5G HEART

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TELE-OPERATION VEHICLE SUPPORT IN 5G: CHALLENGES & FIRST LESSONS FROM 5G-HEART

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5G HEART Webinar #2

04 December 2020

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1. Tele-operation vehicle support

5G-HEART Use-case Description (I)

Traveling vehicle bearing

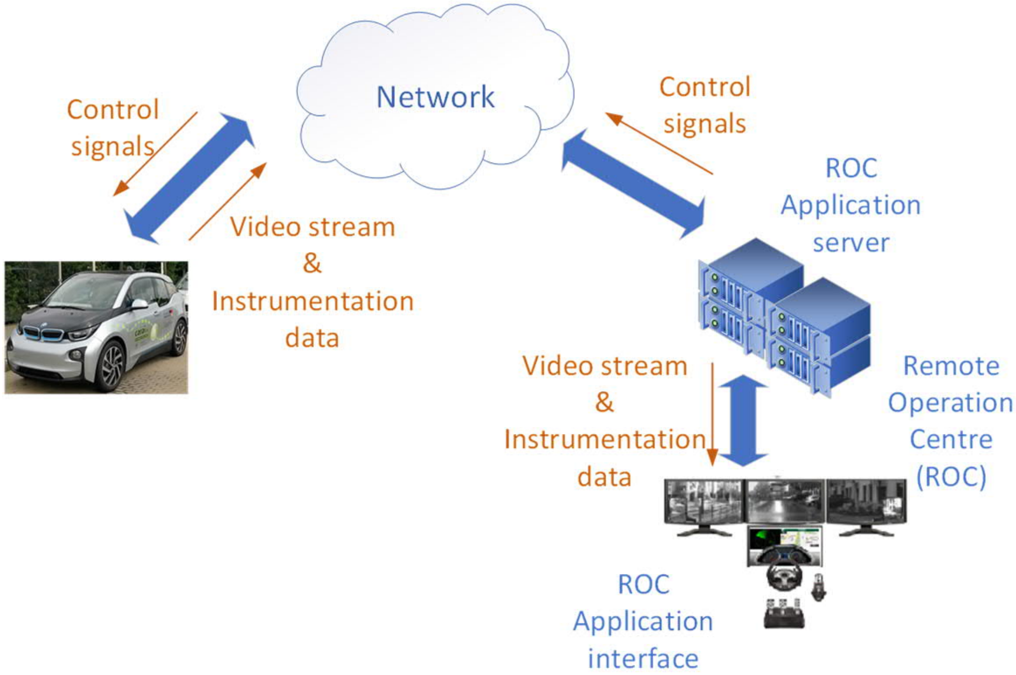
- HD video cameras (Front, Right-Left, Rear views)
- Sensors (instrumentation data on driving conditions)

Remote human operator can monitor the vehicle and perform maneuvers, if required

- Control direction and speed of vehicle

Tele-operation may be considered throughout the vehicle journey, or on-demand after the request of the driver for remote assistance.

- In 5G-HEART tele-operation will take place on-demand



5G-HEART Use-case Description (II)

Instrumentation data & video streams communicated to the remote operation centre (ROC) for the human operator, accessed through the core or at the edge

- In the considered scenario the ROC will be at the edge of the 5G network

Instrumentation data + video feed ⇒ sufficient ambient information

- No need for sophisticated/expensive AI computing infrastructure

The outcomes of this scenario, can be ideally combined with the Human Tachograph scenario (following this presentation)

2. Motivation

Motivation

- Remote driving: vehicle(s) controlled remotely by
  - human operator
  - Cloud computing software
- Remote driving with human operators can be realised using less infrastructure
  - provided ambient information properly transferred and visualized
- TeSo capability, enables a single human operator to remotely monitor potentially multiple vehicles and control one of them on-demand for a short period of time
  - Business potential
- Multi-fold benefit of realizing Tele-operation Support (TeSo) for several involved stakeholders
  - automotive industries, Autonomous Vehicle technology suppliers (lower technical level)
  - certified human operators, companies offering TeSo-as-a-Service
  - network operators/providers enabling such scenarios
  - public administration bodies involved in the regulation domain (top level)
- Allowing tele-operated driving support can be a first cost-feasible step for realizing purely automated driving

Emerging Challenges

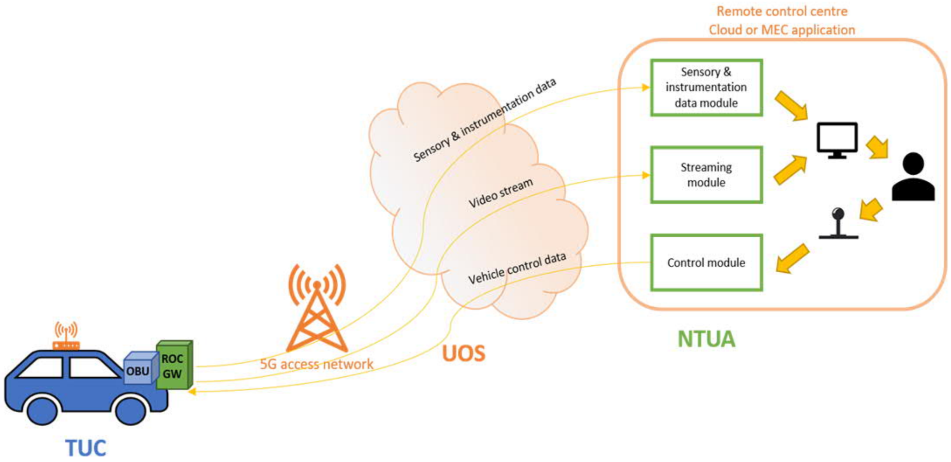
- Remote driving not a new problem
  - Various attempts in the near past
- Most scenarios based on 4G and RSU infrastructure
  - Demonstrated the feasibility
  - But solutions suffer from some shortcomings:
    - QoE/QoS, reliability, wireless environment, density, etc.
    - 5G can potentially address such issues (e.g. via slicing)
- 5G-HEART will perform trials to investigate the pain points
  - Independently for this scenario
  - In relation to concurrent execution of other scenarios

3. Proposed solution

High-level System Architecture

Three main endpoints:

1. Remote Operation Center (ROC): interfaces with the human operator, responsible for the visualization/presentation of the vehicle's state and remote control
2. ROC Gateway (ROC-GW): serves as an intermediate point for the communication between the vehicle and the ROC
3. OBU: interfaces with the vehicle's sensors and actuators

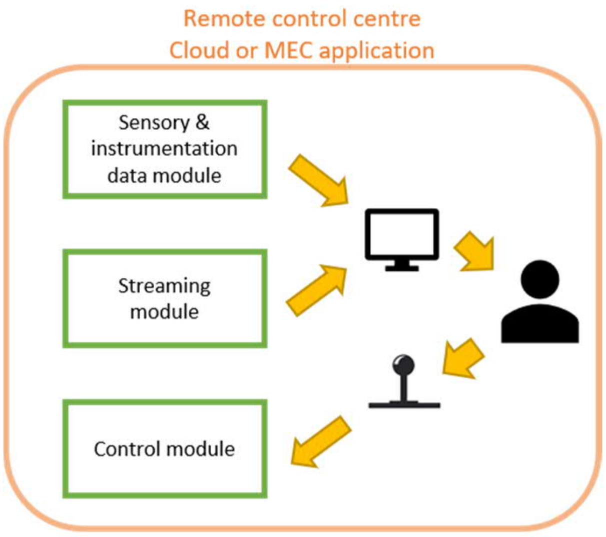


In-between: 5G infrastructure to serve data transfers

Software Component Organization

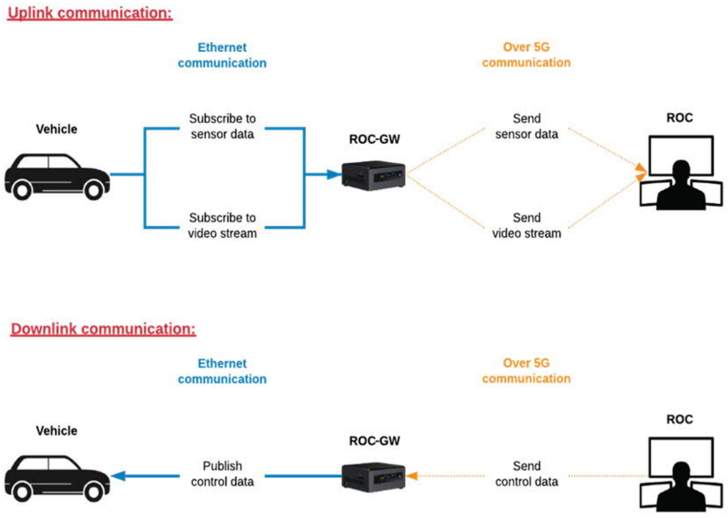
Based on functionality, both ROC-GW and ROC applications consist of the following logical components:

- Video streaming module: 4 video streams (front, back, left and right), from vehicle to ROC
  - ROC-GW collects and transmits the video streams
  - ROC application receives and displays video streams
- Sensor and Instrumentation module: vehicle's state (velocity), automation state (current throttle/brake percentage and steering wheel angle) and geospatial position, from vehicle to ROC
  - ROC-GW collects and transmits the video streams
  - ROC application receives and displays video streams
- Remote control module: desired throttle percentage, brake percentage, and steering wheel angle
  - Commands transmitted from ROC to the vehicle



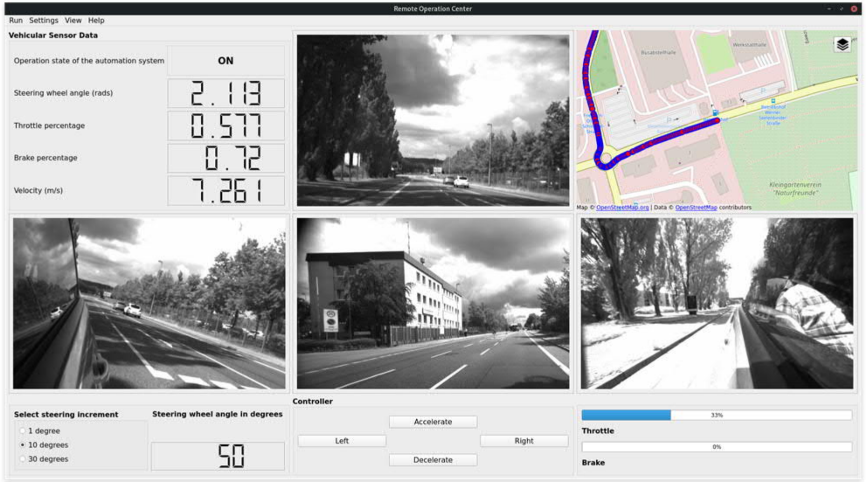
Individual Component Development

- Based on a publisher-subscribe model for data collection at the vehicle
- 5G network for in-air transmission
- All modules have been developed and integrated

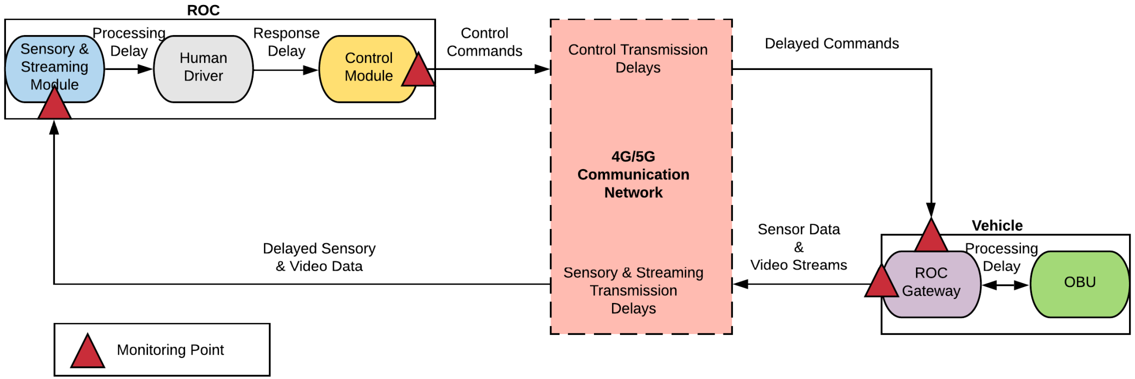


Remote Operation Center GUI Application

- Developed using the Qt5/QML framework
- Right upper right corner: a map depicting the vehicle's trace, constructed based on the received GPS coordinates
- Left upper corner: telemetry information regarding the automation state and the vehicle state
- Four video streams from the vehicle-mounted cameras
- Bottom row: control-related components for accepting and visualizing user input



TeSo Closed Control-loop Delay Analysis



- The considered closed control-loop of the use-case
  - Interested in end-to-end delay and other KPIs
- Several monitoring points
  - Allow segregating delay components
- Some components are of greater significance
  - Over-the-air delay: it is something the network designer can control
- Some components are pertinent to the development and human intervention
  - E.g. human response time, etc.

4. Key take-aways

Lessons Learned to Date

- Synchronization of 4 streams is a tough problem
  - But could be solved at a lower level (i.e., system not network)
- Time-stamping for accurate measurements is complex and requires significant attention
  - GPS-enabled timestamping possibly needed
- Encoding and compression needed for the streaming capability
  - To reduce as much as possible the cumulative bandwidth required
- Careful treatment of e2e delay components needed
  - Some components will be minimized in a real implementation (single-board solution)
  - Some components depend on human factor in the loop
  - Careful treatment of network-dependent components
- Significant issue: performing trials at high-speed safely and lawfully

5. Future steps

Further Developments & Actions

- Communication latency scenario
  - Uplink, downlink, end-to-end
- Service latency tests
  - Sensor data/video streaming responsiveness, haptic behavior
- Reliability testing
- Comparison with 4G case
- QoE assessment by remote operator
- Cloud-based scenario: ROC residing at NTUA
- Business evolution
  - Key Exploitable Results (KER), Market analysis/target group
  - Business model – business plan

THANK YOU FOR YOUR ATTENTION

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This project received funding from the European Union's Horizon2020 research and innovation programme under grant agreement No 857034