Measuring the Feasibility of Teleoperated Driving in Mobile Networks

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Outline

- **Introduction**
- **Requirements**
- **Setup**
- **Dataset + Results**
- **Conclusion**

Teleoperated Driving

- **Remote control of Vehicles**

- **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

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

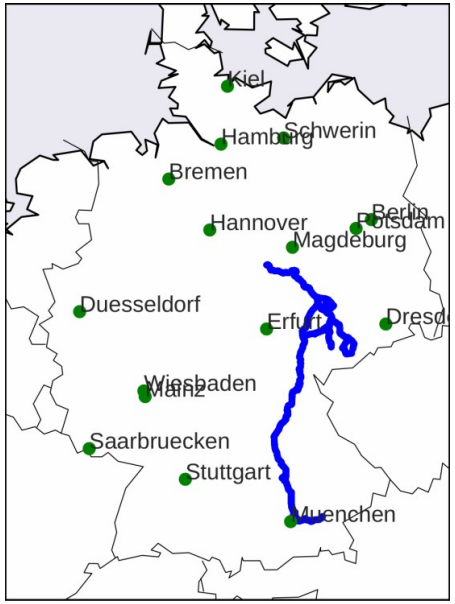
- **Downlink:**
  - 0.25 MBit/s
  - Based on: Steering command all 10 ms
- **Uplink:**
  - Min. 3 MBit/s
  - Based on: Resolution 640 x 480; three 90° cameras (front: two, back: one)
- **Latency:**
  - Max. 250 ms
  - 300 ms tolerable latency based on user study (- Time for Sensors/Actuators of 50 ms)
  - Jitter max 150 ms

Measurement Setup

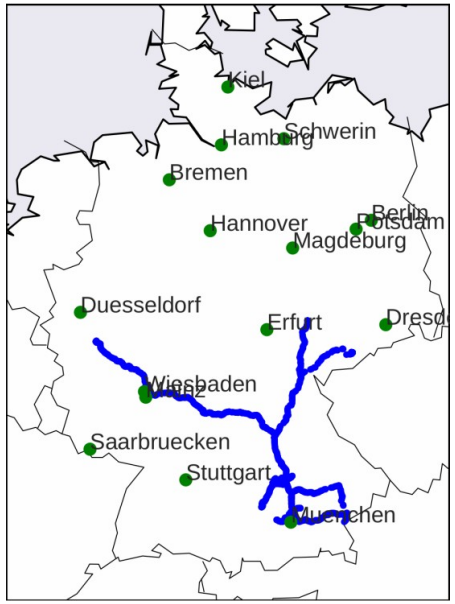
- **Hardware**
  - Lenovo B
  - SierraWireless
- **Software**
  - Ping
  - Netradar
    - Smartphone measurement tool
  - Iperf3
- **Two setups for easy use and comparison**
  - Availability of test vehicle
  - Easiness in using

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

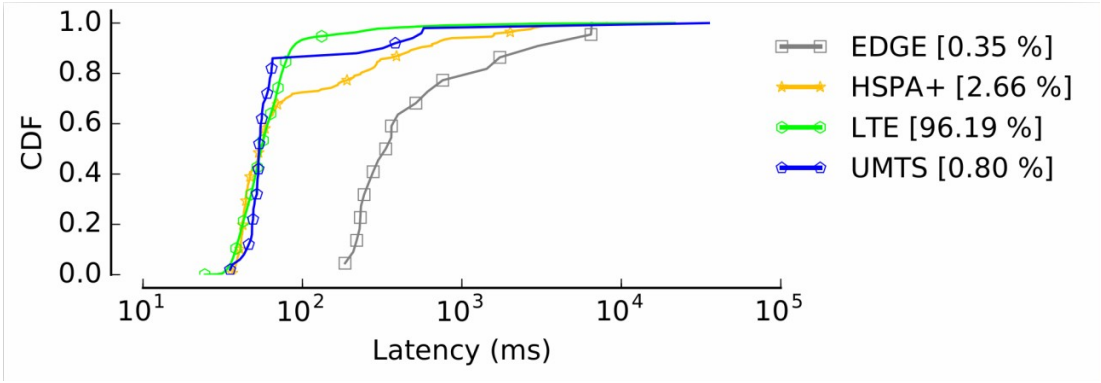


Netradar

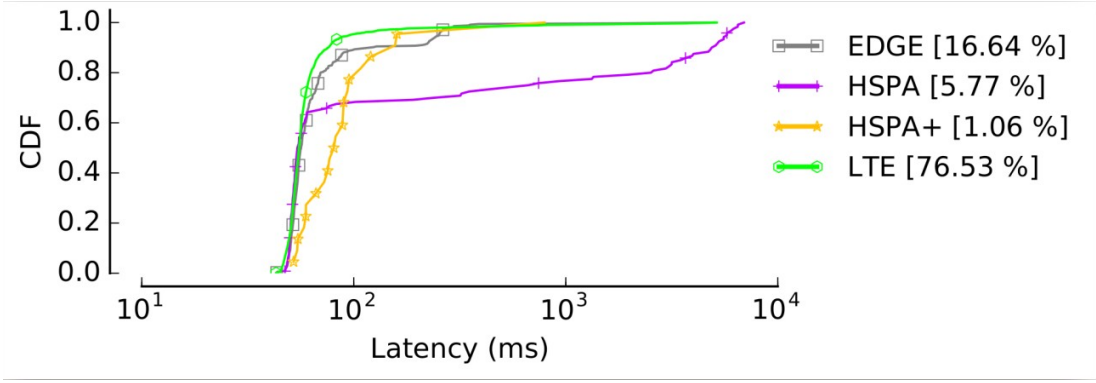
SierraWireless

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



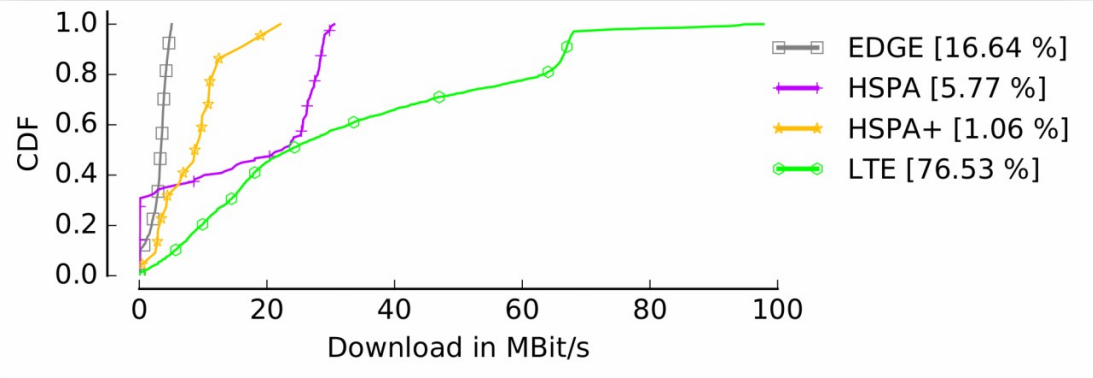
Ping



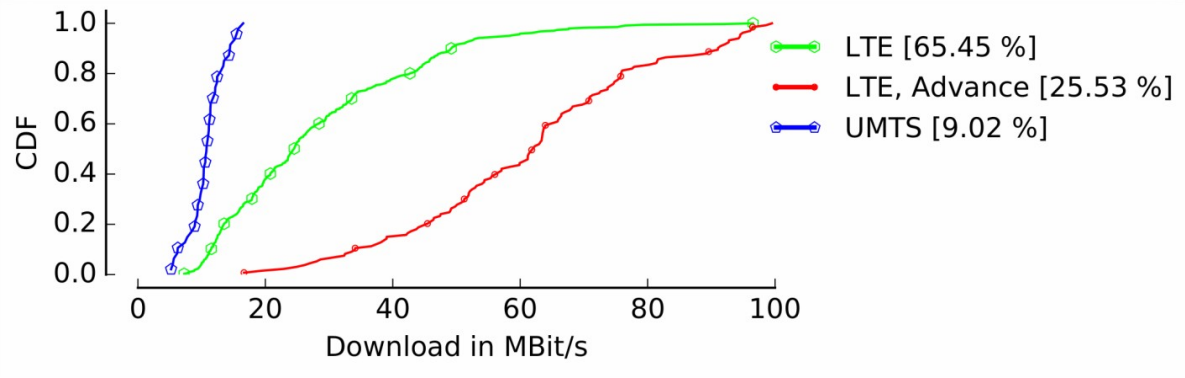
Netradar

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



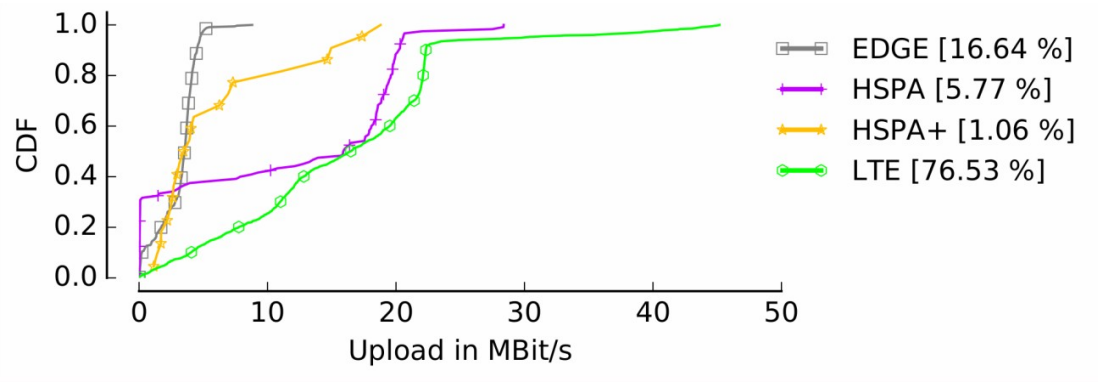
Netradar



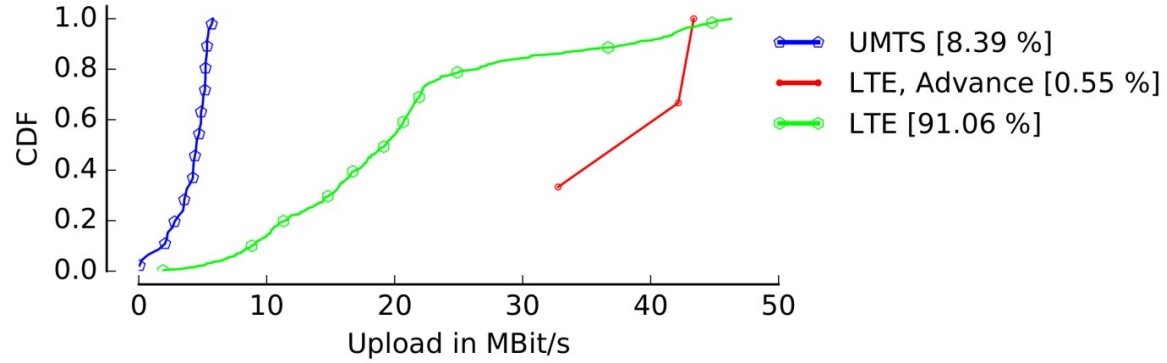
SierraWireless

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



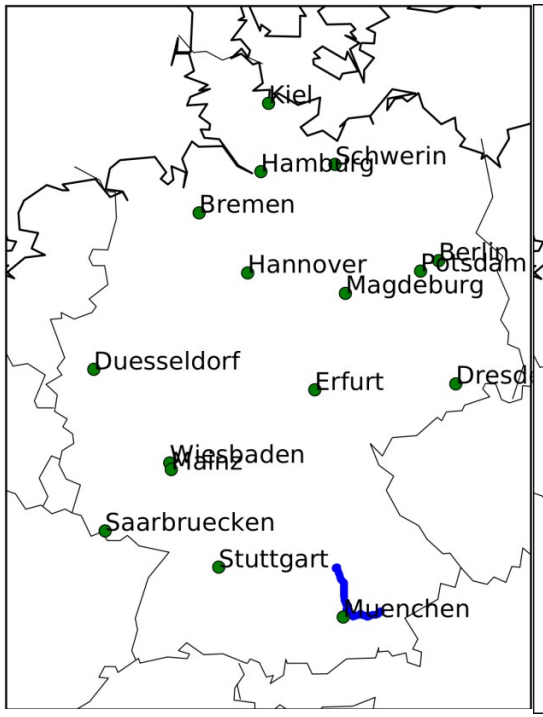
SierraWireless

Results – Identical Routes

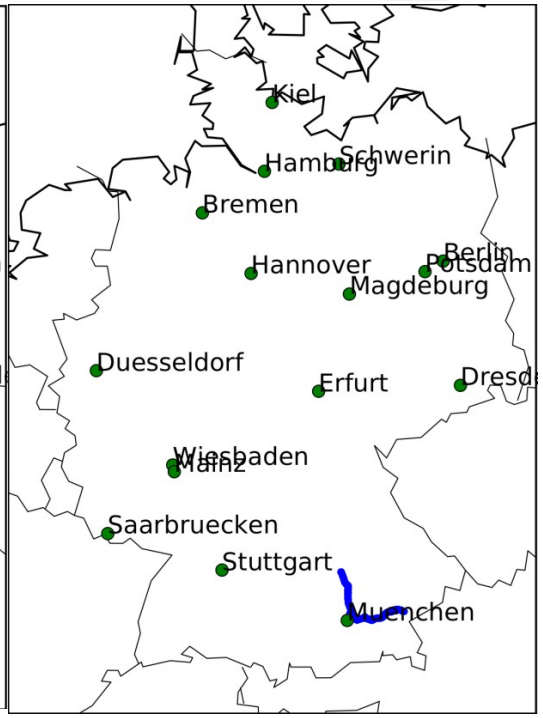
- **Latency - Ping and Netradar**
  - Ping: about 57 ms
  - Netradar: about 55 ms

    → 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



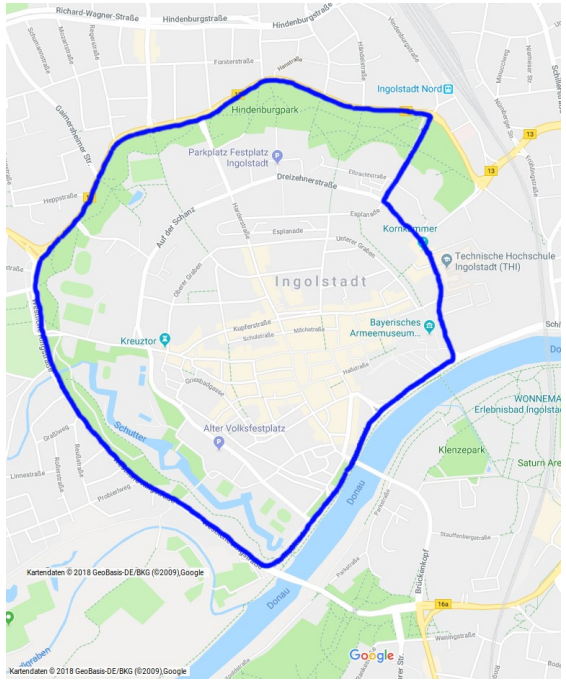
Netradar/SierraWireless

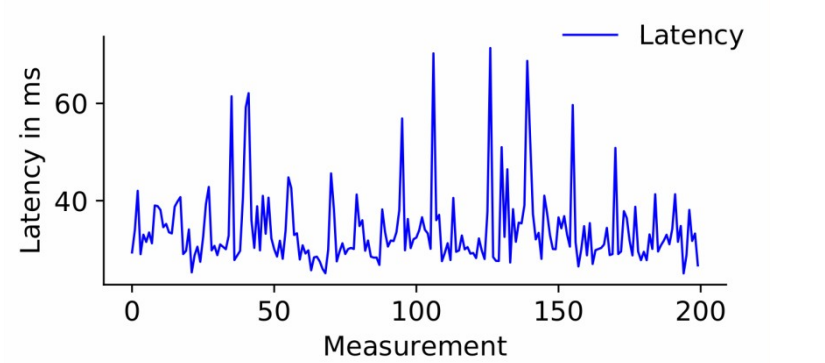
Results – Different Scenarios

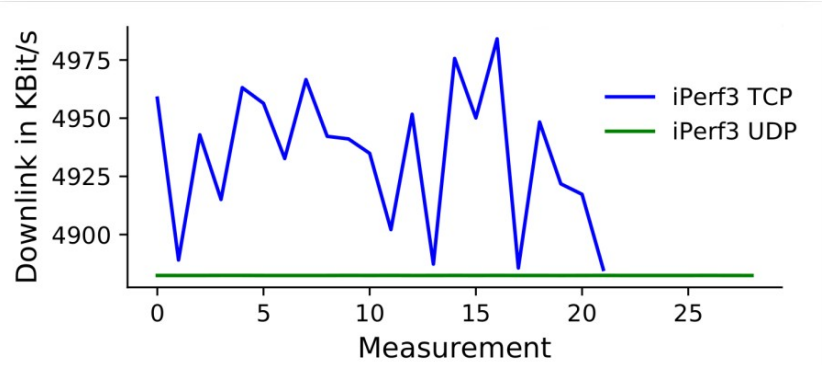
- **Handover**
  - Latency and Throughput get worse if changing cellular technology (e.g. LTE → 3G)
  - Median decrease to 15 % of original speed (Throughput)
  - Median increase of 15 % in Latency
- **Speed**
  - 0 – 150 km/h
  - No influence on latency or throughput
- **Signal-Strength**
  - Better Signal-Strength, higher throughput
  - Latency: No tendency can be seen
- **Distance to base station**
  - Usually < 5 km
  - No influence can be seen

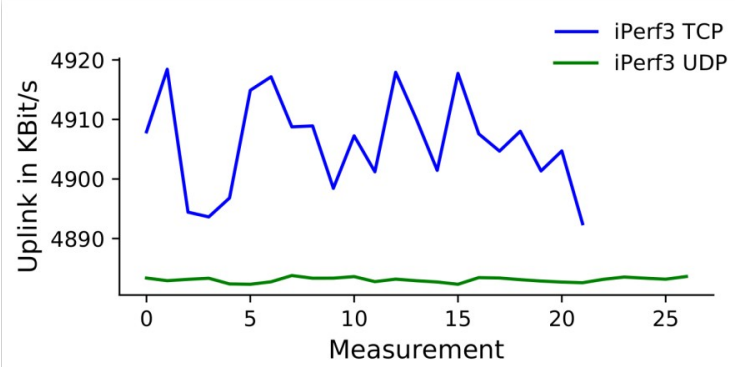
Results – Whitelisting as possible Approach

- **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***