# 5G seamless roaming for teleoperated driving and sailing

## 5G-Blueprint approach

Dr. Nina Slamnik-Kriještorac
Senior researcher, Principal investigator

IDLab, imec research group at Ghent University and University of Antwerp

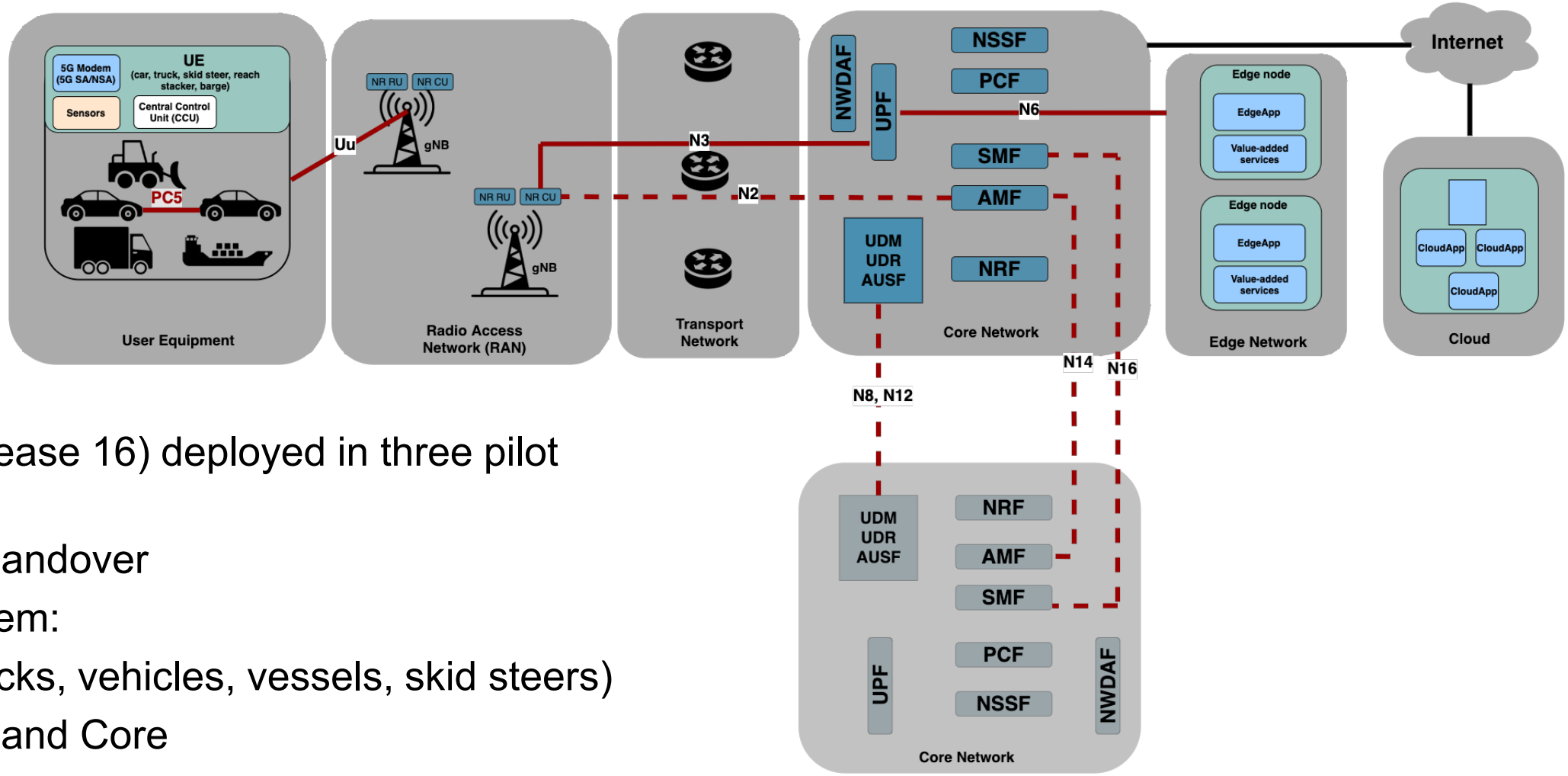
# Outline

- Quick overview of 5G-Blueprint project
- Use cases
- 5G seamless roaming
- Summary & Lessons learned

# Outline

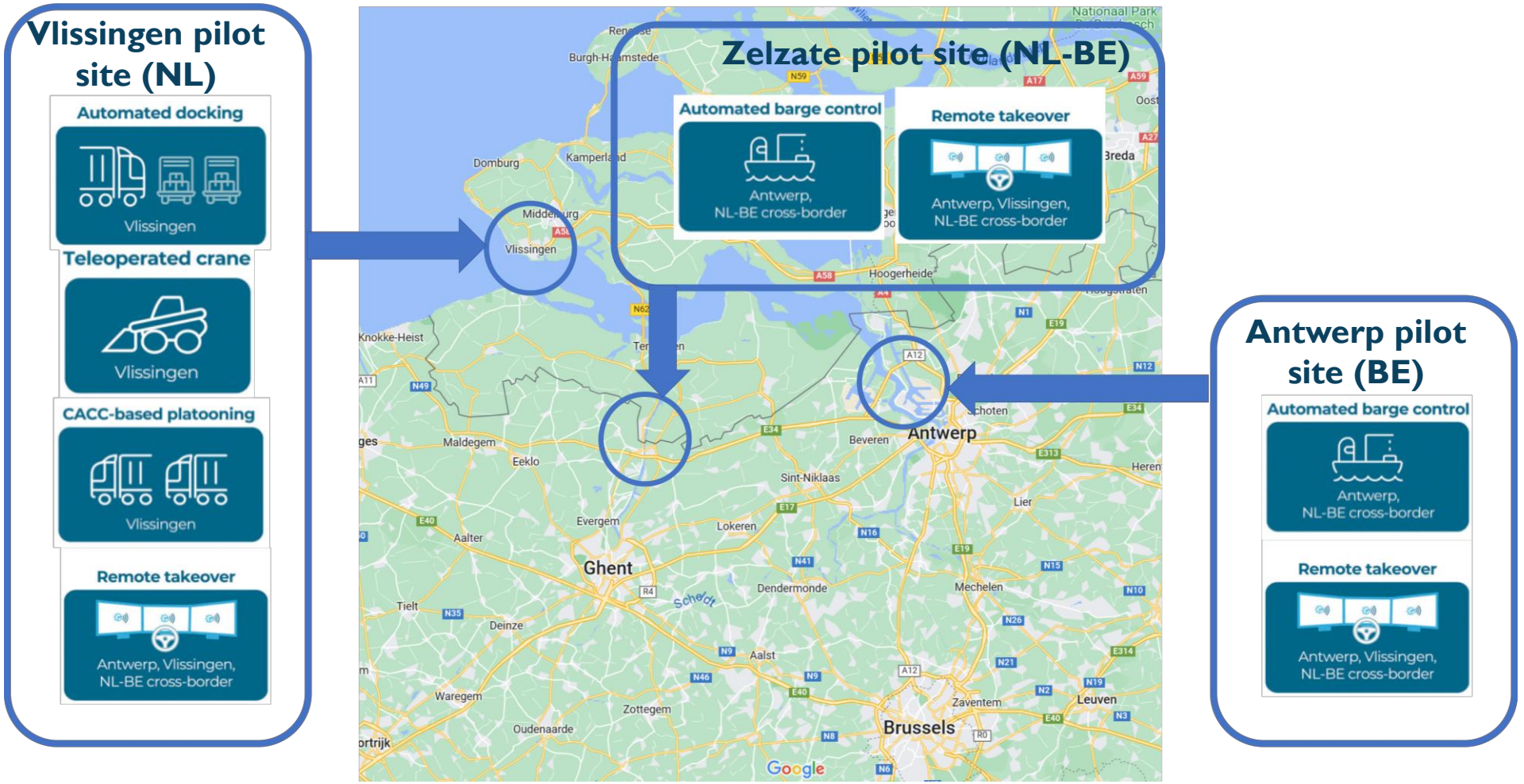
- Quick overview of 5G-Blueprint project
- Use cases
- 5G seamless roaming
- Summary & Lessons learned

# 5G-Blueprint combines (cross-border) 5G SA with teleoperated driving and sailing




- 5G SA (Release 16) deployed in three pilot sites
- Seamless handover
- 5G ecosystem:
  - UE (trucks, vehicles, vessels, skid steers)
  - 5G NR and Core
  - Data network (Enabling functions and Use case components)

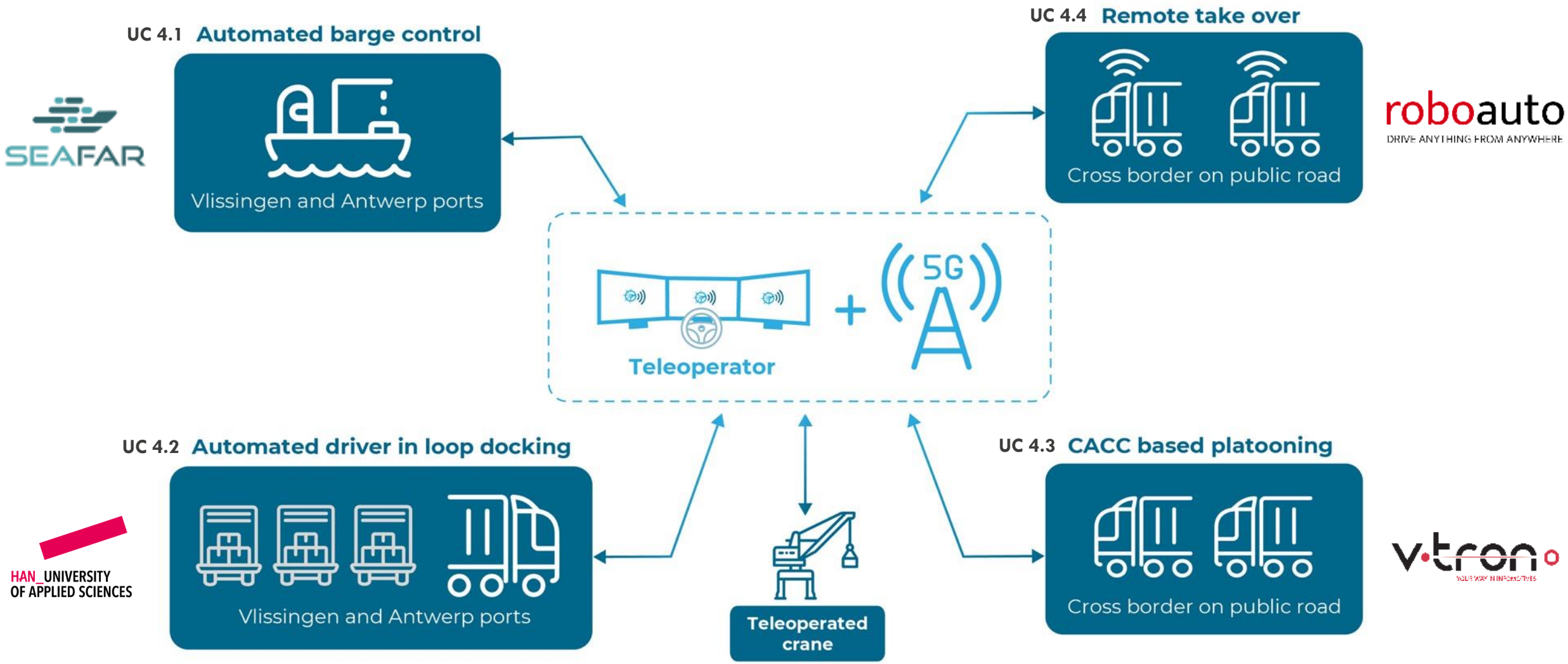
# Use cases are mapped to national and cross-border pilot sites



# Outline

- Quick overview of 5G-Blueprint project
- Use cases
- 5G seamless roaming
- Summary & Lessons learned

# Use cases are tested in real-life environments such as busy ports and public roads



# Shadow mode testing of remote barge control is essential for testing 5G SA capabilities before proceeding with actual teleoperation


Shore control Center

Control and Monitor

5G

vessel

-Sensors' data
-Sensors Processor

Seafar Cloud

Telenet Backbone

# Teleoperated Docking scaled from simulations to pilot with trucks


Truck-Trailer combination

Teleoperator view

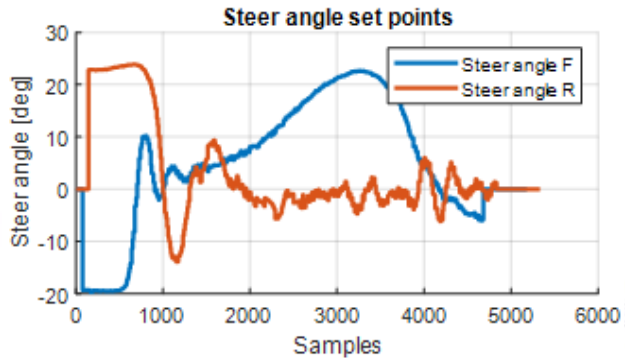

Cabin

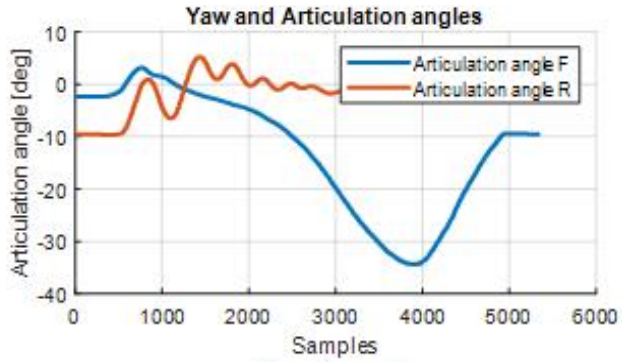
# Average tracking error 0.16m, target values less than 0.5m

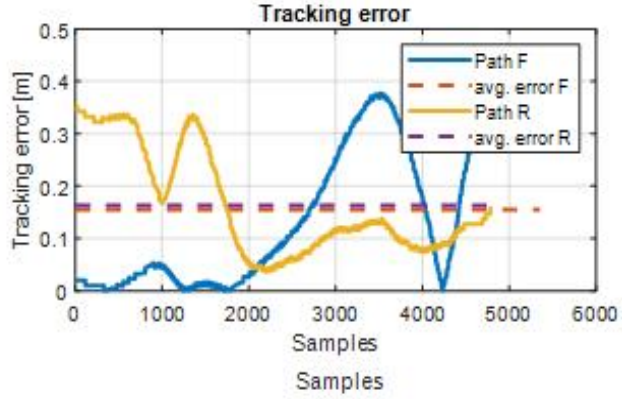
An example test run at MSP Onions

Final docking state error:

- A = 3.6cm, required < 10cm
- B = 8.4cm, required < 10cm
- C = 0.4deg, required < 2deg

# Overall robustness of the teleoperation system improved, full takeover of DAF truck achieved

Steering accuracy: Mean absolute error 4.83deg (<6deg)

Braking accuracy: Mean absolute error 0.72% (<4%)

Steering accuracy: Mean absolute error 2.41deg (<3deg)

Braking accuracy: Mean absolute error 0.51% (<4%)

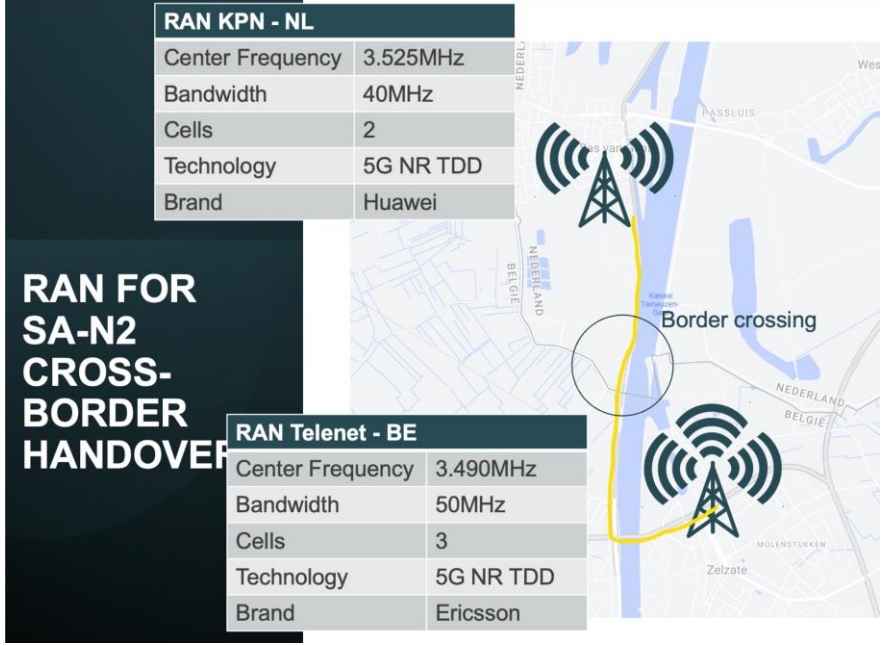
**Overall robustness of the teleoperation system improved**

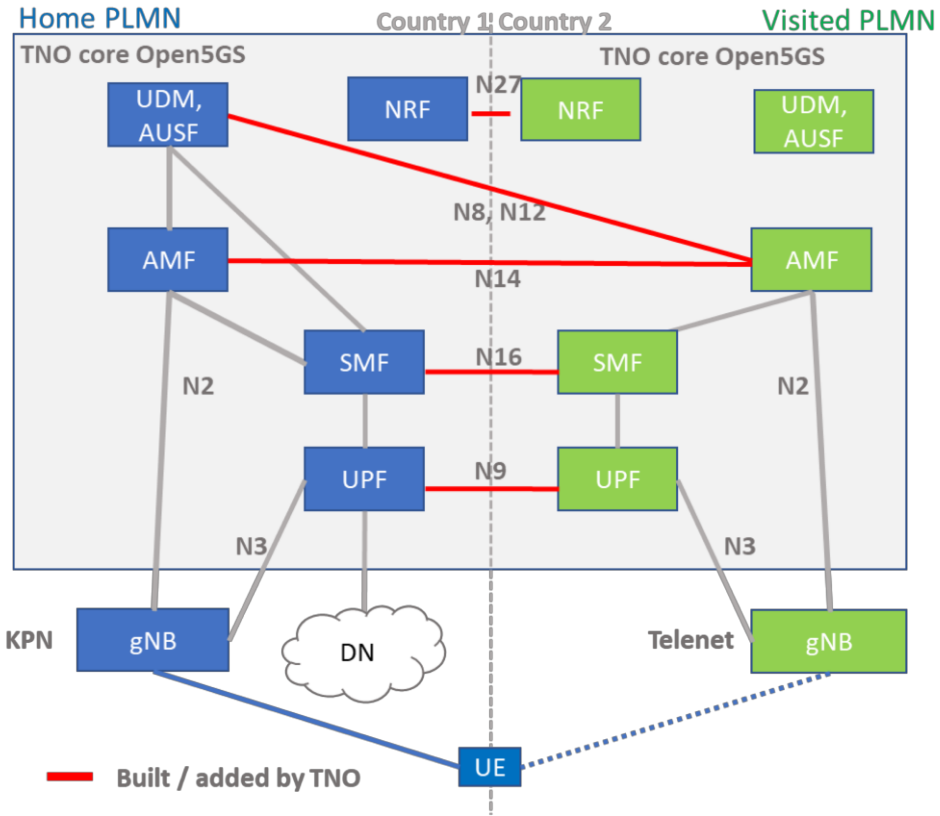
# Outline

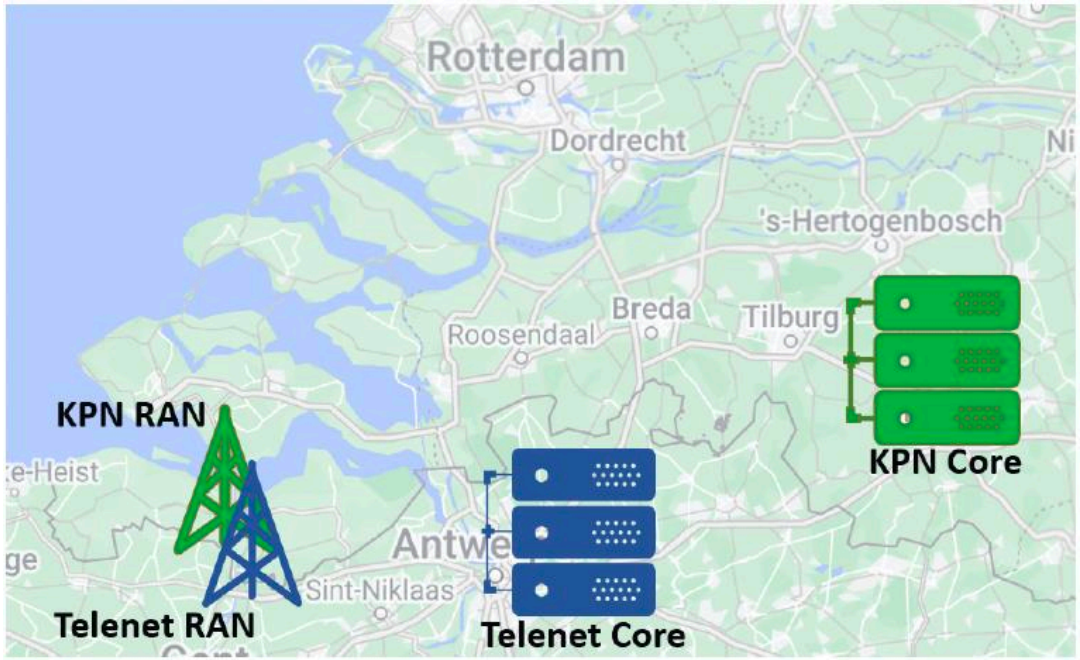
- Quick overview of 5G-Blueprint project
- Automotive use cases and teleoperation
- 5G seamless roaming
- Summary & Lessons learned

# Seamless roaming crucial for safe cross-border teleoperation

- 5G SA seamless roaming working and deployed at cross-border site
- Network evaluation done at BE and NL sites
- Successful seamless roaming demos

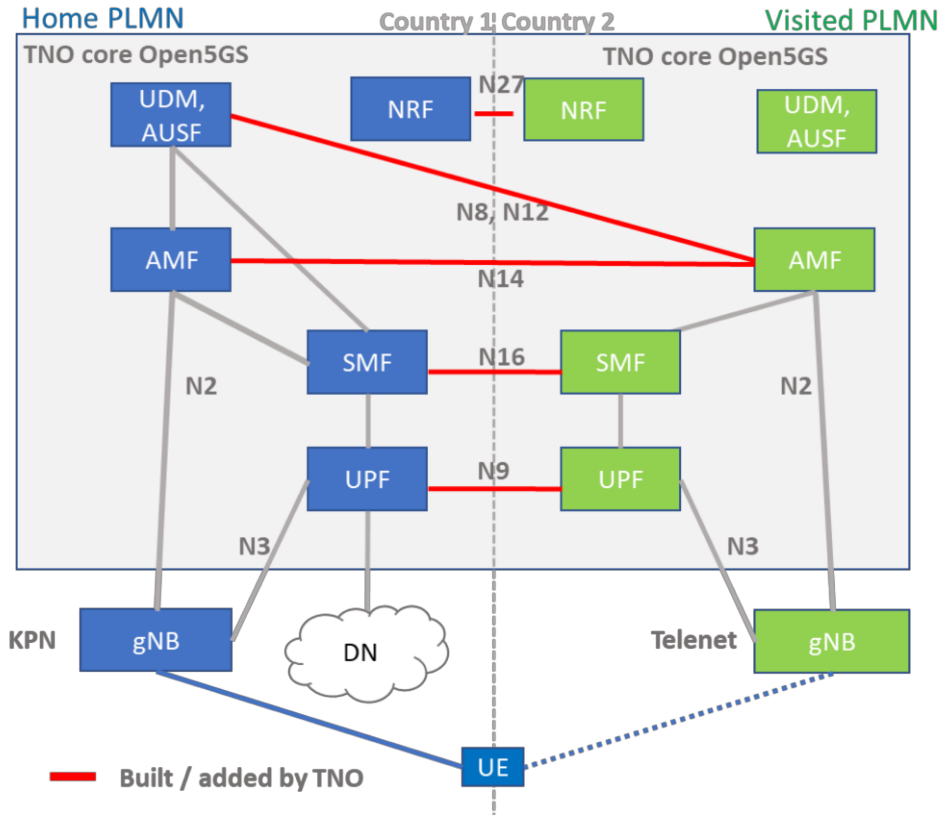


# Home Routing & N14-based routing with novel optimization to reduce downtime are needed

- UE's PDU session data exchanged between home and visited networks via N14 interface
- Both visited and home networks are configured as equivalent PLMNs (E-PLMN)
- Roaming behaves similarly to a normal handover procedure
- No new PDU re-establishment at visited network needed



# Roaming procedures can be optimized by combining Home routed SA principles with N14-based roaming

**N14 vs N2**

Seamless cross-border N14 handover performs similar to the N2 handover, the main difference is that it depends on the latency between the cores

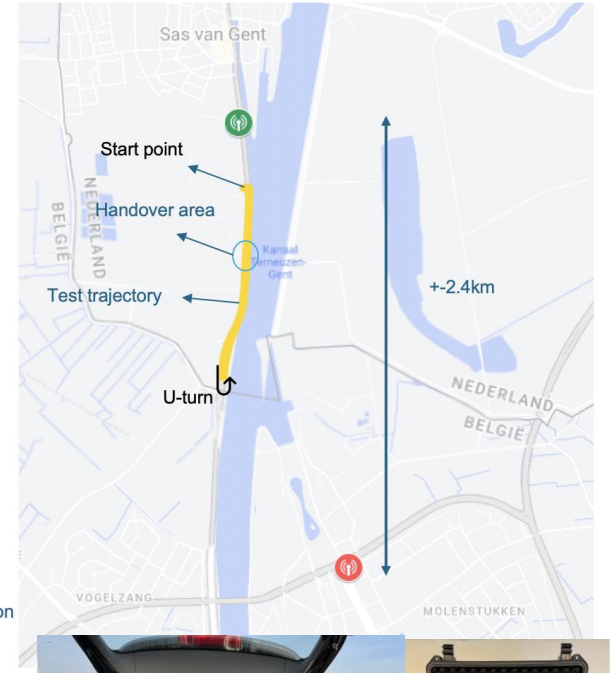
**Lab results**

- N2 handover: 100-120ms
- N14 handover: 100-150ms

**Field results**

- N14 handover: ~100ms
- Latency between the two cores: ~7ms → small impact compared to the other latency components

- Uplink throughput: 32.4 Mbps
- Downlink throughput: 145 Mbps




# Outline

- Quick overview of 5G-Blueprint project
- Automotive use cases and teleoperation
- 5G seamless roaming
- Summary & Lessons learned

# Summary

## Teleoperation of vehicles and barges

- Autodocking successfully tested with the full-scale trucks over 5G SA
- Teleoperation of vehicles (Toyota vehicles and DAF trucks) and barges successfully tested over 5G SA in the national sites (BE, NL)
- Network testing demonstrated that its performance enables **safe teleoperation across borders**
- Testing campaigns with teleoperation of vehicles and barges ongoing in the cross-border setup

## Seamless roaming

- 5G-Blueprint solution one of the first practical implementations for seamless roaming in 5G SA
- Solution combines Home routed SA roaming with the N14 interface
- Service interruption time significantly reduced → sufficient for teleoperation (<150ms)

# Lessons learned

## Teleoperation of vehicles

- Human factors need to be considered for teleoperation: varying driver experiences, resolutions and frame rate effects, fatigue
- Handover-caused interruption times sufficient for cross-border teleoperation

## Seamless roaming

- Standardization potential:
  - New procedure to enable Home-Routed Seamless roaming in 5G SA → **merges** N14 handover with Home-Routed Roaming
  - Seamless roaming with inter-PLMN handover in **both** directions → procedure for V-PLMN to H-PLMN direction is also missing in standards.

- Handover decisions currently based on signal strength, exploring other criteria (allowed IMSI, service availability, contractual relations)
- Vast amount of configuration parameters → to be automated

# Join us at the final event


**Date**: November 21st 2023

**Location**: Industrial Museum Zeeland, Sas van Gent, The Netherlands

The event is free of charge, but registration is mandatory, due to limited seats