1

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# 5G Cross Border Control

**Innovation Action H2020-ICT-18-2018**
**Contract 825050**

**Cooperative, Connected and Autonomous Mobility (CCAM)**

**a 5G PPP Phase III Project**

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

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# Selected results

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June 21st, 2022, IoTWEEK'22 (Dublin). 5G for CAM Session

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

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# Outline

- Motivation & Challenges
- Use cases
- Test sites, trials & results
- Achievements
- Deployment study
- Conclusion

# Main challenges for 5GCroCo

- Seamless 5G connectivity in border areas
  - Experimental validation through three use cases
    - Tele-operated Driving
    - High Definition Map Generation and Distribution for Autonomous Driving (HD Mapping)
    - Anticipated Cooperative Collision Avoidance (ACCA)
- All these use cases have been trialed and tested along the borders between France, Luxembourg, and Germany in the Metz, Merzig, Luxembourg corridor
  - Corridor 1: Germany – Luxembourg
  - Corridor 2: France – Germany
- We have tested and trialed the validation of services across borders, but also cross MNOs and cross car manufacturers
- The 5GCroco network – 5G NSA – is not a production network, but a test/experimental one and, as such, it is not optimized for stability and commercial exploitation, but for agility to try new technologies and applications



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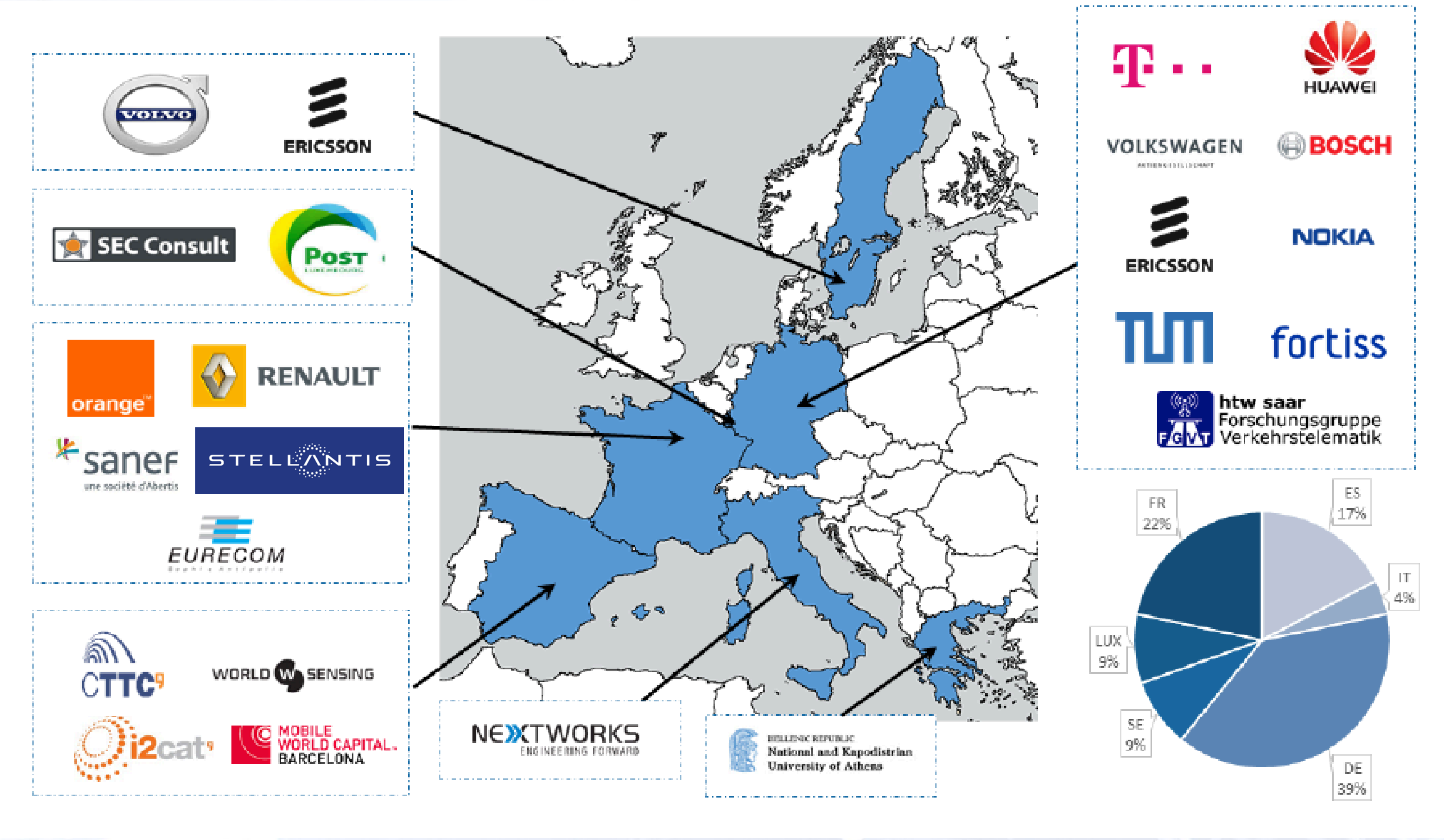
# Facts and Figures




- **24 partners** from **7 European Countries**
- Total project budget ≈ **17M€** (EC Contribution ≈ **13M€**)
- Project duration: **44 Months** (Nov 2018 – June 2022)

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# Tele-operated driving

## Remotely Controlled Manoeuvring

# HD Mapping

# Anticipated Cooperative Collision Avoidance

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# 5G Large-Scale Trials

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Validation of **5G cross border mobility**
along **France, Germany,** and **Luxembourg**

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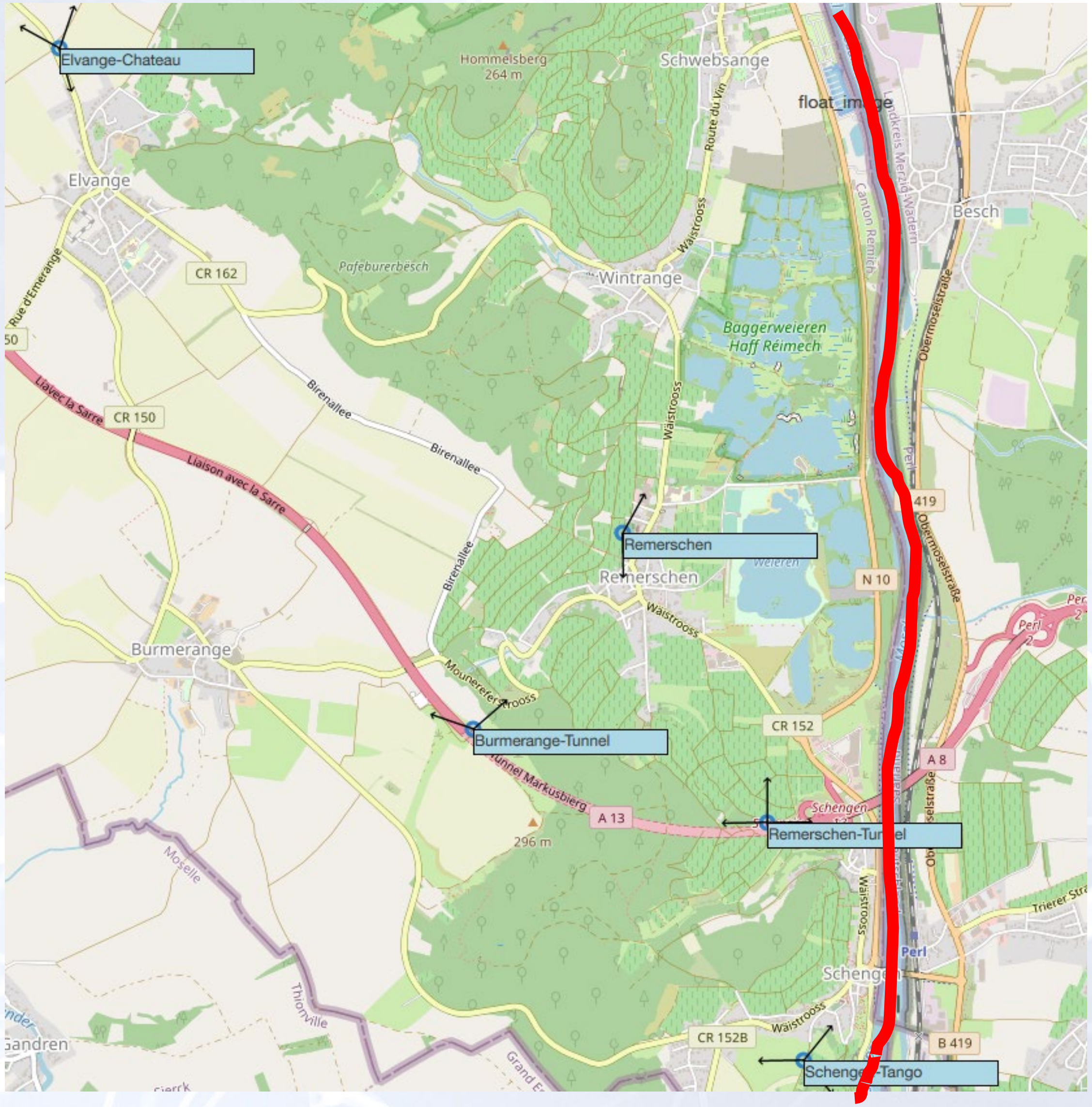
12

# Network corridor Germany-Luxembourg




| Parameter | Network Luxembourg |
|---|---|
| Number of sites | 5 |
| Sectors per site | 3 (2 on 1 site) |
| 5G band / frequency | n78 / 3.5 GHz |
| 4G band for anchor cell / frequency | B28 / 700 MHz |
| Bandwidth | 40 MHz in n78<br>2 x 10 MHz in B28 |
| 5G TDD pattern (DL:UL) | DDDSU (~4:1) |
| Max. TCP Throughput DL / UL | 306 Mbps / 46 Mbps |



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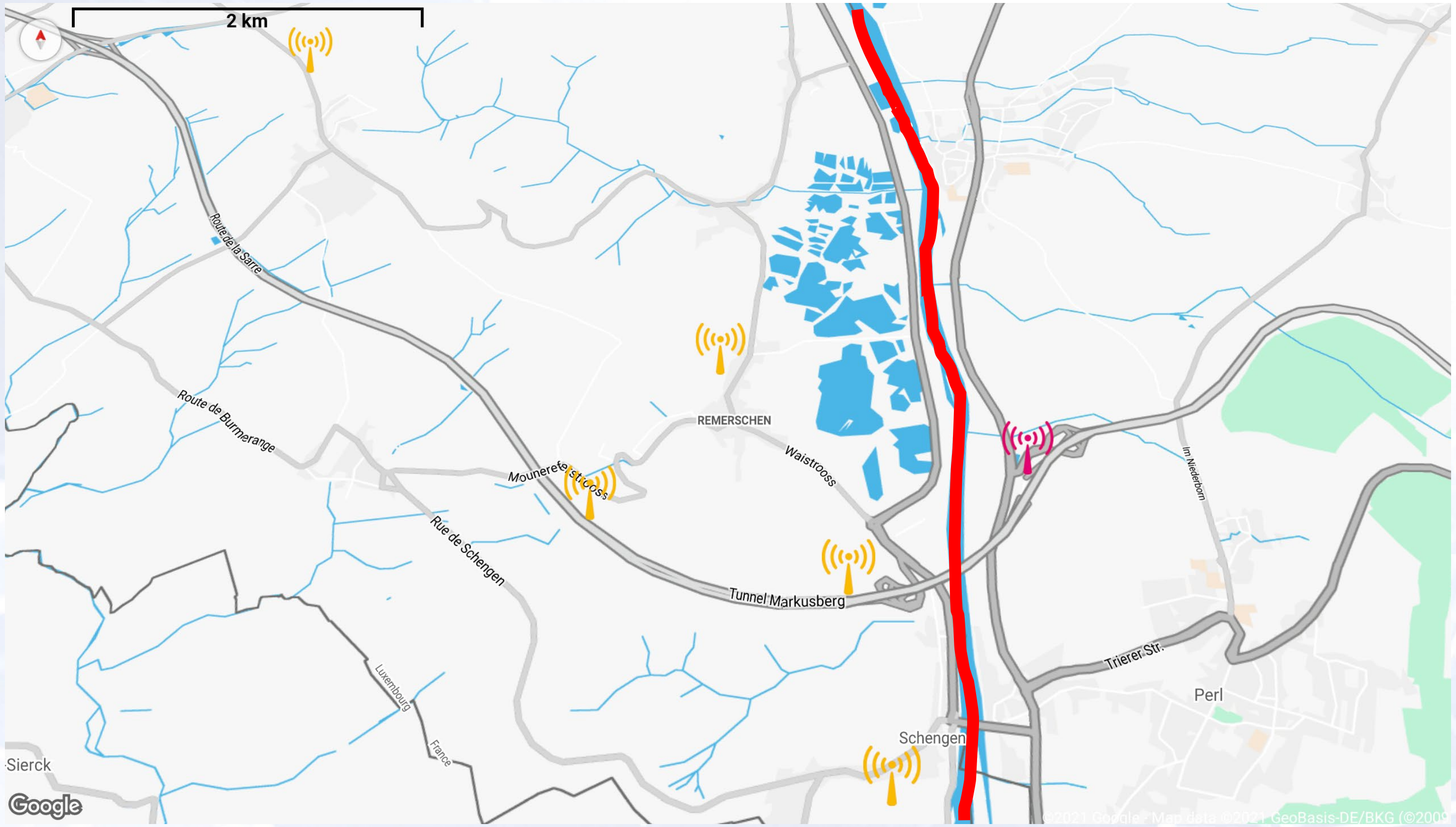
13

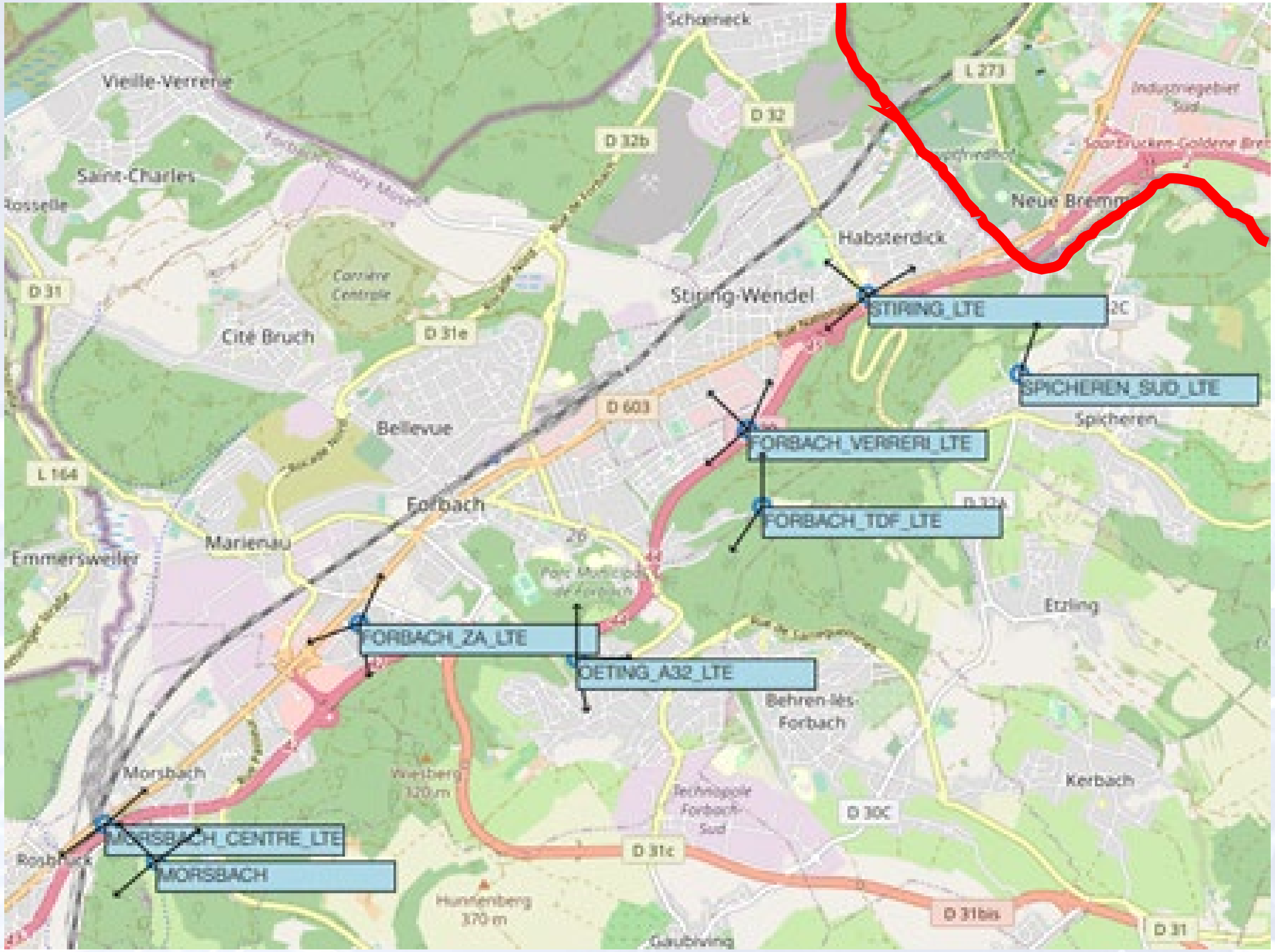
# Network corridor Germany-Luxembourg




| Parameter | Network Luxembourg |
|---|---|
| Number of sites | 1 |
| Sectors per site | 2 |
| 5G band / frequency | n78 / 3.6 GHz |
| 4G band for anchor cell / frequency | B3 / 1.8 GHz |
| Bandwidth | 40 MHz in n78<br>2 x 10 MHz in B3 |
| 5G TDD pattern (DL:UL) | DDDSU (~4:1) |
| Max. TCP Throughput DL / UL | 200 Mbps[1)] / 46 Mbps |

1) Bottleneck is in the backhaul, not the radio

# Network corridor France-Germany




| Parameter | Network Luxembourg |
|---|---|
| Number of sites | 8 |
| Sectors per site | 3, sometimes 2 |
| 5G band / frequency | n78 / 3.6 GHz |
| 4G band for anchor cell / frequency | B28 / 700 MHz |
| Bandwidth | 90 MHz in n78<br>2 x 10 MHz in B3 |
| 5G TDD pattern (DL:UL) | DDDDDDDSU (~8:2); different than Germany & Lux. |
| Max. TCP Throughput DL / UL | 790 Mbps / 98 Mbps |

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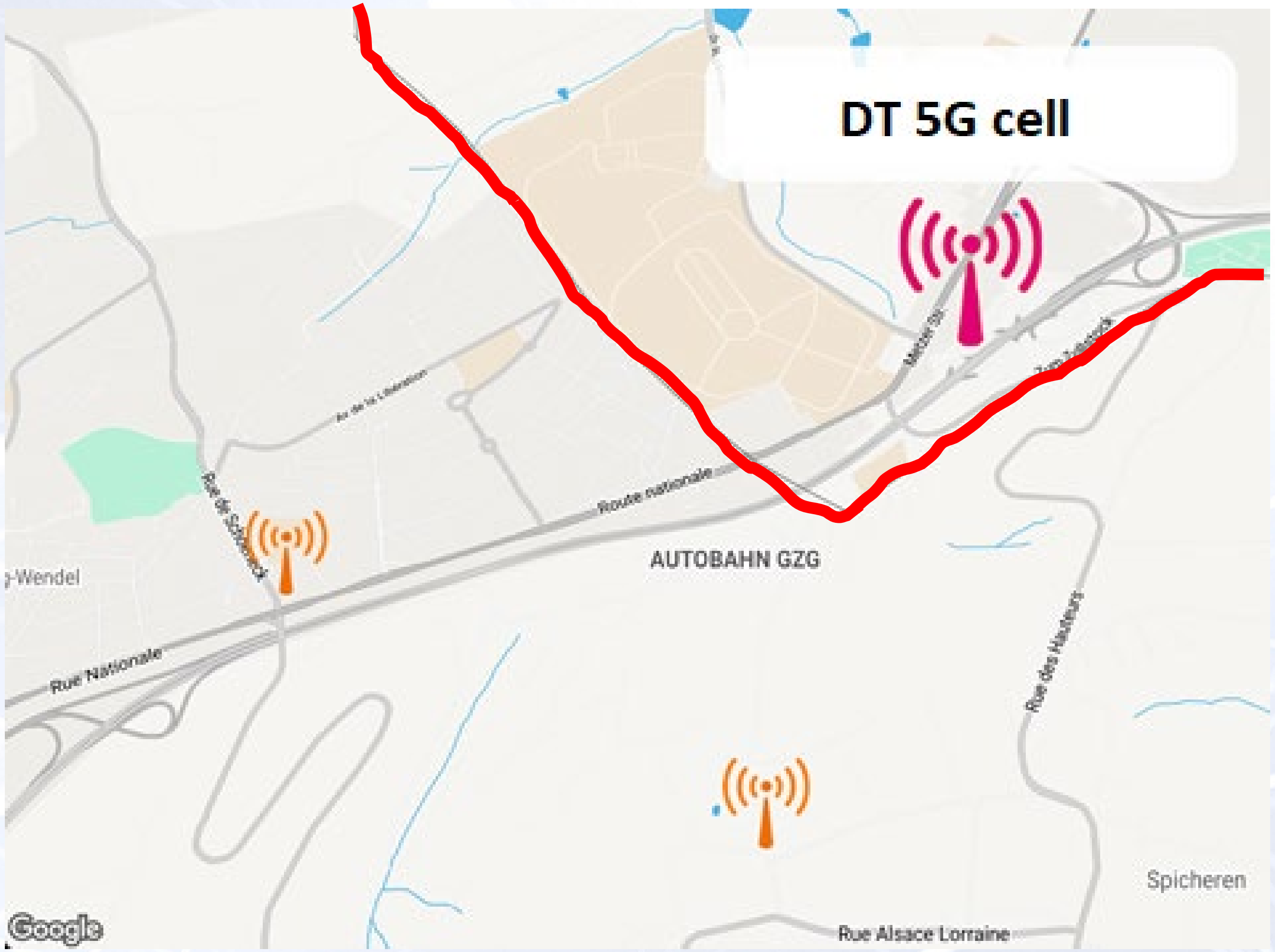
# Network corridor France-Germany




| Parameter | Network Luxembourg |
|---|---|
| Number of sites | 1 |
| Sectors per site | 1 |
| 5G band / frequency | n78 / 3.6 GHz |
| 4G band for anchor cell / frequency | B3 / 1.8 GHz |
| Bandwidth | 40 MHz in n78<br>2 x 10 MHz in B3 |
| 5G TDD pattern (DL:UL) | DDDSU (~4:1) |
| Max. TCP Throughput DL / UL | 200 Mbps1) / 46 Mbps |

1) Bottleneck is in the backhaul, not the radio

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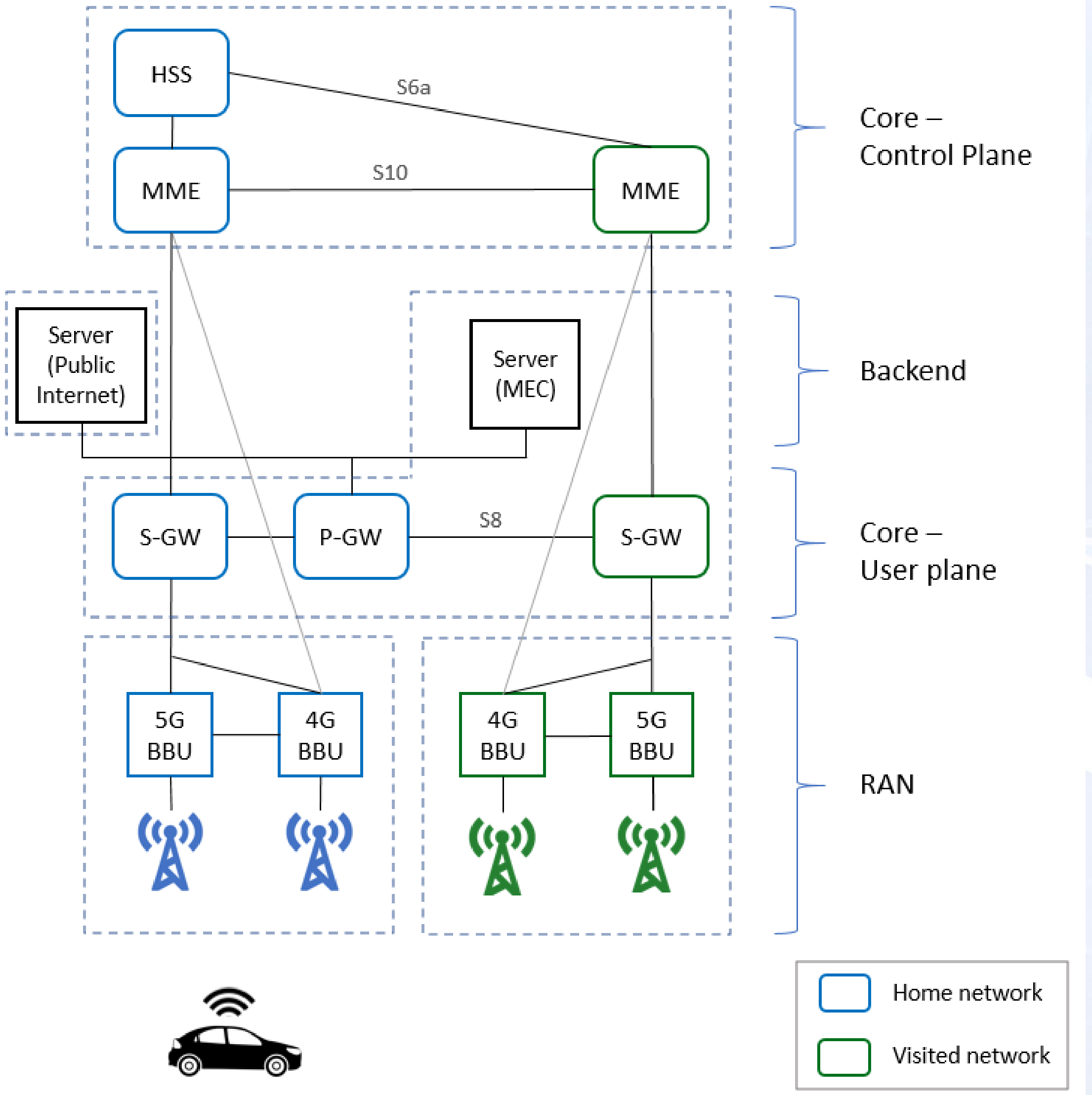
# 5GCroCo network architecture

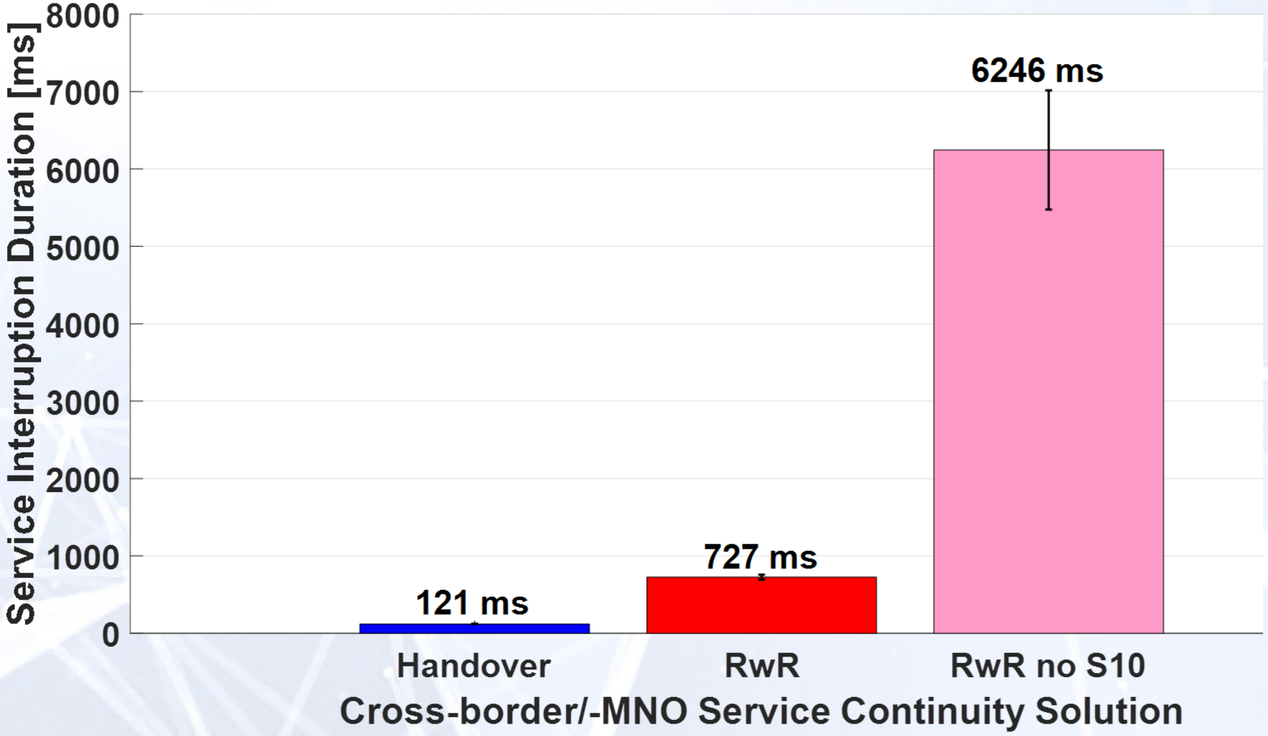
PLMN: Public Land Mobile Network
MME: Mobility Management Entity
HSS: Home Subscriber Server
BBU: Baseband Unit
GW: Gateway
P/S-GW: Packet Data Network / Serving GW

- Handover and Release with Redirect (RwR) enabled by the HW
- Roaming is the prerequisite for inter-PLMN handover / RwR
  ➔ S6a & S8 interfaces
- S10 interface enables inter-PLMN handover (same as for normal handover with MME-change)
- App Server on public Internet (Amazon Web Services (AWS) in Frankfurt) for comparison to MEC-hosting in, e.g., Luxembourg City



# Use case agnostic results

- Compared solutions for service continuity across borders
  - Cross-border/-MNO handover
  - Release with Redirect (RwR) + S10
  - RwR without S10
- In case no solution is applied, the UE must connect to a new network and this procedure takes up to a few minutes

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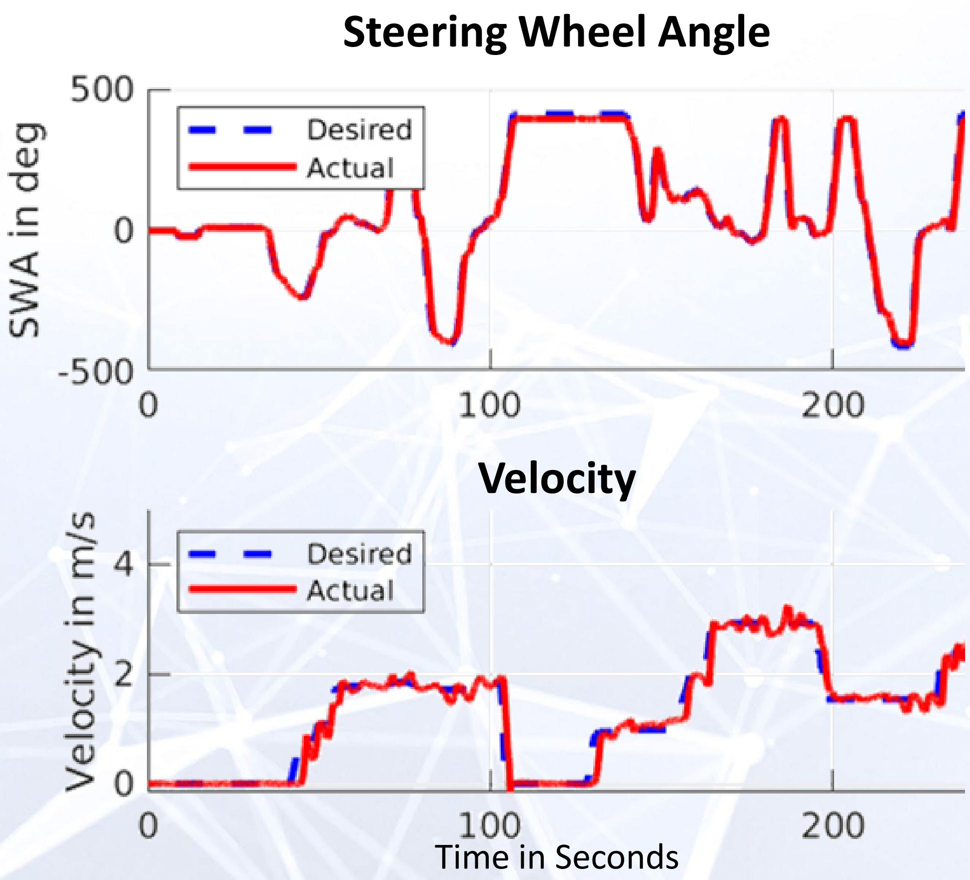
# Results: ToD – Direct control

- Bosch vehicle France-Germany trial site
- Vehicle Control Center (VCoC) ~70 km away in Luxembourg
- **The vehicle follows the remote input from the VCoC very well**

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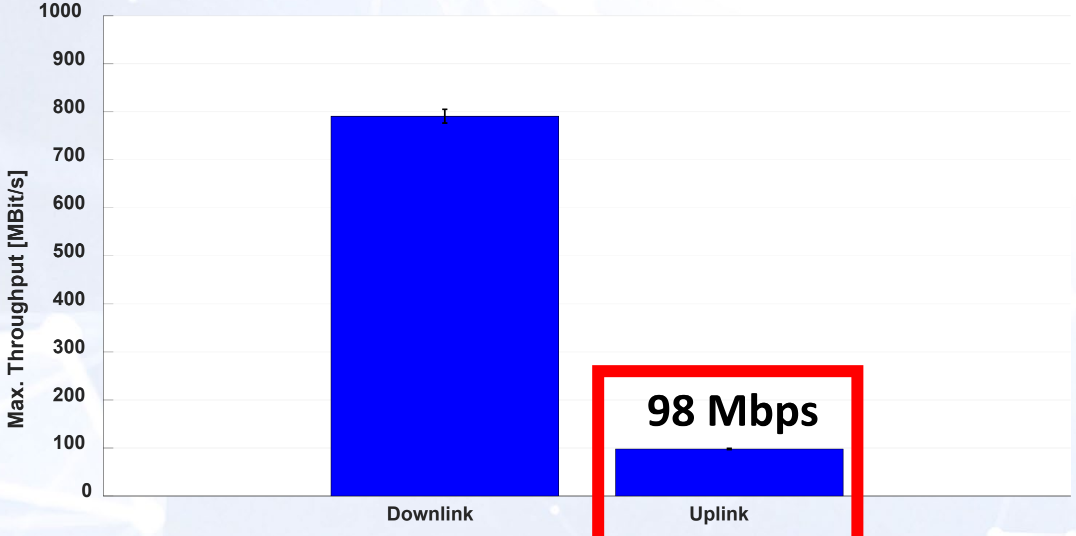
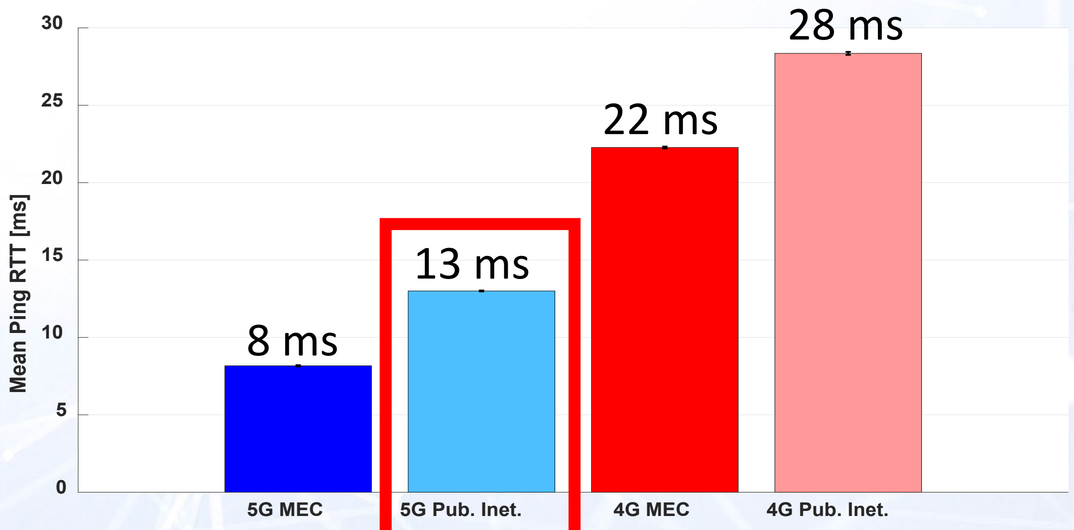
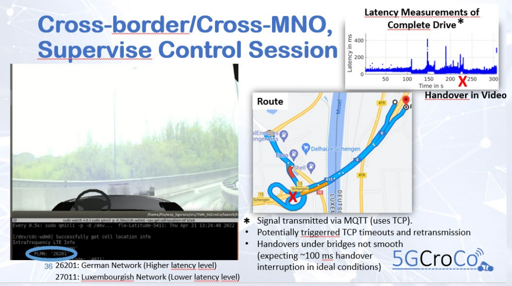
# 5G technologies demonstrated for ToD




High uplink throughput



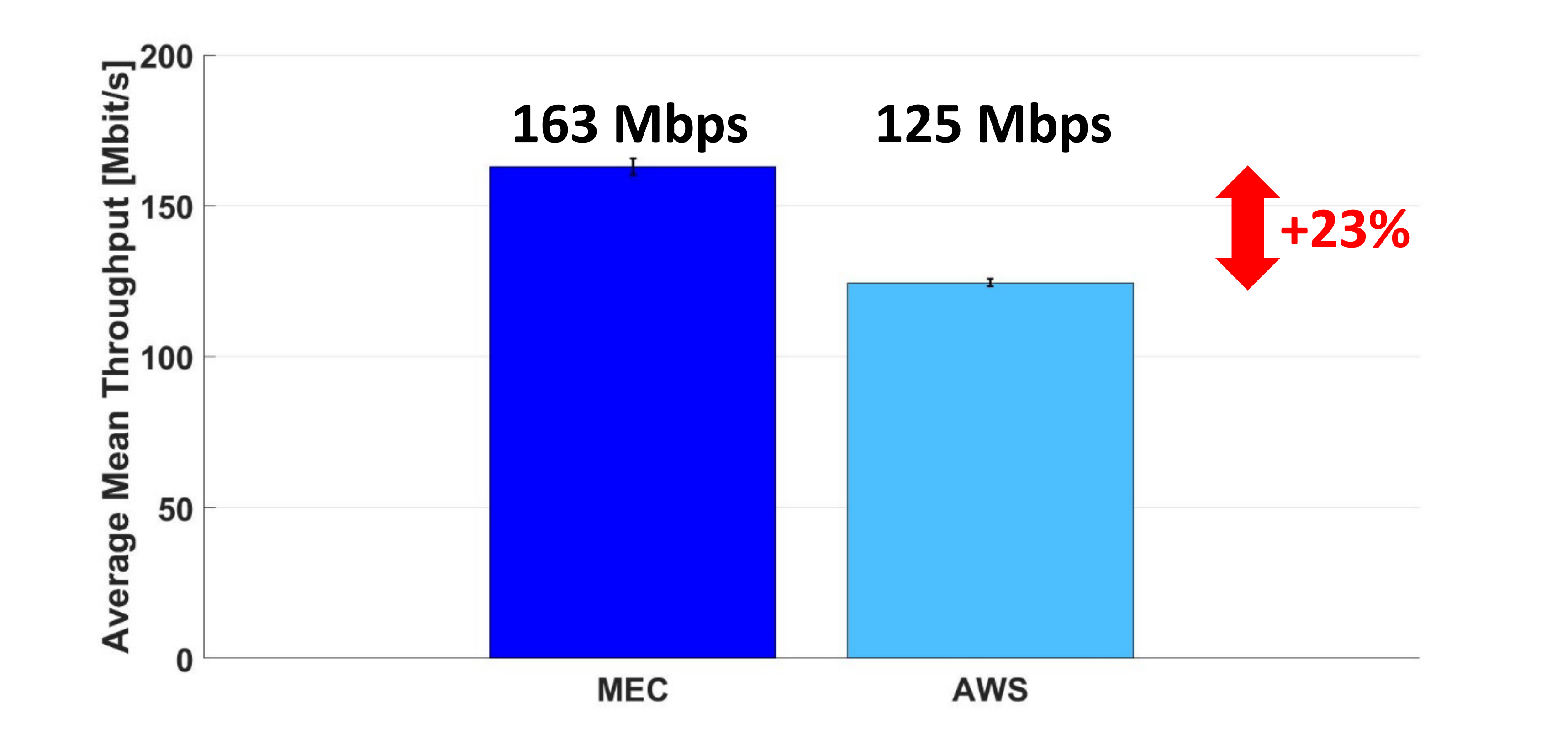

Low network latency




Cross-border service continuity
(21. April 2022)

# Results: HD Mapping – MEC vs. public Internet download

- Stress test: 100 Mbyte large tiles
- Tiles are downloaded 23% faster from the MEC host
- The 5 ms (8 ms vs 13 ms) lower delay allows TCP to faster reach the maximum throughput



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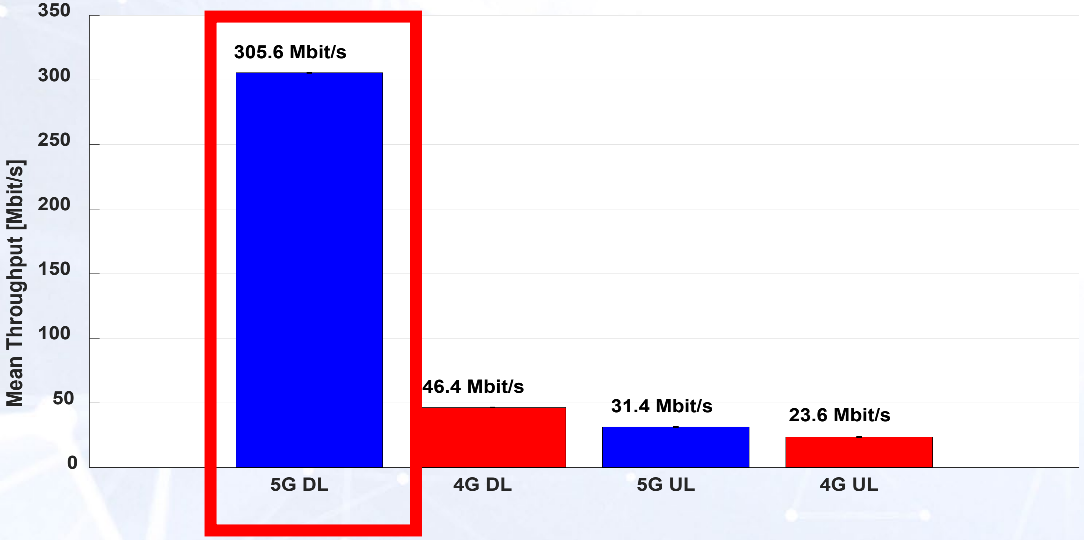
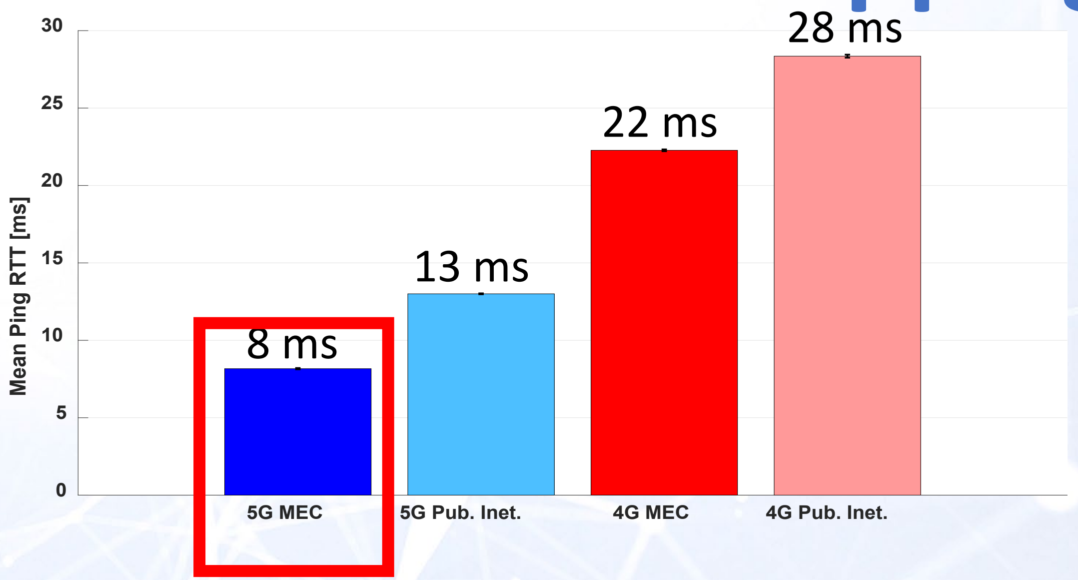
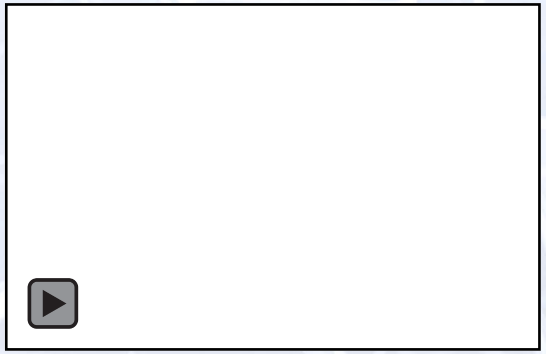
# 5G technologies demonstrated for HD Mapping




**High downlink throughput (also uplink, but not shown in this presentation)**



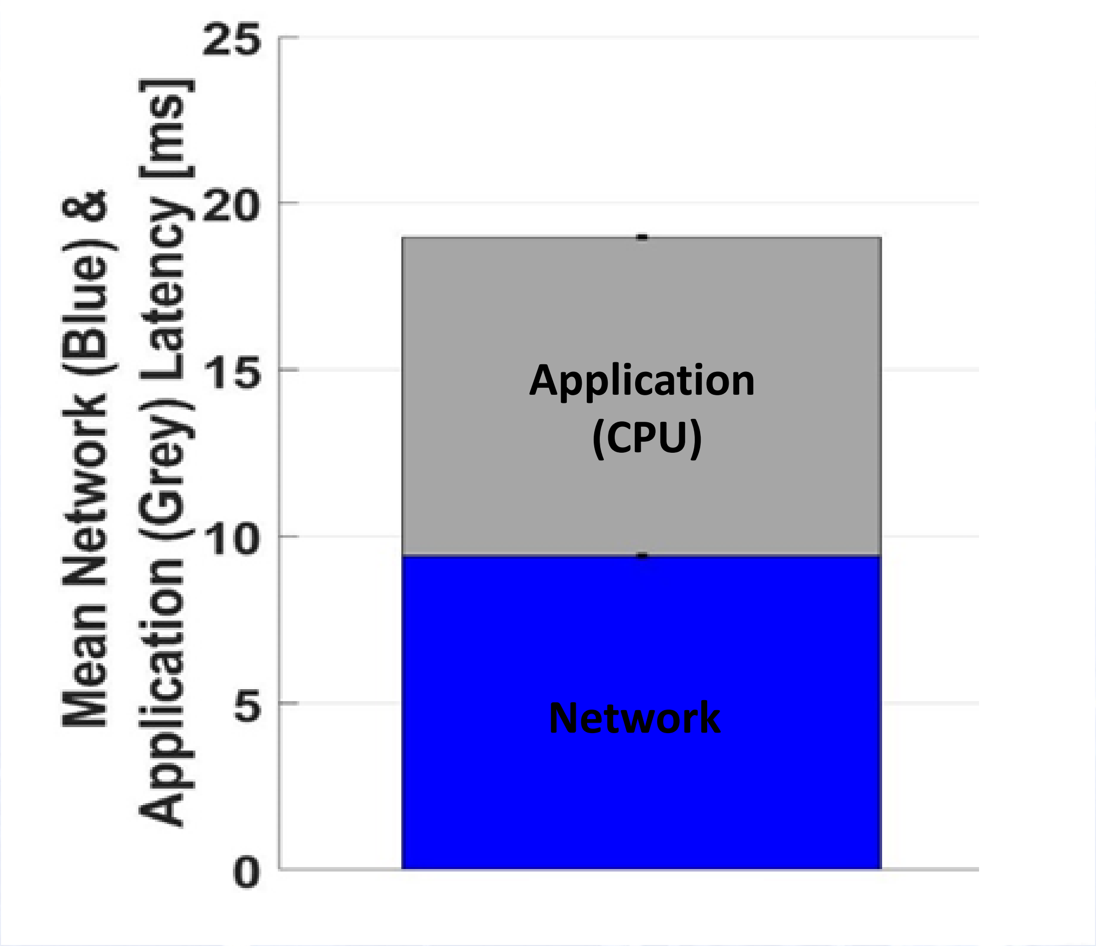

**Low latency when using MEC**



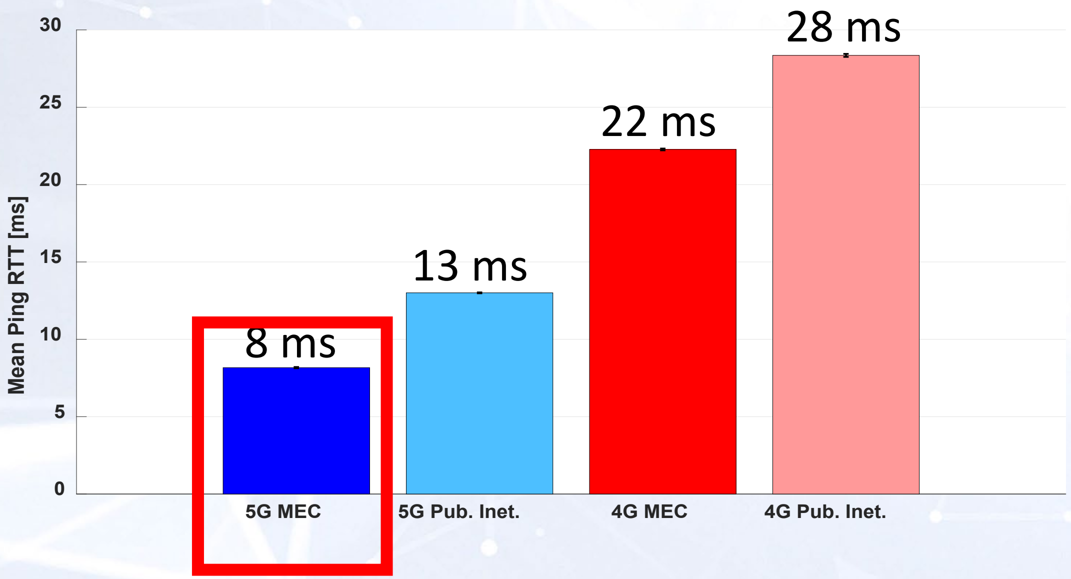
**Cross-border service continuity**

# Results: ACCA – Application Level Latency

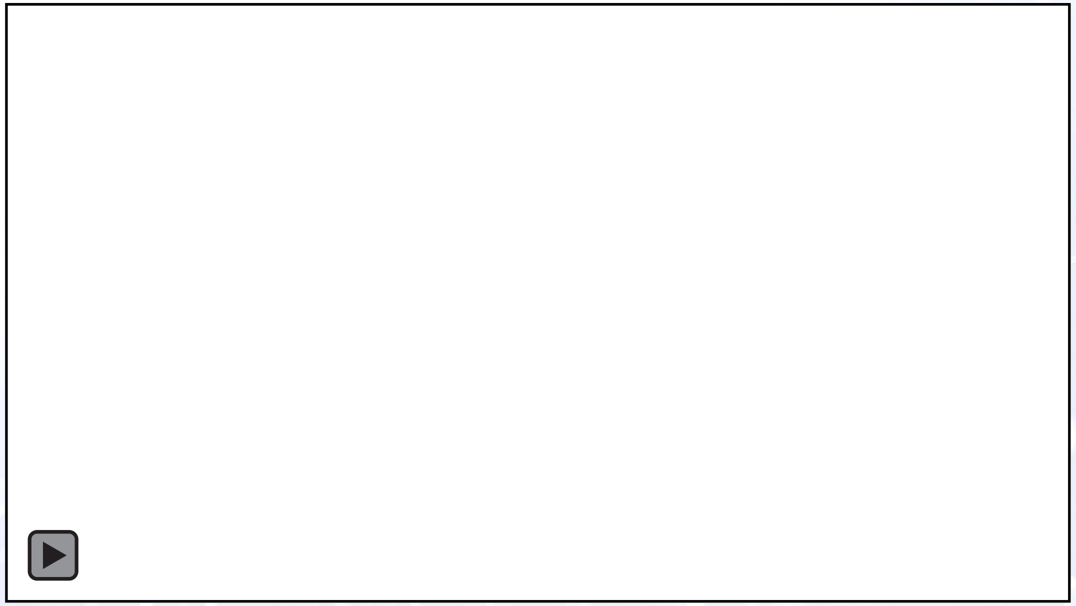
- From sending a hazard notification until receiving the hazard warning
- <20 ms end-to-end application delay
- Application processing in the backend (CPU) has similar latency impact as the network



# 5G technologies demonstrated for ACCA

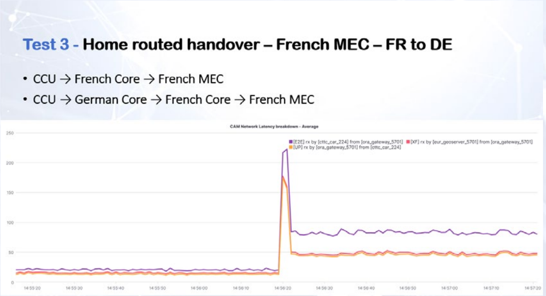



Low latency when using MEC



Gateway and MEC host switching after crossing border (done manually in trials; no network support)

**(03. May 2022)**




**Cross-border service continuity**

**(03. May 2022)**



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# Achievements

In general, and for the use cases Tele-operated Driving (ToD), HD Mapping and Anticipated Cooperative Collision Avoidance (ACCA) we showed…

- …. 5G cross-border / -MNO service continuity through Inter-PLMN handover
- …. how 5G reduces latency and increases throughput compared to 4G
- … how MEC hosting provides lower, controlled, latency

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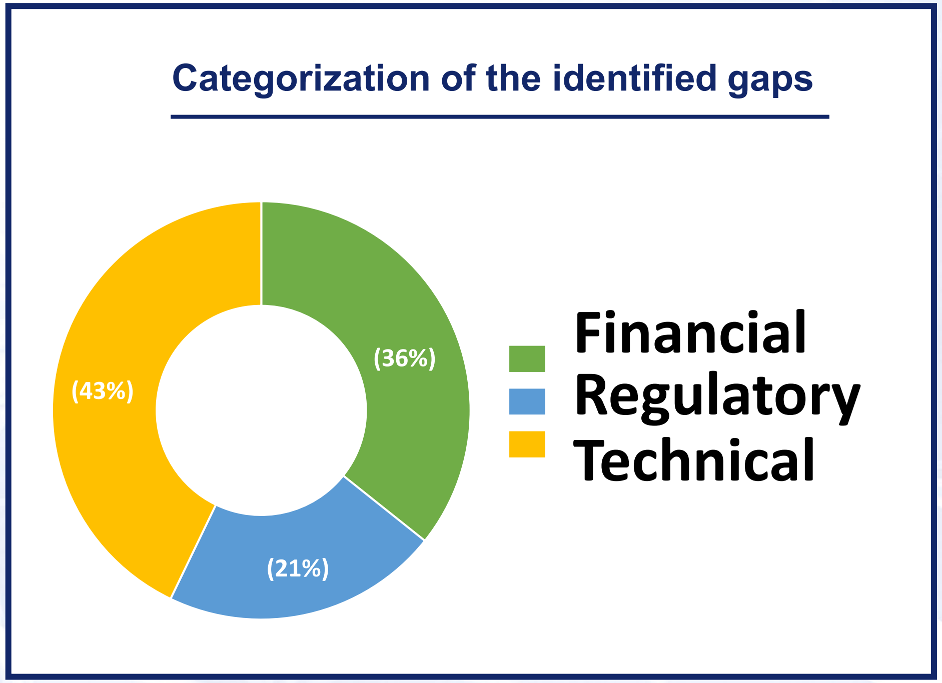
# 5GCroCo deployment study: Main Conclusions

- Key driver for 5G deployment:
    - standard eMBB traffic generated by end-users in proximity of the corridors
    - plus M2M/eMBB traffic generated by connected vehicles (<level 3 automation)
- The deployment of cross-border corridors will require
    - a change of radio planning approaches at the borders,
    - a constant exchange of up-to-date RAN planning parameters (like it is the case today for national roaming scenarios),
- Network densification in mid/higher band spectrum (3.x GHz and beyond) presents a significant cost driver along hundreds/thousands kilometers of transportation corridors, which is likely to be only economically sustainable if national MNOs, network suppliers, tower companies and operators / authorities of the transportation infrastructures cooperate.

# 5GCroCo Deployment study: Detected gaps

- Importance of identifying new major stakeholders and the way they will benefit from the deployment
- Importance of alignment between the national regulatory authorities in order to avoid future roadblocks and assure necessary coverage at border crossing areas
- Importance of considering additional costs for the CAM service requirements and deployment cost, such as: cloud costs, mitigation of cross-border interference between MNOs

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# Spectrum coordination in border areas: the challenge

- The coordination of spectrum usage cross-border is still in an early stage especially for TDD spectrum, i.e. the 3.x GHz spectrum bands.
- There are no clear rules laid out specifically for TDD bands, other than requiring cross-border coordination between MNOs.
- CEPT and ETSI performed an analysis with regards to the TDD slotting (UL/DL patterns and time slot sync) → It has not been translated into agreed procedures between neighboring countries, their NRAs (regulatory authorities) and the MNOs, yet.
  - Networks need to be synchronized (share a common time reference) both inland and cross-border to avoid any interference, even then using the same pattern.

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# Spectrum coordination in border areas: the 5GCroCo case

- Reminder: Germany-Luxembourg and France-Germany border areas
- France: 8+2 pattern to protect FWA legacy based on LTE
- Luxembourg and Germany: 4+1/4+1 for legacy free operations
- Implications:
  - Potential to create significant interference between networks
- The setup of the German 5GCroCo network was completed after the setup of the 5GCroCo networks in France and Luxembourg
- The German 5GCroCo network was also confronted with a commercial French 5G NSA network under deployment by Illiad/Free very close to the border in the Saarbrücken area.
  - This network is using an overlapping part of the spectrum in 3.6 GHz, which is also used by the German 5GCroCo network.
- DTAG’s German subsidiary Telekom Deutschland is leading an activity for an enhanced cross-border frequency coordination exactly for the purpose of addressing the TDD issue
  - Thus, a simple “trial and error”, i.e. deploy/operate 5G NSA without coordination and wait for possible complaints to be filed via the German NRA, was not acceptable.

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# Spectrum coordination in border areas: a potential way forward

- Technical solution: downlink symbol blanking: no downlink transmission on near-border base stations in slots which are used for uplink on the other networks on the other side of the border
  - This solution was not available for the RANs used in 5GCroCo
- Thus, to avoid interference, either:
  - Having no deployment in the exactly the same frequency band at least on one side of the border
  - Being prepared to significantly limit transmission on sectors pointing towards the border in case that significant (potential) interference is being observed
- In addition, potentially affected MNOs should be aware of each other's plans, deployment and operational status. Telekom Deutschland diligently reached out to all MNOs in both France (Bouygues Telecom and Free/Illiad) and Luxembourg (Orange) specifically for the TDD 3.6 GHz band
- Orange Luxembourg informed Telekom Deutschland about observed interference with their commercial LTE network at 1800 MHz and radiated power was adapted to a lower level. No complaints were received for the 3.x TDD bands, neither directly nor via the German NRA
- However, given the circumstance that usage on the 5GCroCo networks has been very low and only limited to the days and weeks of testing and trialing overall, while the usage of 5G NR TDD 3.x GHz on commercial networks is also hardly noticeable it may be difficult to assess the true interfering situation

# Conclusion

- 5G supports the Connected and Automated Mobility (CAM) use cases ToD, HD Mapping and ACCA (and many more)
- Trials including cross-border measurements now complete:
  - The trial results will be available in Deliverable D4.3 end of June
  - The architecture (incl. 5G SA), in Deliverable D3.3 end of June
- Cross-border / -MNO service continuity is technically feasible, but:
  - Organizational, business and legal aspects need to be further evaluated

# Thanks!!

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The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825050

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