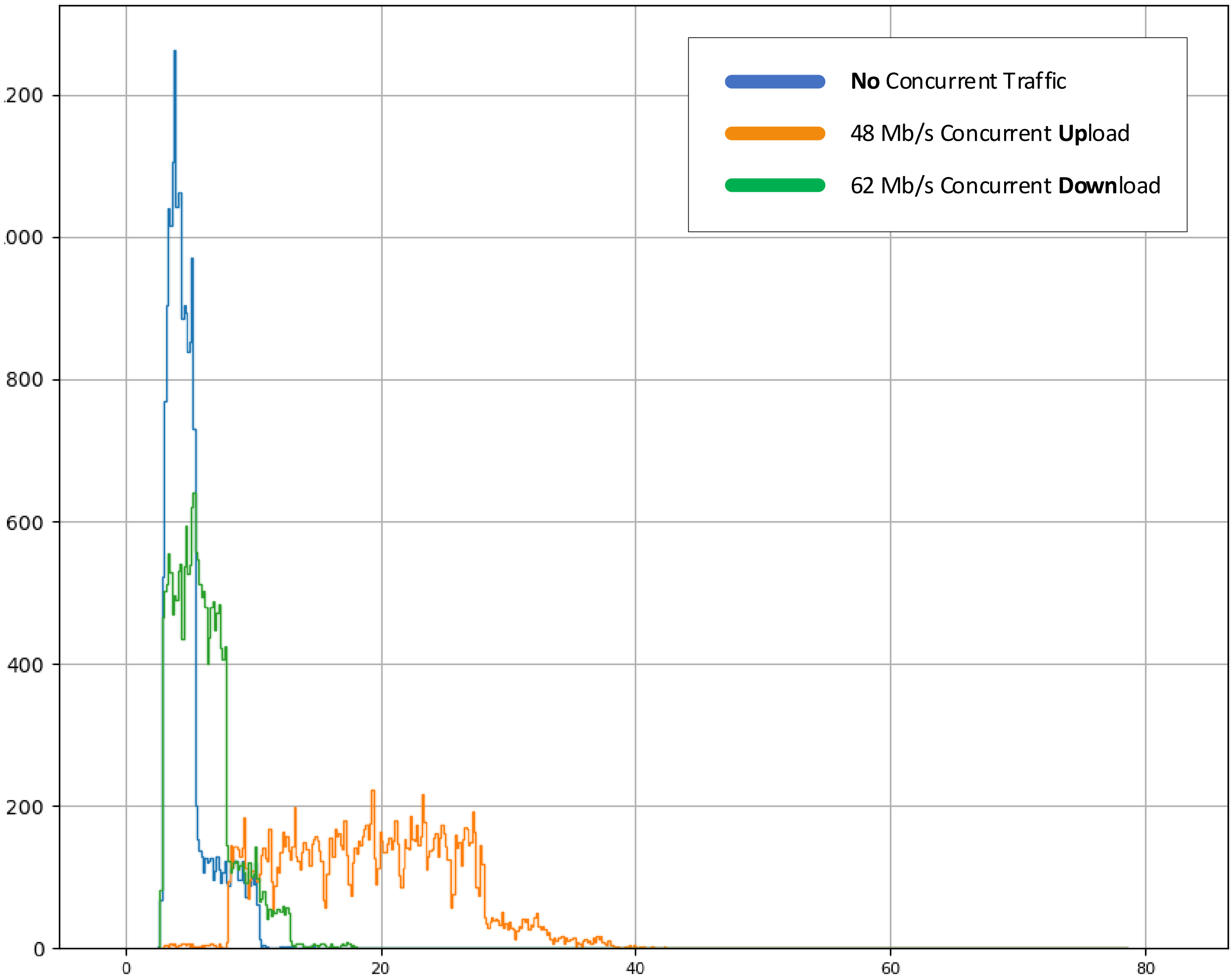

Figure 10: Uplink Latency, lab test

As can be seen a concurrent download has little effect on the latency of the uplink (green line). In contrast a concurrent upload exerts considerable influence on the uplink performance (orange line), even though the device under test has low latency settings.

4.1.1.2 Downlink lab-tests

Downlink Latency (N = 19875)	No concurrent traffic	Concurrent **upload** 48000 kbps	Concurrent **download** 62000 kbps
In graph:	Blue line	Orange line	Green line
Min	4.0	4.1	4.1
Mean	4.9	4.9	4.9
95th Percentile	5.548	5.549	6.399
99th Percentile	6.405	6.401	9.016
Max	30.4	22.1	24.8
Std. Dev.	0.6	0.5	0.6

Table 7: Downlink Latency, lab test (values in ms)

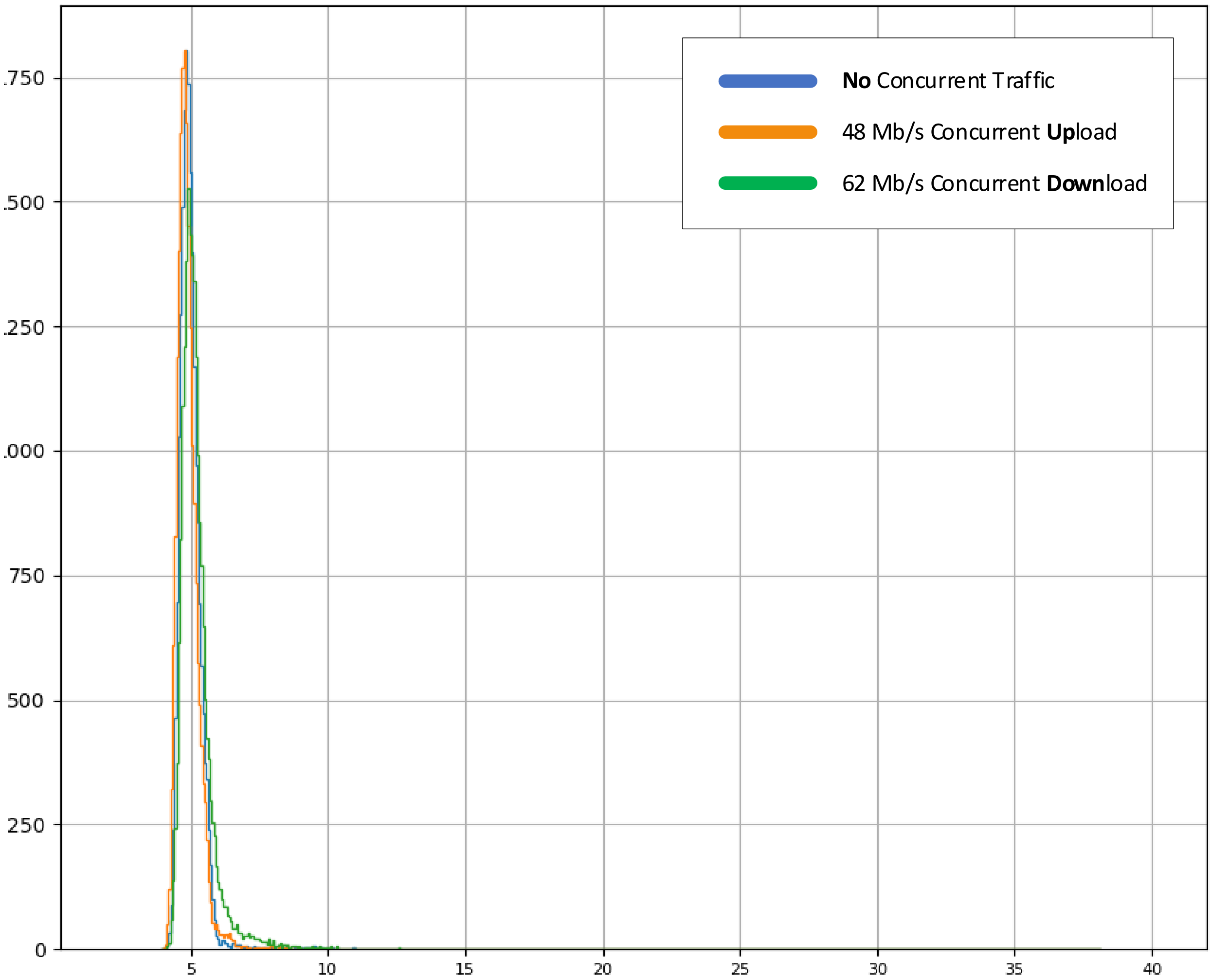

Figure 11: Downlink Latency, lab test

As can be seen a concurrent up- or download has little to no effect on the latency of the downlink.

4.1.1.3 Measurements at the Fieldlab in Nuenen

Figure 12: Nuenen Fieldlab test area

Close to the Automotive Campus a parking lot next to the A270 has line of sight coverage from site 3101. This site is equipped with both NSA (700 MHz, 2100 MHz, anchor 1800 MHz) and SA (3500 MHz on a temporary licence). This parking lot can (incidentally) be closed off for regular traffic to allow for various mobility related tests. This has been done for 5G Mobix and in May 2022 for 5G-Blueprint. The characteristics of the local radio network are well known.

In this fieldlab the two rugged modems were tested in real remote driving tests. The Digi TX64 modem was tested both on the NSA network (using QCI-8) and the SA network (using 5QI-8). The Sierra Wireless XR80 modem was tested on the SA network (using 5QI-8). These modems do not (yet) implement slicing.

Uplink Latency (using UDP video)	Digi TX64 on NSA	Digi TX64 on SA	Sierra Wireless XR80 on SA
Min	14.375	4.04	3.579
Mean	31.2	17.6	256.4
95th Percentile	40.061	20.681	837.636
99th Percentile	45.296	28.072	1302.526
Max	113.475	1437.563	1499.686
Std. Dev.	5.5	59.3	101.4

Table 8: Field Measurements Uplink (values in ms)

Downlink Latency (for teleOperations)	Digi TX64 on NSA	Digi TX64 on SA	Sierra Wireless XR80 on SA
Min	9.781	3.553	3.0
Mean	15.2	8.2	7.4
95th Percentile	22.29	13.082	12.851
99th Percentile	24.517	15.581	14.851
Max	66.902	45.32	27.836
Std. Dev.	3.5	2.6	2.7

Table 9: Field Measurement Downlink (values in ms)

As can be seen the uplink performance of the used Sierra Wireless XR80 modem was well below expectations. Since the downlink performance was on par with the Digi TX64 modem this is believed to be an incident which can be solved by the vendor[1]. In general the performance difference between NSA and SA is evident.

4.1.2 Initial test results in the laboratory in Belgium

As mentioned in Section 4.2, the testing in Mechelen lab and Mechelen PoC site focus and functionality and network management. The initial performance testing was done in Port of Antwerp area for both 5G NSA and 5G SA network.

From use case side, 5G devices from Peplink with Qualcomm X55 chipset are tested and deployed for use cases. The devices are verified to be reliable for both 5G NSA and SA. But the firmware versions are different. This applies to all tested Peplink devices with X55. After testing, a Peplink 5G BR1 is tested and installed in the smart beacon for EF8 scene analytic. For UC1 automated barge control, two Peplink 5G Dome are tested and installed for Seafar vessel, one with 5G NSA firmware and one with 5G SA firmware. In performance testing, all Peplink device with X55 chips showed a disadvantage in NSA mode comparing with devices with X62 chip, that

[1] As an afterthought: at the moment this report was written the Sierra Wireless XR80 modem has received a firmware upgrade which indeed solved these problems. Both modems are now comparable in performance.

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only three LTE carriers are aggregated for downlink in ENDC mode. For this reason, all network performance testing is done or scheduled with 5G device with X62. However, this does not have much impact on the project use cases.

The Snapdragon X62 5G modem-RF system is Qualcomm's latest generation chipset which support 3GPP R16 features (some with later firmware upgrades). It comes with Qualcomm's latest technology on power saving and RF boosts. It supports both 5G SA and 5G NSA by default, together with global 5G band including mmWave. On sub-5GHz band it supports maximum 120MHz bandwidth, 256QAM modulation and 4x4 MIMO, which is sufficient for Telenet's 5G network. Comparing with the more powerful X65 chipset, which support maximum 300MHz bandwidth on sub-5GHz, the X62 modem does not make any practical difference.

4.2 5G network in Vlissingen pilot site

In the harbor of Vlissingen a number of Base Stations have been upgraded to support 5G NSA using the 700 MHz FDD band. In addition, on site 7672 (see Figure 13), also a 3500 MHz TDD gNb was installed, connected to the 5G SA core of the KPN Fieldlab. This 5G SA site uses one mMiMo antenna in the direction of the south-eastern quay (to support Use Case 2b) and is capable of 16 beams. It operates on a temporary license, has a bandwidth of 100 MHz and a maximum transmission power setting of 50 Watt.

4.2.1 5G NSA Coverage Vlissingen

The 5G NSA coverage in Vlissingen as shown in Figure 13 (taken from the "ASSET" Radio Plannings tool) was not extensively measured at all grid-points at the designated pilot area. The coverage of the SA network was sampled in the pilot area. This is discussed in section 4.2.

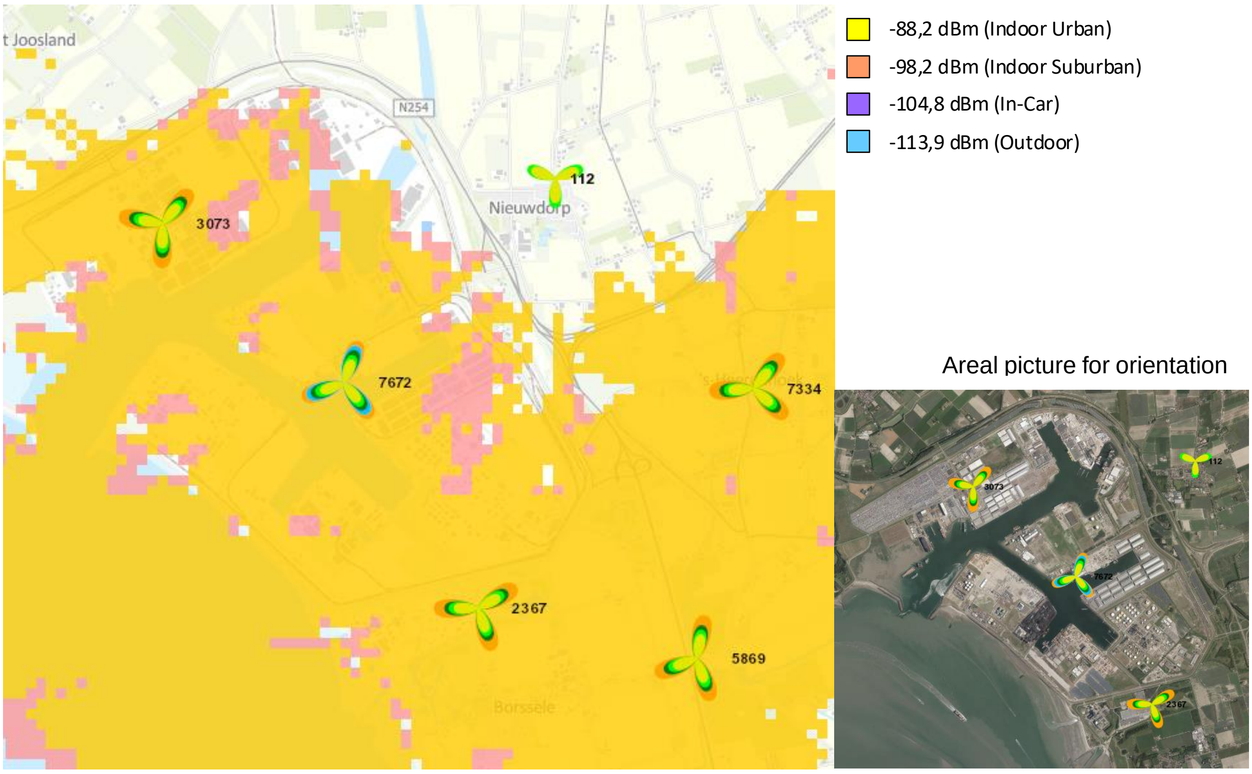

Figure 13: NSA Coverage in Vlissingen Pilot Area

When coverage maps are shown, these stem from the radio planning tool “ASSET”[2]. The “tiles” or “pixels” on these maps are 40 x 40 meter squares. The predictions from ASSET are important to KPN as they have budgetary consequences. The Radio planning tool is validated and calibrated to the KPN implementation regularly as part of the operational radio planning process.

The 5G SA coverage in Vlissingen pilot site is only accessible for a limited number of UICC’s connected to the SA Core of KPN Fieldlabs. The 5G RAN vendor is Huawei. The 5G SA core is made by Ericsson. The 5G NSA coverage is provided by the commercial network of KPN. It is publicly accessible using any KPN USIM in suitable User Equipment.

4.2.2 5G SA Network in Vlissingen

To assess the coverage of the SA cell at Vlissingen, initial measurements were performed On the 3500 MHz SA site 7672 measurements were made to establish evaluate its performance. The Digi TX64 modem was used in all tests. During the course of Task 5.4 extensive measurements are planned.

The Reference Signal Received Power (RSRP) is a measurement of the received power level in an cellular network.

The Reference Signal Received Quality (RSRQ) is a Quality indicator considering also the Received Signal Strength Indicator (RSSI) and the number of used Resource Blocks (N) RSRQ = (N * RSRP) / RSSI measured over the same bandwidth. RSRQ is a C/I type of measurement and it indicates the quality of the received reference signal.

The RSRQ measurement provides additional information when RSRP is not sufficient to make a reliable handover or cell re-selection decision.

The received RSRP and RSRQ are color-coded using the below schema (Table 10):

		RSRQ (dB)				
		>= -10	>= -14	>= -17	>= -20	< -20
RSRP (dB)	>= -80					
	>= -90					
	>= -100					
	>= -124					
	< -124					

Table 10: RSRP and RSRQ evaluation (and colour coding).

During the initial tests in Vlissingen a large seafaring ship was being unloaded. Therefore, a part of the quay was not accessible. For the measurements a route was chosen between the warehouses next to the quay (Figure 14). These warehouses are large metal constructions, and they possibly have an impact on the observed performance. More tests will follow in the short-term in order to further evaluate the deployed 5G SA network. These tests are in the scope of task 5.4.

[2] https://www.teoco.com/products-services/ran-solutions/planning/radio-planning/

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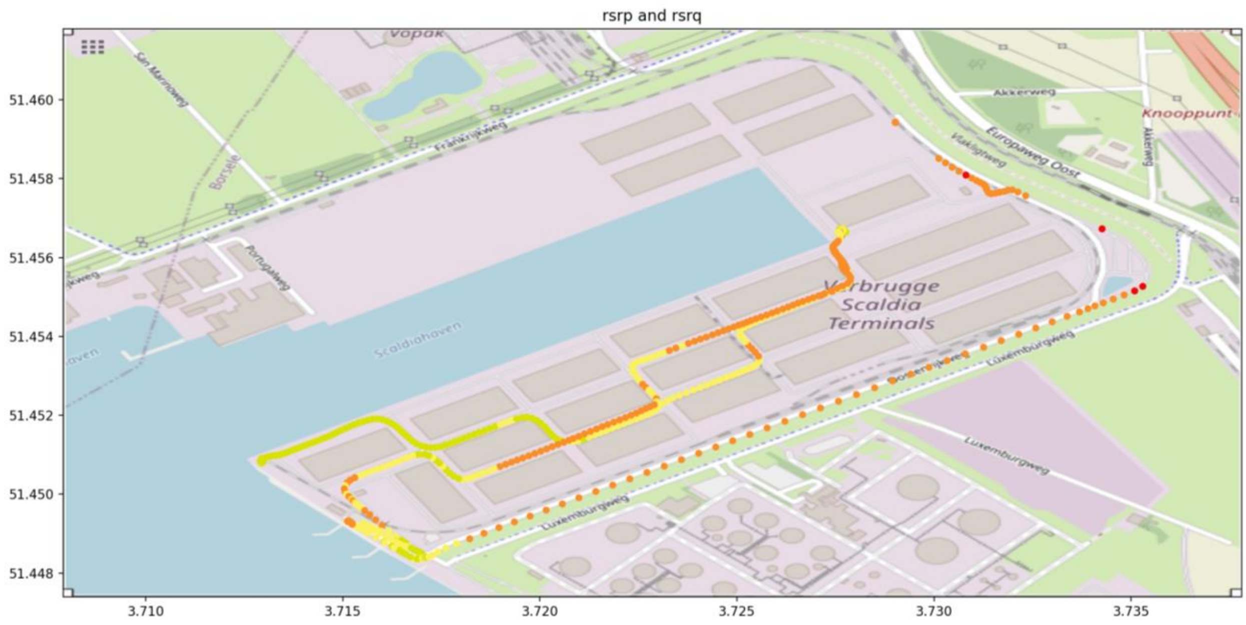

Figure 14: Quality of the 3500 MHz signal in Vlissingen.

Apart from the signal quality the latency and throughput have been measured. During the measurement of the Round Trip Time (RTT) using PING with a payload of 100 bytes and a repetition time of 200 ms, parallel uplink traffic was generated with an average bandwidth of 69 Mbps. The colour-coded results of the PING tests is shown in Figure 15. The actual throughput of the uplink traffic generated in parallel with the PING test is shown in Figure 16.

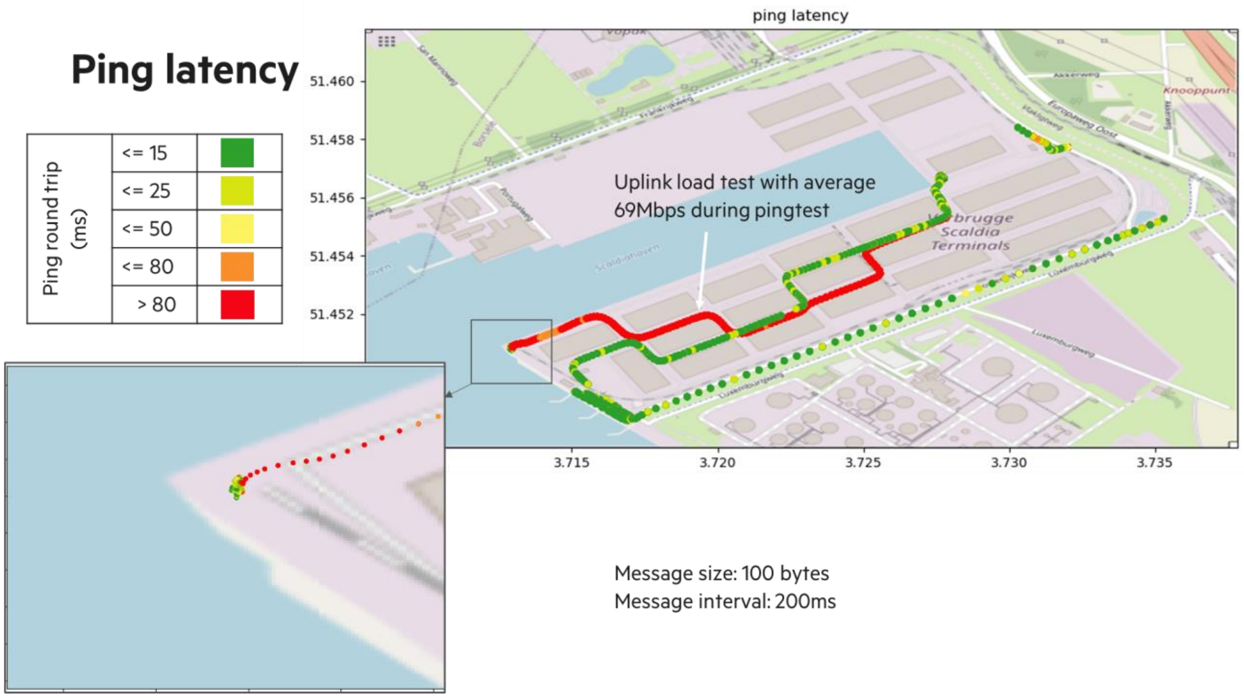

Figure 15: RTT Measurements using PING in Vlissingen.

Uplink throughput drivetest

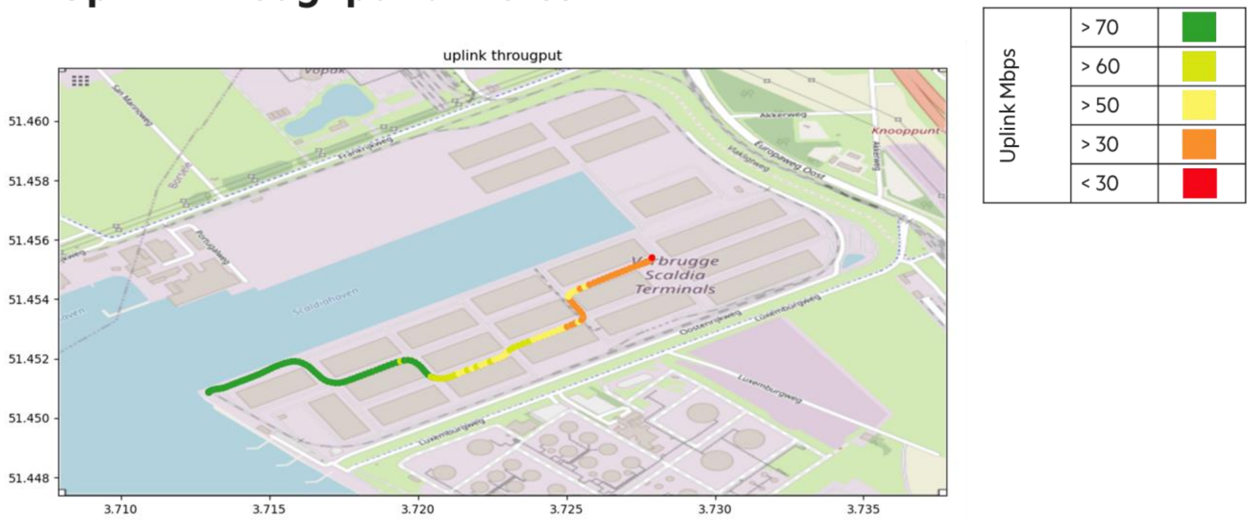

Figure 16: Uplink throughput test in Vlissingen.

Finally, an elaborate stationary performance test was done at the start point and end point of the afore mentioned drive test (these locations are indicated A and B on the map inserted in Table 11 with the results).

Throughput tests

Location	Direction	Limit (Mbps)	Actual	Packet loss	Average latency (ms)	Duration (sec)	Protocol	Tool
A	Uplink	20	20	0.0%	11.6418	60	UDP	nuttcp
A	Downlink	100	98	2.21%	12.6875	60	UDP	nuttcp
A	Downlink	-	365	-	-	861	TCP	iperf3
A	Downlink	-	383	-	-	429	TCP	iperf3
B	Uplink	20	20	0.0%	11.2718	60	UDP	nuttcp
B	Downlink	100	98	2.29%	12.5215	60	UDP	nuttcp
B	Uplink	-	70	-	-	60	TCP	iperf3
B	Uplink	-	70	-	-	60	TCP	iperf3
B	Downlink	-	363	-	-	60	TCP	iperf3
B	Downlink	-	355	-	-	60	TCP	iperf3
A to B	Uplink	-	68	-	-	300	TCP	iperf3

Table 11: Stationary throughput tests in Vlissingen.

The SA Core provided by the KPN selected vendor (Ericsson) is not ready for SA Roaming. Thus, for the development of Seamless Handover at the Zelzate border crossing another dedicated network is required. In this network the SA Core is provided by TNO. This network is described in section 4.4.1. The gNB at the Dutch side of the border crossing deploys an 4T4R 2600/3500 MHz antenna. The SA Core provided by TNO is connected to another instance of the SA Core of TNO at the Belgium side.

4.3 5G Network in Antwerp pilot site

The overview of coverage in Port of Antwerp is as following:

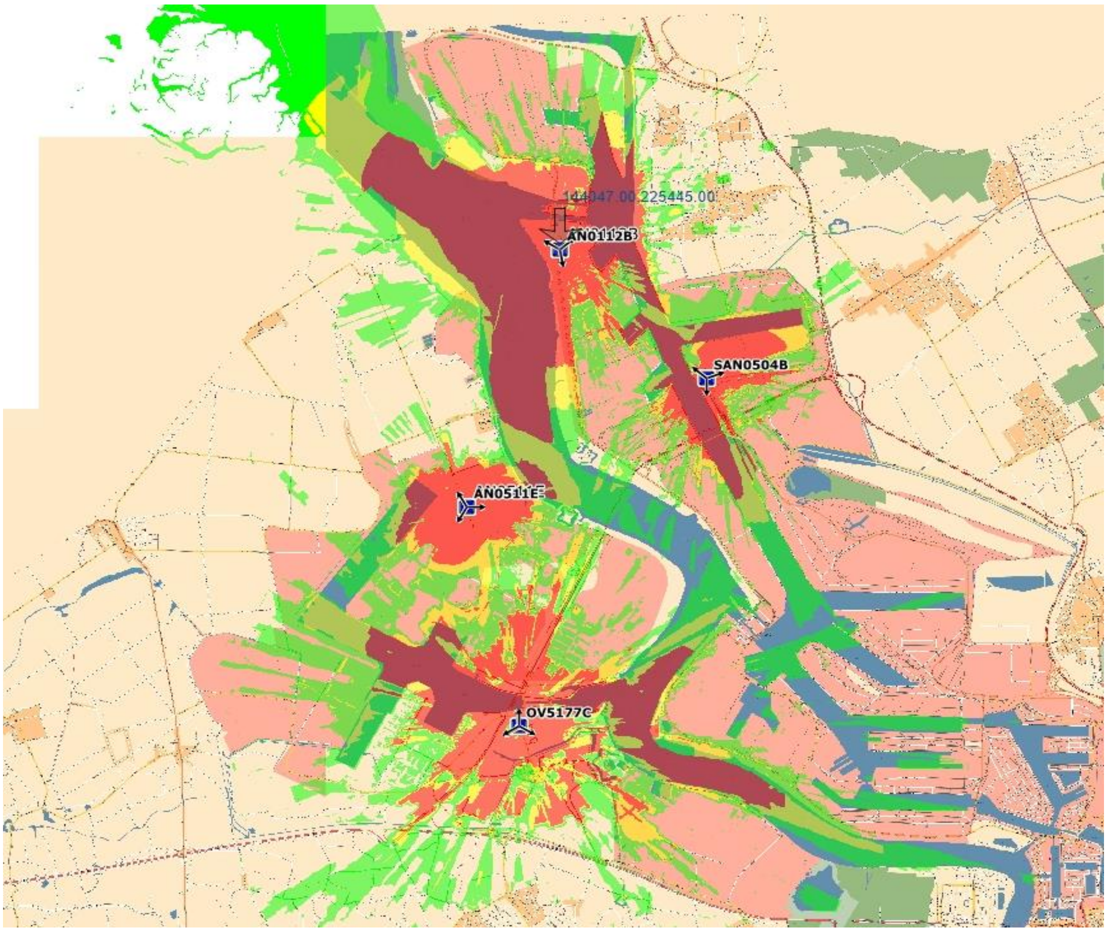

Figure 17: N78 Coverage Port of Antwerp

As shown in figure above, the area colored in red, yellow, and green illustrate the N78 coverage are in Port of Antwerp. The red area indicates an expected signal strength of as least -94dbm. The yellow area indicates the expected signal strength between -98 to -95dbm. The green indicates the expected signal strength of minimum -106dbm. For the 5G BP use cases where most UEs are on mobile, only the red and yellow area can be considered as useable.

This coverage zone includes four sites: AN0012, AN0504, AN0511 and OV5177. In which AN0511 and AN0504 are new build sites from ground. The other two are existing sites but completely swapped to new vendor together with 5G upgrades. The plan for phase two deployment is to add 5G N78 site in south part of Port of Antwerp, following the waterways. This will expand the coverage for the maritime use cases.

The first performance test was done at AN0112B near the north lock. The testing was done in both south and east side of AN0112B. On the north side across the lock there is a hill that blocks the 5G signal on the lower ground level. This creates an unique 5G NSA network issue with current 5G NSA setup. In such scenarios, the 4G signals from neighboring cells will kick in with stronger RSRP and trigger a handover to the neighboring cell where 5G NR is no longer available for ENDC. This can be solved by adding cell lock information on 5G UE. On 5G SA network however, this will not be an issue as 5G SA can be forced on device side.

The testing location is 250m away from cell lower, where the 5G UE stabilize at around -85dbm RSRP on N78.

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Figure 18: Initial testing location in Antwerp

The AN0112 setup is the standard one with all available LTE bands and 5G N78. The first test result of both X55 and X62 devices are as following:

Item	Service bands	Max speed (Mbps)	Avg speed (Mbps)	Avg latency (ms)	Avg Jitter (ms)
X55 downlink	L8+L18+L21+L26 +N78	554Mbps	505Mbps	31	4
X55 uplink	L18+N78	92Mbps	70Mbps		
X62 downlink	L18+L21+L26 +N78	663Mbps	630Mbps	33	4
X62 uplink	L18+N78	95	74Mbps		

Table 12: Initial network test results in Port of Antwerp

4.4 5G network at Zelzate pilot site (the border crossing)

At Sas-van-Gent / Zelzate trucks and barges can cross the Dutch-Belgian border. As barges and trucks are automated, they rely on connectivity. Although it is expected that both the barges and trucks will be able to automate a lot of the sailing and driver tasks in the future, there are still parts of trajectories at which the barge or truck needs to be operated manually. An example of such a situation where sailing needs to be performed manually by a tele-operator is when passing a bridge. At Zelzate that bridge is in the cross-border handover area. When they are operated remotely, they depend heavily on the network, allowing no gaps in the continuity of services.

During the first phase of the 5G-Blueprint project it became clear that MNOs have no unanimous opinion on the prioritization of the development NRI (Seamless Handover) in NSA and SA. Both of these avenues will be discussed in this section.

At the border crossing the key focus is on continued connectivity while crossing the border. This is trialed with different technologies and with different methods. The following technologies will be trialed in different setups:

- 5G NSA core
- LTE with 5G NR
- 5G SA Core
- 5G NR

- S1 Handover
- N2 Handover
- Dual modem
- Remote UE/Modem configuration using URSP

4.4.1 5G NSA Seamless Roaming

In 5G Mobix seamless handover between a Home PLMN (H-PLMN) and a Visited PLMN (V-PLMN) was developed using a NSA network and the same vendor on both sides of a border. In their deliverable 7.3 an extensive description of the set-up and the learnings is provided. It is on these results the 5G-Blueprint intents to contribute. The findings of the 5G Mobix project will be extended in three ways:

a) To allow successive handovers 5G-Blueprint will develop a V-PLMN – V-PLMN handover.
b) 5G-Blueprint will develop a multi-vendor solution (using an Ericsson, a Nokia and, for SA, a TNO Core network).
c) 5G-Blueprint will develop an improvement of the 5G SA inter PLMN handover procedure, based on the NSA learnings of 5G Mobix, having further enhancements to it.
d) 5G-Blueprint will explore the possibilities to automate the exchange of RAN Configuration data between MNOs.
e) 5G-Blueprint will explore the possibilities to, from the H-PLMN, distribute the number of roaming customers over the different V-PLMNs (Steering of Roaming).

Currently there are no provisions for steering of roaming while performing a handover. The goal is to have the Home-PLMN influence the current visited-PLMN to handover the connection to a preferred next Visited-PLMN.

The S1 handover will be performed using the following setup in Figure 19.

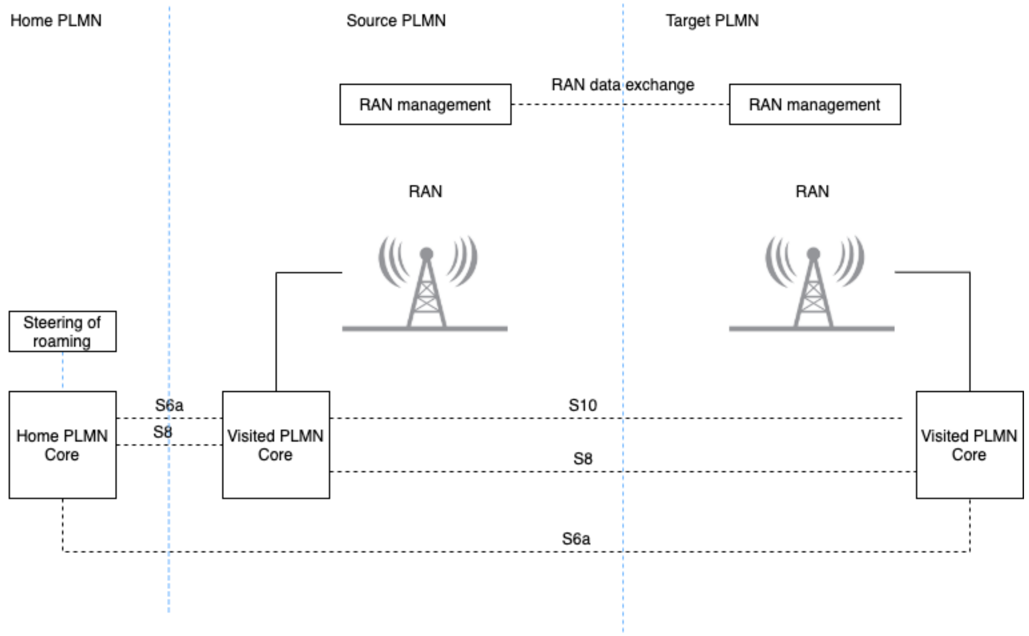

Figure 19: Visited to Visited roaming architecture

The regular roaming interfaces S6a (home HSS to visited MME), S8 (user plane data) and S9 (home PCRF to visited PCRF) exist between the home PLMN and visited PLMN's. Only between the networks where the handover takes place an additional S10 interface is needed. The S10 interface will relay the handover messages between the source gNB and target gNB. Using this interface the S1 handover will be enabled between the two PLMN's.

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To configure an S1 handover, the source gNB needs to be configured with information about the target gNB. To improve scalability the process of RAN data exchange regarding between MNOs needs to be automated.

4.4.1.1 NSA setup at the border

At different earlier projects similar tests have been performed at a small scale and with several limitations. Past setups consisted of the same vendor at both sites of the border and involved a crossing between a Home-PLMN and a Visited-PLMN. Within 5G-Blueprint the focus is on how to create a setup that is scalable across Europe. To enable scalability, we will test the handover using:

- Different vendors at both sites of the border (BE site: Ericsson RAN + Nokia Core, NL site: Huawei RAN + Ericsson Core)
- Handover with a roaming subscriber to another visited network
- Steering of roaming
- Automated exchange of RAN data

To achieve these goals we will implement different increments and increment the complexity with each step.

<u>Step one</u>

Tests will be limited to two PLMNS with each its own vendors. This way the multi-vendor setup is tested and the basic principle of a handover can be explored.

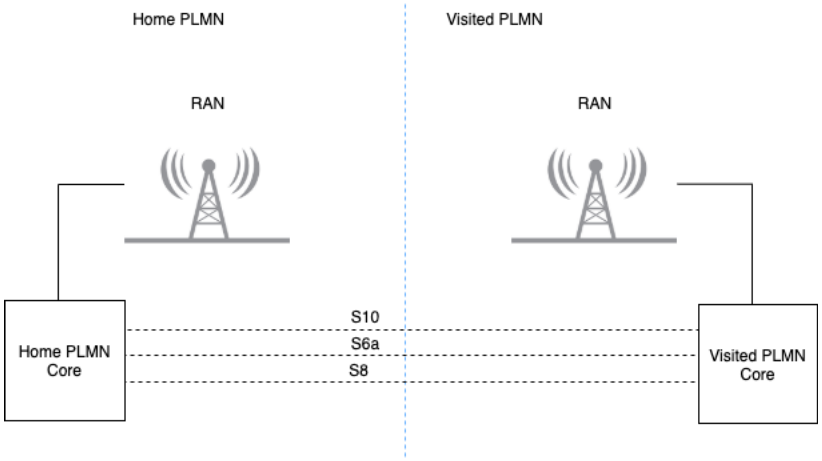

Figure 20: NSA Roaming Increment 1: HPLMN - VPLMN

This setup is depicted in Figure 20. At the border only one other operator can be chosen and one of those operators is also the Home-PLMN. The main difference with previous projects is the difference in vendors. At both sides of the border other Vendors are used.

<u>Step Two</u>

In the second increment a third PLMN is introduced. The handover will take place between two visited PLMN's. This setup is depicted in Figure 21.

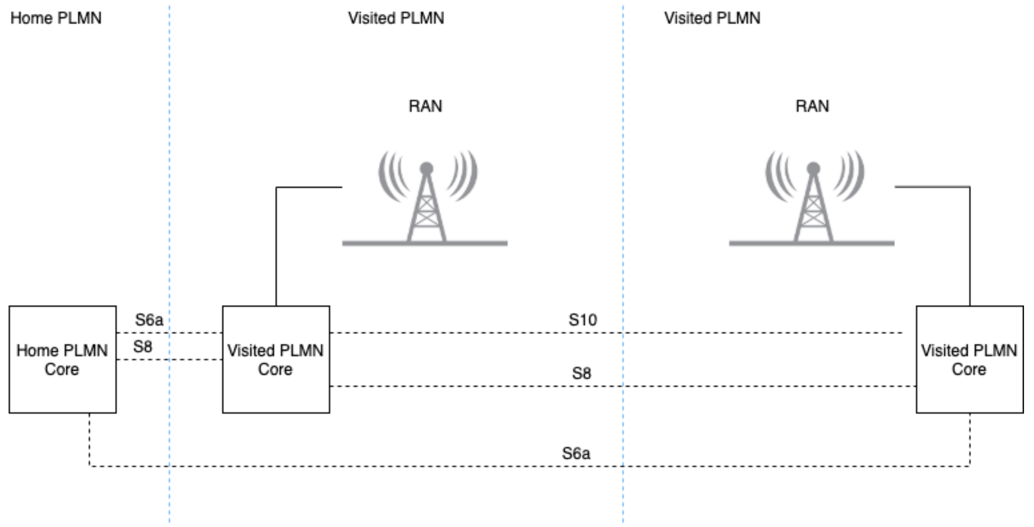

Figure 21: NSA Roaming increment 2: two VPLMNs

<u>Final step</u>

In the final step, steering of roaming and RAN data exchange is introduced. The Source RAN can choose between different networks to handover to

Currently there are no provisions for steering of roaming while performing a handover. The goal is to have the Home-PLMN influence the current visited-PLMN to handover the connection to a preferred next Visited-PLMN.

The S1 handover will be performed using the following setup in Figure 22.

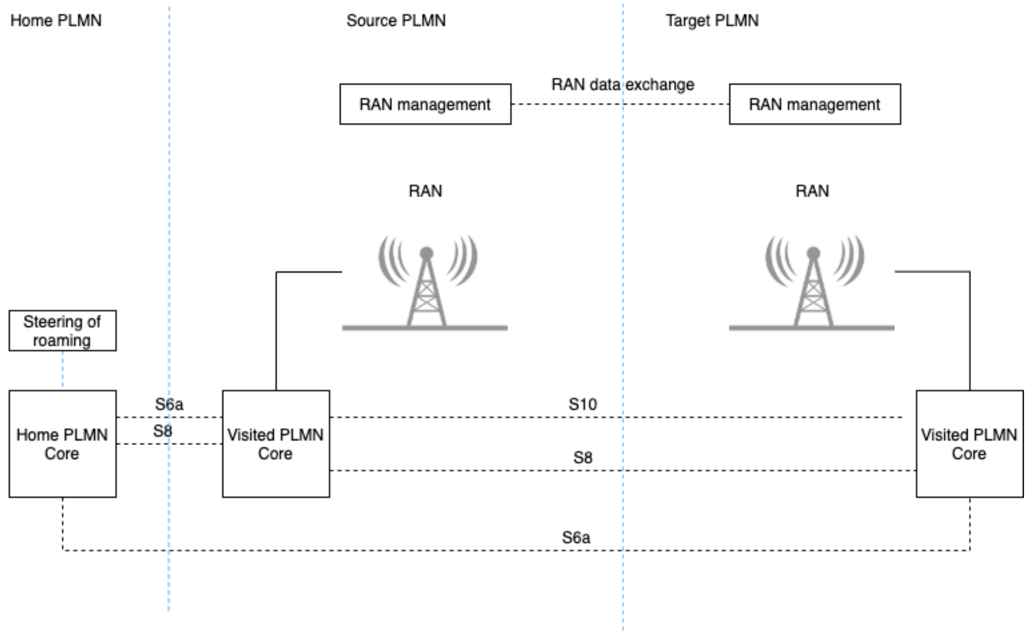

Figure 22: NSA Roaming final step.

The regular roaming interfaces S6a (home HSS to visited MME), S8 (user plane data) and S9 (home PCRF to visited PCRF) exist between the home PLMN and visited PLMN's. Only between the networks where the handover takes place an additional S10 interface is needed. The S10 interface will relay the handover messages between the source gNB and targed gNB. Using this interface, the S1 handover will be enabled between the two PLMN's.

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To configure an S1 handover, the source gNB needs to be configured with information about the target gNB.

4.4.2 5G SA Seamless Roaming

The development of Seamless Roaming for 5G SA networks will be developed in two stages. First in the TNO lab in the Hague the N8, N9, N14 and N16 interfaces will be developed and configured between the TNO Core and, via a VPN, the Nokia Core. The RAN will be local, using 3500 MHz. The set-up is shown in Figure 23.[3]

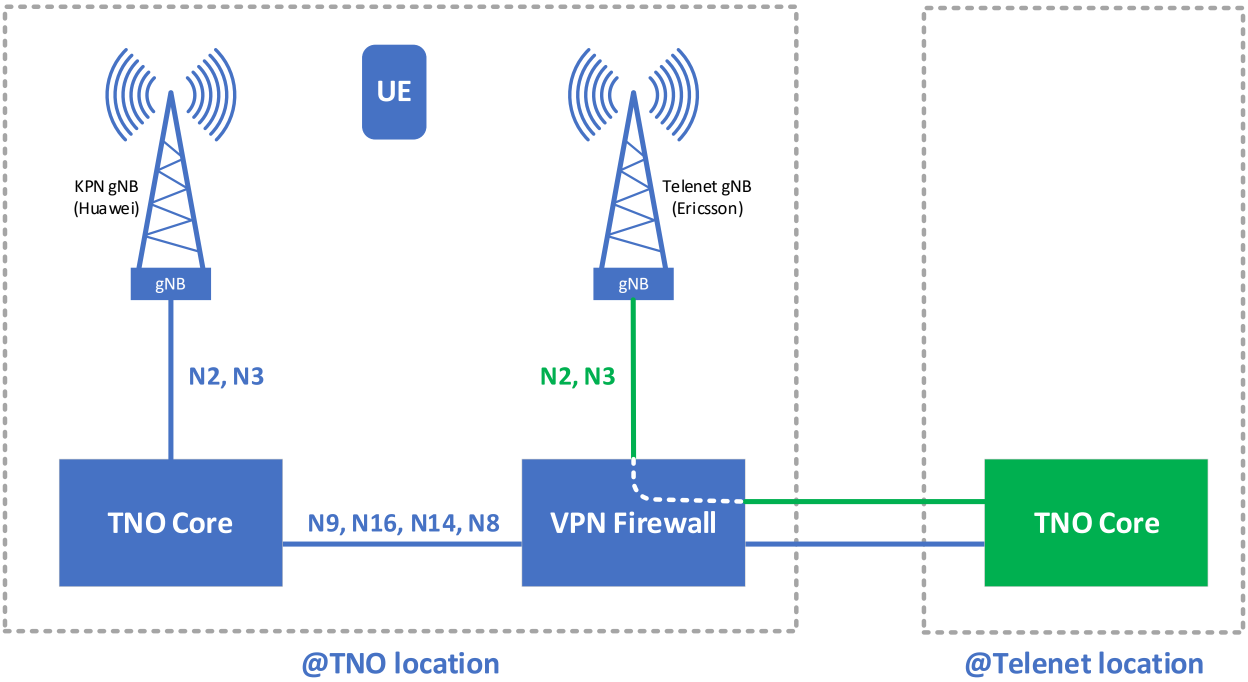

Figure 23: Lab set-up SA Seamless Roaming

After the successful completion of these integrations a new instance of this configuration is made using gNBs at the border crossing at Zelzate. This network is shown in Figure 24.

The basic assumptions for this network are:

- Interfaces used: N9, N14 and N16
- Home Routing
- gNB setting for E-PLMN

In this network the handover performance between the coverage areas of the two MNOs can be assessed with sufficient statistical power.

The global planning of this phase is shown in Table 13

[3] This turned out to be unfeasible: The Nokia network was not yet ready. Thus it was decided to use two instances op the TNO SA Core network.

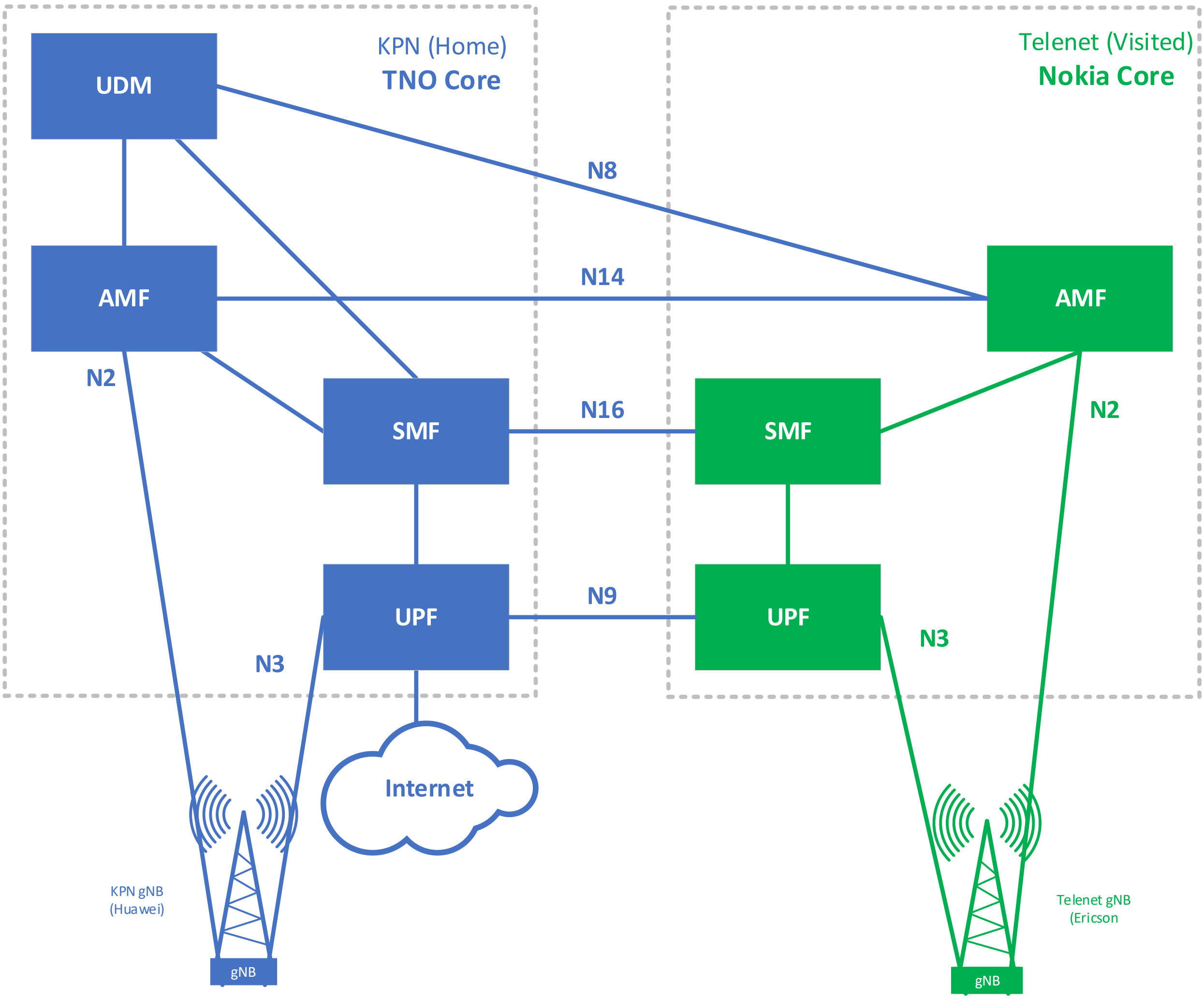

Figure 24: Field set-up SA Seamless Roaming

Work Task	2022		2023	
	Q3	Q4	Q1	Q2
Development of new interfaces N9, N14 and N16 in TNO's SA Core				
Setting up the test environment at the TNO lab location				
Setting up the test environment at the cross-border location with TNO SA Core				
Technical support during the Cross-Border tests involving the TNO SA Core				

Table 13: Global planning SA Seamless Roaming tests

4.4.2.1 RAN at Zelzate

The current coverage of Zelzate area (Belgium side of the border) is illustrated in the following figure.

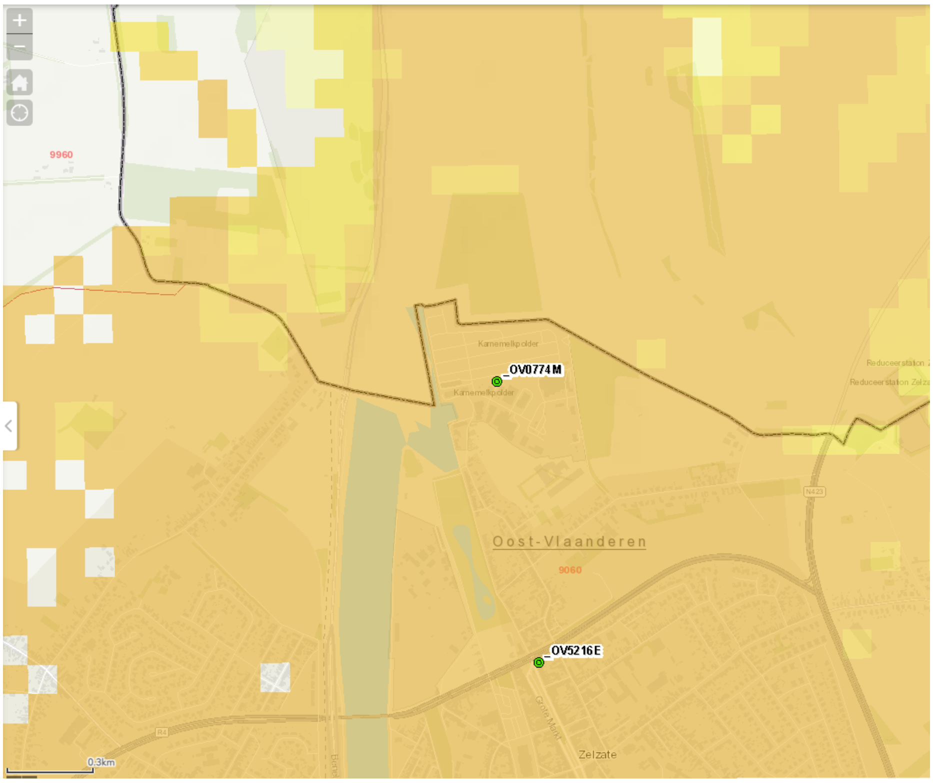

Figure 25: Coverage at Zelzate Border Crossing

Note that the old N78 RAN network in Zelzate has been swapped by a new vendor and currently only N1 production network is available. The figure above shows the current N1 coverage: the dark brown color indicates signal strength above -94dbm; the orange color indicates signal strength between -98 to -95dbm; the yellow color indicates signal strength from -106 to -99dbm. With on boarding TNO for 5G SA roaming task, the network design and plan in Zelzate has also changed. The old coverage was from OV5216 with N78. The new plan is to also include OV0774 and use two sites separately for 5G NSA and 5G SA roaming. This also means that the 5G NSA site will no longer exactly follow the design in Section 4.1. Meaning that, OV5216 will be connected to a dedicated 5G NSA cloud core and the production core at the same time, instead of being connected to 5G trial core and production core at the same time.

4.4.2.2 RAN in NL at Zelzate

At the KPN site at Sas van Gent, on the Dutch side of the Zelzate border crossing, a Huawei setup will be created using 4 cells in total. Two cells will point to the border and two to the other site. This way we will be able to connect well in advance approaching the border to test the handover.

The NSA setup will consist of two bands:

Technology	Band
LTE	B7 (FDD) or B38 (TDD) at 2600MHz
5G NR	N78 (TDD) at 3500MHz

Table 14: Frequency Allocation in NL at Zelzate

Site 3013 will be used for the KPN setup. This is Novec site (ID 7505) with the production antenna at 40 meters. This is a low cap site at which no B7 or B38 is used. At this site an

A114521R5v06 antenna is deployed which is capable of 2600MHz and 3500MHz. To be researched if we can use the unused antenna ports for this trial.

Site 3013 will be used for the KPN setup. This is Novec site (ID 7505) with the production antenna at 40 meters. This is a low cap site at which no B7 or B38 is used. At this site an A114521R5v06 antenna is deployed which is capable of 2600MHz and 3500MHz.

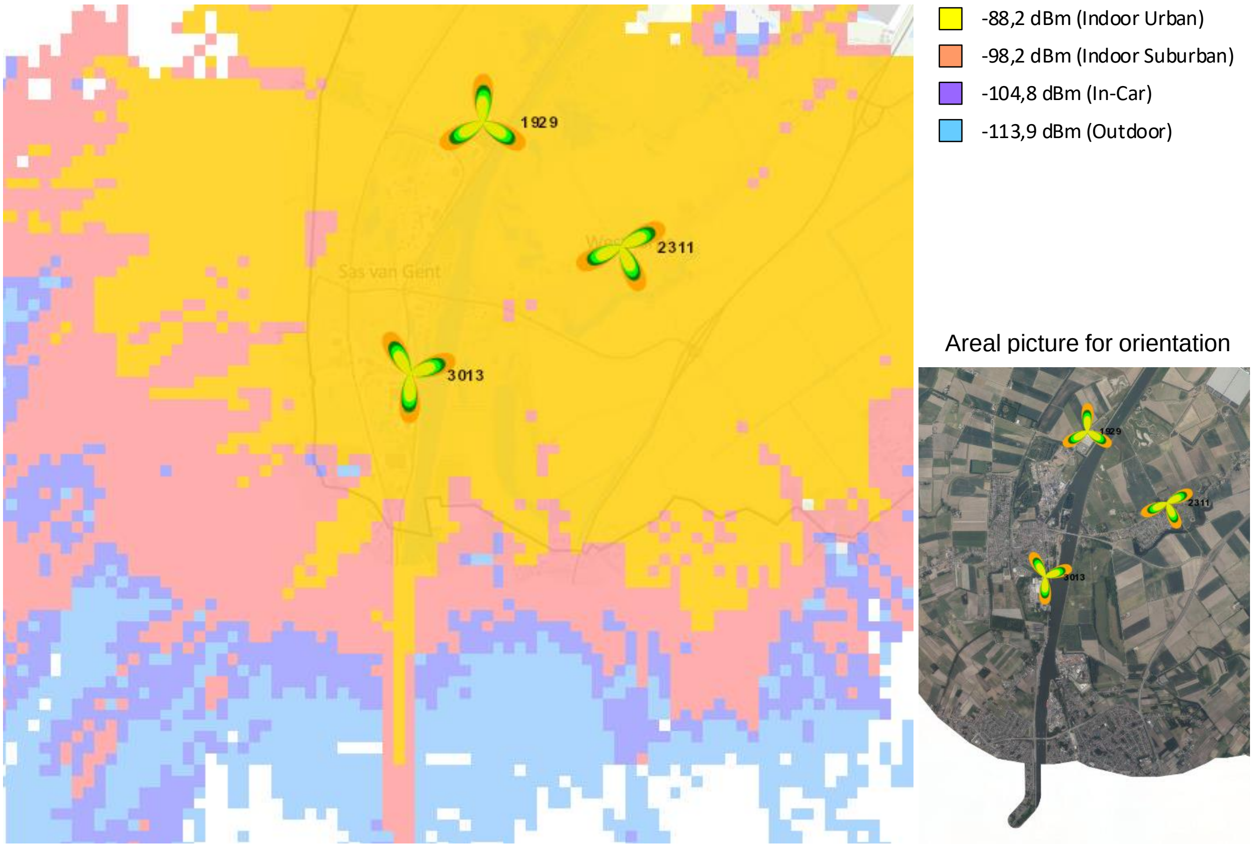

Figure 26: Coverage (NSA) from NL at Zelzate Border Crossing

4.4.2.3 Possible challenges border setup

Based on known simplifications and learning in preceding NRI projects at least the subjects in Table 15 will be addressed in the test at the border crossing.

Name	Description	
Encryption S1 interface	Different vendor networks are used at both sites of the border. Both using their own encryption keys and security parameters. These security parameters will need to be renegotiated when entering the new network and may cause a disconnect.	
Max timeout handover	There is a maximum timeout in which the handover needs to take place (between 30 and 40ms). During this time different messages are send back and forth to prepare the handover.	

Table 15: Attention points NRI

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5 CONCLUSIONS

Initially both MNO's focused on the deployment and performance of the 5G NSA network. This was partly due to the availability of suitable radio spectrum and user equipment. The coverage at the border crossing between Belgium and the Netherlands and the network reselection between Telenet and KPN will be improved to a level which can reliably support the tele-operations of vehicles and barges

Other projects (5G Mobix, 5G CroCo) demonstrated that in a NSA network seamless handover between two MNO's is technically possible. The methods used in these projects are very basic and in need of refinement. This refinement and the expansion of the methods into a 5G SA network is discussed in context of 5G-Blueprint. Steps are described to realize some of these refinements.

During this phase it was shown that industrialization of 5G SA is not complete yet. Many typical 5G functions, such as Slicing, convincingly Low Latency and ("Ultra") High Reliability as envisioned by 3GPP and GSMA are still an unfulfilled promise by the selected vendors.

Seamless cross border mobility is the most prominent objective of the 5G-Blueprint project. At the moment 5G SA Roaming functionality is not available from commercial vendors. To circumvent this shortcoming we elected to use a experimental open source SA Core network. Our newly invited partner TNO will develop SA (seamless) roaming functionality on this platform.

The continuation of the 5G-Blueprint WP5 will consist of three pathways:

1. The establishment of the unique characteristics of a 5G SA network with parameter settings for Slicing. This will be done during the activities in task 5.4.
2. The refinement, further improvements, and the expansion of the methods for Seamless Handover as found by preceding projects (e.g. 5G Mobix, 5G CroCo) into a 5G SA network. This will be done during the activities in task 5.3.
3. In the experimentally programmable open, source 5G SA Core Network provided by TNO a prototype of the seamless roaming capability will be developed. Relevant findings can be reported back to 3GPP and GSMA as both TNO and KPN are active contributors to these organizations

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