Extended sensors

The role of 5G in autonomous driving and intelligent transport systems

Peter-Paul Schackmann (TNO)

5GMOBIX

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Automation of vehicles

Automation in vehicles is increasing

- High levels of automation: See Tesla, Uber and Waymo, able to drive autonomous on (some) roads

But much more present already on the road

- The lower levels of automation in vehicles: ADAS (Advanced Driver Assistance Systems) functionality in vehicles like adaptive cruise control (ACC), collision avoidance break, lane departure warnings, Lane Change Assist, blind spot detection and automated parking.

But this does not always work flawless (1)

- Vehicles rely on their own build-in sensors (camera / radar / lidar), but these have limitations, so the "world map" of the vehicle will not be 100% accurate. The sensors
  - can be obstructed; they cannot look around the corner or through other vehicles
  - can make mistakes (wrong recognition of object/traffic sign)
  - can be hampered by weather or darkness
  - can be broken.

But this does not always work flawless (2)

- Vehicles do not always know the current traffic rules, their map information is mostly static. Dynamic maximum speeds, temporarily lane markings due to road works and traffic light status should also be dealt with
- Vehicles cannot (yet) predict what other road users intend to do as well as human drivers
- Vehicle do not always know in what exact lane they are driving

But this does not always work flawless (3)

- This leads to unpredictable behavior of a CCAM vehicle compared to regular vehicles, resulting in unsafe situations and traffic inefficiency
  - ACC+ brakes (or accelerates) due to unclear max speed traffic sign
  - Vehicle does not anticipate to approaching emergency vehicle
  - Vehicle breaks at roadworks warning due to unclear lane markings..
  - Vehicle does not allow other vehicle to merge, or cannot merge itself ("merging in busy traffic requires human anticipation")
  - Vehicle gets into an accident

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Mindset of vehicle manufacturers has changed

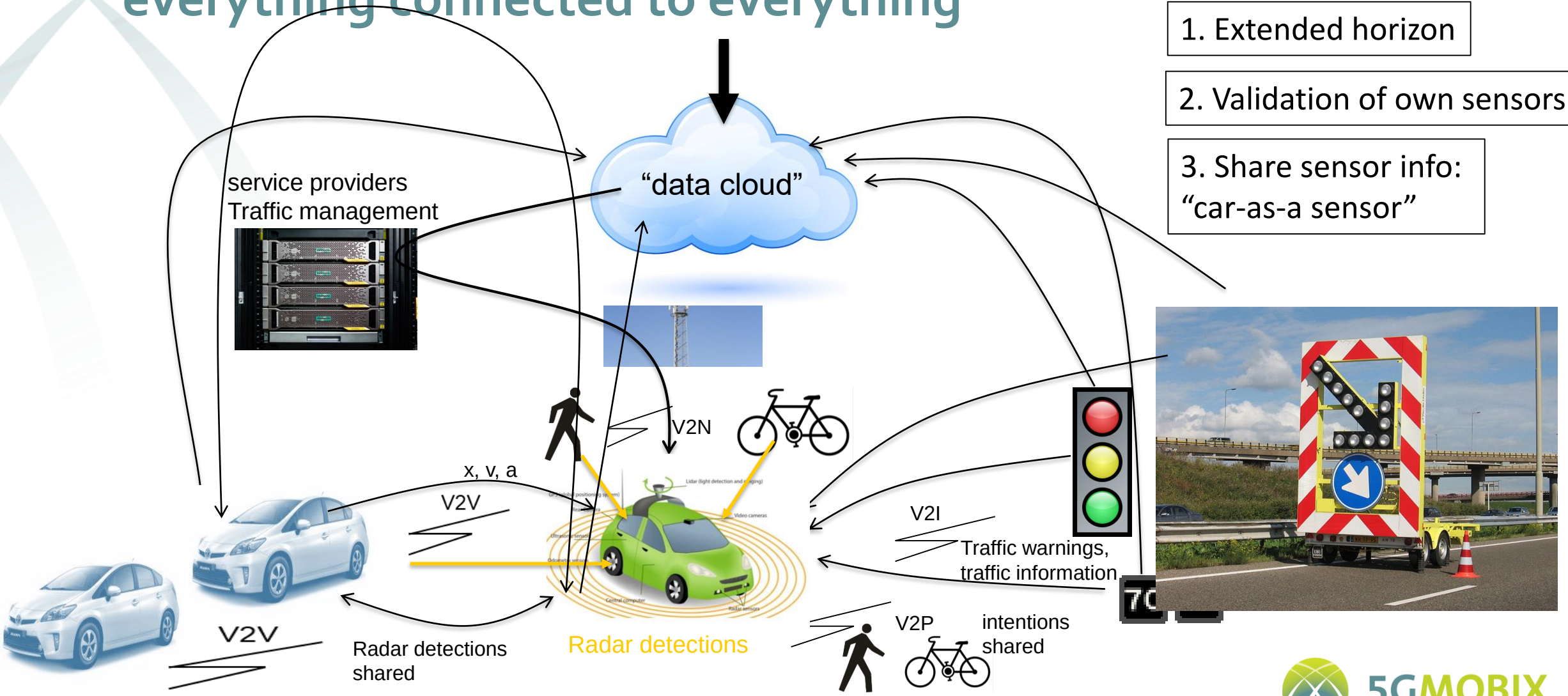
In recent years vehicle manufacturers have acknowledged that the approach of autonomous vehicles, only depending on their own sensors, has limitations.

- Due to the limitations of sensors explained and shown before. Not only for safety and efficiency an issue, also for comfort (important reason for ADAS) the explained effects are not ideal
- Also positioning: GPS is very usable for many applications, but for exact positioning, necessary for automated driving, this is not (always) good enough.
- Costs: different sensors (camera, lidar, radar) have pros and cons, but to combine them all comes with a cost. Do we need them all? Is it realistic to assume it will be economically feasible that these vehicles will be equipped with all?
- Last but not least: Upcoming possibilities of connectivity and data sharing present alternatives which have been recognized

Connectivity as additional sensor

"everything connected to everything"

1. Extended horizon
2. Validation of own sensors
3. Share sensor info: "car-as-a sensor"



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Role of use cases in 5G-MOBIX

- Potential of connectivity, among which 5G, is great, but what exact functionality is required? What can be provided by 5G? What is still (partly) missing?
- Requirements of use case
  - Sufficient bandwidth (up & down) & maximum E2E latency
  - It should still be working in operational setting, with other users and services in same network
  - It should still be working in a multi-operator environment
  - It should be working cross-border
- Meaning
  - Guarantees for the connectivity are necessary (to guarantee min bandwidth and max latency), taken other users, services and multiple operators into account

  And, taken cross-border in mind,
  - (Seamless) roaming, switching from one operator/country to another

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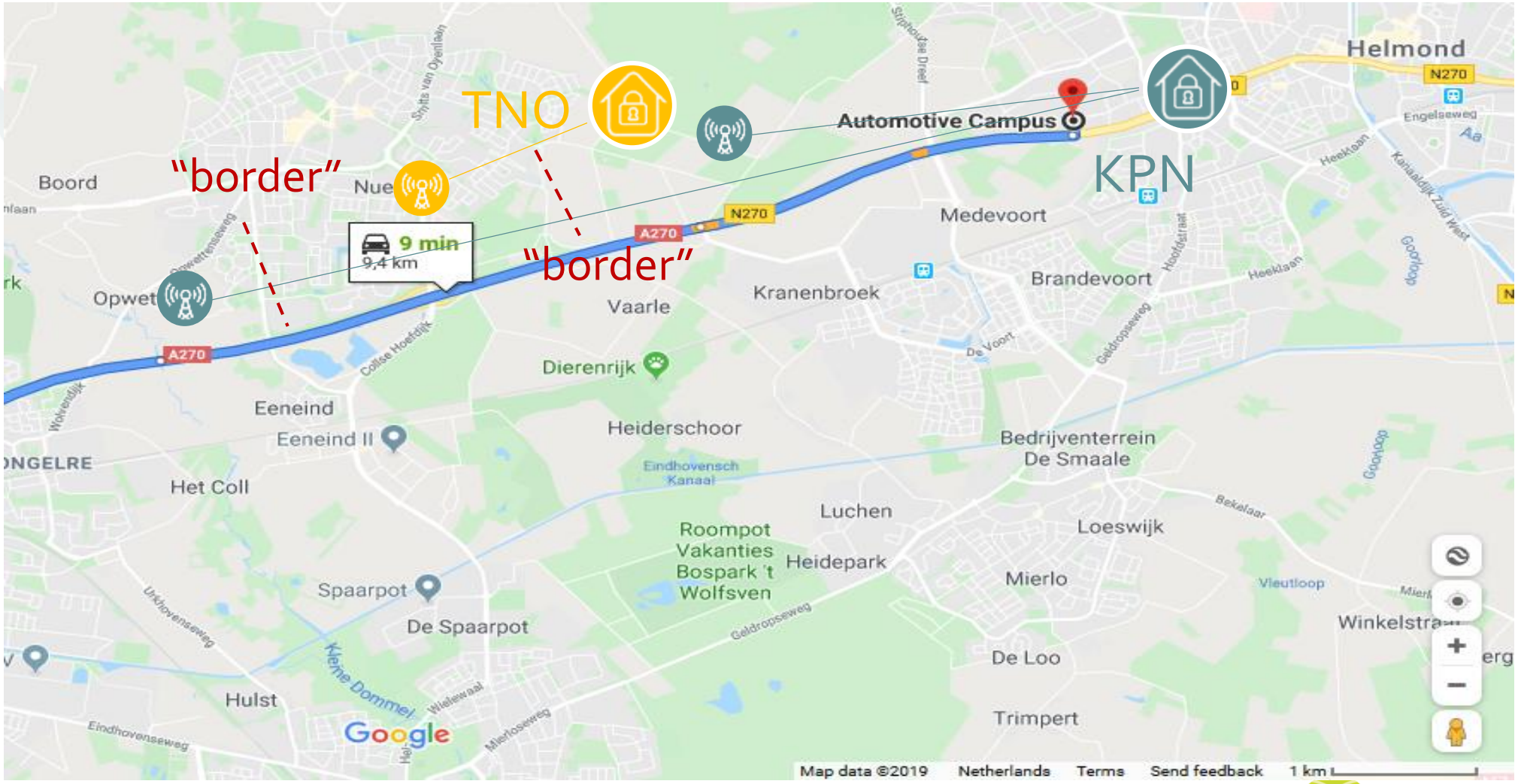
Eindhoven – Helmond test site



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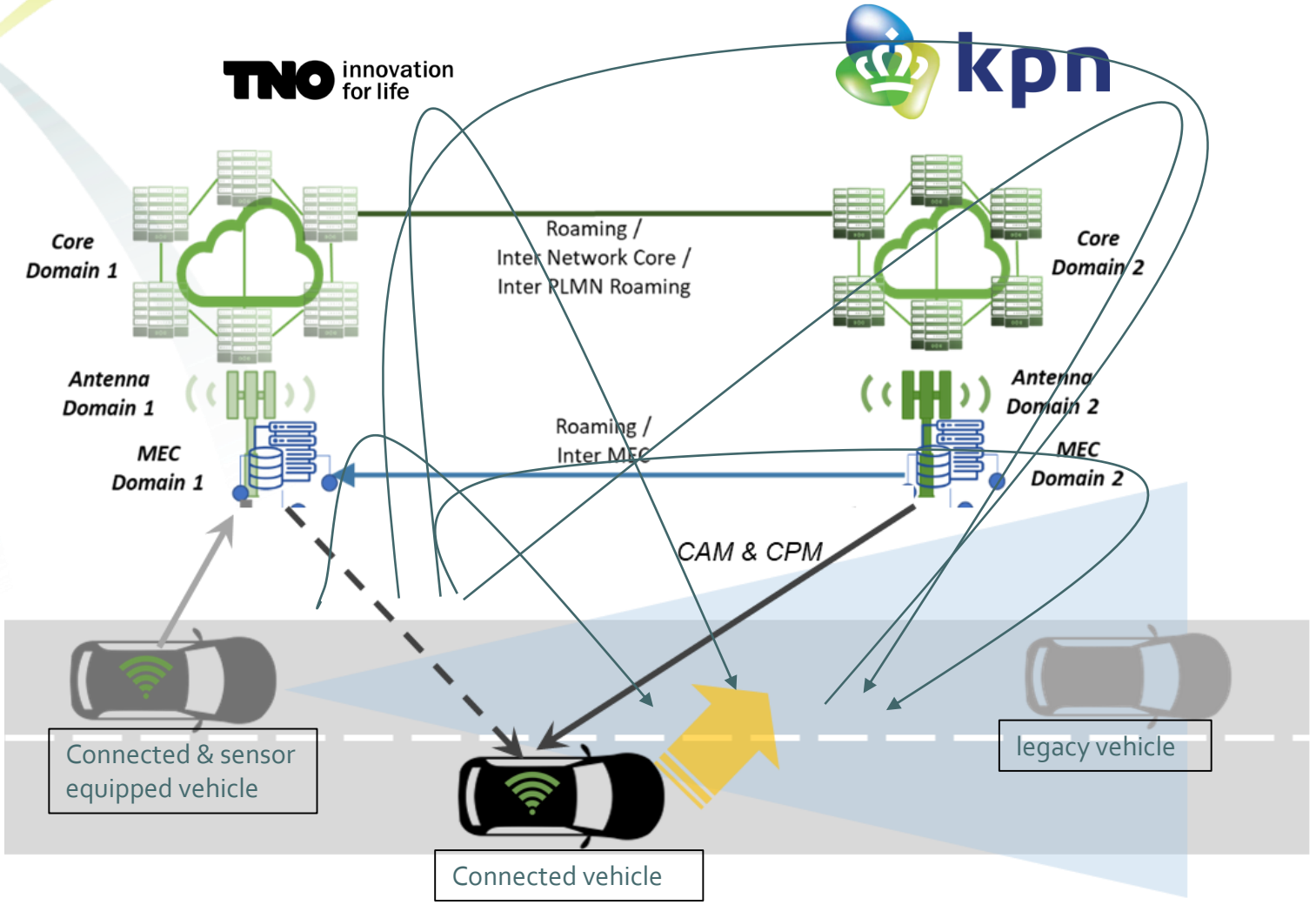
Extended sensors test scenarios



1. TNO LTE
2. KPN 5G NSA
3. TNO SA core
4. TNO SA edge
5. TNO SA edge + slicing
6. **TNO SA edge – KPN SA edge + slicing**
7. TNO SA –KPN SA basic roaming
8. TNO SA –KPN SA optimized roaming
9. TNO SA – KPN SA Release & Redirect (multiple steps)
10. TNO SA – KPN SA slice roaming

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TNO SA edge – KPN SA edge + slicing

[TNO Extended_Sensors]

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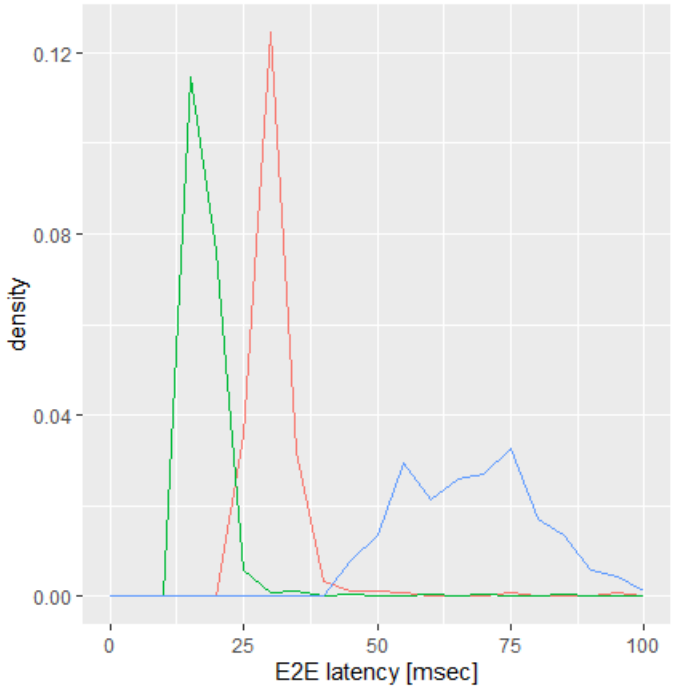
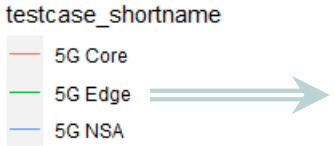
Extended sensors results: Latency

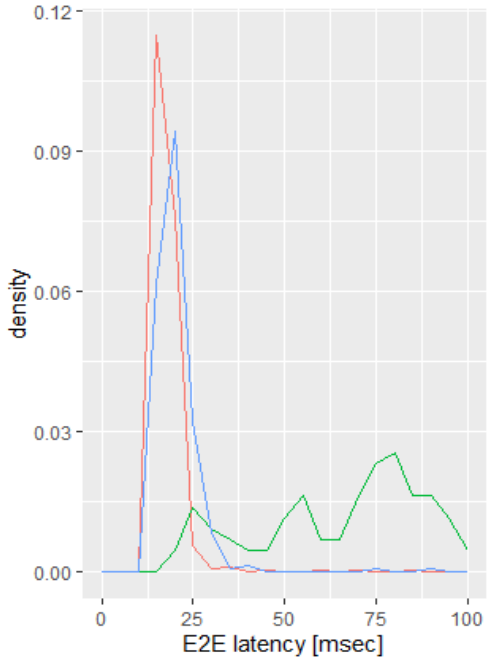
Without Slicing, Without background traffic

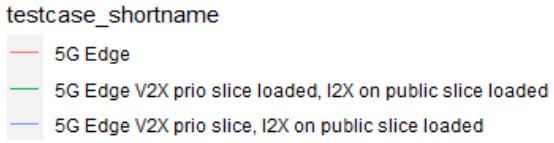




- Lowest latency with MEC (Edge) routing *(green line)*
- *Target for E2E latency = 50 msec*

5GSA – Edge routing - with Slicing and background traffic





- Background traffic on V2X slice strongly deteriorates performance *(green line)*
- Background traffic on other slice much less effect on CPM latency *(blue line)*

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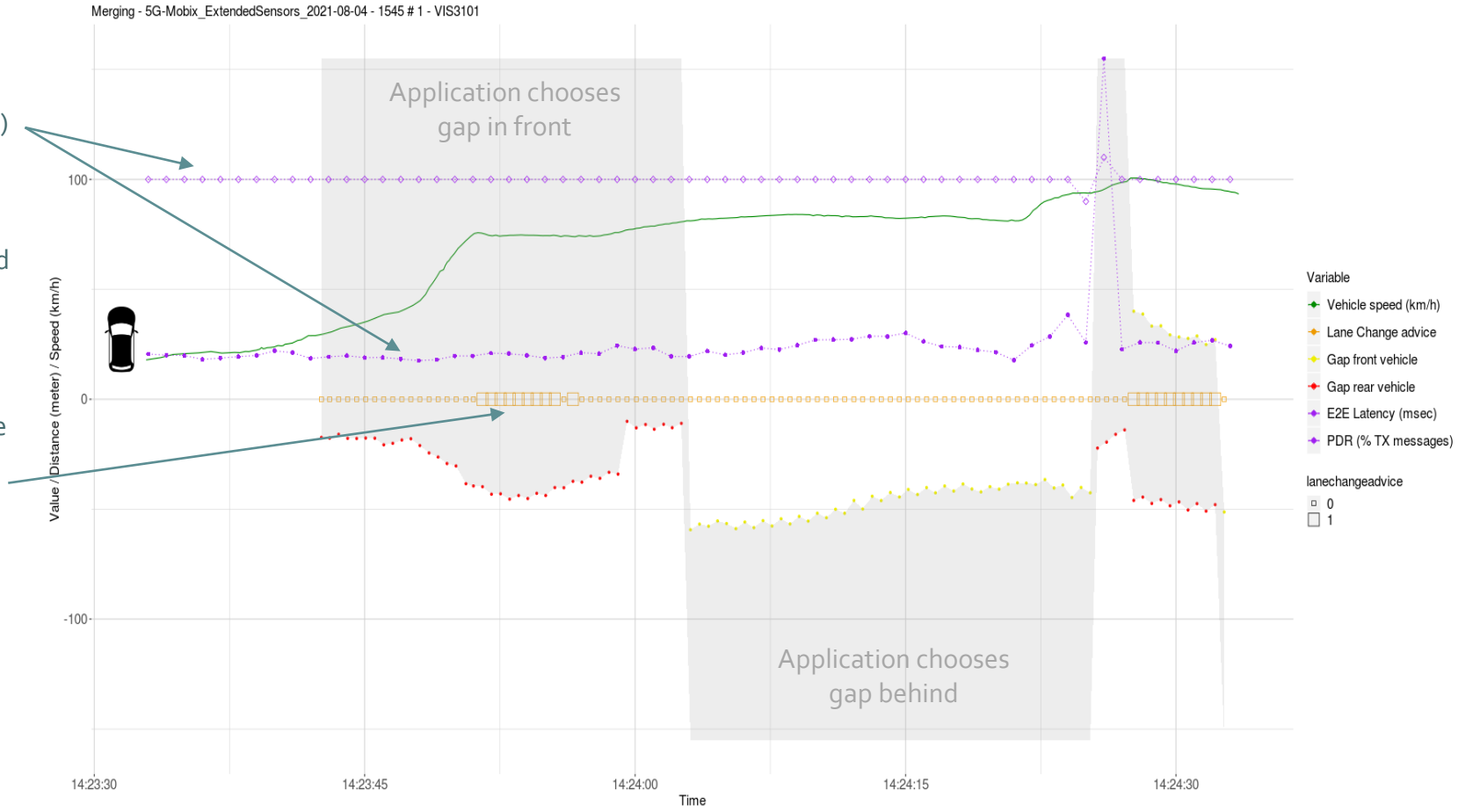
Extended sensors → Lane Change advice

5G-SA with Edge routing and Priority Slice

- Reliable reception of CPM and CAM
  - Steady latency and PDR (purple lines)
- Application continuously receives information to assess gaps
  - Gray zones ahead, adjacent or behind the host vehicle
- Lane change advice is not interrupted during test run
  - Larger orange boxes indicate positive advice for a lane change opportunity
  - Stable performance of lane change advice services



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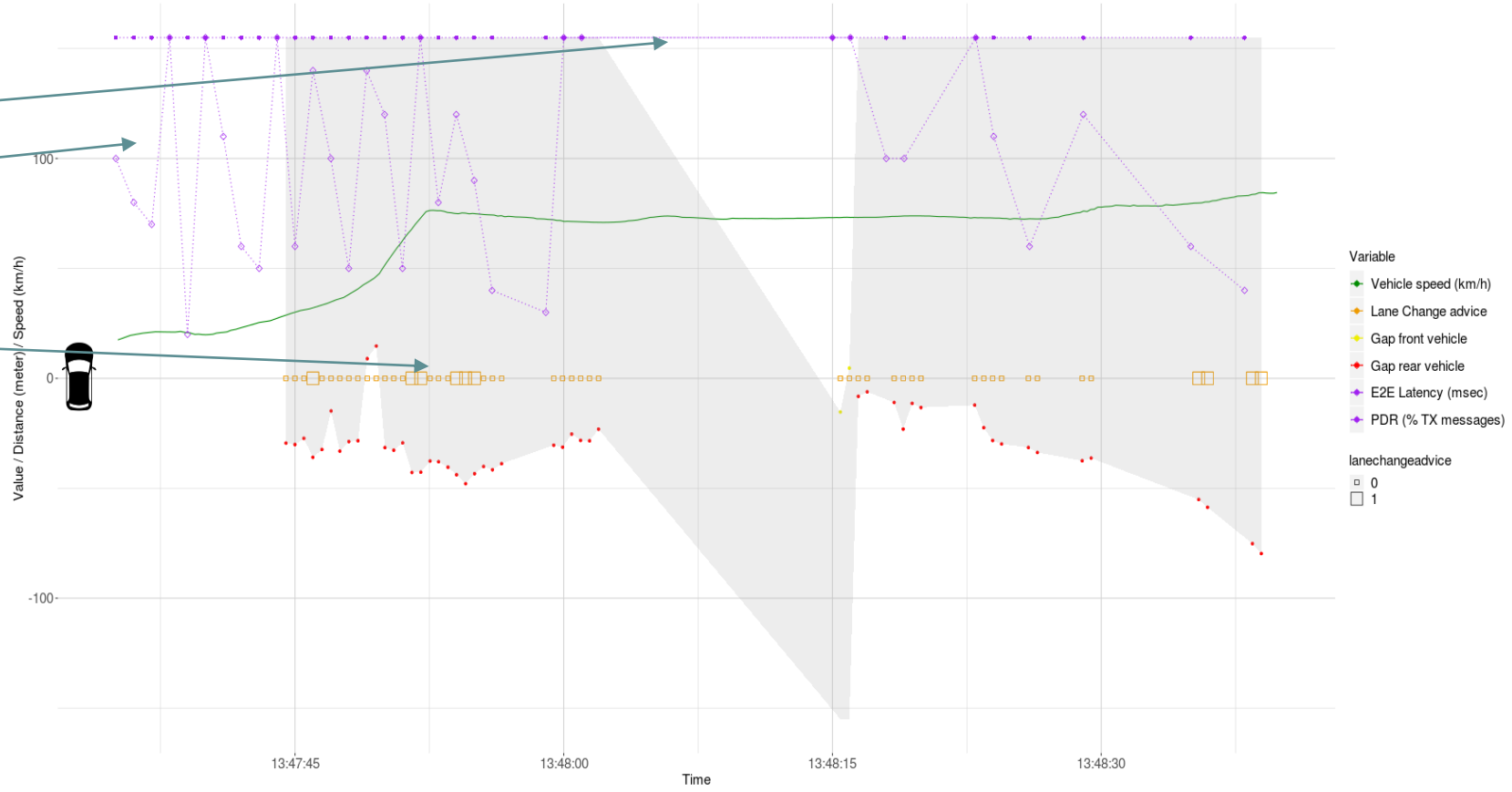
Extended sensors → Lane Change advice

5GSA with Edge routing and background traffic on V2X slice

- Unreliable reception of CPM
  - Messages received in later time windows
    - PDR > 100%
  - Large delays (>> 100 msec)
- Application frequently interrupted
  - Advice interruptions
  - Large periods (> 10 sec) without any advice



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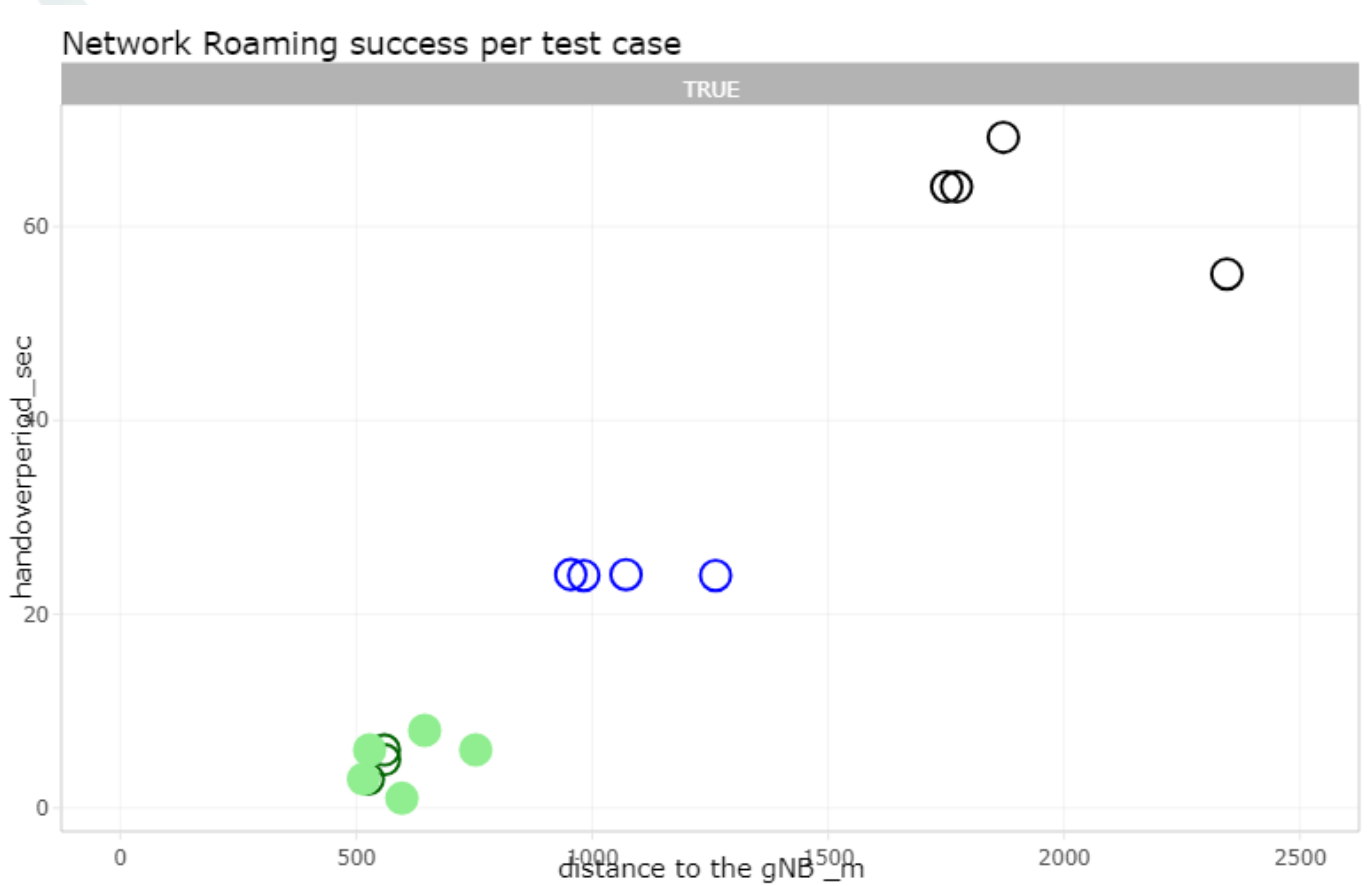
5G SA Roaming results at Motorway speeds



Basic roaming interruption time

Semi-optimised roaming interruption time

Optimised roaming interruption time

Results for Release & redirect have not been obtained. The results for the optimised roaming interruption time are a first indication for the "redirect"part, and it is expected that the "release" part will lower the interruption time significantly further.

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Extended Sensors in NL-TS results

- 5G-SA reduces latency (compared to 5G-NSA)
- 5G-SA Edge routing reduces latency (compared to Core routing)
- Slicing functionality will be essential to harvest the potential of 5G for CCAM in operational networks
- Test cases have been executed with network configurations up to basic and optimized 5G SA roaming between TNO and KPN network. Also 5G SA slice roaming has successfully been executed
- Next steps (for extended sensors) , out-of-scope for 5G-MOBIX:
  - More improvement possibilities for roaming (in terms of interruption time, up to seamless roaming) have been identified and are described. Necessary functionality is not yet available.