CARISSMA
Automotive Safety Research

Aalto University

Measuring the Feasibility of Teleoperated Driving in Mobile Networks

Stefan Neumeier, **Ermias Andargie Walelgne,**
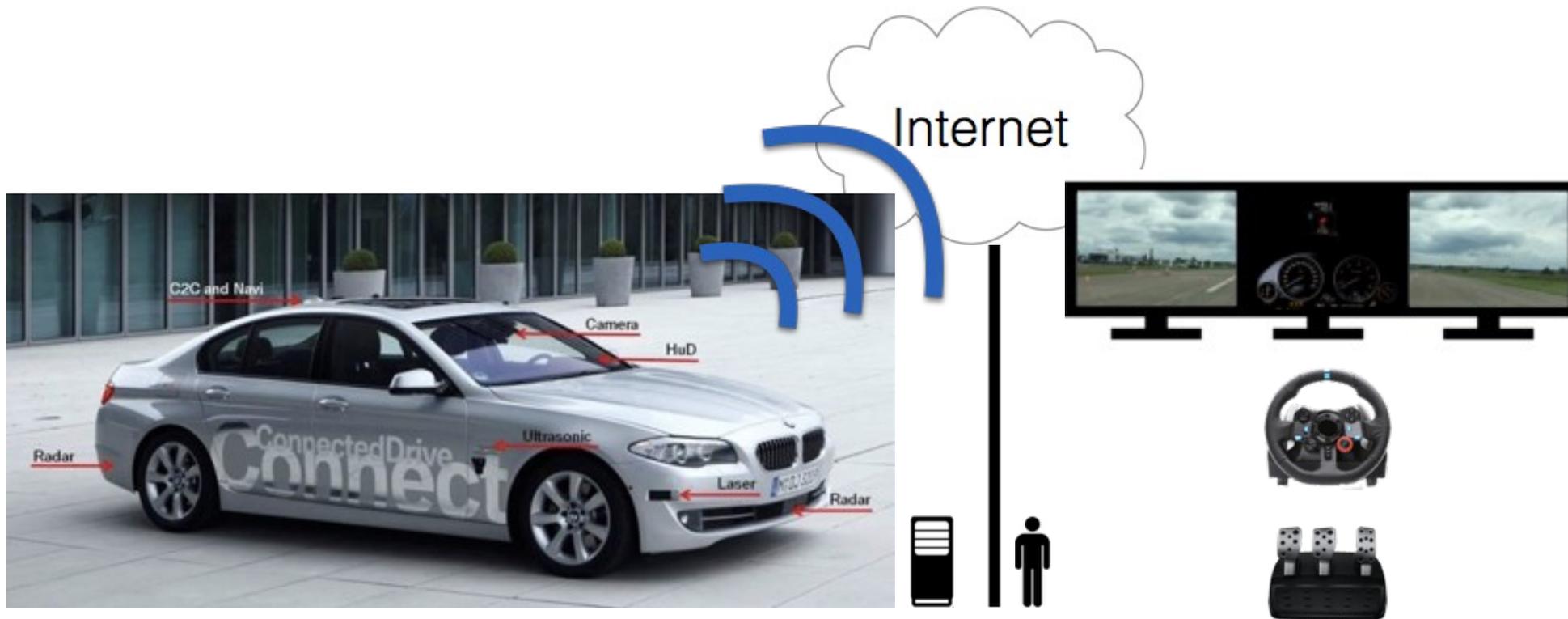**Vaibhav Bajpai, Jörg Ott, Christian Facchi**

20.06.19

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Technische Hochschule Ingolstadt

Outline

- **Introduction**

- **Requirements**

- **Setup**

- **Dataset + Results**

- **Conclusion**

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What is Teleoperated Driving
What is Teleoperated Driving

- **Remote control of Vehicles**

Based on: T. Tang, F. Chucholowski, and M. Lienkamp, "Teleoperated driving basics and system design," ATZ worldwide, vol. 116, no. 2, pp. 16–19, Feb 2014. [Online]. Available: https://doi.org/10.1007/s38311-014-0018-1

Why Teleoperated Driving?

- **Vehicles may not solve all situations autonomously**

  - Until Level 5 (fully autonomous vehicles)

  - Supporting of non autonomous features

- **From Level 5**

  - Software/Hardware failures

  - Exceptional situations

- **Use Cases**

  - Emergency Support

  - Valet Parking Service

  - Etc.

Challenges in Teleoperated Driving

- **Teleoperated Driving needs Cellular Network**

- **Bandwidth**

  - Variable

  - Probably Low

- **Latency**

  - Variable

  - Probably High

- **Jitter**

- **No Connection**

- **-> Leads to problematic situations**

Requirements for Teleoperated Driving

- **Downlink:**

  - 0.25 Mbit/s

  - Based on: Steering command all 10 ms

- **Uplink:**

  - Min. 3 MBit/s

  - Based on: Resolution 640 x 480; three 90° cameras (front: two, back: one)

- **Latency:**

  - Max. 250 ms

  - 300 ms tolerable latency based on user study (- Time for Sensors/Actuators of 50 ms)

  - Jitter max 150 ms

Measurement Setup

- **Hardware**

  – Lenovo B

  – SierraWireless

- **Software**

  – Ping

  – Netradar

    • Smartphone measurement tool

  – Iperf3

- **Two setups for easy use and comparison**

  – Availability of test vehicle

  – Easiness in using

Dataset

- **Measurement Period**

  - May 2017 – end of December 2017

- **About 5200 km and 78 h of driving**

  - Ping: 2180 km

  - Netradar: 2670 km

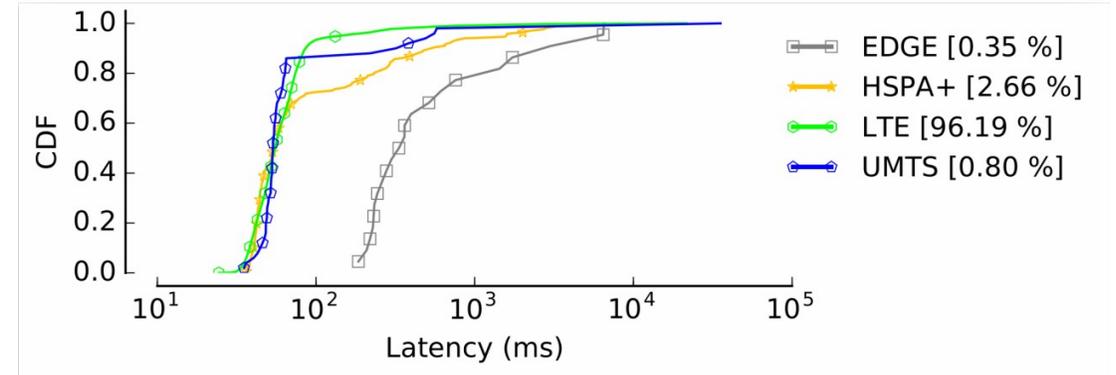 - SierraWireless: 354 km

Ping

Netradar

SierraWireless

Results - Latency

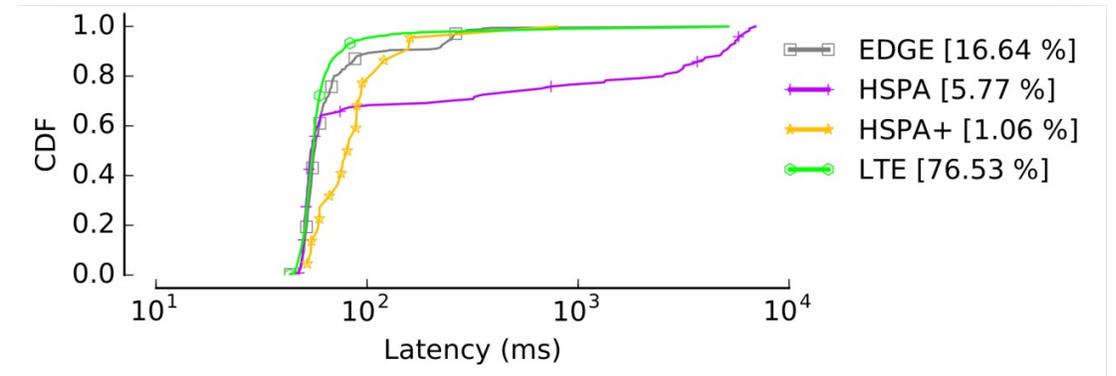- **Ping**

  - Median latency of about 55.14 ms

  - 96 % below 250 ms

  - Median jitter of about 10 ms

  - 5 % above 150 ms

- **Netradar**

  - UDP latency

  - Median latency of about 55 ms

  - 96 % below 250 ms

  - Median jitter of about 2 ms

  - 4 % above 150 ms

Ping

Netradar
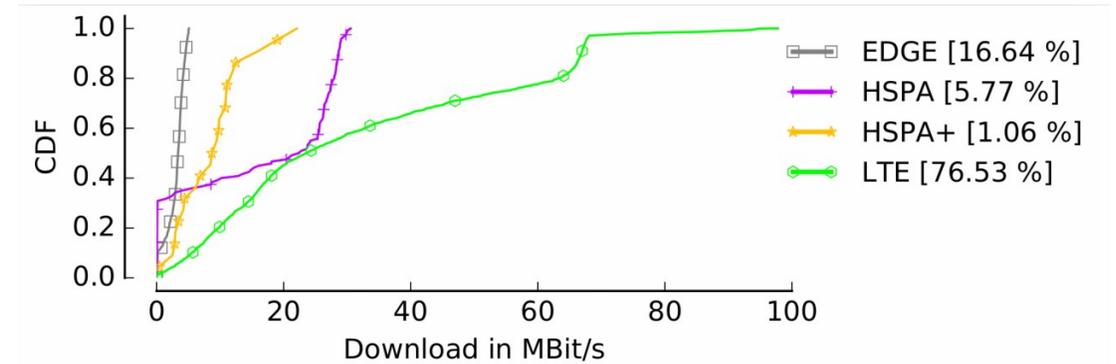
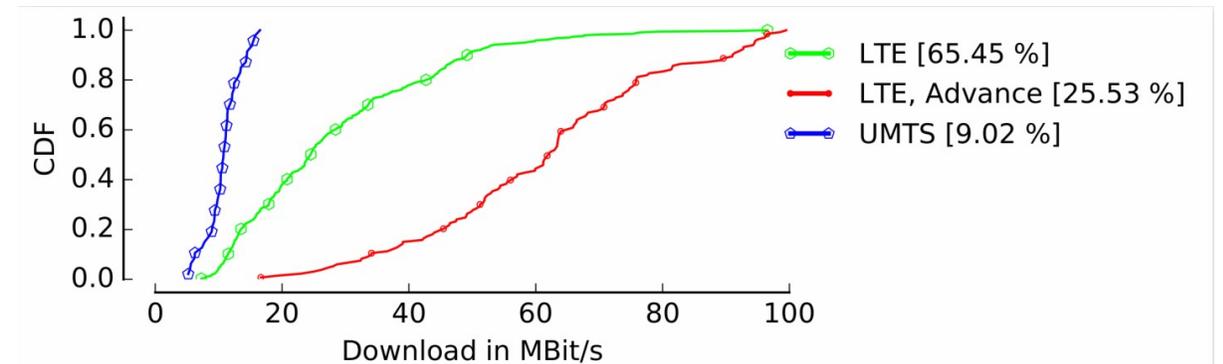# Results – Downlink Throughput

- **Netradar**

  - TCP troughput

  - Median of about 17 MBit/s

  - 95 % above 0.25 MBit/s

  - Median variance of 0.15 MBit/s

- **SierraWireless**

  - Iperf3 throughput

  - Median of about 28 Mbit/s

  - 99 % above 0.25 Mbit/s

  - Median variance of 0.41 MBit/s

Netradar

SierraWireless

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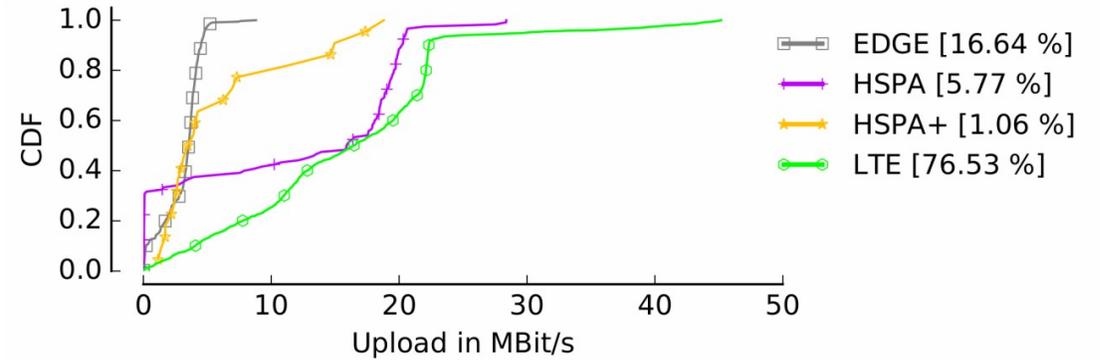
Results – Uplink Throughput
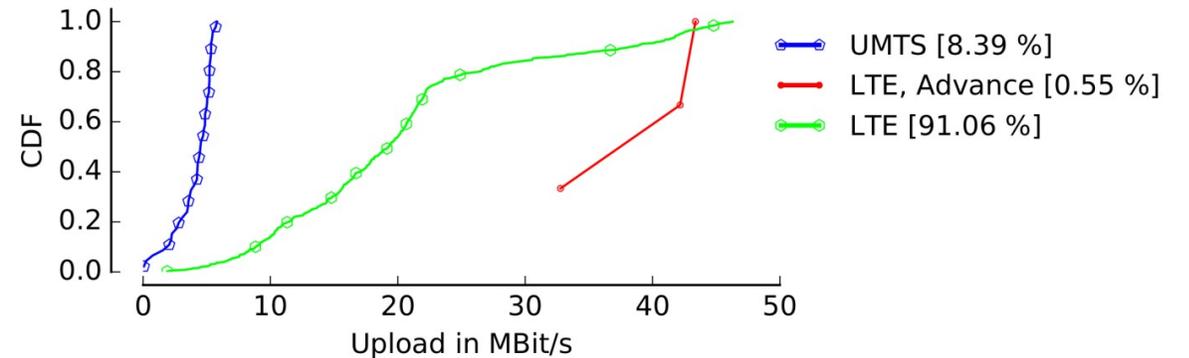
- **Netradar**

  - Median of about 12 MBit/s

  - 87 % above 3 MBit/s

  - Median variance about 0.07 MBit/s

- **SierraWireless**

  - Median of about 18 Mbit/s

  - 98 % above 3 Mbit/s

  - Median variance about 0.07 MBit/s

Netradar

SierraWireless

Results – Identical Routes

- **Latency - Ping and Netradar**
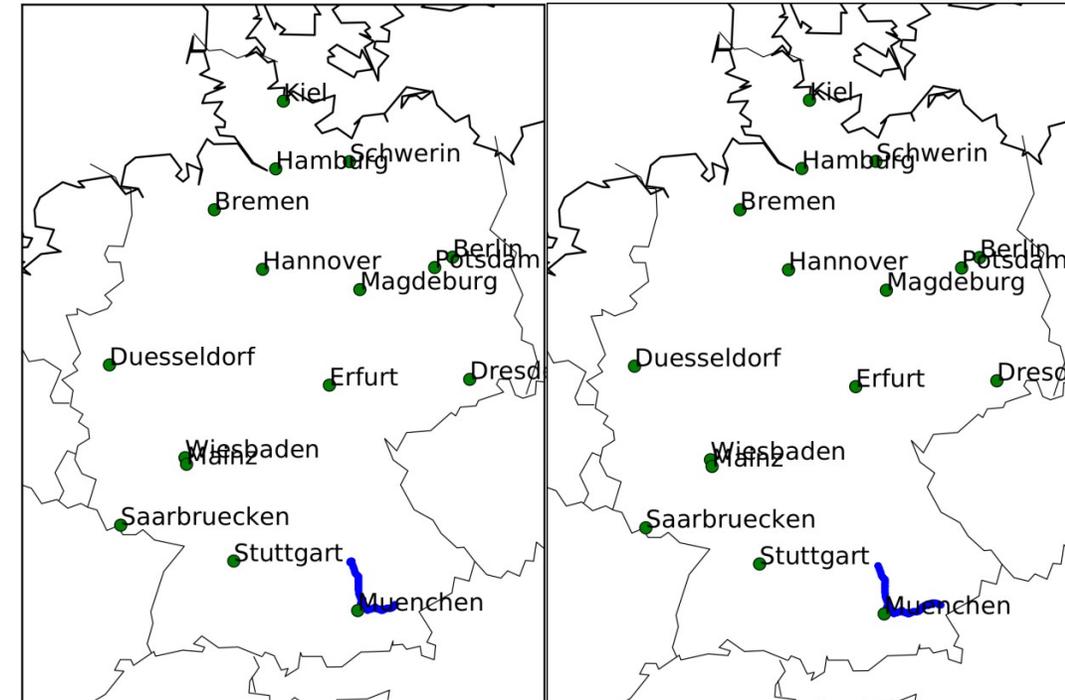
  - Ping: about 57 ms

  - Netradar: about 55 ms

    → Results are roughly comparable with same Hardware

- **Throughput – Netradar and SierraWireless**

  - Downlink: 15 MBit/s (Netradar) ↔ 32 MBit/s (SierraWireless)

  - Uplink: 13 MBit/s (Netradar) ↔ 20 MBit/s (SierraWireless)

    → Most likely attributed to the two antennas

Ping/Netradar   Netradar/SierraWireless

Results – Different Scenarios

- **Handover**

  – Latency and Throughput get worse if changing cellular technology (e.g. LTE → 3G)

  – Median decrease to 15 % of original speed

- **Speed**

  – 0 – 150 km/h

  – No influence on latency or throughput

- **Signal-Strength**

  – Better Signal-Strength, higher throughput

  – Latency: No tendency can be seen

- **Distance to base station**

  – No influence can be seen

Results – Whitelisting as possible Approach

- **Whitelisting: Teleoperated Driving only in areas that provide sufficient network performance**

Limitations
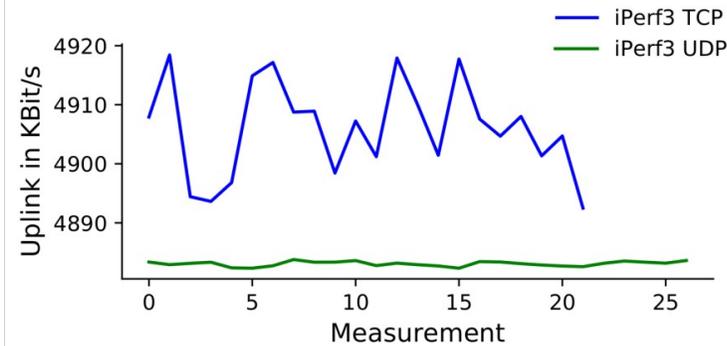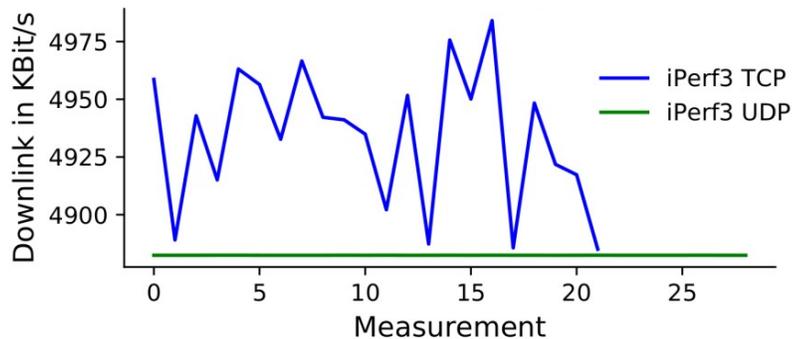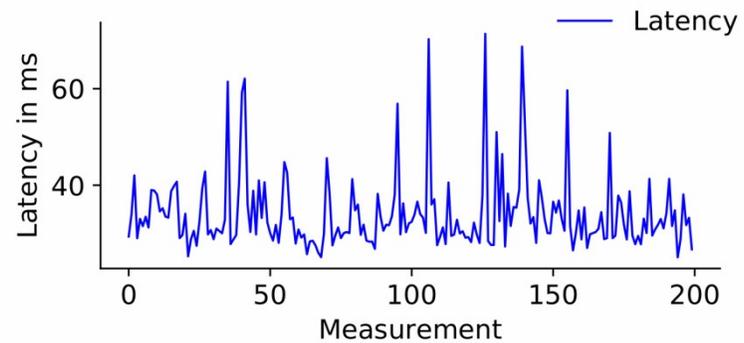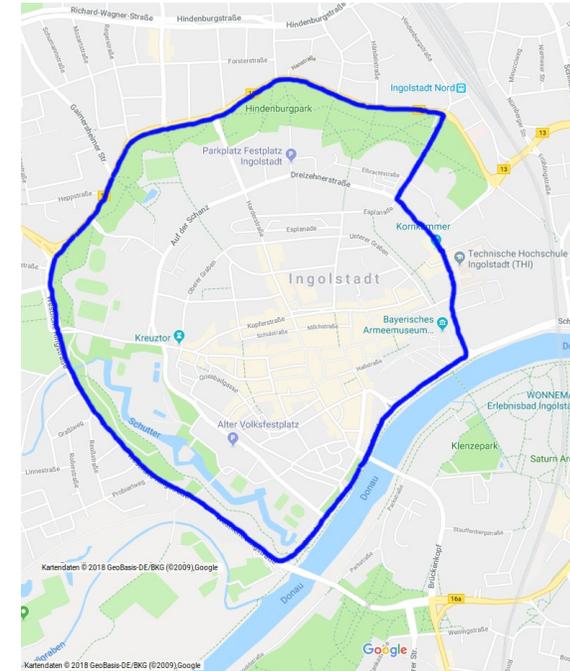
- **Amount and type of measurements**

- **Changes in network are likely to occur**

- **Results reflect client's perspective**

- **Network is treated as Black-Box**

- **No information on how busy cells were**

  → **Nevertheless, results can be used to get a first impression if Teleoperated Driving could work at all with contemporary mobile networks.**

Conclusion

- **Teleoperated Driving may be feasible with contemporary mobile networks**

- **Whitelisting can work**

- **However, Teleoperated Driving can not be used in all situations**

- **Handover can have negative influence**

- **Signal strength can influence throughput**

- **Fluctuation of latency can increase with far vehicles (e.g. more than 250 km away of operator)**

- **Future work has to deal with limitations, e.g. improve the whitelisting**

  - If you have further questions: *stefan.neumeier@thi.de*