# Demonstration and Evaluation of Cross-Border Service Continuity for Connected and Automated Mobility (CAM) Services

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# Outline

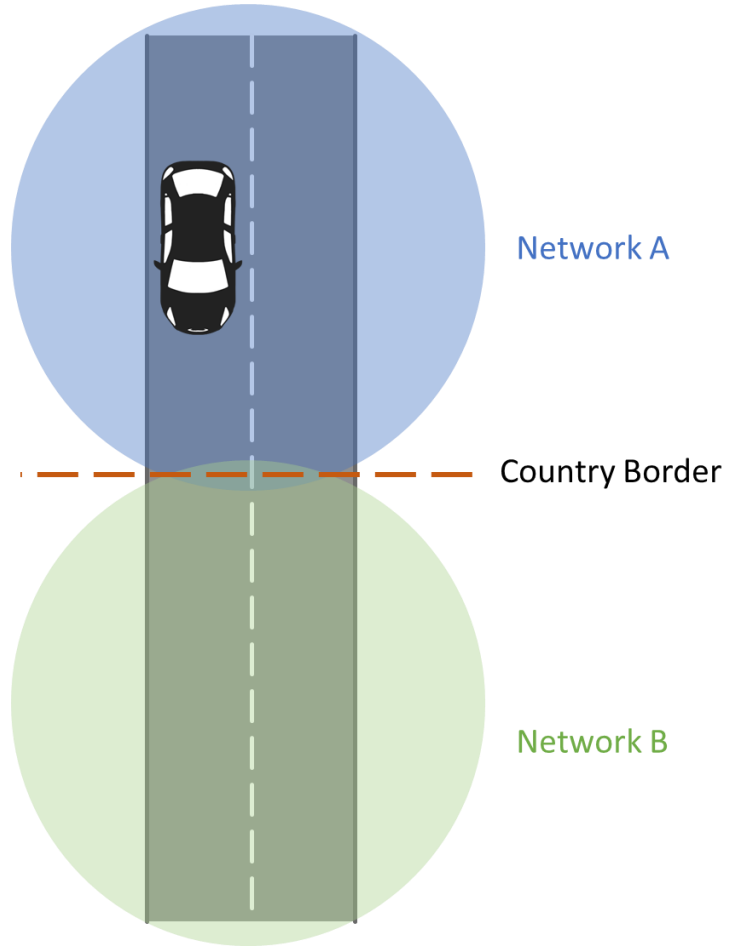
- Motivation
- Cross-border/-MNO handover
- Use case: HD mapping
- TCP performance with small files
- Trials setup and results
- Conclusion

# Motivation

- Moving between Public Land Mobile Networks (PLMNs) results in a long connection interruption (up to minutes)

- Frequent phenomenon in automotive use cases:
  - Particularly frequent at **country borders**, especially with open borders, e.g., Europe
  - **Connected automotive services** can suffer from long interruptions → operational and safety issues

  → Important topic for automotive and telecom industries, focus of different projects: **5GCroCo**, 5G-MOBIX, 5G-CARMEN, 5G-ROUTES, 5G-Blueprint, 5GMed, and 5GRAIL

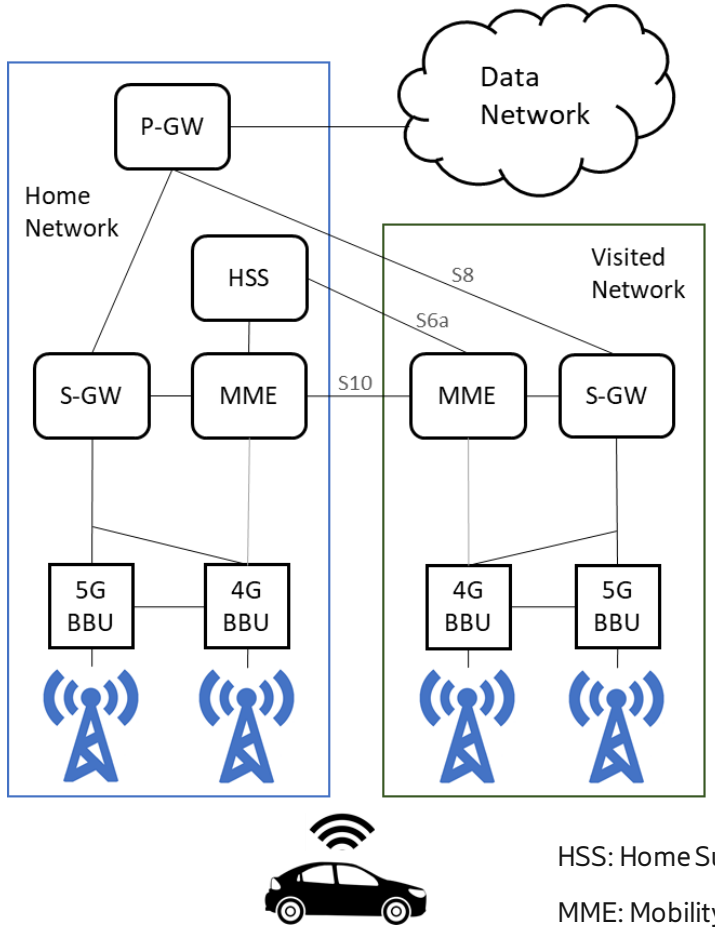


# Cross-border/-MNO Handover

MNO: Mobile Network Operator

- Seamless inter-PLMN handover, 3GPP requirement (3GPP TS 22.278 )
- Involved interfaces:
  - Roaming interfaces: S6a, S8
  - S10 between MMEs

  → similar to handover between MMEs in one PLMN
- Practical challenges: Information exchange between PLMNs about cell IDs and frequencies




HSS: Home Subscriber Server

MME: Mobility Management Entity

S-GW: Serving Gateway

P-GW: Packet Data Network Gateway

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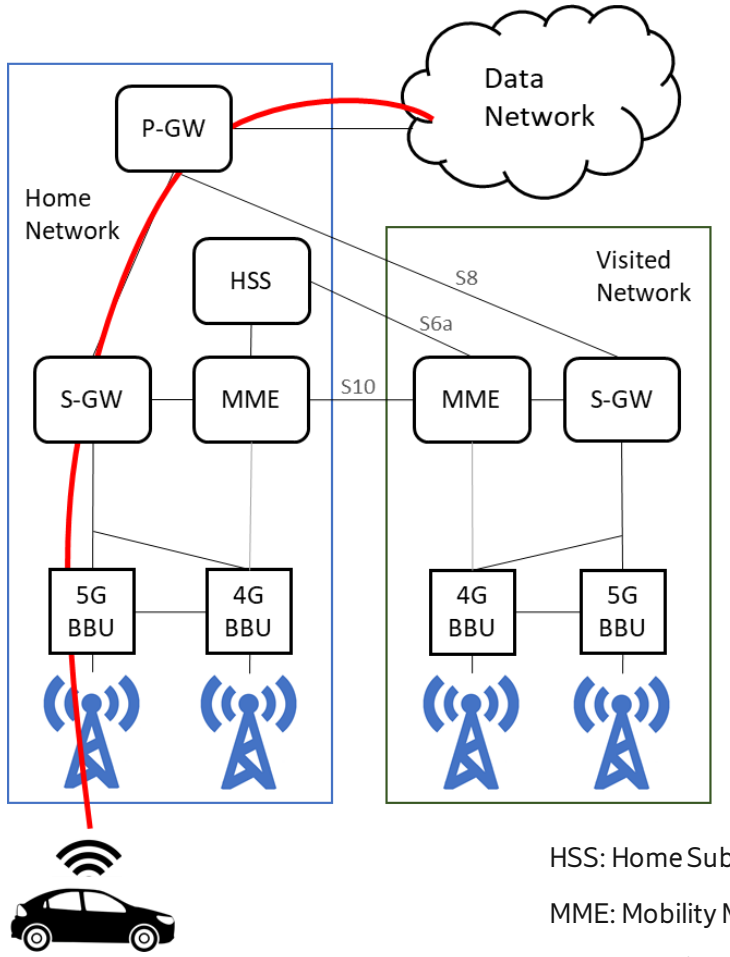


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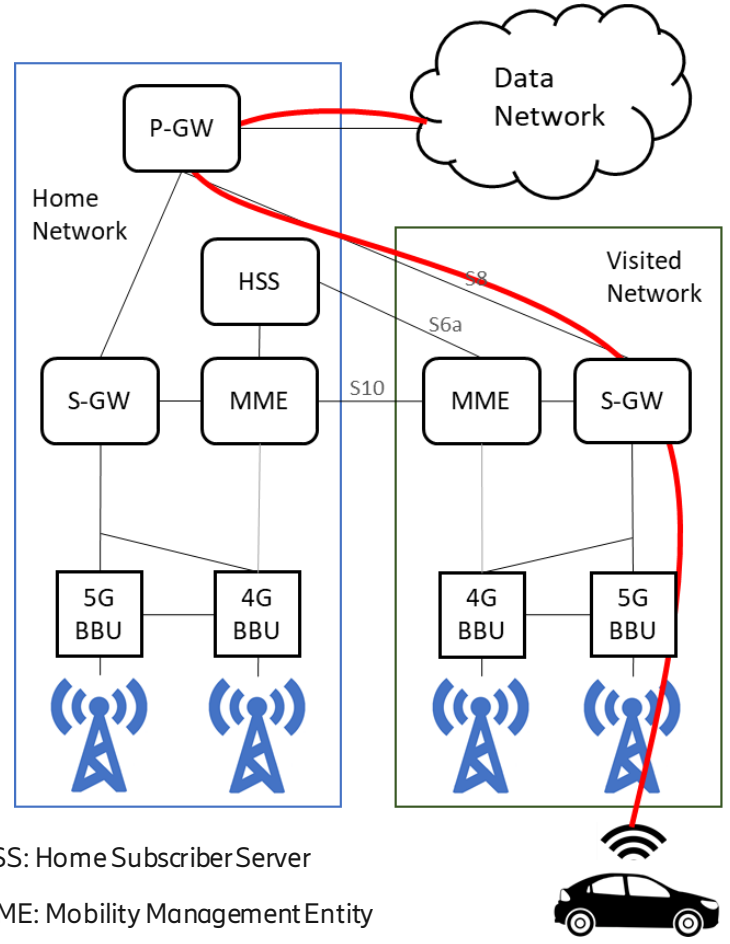


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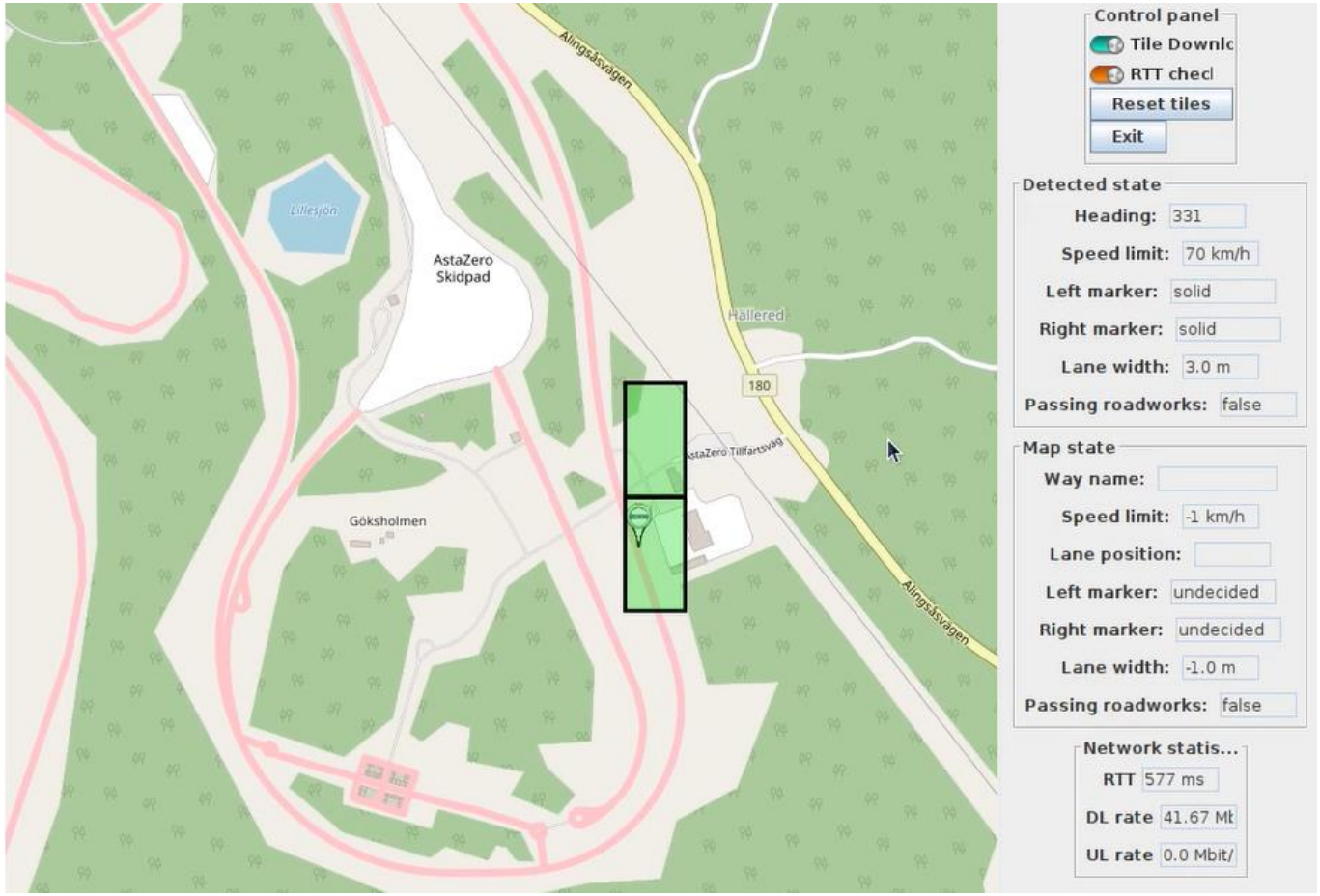
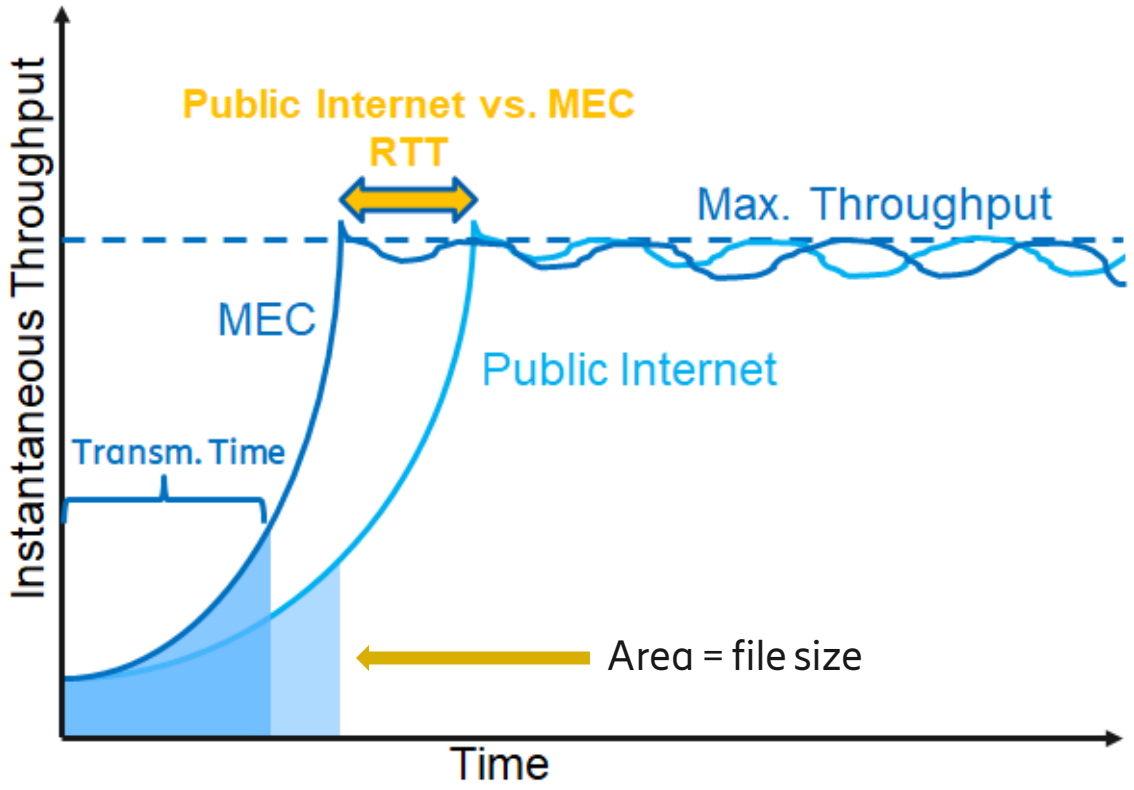
# High-Definition (HD) Mapping

- Highly-detailed road information and traffic rules
- Support assisted and automated driving algorithms
- Frequently updated information
- Commonly divided into tiles



# TCP Performance with Small Files

- Congestion control and maximum throughput "probing"
- Round-trip time determines how fast max throughput is reached → MEC reaches faster than public internet
- File size equals the integration of the curve over time

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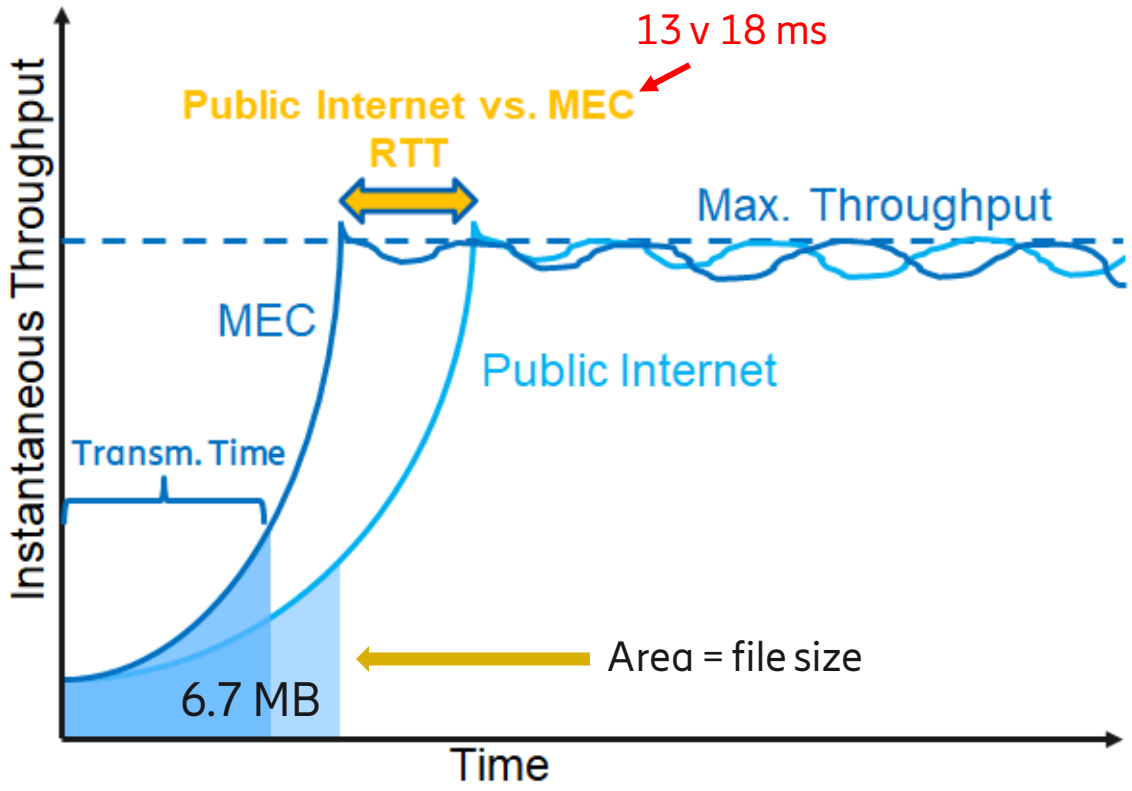


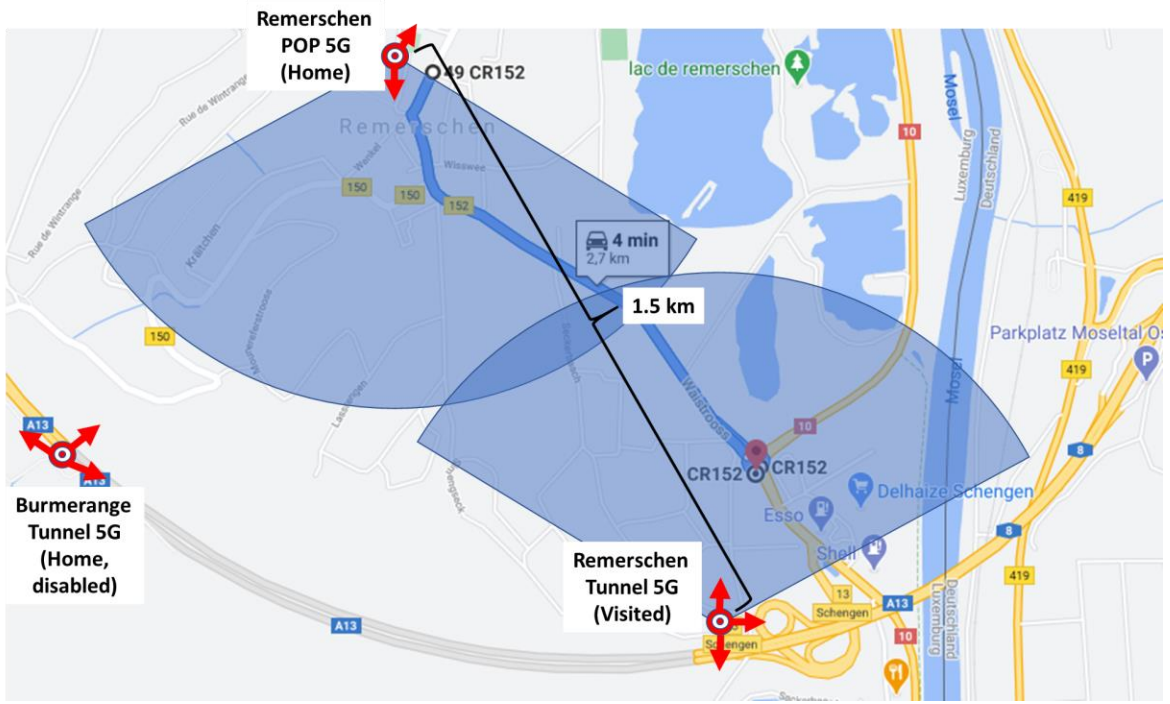

MEC: Mobile Edge Computing/Cloud

# Trials Setup

- Large-scale test and trial network near Remerschen & Schengen, Luxembourg
- Two neighbouring non-standalone 5G networks
- Identical configurations:

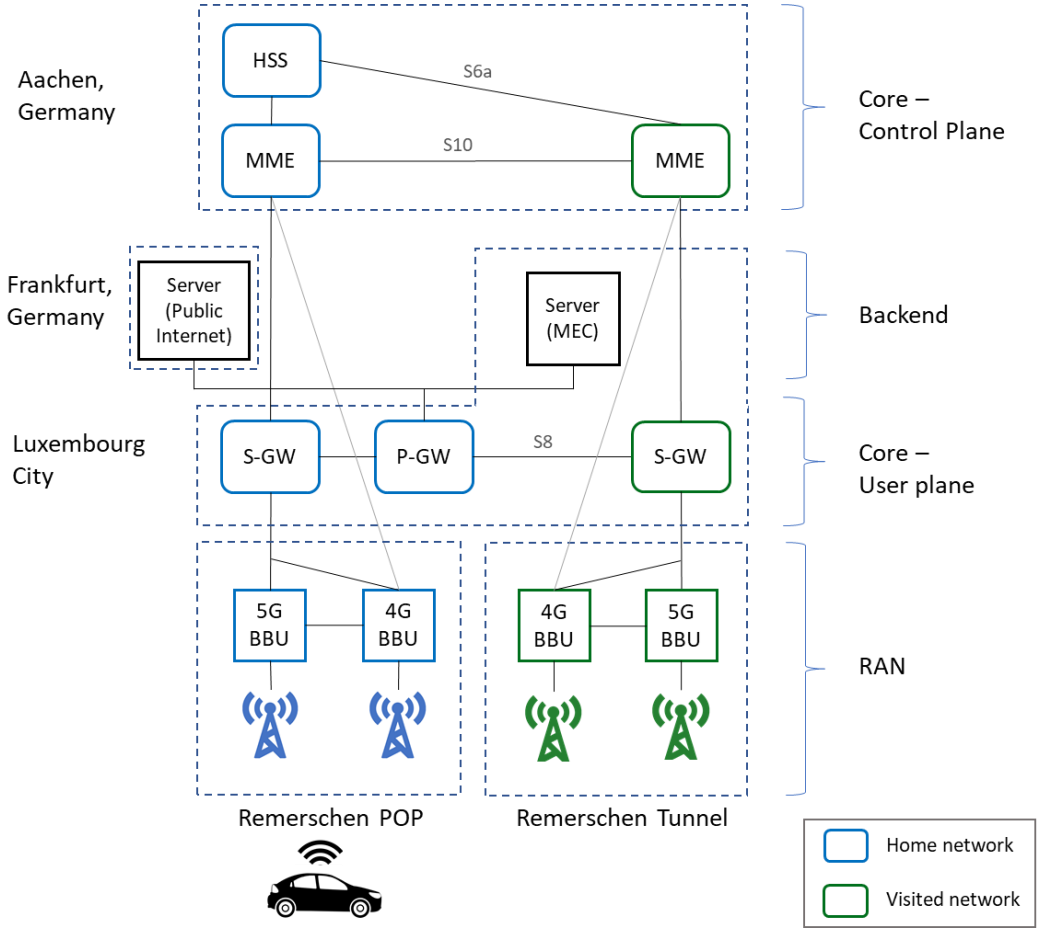
| Configuration | 5G | 4G |
|---|---|---|
| Band | n78 (3.7 GHz) | B28 (700 MHz) |
| Duplex mode | TDD 4:1 (DDDSU) | FDD |
| Bandwidth | 40 MHz | 2 x 10 MHz |
| Effective DL BW | ~32 MHz | 10 MHz |

- 1.5 km road between sites, car drives back and forth @ 30 km/h



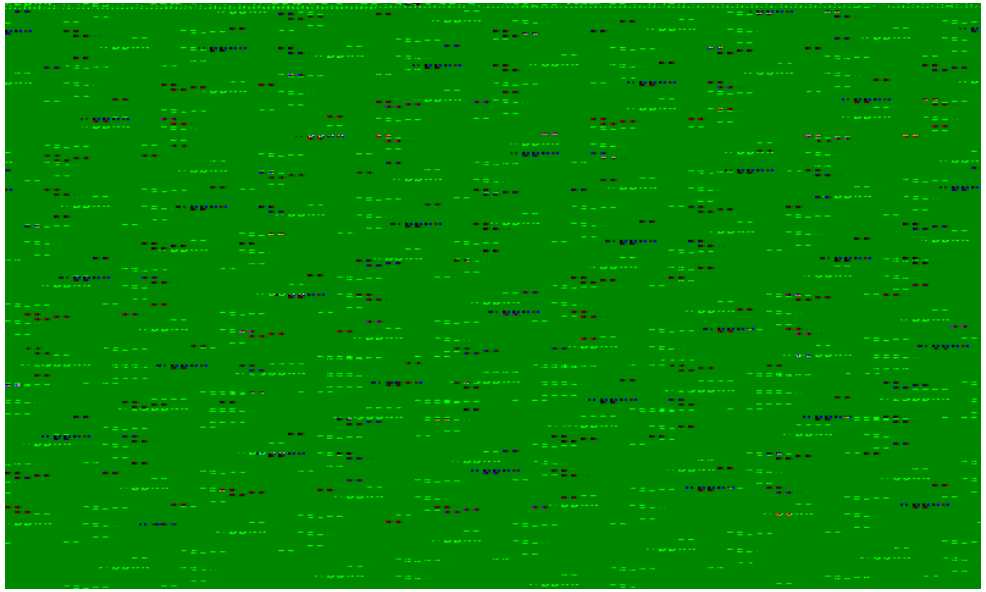
# Trials Setup

- Core network user plane nodes deployed in Luxembourg City
- Core network control plane nodes deployed at an Ericsson lab in Aachen, Germany
- Two servers for use cases:
  - MEC server in Luxembourg City
  - Public internet server in Frankfurt, Germany
- Handover does not change MEC server

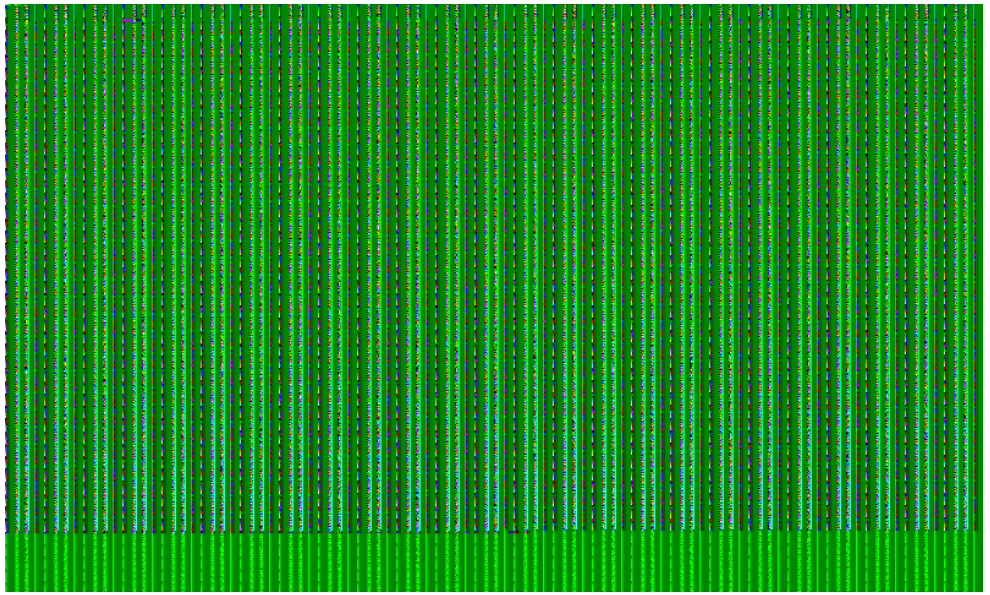


# Trials Results

- HD Maps Download:



Cross-border/-MNO handover disabled



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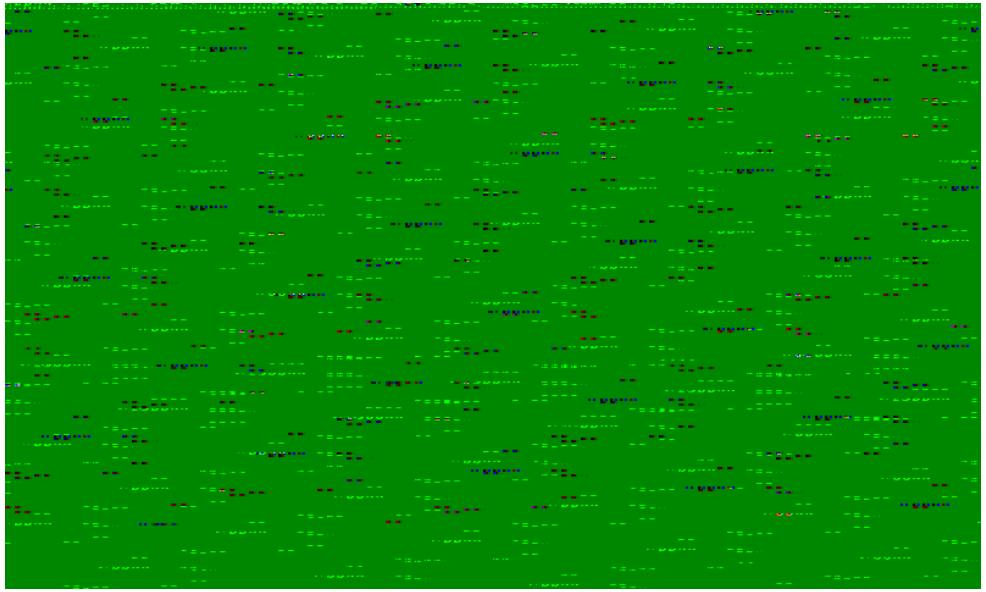

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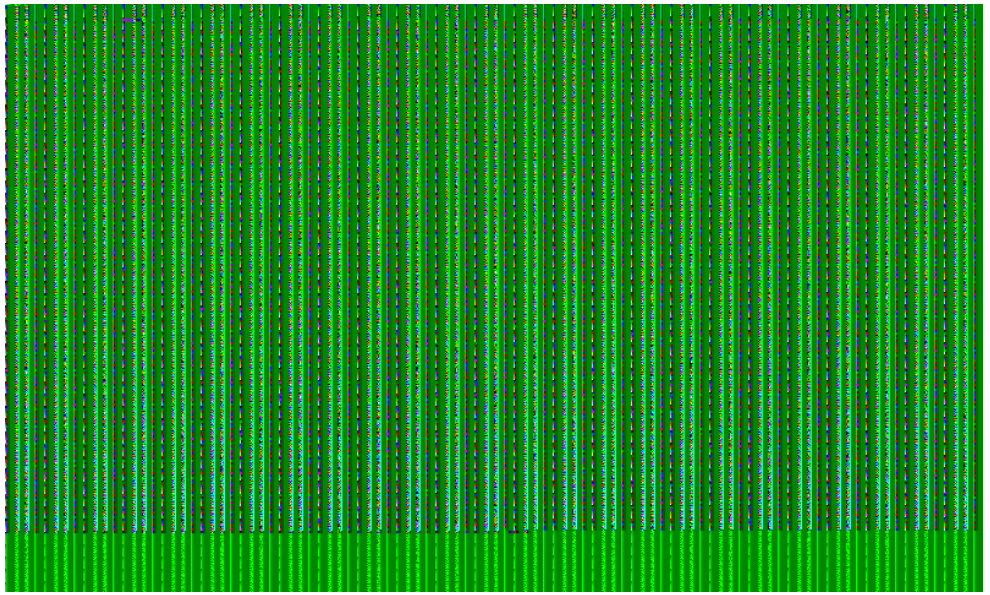

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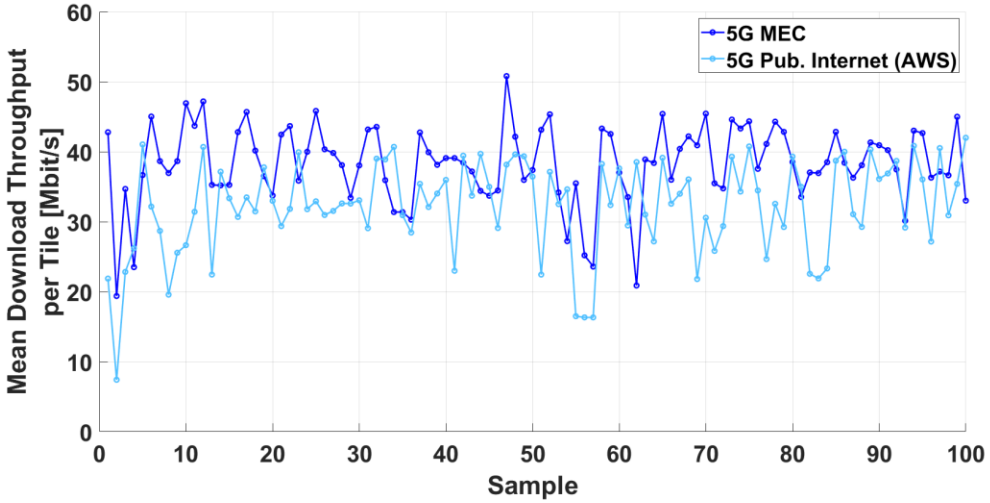
# Trials Results

- HD Maps Download:
  - Tile size ~ 6.7 MB: ~0.3 MB of actual data + 5 MB of padding + 25% increase of Base64 encoding
  - Max throughput: 50 Mbps, avg throughput: 37.6 Mbps for MEC, 32.3 Mbps for public internet
  - TCP behavior has larger effects than radio channel condition on throughput



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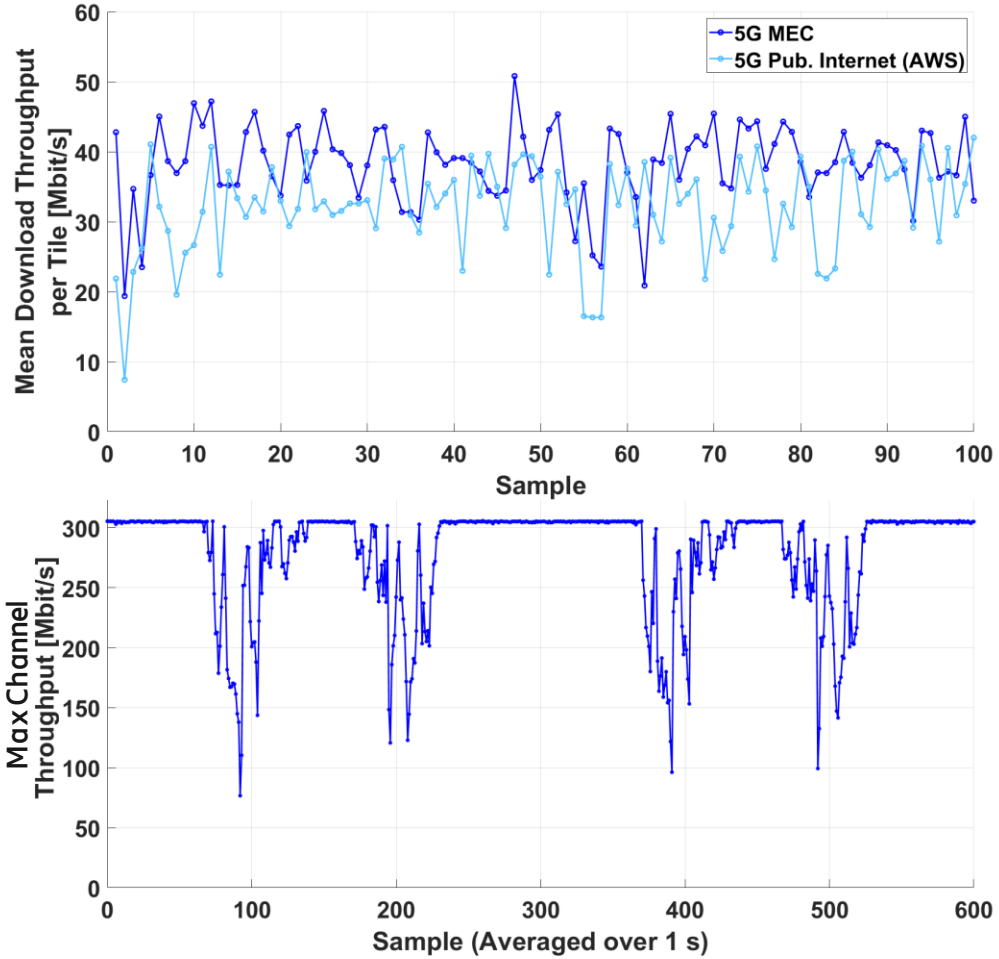
- Maximum Channel Throughput:
  - Max throughput: 305 Mbps, 9.5 bps/Hz spectral efficiency

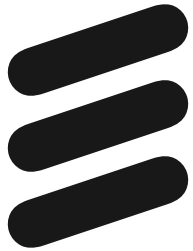


# Conclusion

- Long interruptions in Connected and Automated Mobility (CAM) services lead to operational and safety problems for automated driving

- Cross-border/-MNO handover successfully prevented service interruptions:
  - All HD map tiles downloaded successfully after handover
  - Acceptable minor increase in ACCA application-level latency during handover (not presented)
  - Cross-MNO handover effect is similar to other handovers and comparable to common performance fluctuation

- Future work:
  - New use case: Tele-operated Driving with cross-border/-MNO handover
  - Use Local Breakout roaming



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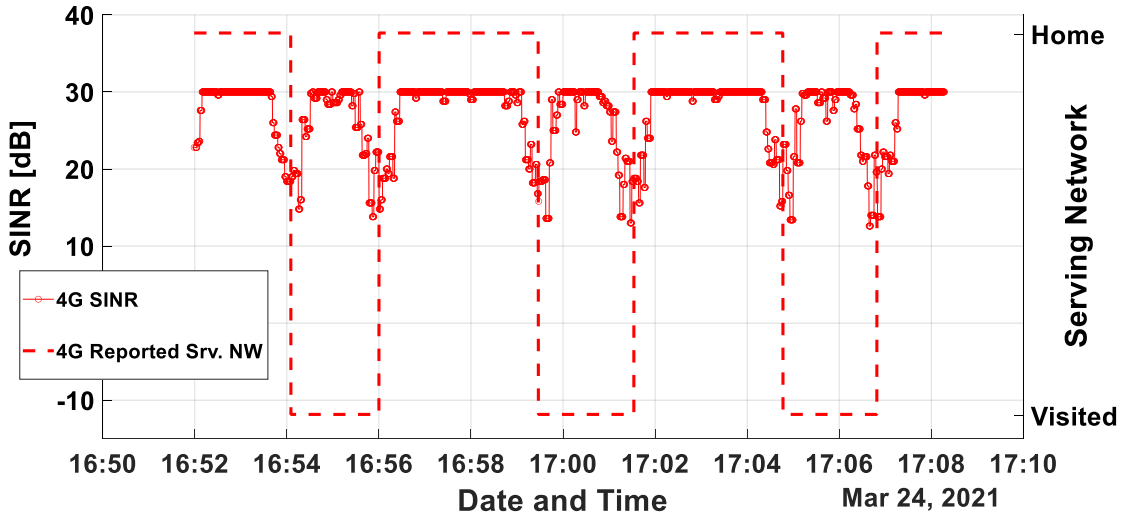

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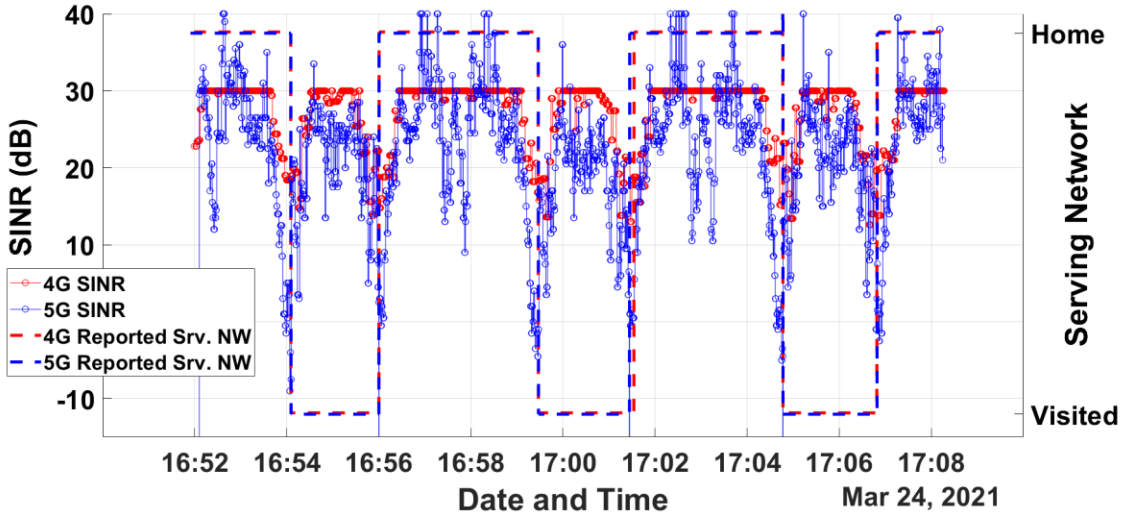
- Handover:
  - Handover decision based on 4G anchor signal quality
  - Higher fluctuation in 5G due to higher frequency
  - Min SINR values: 12 dB in 4G, -5 dB in 5G



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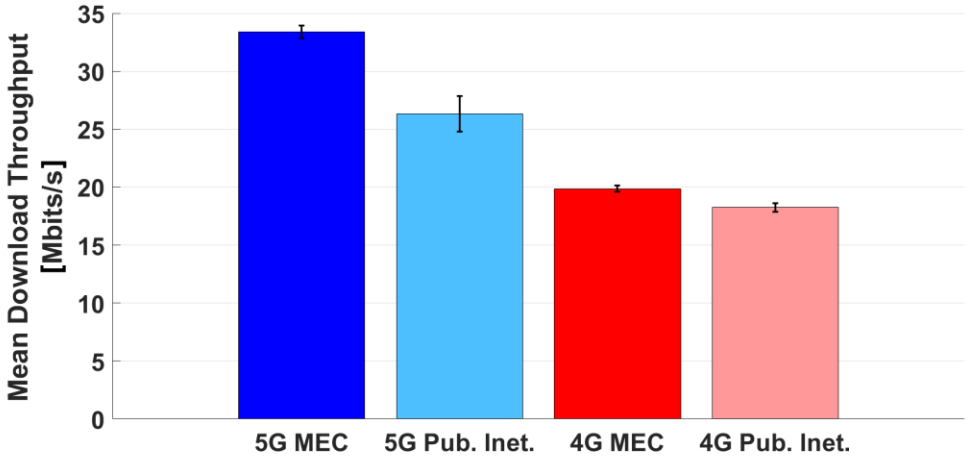
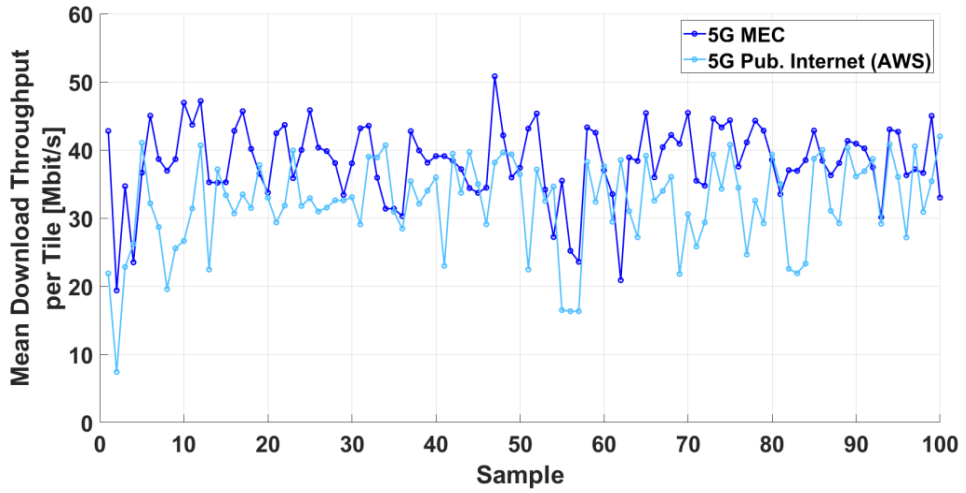
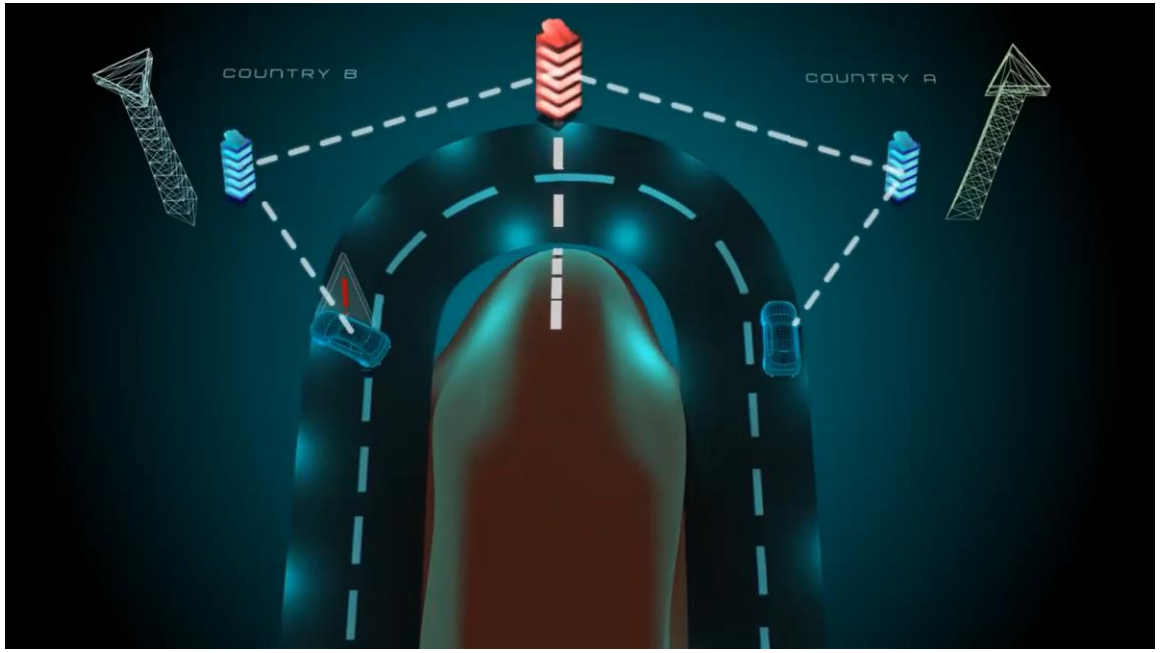


# Connected and Automated Mobility (CAM) Services

- Anticipated Cooperative Collision Avoidance (ACCA):
  - Collect and distribute critical event messages to cars in a relevant area: e.g., hazard warnings, stationary vehicle, traffic jam
  - Cars can anticipate events undetectable in onboard sensor readings
  - Events can be detected by involved vehicles, passing vehicles, or processing in the server



# Trials Results

- ACCA use case:
  - Car generates hazard message every ~5 seconds
  - Server relays message back to the car, message latency is measured
  - Application-Level Latency:
    - Average latency: 18.4 ms
    - At handover: 32 ms and 43 ms
    - Low probability of transmitting/receiving during handover for one car/user, more likely with higher number of users