Remote driving

Applying remote driving using various network configurations

Jos den Ouden

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Contents

- Remote driving key features
- Methodology
- Trials
- Results

Use case partners

roboauto
DRIVE ANYTHING FROM ANYWHERE

- Remote driving technology

SIEMENS
Ingenuity for life

- Remote driving vehicle and station
- Virtual vehicle

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
AI IN MOTION

- Remote driving vehicle and station
- 5G SA network with localisation

kpn

- Providing 5G SA Network (together with Ericsson)

TNO innovation for life

- Providing roaming 5G SA Network (slicing)

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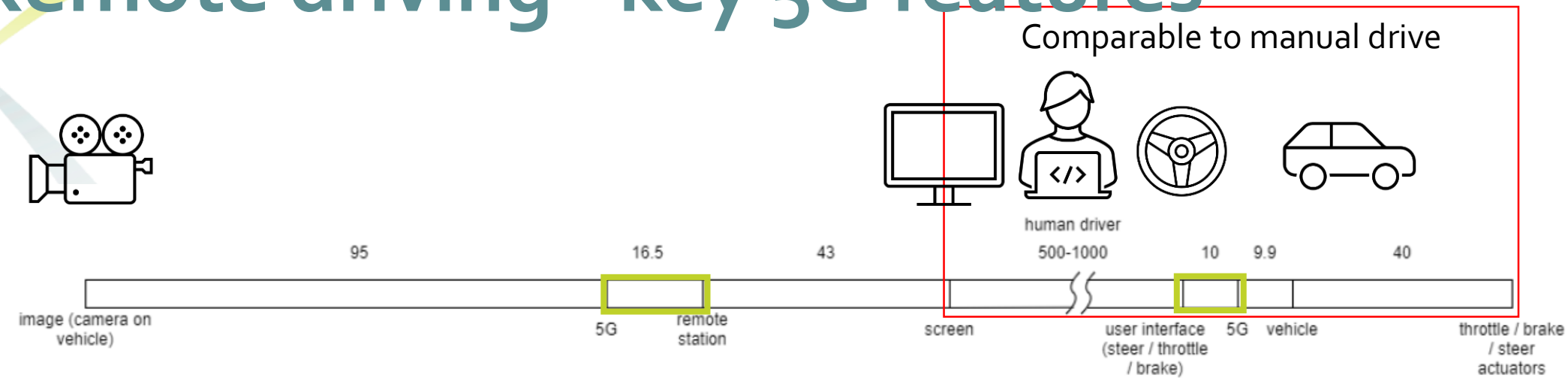
Remote driving - key 5G features



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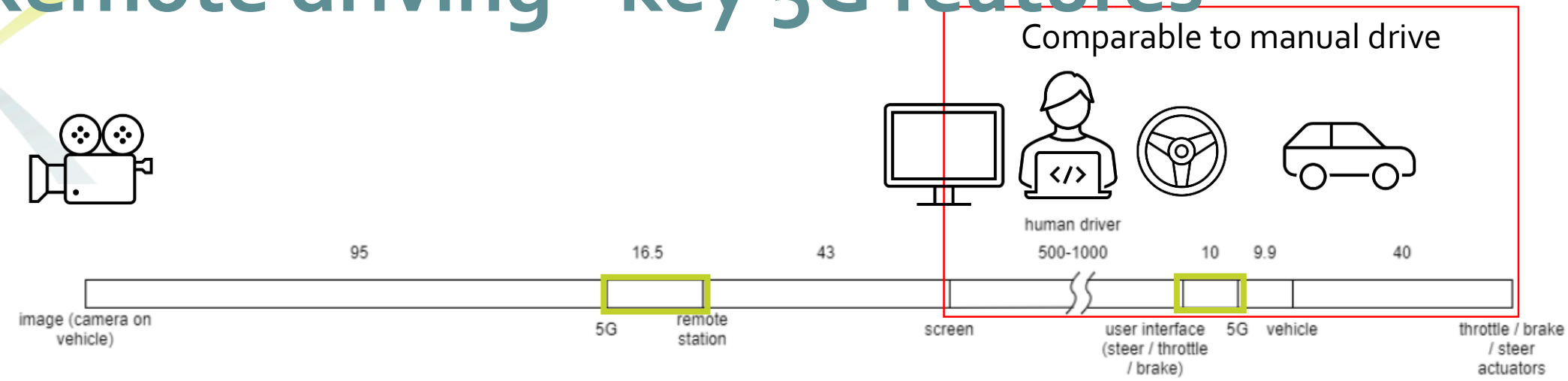
Remote driving - key 5G features



Video stream ≈ 25Mbps, latency req 10ms

~~s-nssai 1.000002~~

Driving Control stream ≈ 5kbps, latency req 10ms

~~s-nssai 2.000002~~

Traffic Control stream ≈ 0.1kbps

~~s-nssai 2.000002~~

Local driving station

Gateway (RD Controller)

- Slices:
  - eMMB slice to guarantee bandwidth video steam
  - URLLC slice to **guarantee low latency and availability** control signals vehicle

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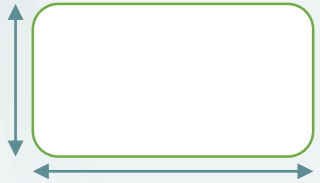
RD-Methodology

Both virtual as well as real testing

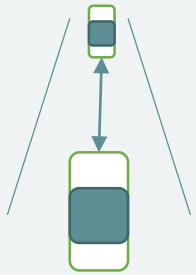
Application level KPI's

to validate network requirements

1



relate screen resolution and video quality to viewing distance



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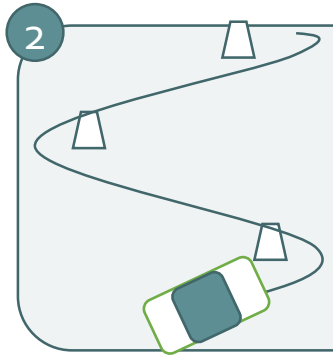
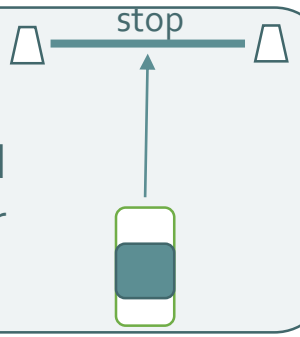


relate communication latency to steering and stopping position error



Network level KPI's

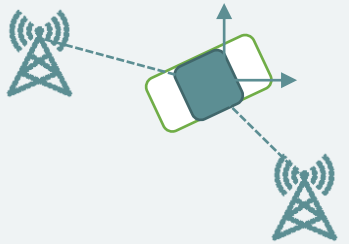
to test network functionalities

3

relate slicing technology to latency and reliability

4

improve positioning using beam angles



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RD-Trials

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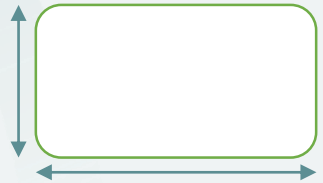

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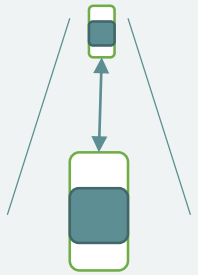

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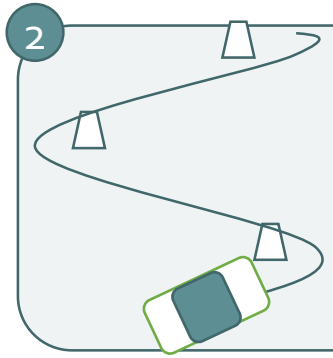

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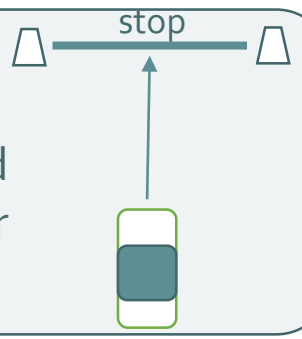

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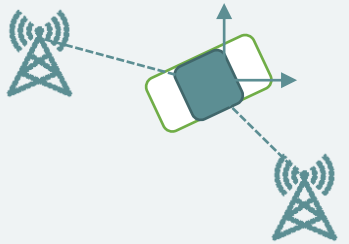

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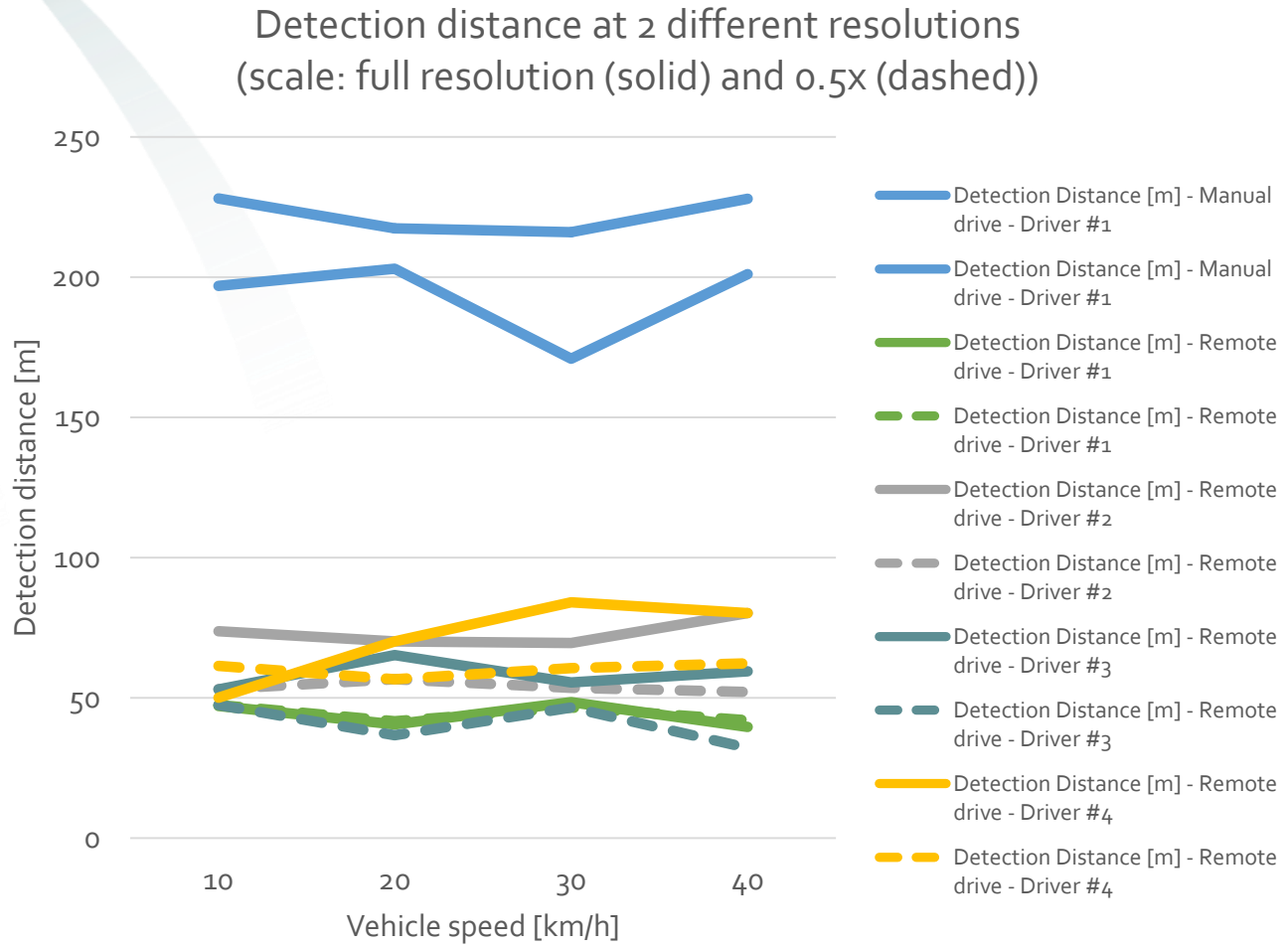
Human perception - distance detection test – results for remote driving



- Manual vs. remote: ~125 [m] difference -> 70% less
- 0.5x resolution: detection 11 [m] less then 1x -> 76% less (wrt. manual)

→ Remote driving requires high bandwidth, high resolution video (not yet taking into account other sensory information: tactile, audible).

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RD-Trials

Both virtual as well as real testing

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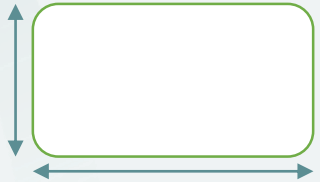

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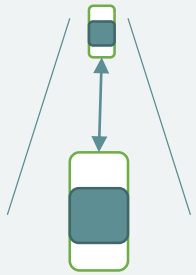

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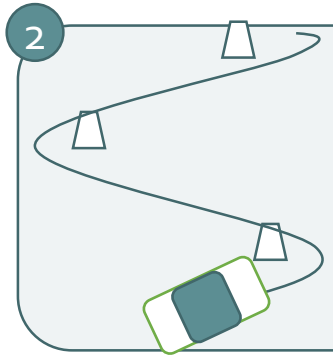

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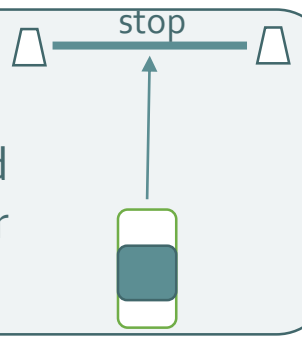

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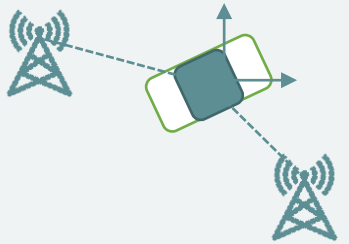

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Straight line braking – virtual setup results

Delay $\mu = 0[ms]$, $\sigma = 0[ms]$

[RemoteDriving1_Virtual_StraightLineBrake_0mu-0sigma]

Delay $\mu = 20[ms]$, $\sigma = 0[ms]$

[RemoteDriving2_Virtual_StraightLineBrake_20mu-0sigma]

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Slalom – virtual setup results

Delay $\mu = 0[ms]$, $\sigma = 0[ms]$

RemoteDriving3_Virtual_Slalom_0mu-0sigma

Delay $\mu = 20[ms]$, $\sigma = 5[ms]$

RemoteDriving4_Virtual_Slalom_20mu-5sigma

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[RemoteDriving5_NL_Trials_RemoteDriving_Vaarle]

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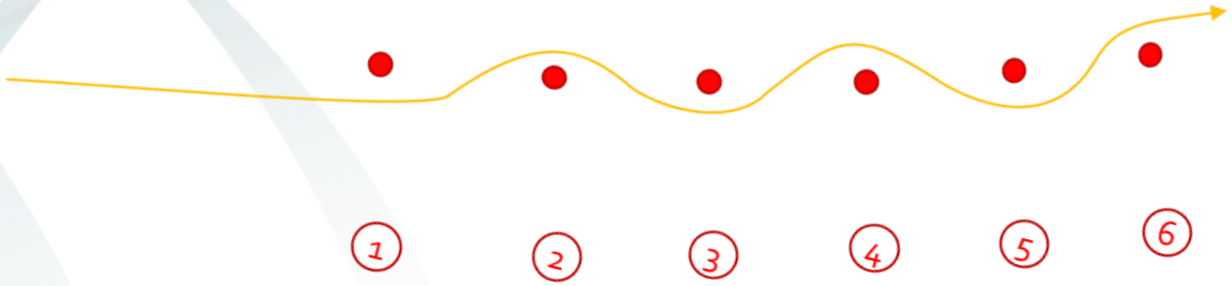
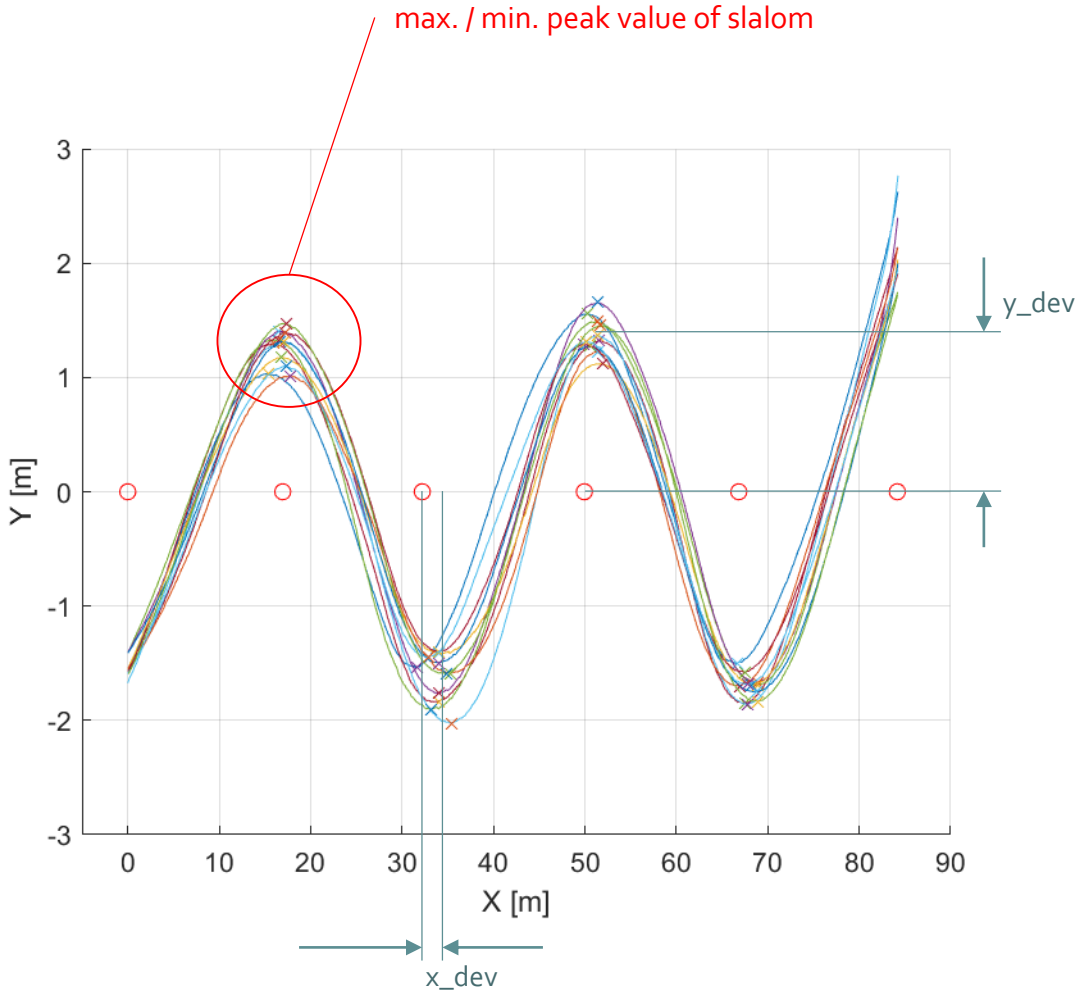
Remote driving
Dutch test site

SIEMENS kpn roboauto TU/e AIM AI IN MOTION OBIX

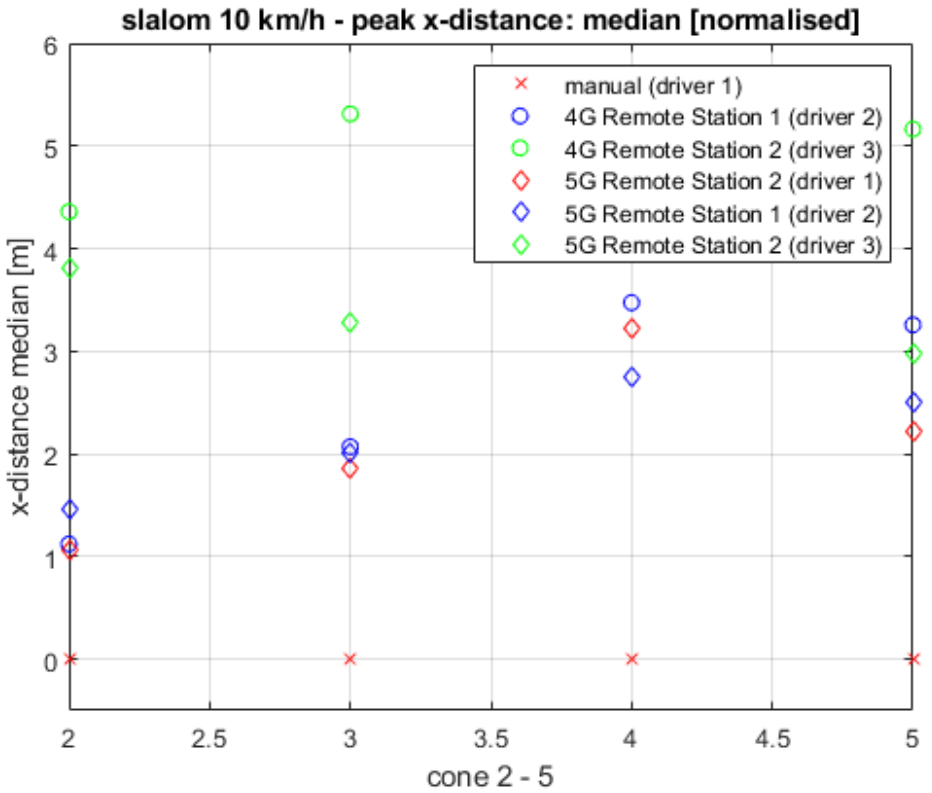
RD-Evaluation metrics

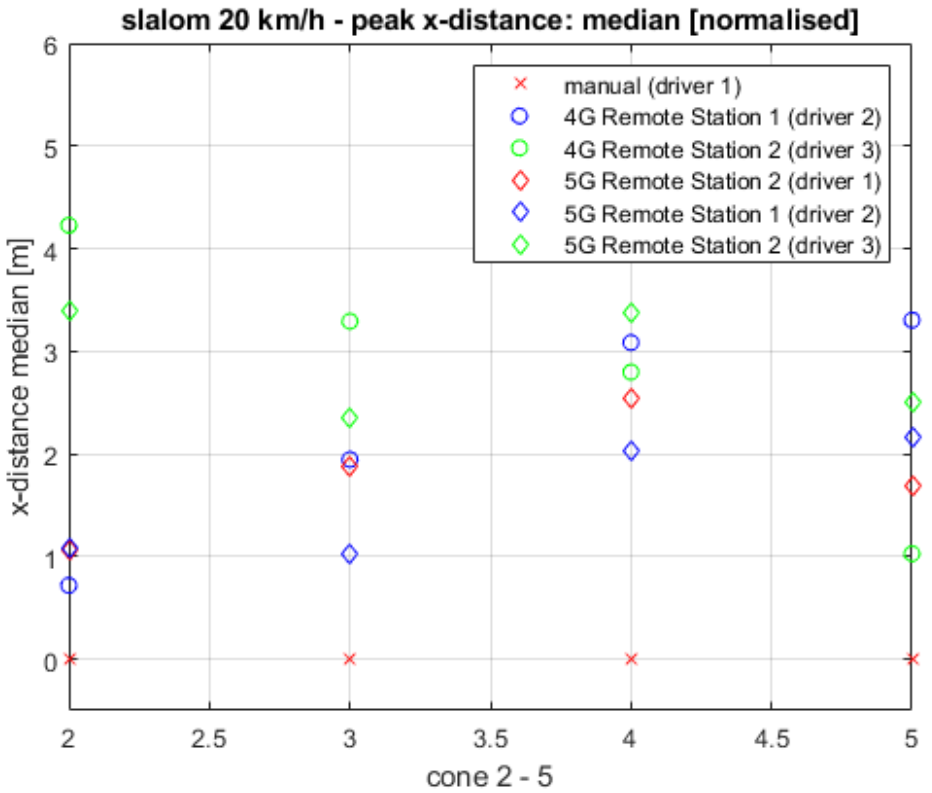




- x_dev:
  - Mean values: deviation from cone position in x-direction -> positive: possible influence of delay, low resolution screen (remote station), weather influences
  - Variance: high levels: less consistent driving, caused by remote driving difficulty wrt. manual

RD-Positioning results – 10/20 km/h





- Remote driving vs manual drive: standard 1 - 5 [m] position error
- No clear difference between 4G and 5G implementation

ref.: den Ouden et al. – "Design and Evaluation of Remote Driving Architecture on 4G and 5G Mobile Networks" - https://doi.org/10.3389/ffutr.2021.801567

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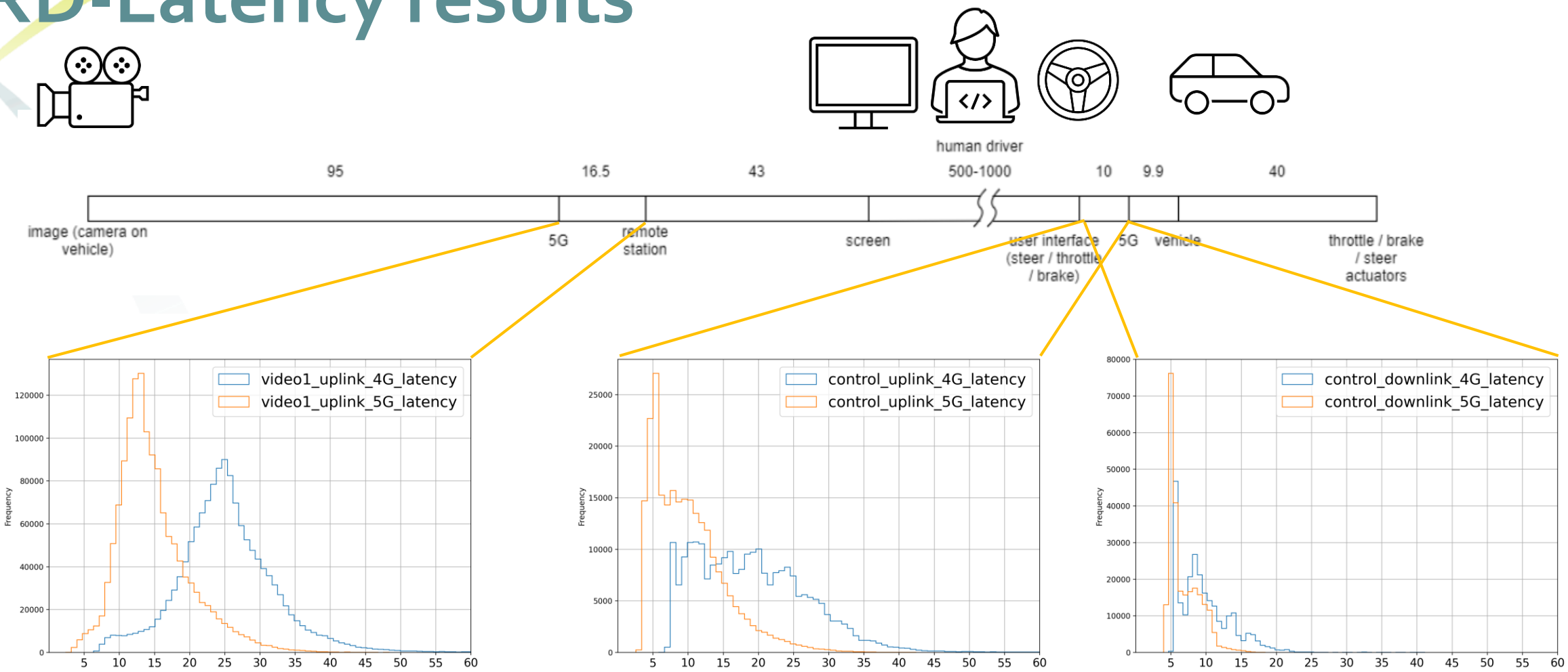
RD-Latency results



- Communication delay only small part of entire pipeline (~10 – 17 [ms] of total ~220 [ms] (without human in the loop))
- However, increase in communication delay and variations have direct impact on performance and safety

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RD-Trials

Application level KPI's
to validate network requirements

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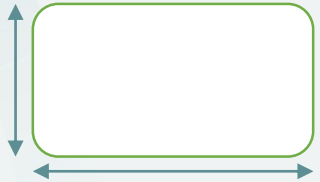

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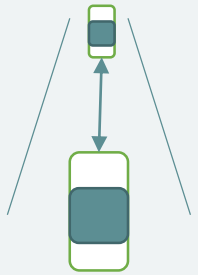

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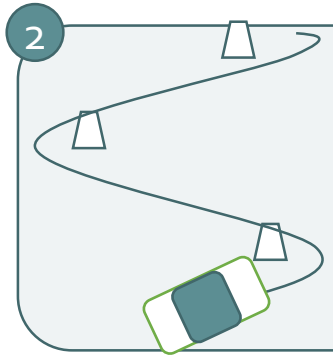

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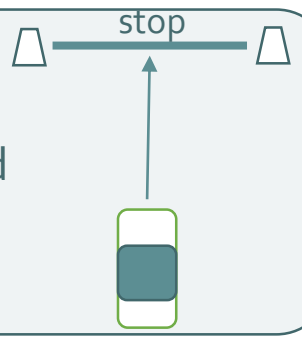

Network level KPI's
to test network functionalities

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relate slicing technology to latency and reliability

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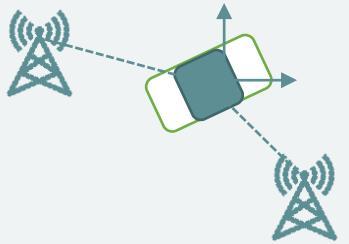
improve positioning using beam angles



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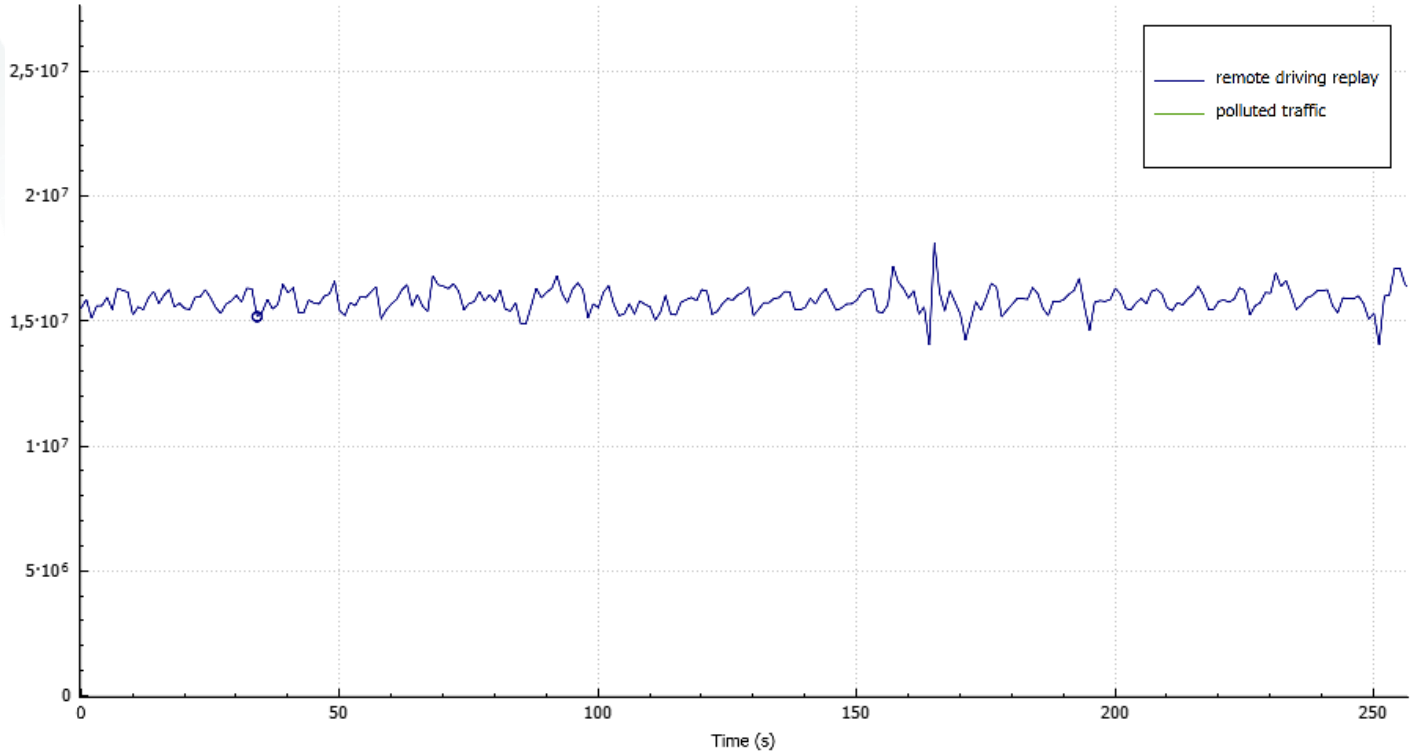
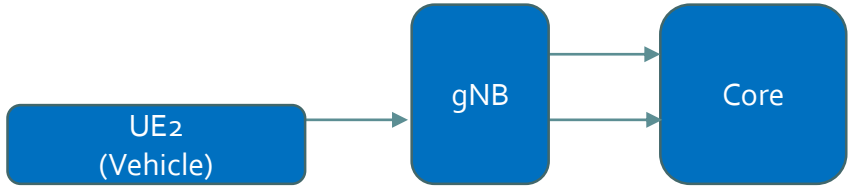
Slicing - 1.Single UE sending remote driving video stream (throughput)



- With no background 'polluted' traffic UE at TNO vehicle can send the remote driving data at the rate the remote driving client requires => ~>15 Mbit/s



Ref.: Ramon de Souza Schwartz & Remko Kruize (TNO)

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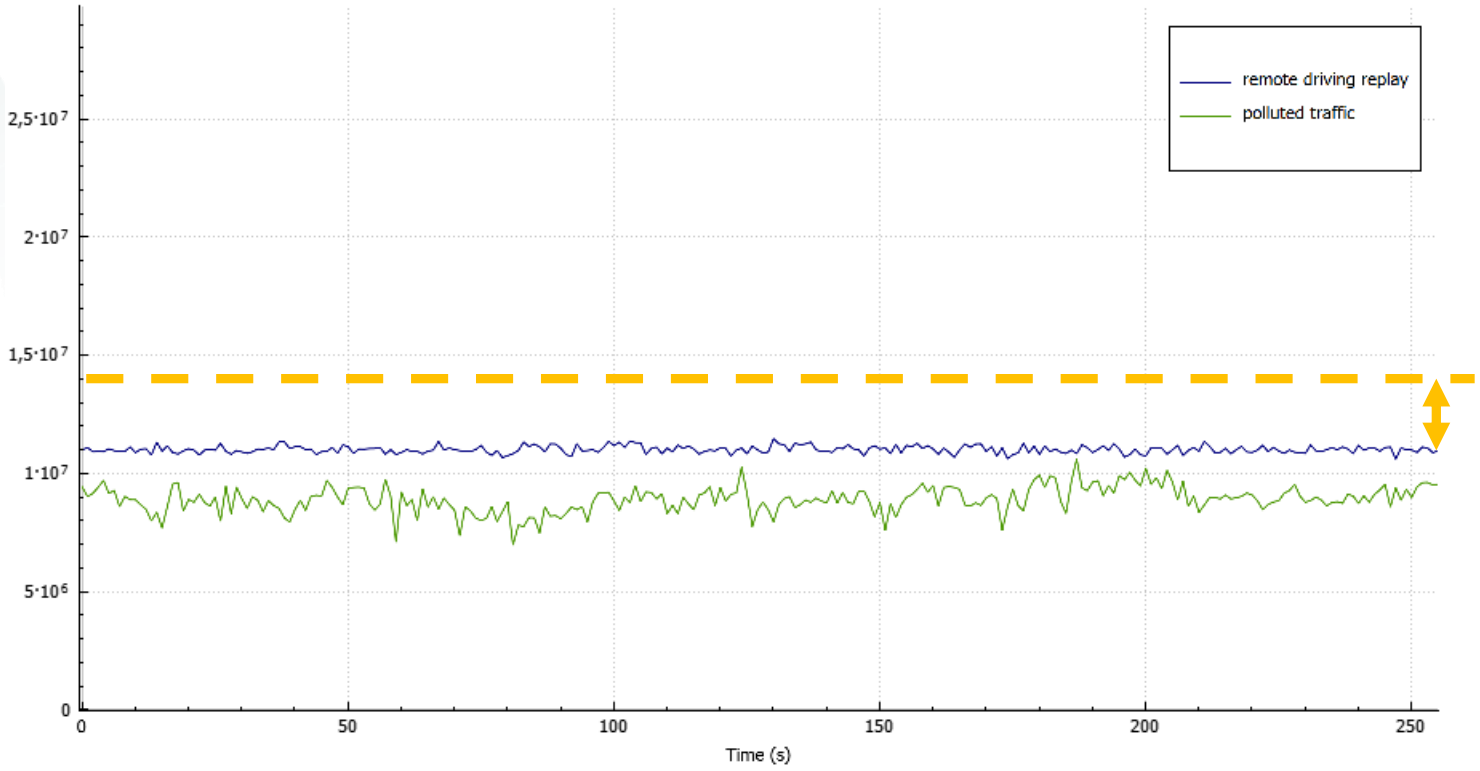
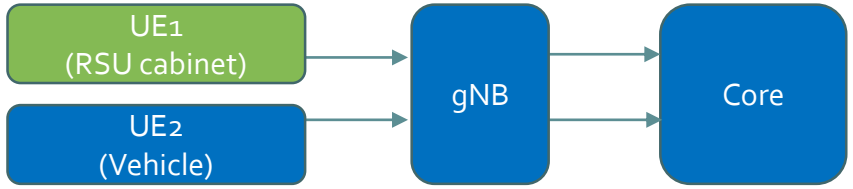
Slicing - 2.Both UEs connected on same slice ID (throughput)



- With background 'polluted' traffic, remote driving traffic is affected as it competes with the background traffic;
- Drop in performance: desired rate (>15 Mbit/s) vs. achieved rate (~11 Mbit/s)



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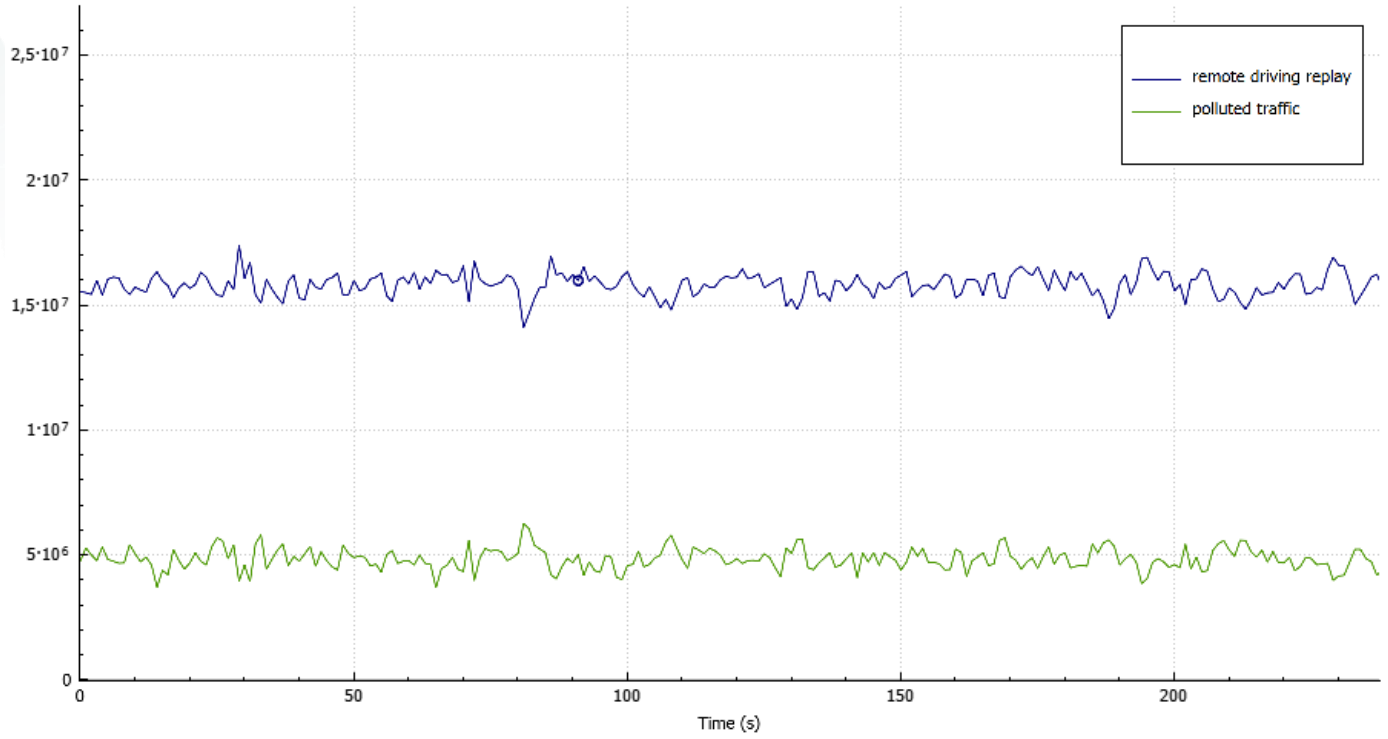
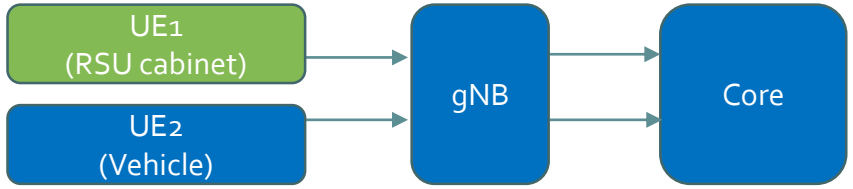
Slicing - 3.UEs connected on different slice IDs (throughput)



- When vehicle sends data on the highest priority slice, the required rate of >15 Mbit/s is achieved;
- Polluted traffic gets the remaining available bandwidth of about 5 Mbit/s



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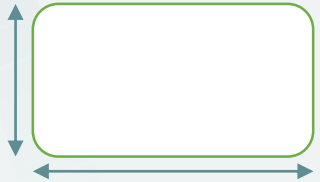

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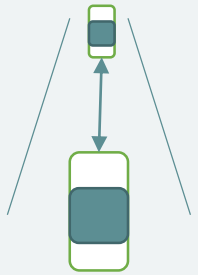

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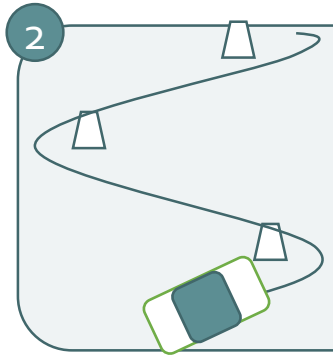

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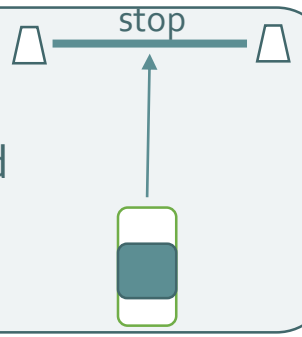

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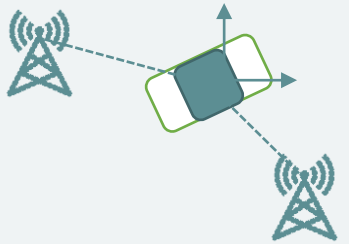

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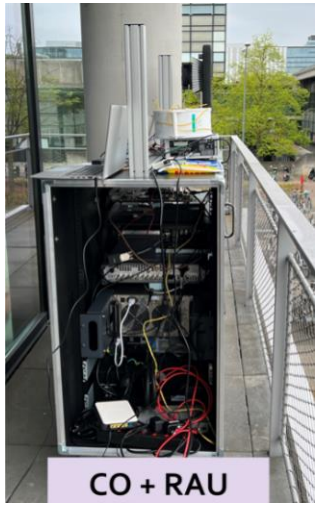
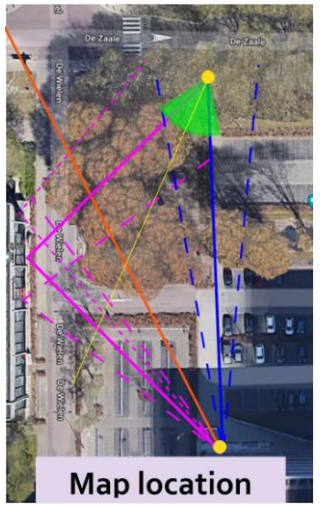
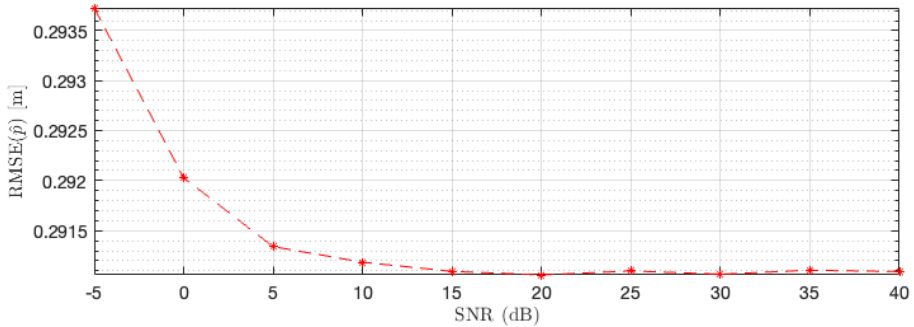
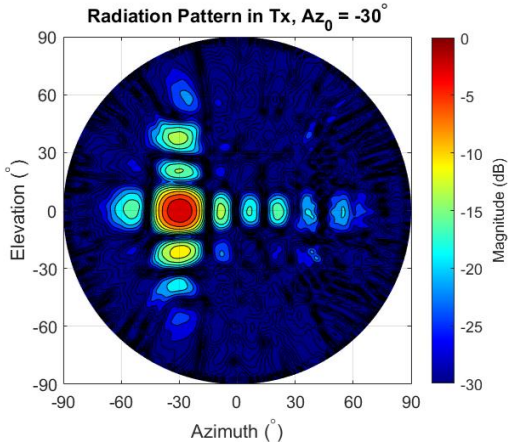
5G-Positioning using mmWave

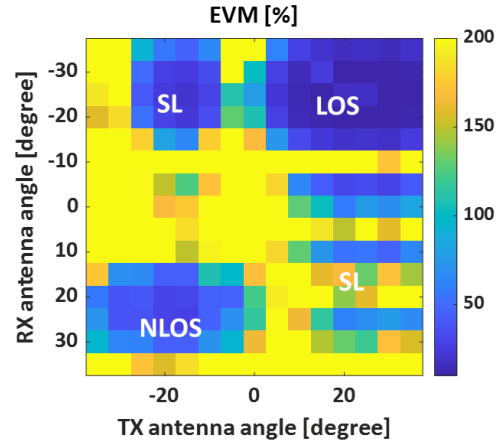
- Position accuracy (at 60 [m] distance) (based on simulations):
  - up to 0.3 [m] RMSE for LOS
  - up to 0.4-0.6 [m] RMSE for NLOS
- Future work: implement beamforming measurement data for improving localization











Ref.: Pavol Jancura, Elmine Meyer, Simon Rommel, Jos den Ouden

5GMOBIX