5G Ride
Control Tower

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1. Summary

The 5G Ride project has continued the development and tests to enable the implementation of self-driving vehicles in public transport.

The focus during this year has been to create a safe and secure journey. That has been developed through increased communication between the control tower and self-driving vehicle where the control tower has been given a greater possibility to verify more variables in the vehicle. The control tower also receives information about passengers in need of emergency help since AI (artificial intelligence) identifies sudden illness among other things.

The control tower's function to remotely control the vehicle, if necessary, can now be done with even more precision and lower delay in the communication-chain. During the end of the project, stakeholders got the opportunity to drive the self-driving vehicle remotely by themselves.

2. Swedish Summary

5G Ride projektet har fortsatt utvecklingen för att möjliggöra implementeringen av självkörande fordon i kollektivtrafiken.

Fokus under detta år har varit att skapa en trygg och säker resa. Det har utvecklats genom ökad kommunikation mellan kontrolltornet och självkörande fordon där kontrolltornet har fått en större möjlighet att verifiera flera variabler i fordonet. Kontrolltornet får även information om passagerare i behov av akut hjälp eftersom AI (artificiell intelligens) bland annat identifierar plötslig sjukdom.

Kontrolltornets funktion, att vid behov fjärrstyra fordonet, kan nu göras med ännu mer precision och mindre fördröjning i kommunikationskedjan. Under projektets demo fick intressenter möjlighet att själva köra det självkörande fordonet på distans.

3. Background

The 5G Ride project started in 2020 with the main ambition to develop and run tests to improve the public transport and enable self-driving vehicles. During the first phase we connected the self-driving vehicle to the control tower via 5G.

This was the second phase for this consortium to continue the journey towards efficient and sustainable traffic to contribute to the Smart city with self-driving vehicles with security drivers outside the vehicle.

Problem to be solved

If the journey doesn't feel safe, people won't use autonomous vehicles, no matter how good the technology is.

Utility & Impact:
The project wanted to develop and test functions to enable to put the security driver outside the vehicle and ensure that the passenger will feel and be safe. This through research, development and tests of what is important for the passenger during the trip and what functions which make the journey safe.

4. Project set up

4.1 Purpose

The main ambition with 5G Ride, for this phase, was to further develop functions in the concept of "connected Traffic Tower" which include the chain of control tower, fleets, network and connected services, to enable safe and efficient autonomous fleets.

The goal with the project was also to build knowledge of what needs the automotive industry has of the future automotive- and mobility services. One part was to build knowledge of how to promote gender equal travel.

4.2 Objectives

The objective of the project was to make further developments together and run end-to-end tests with all technology (Control tower, Self-driving vehicle, 5G Network, Edge node and AI) needed to provide a safe ride with a self-driving vehicle, by conducting selected use cases.

- Further development and testing of the control tower digital checklist
- Further development and testing of Control tower assistance to the self-driving vehicle
- Further test of 5G network
- Knowledge of what is needed to promote a gender equal travel

4.3 Project period

February 2021 – November 2021

4.4 Partners

Kista Science City led the project by providing an experienced project manager and creating synergies with relevant stakeholders from the public sector, which is important in these types of collaboration and projects.

Keolis has been an important stakeholder in order to specify requirements for all processes to secure the need in public transport and to take another step towards a sustainable, attractive, and seamless trip for the passengers. In this project, with focus on a safe journey, Keolis has contributed research for gender equality. Together with Intel, who provided, in-kind, AI for improved safety for the passenger, Intel in this phase also developed a text to speech solution to be able to communicate with the passengers.

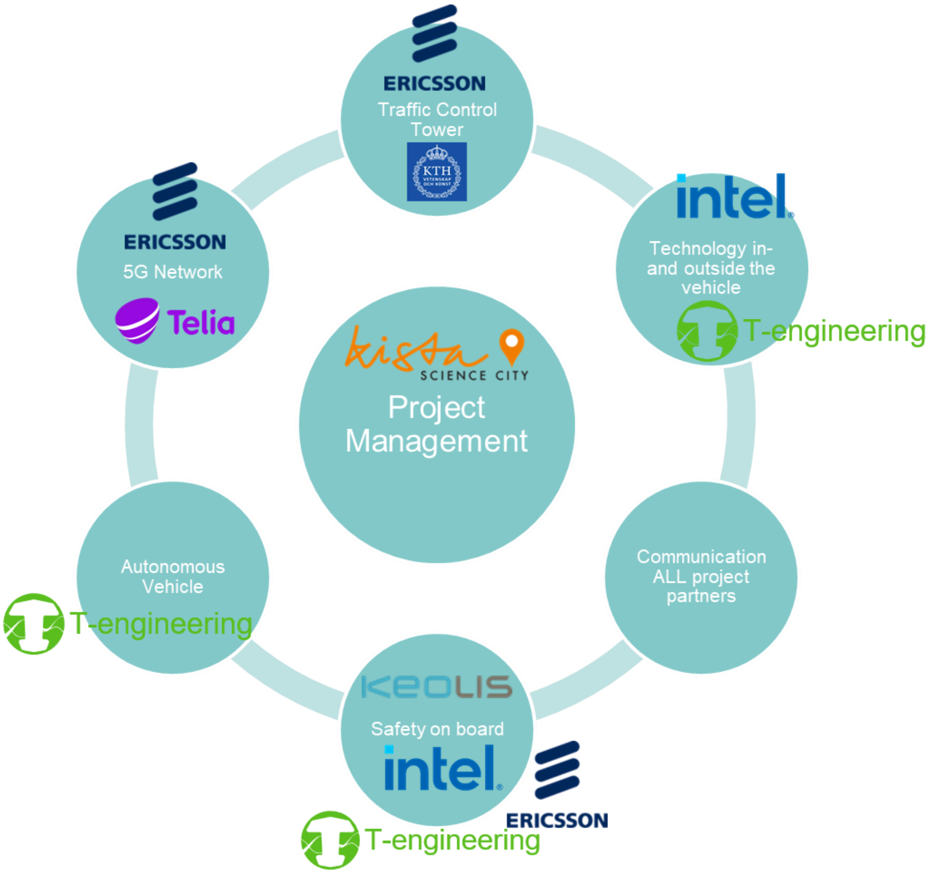
Ericsson provided a 5G Stand Alone (SA) system including the New Radio (NR) technology according to the latest 3GPP technology, this system was dedicated for the project, i.e. a so called private network providing radio coverage in certain parts of Kista. Telia has contributed with frequencies in the 5G network.

T-Engineering, providing the autonomous vehicle itself in-kind, but also developed the software and interfaces together with Ericsson to communicate with the control tower. This allowed vehicle data to be transmitted to the control tower for monitoring and checklist verification, but also enabled remote driving capabilities with seamless switching between automatic and remote operation. The Intel edge node and related hardware was also installed in the vehicle by T-engineering.

Ericsson also provided a so-called Control Tower (CT) which provides a digital twin and contains functionality to support autonomous vehicles when encountering problems, the CT can also provide indirect control commands to the vehicle. Ericsson also provided a driving station for remote control of the vehicle when needed. Together with KTH, a safe haptic teleoperation mode was developed where an operator can control the vehicle while guaranteeing the vehicle’s safety.

The project was also supported by Region Stockholm and the City of Stockholm.

Project organization



5. Method and activities

The team decided early that we wanted a demonstration to be performed at the end of the project to be able to show the complete system in an understandable and use-case based way.

The goal was set to implement the following ten use-cases during the project:

- Auto mission activation
- Control tower monitoring of vehicle health during startup and drive (checklist verification)
- Vehicle request remote assistance
- Handover Auto drive to remote operation
- Direct control of vehicle from drive station at control tower
- Handover remote operation to auto drive
- Indirect control of vehicle (vehicle suggest maneuver that approves/declines from control tower)
- 2 way passenger/control tower communication
- Passenger safety monitoring
- Forgotten item detection

5.1 Autonomous Vehicle

From T-engineering perspective most work was together with Ericsson to make the control tower and vehicle to communicate and operate together. Each week a separate technical team meeting was held to synchronize work, specifications, testing etc. Since T-engineering is located in Trollhättan the initial testing was performed using public 4G but still connected to the Kista control tower over the public internet, but this did not cause any major hurdles since most functionality could still be evaluated. The vehicle was later in the project shipped to Kista and the final system integration work and testing was then made together on site using the Ericsson own private 5G network.
The edge node system from Intel was also installed in the vehicle in Kista, basically the same components used in the 5G ride demo in Djurgården last year.

5.2 5G network

To understand the requirements on the 5G network for safe remote operation of vehicles, two demanding use cases were developed and investigated. First, we wanted to look at the case where the vehicle has collision avoidance sensors onboard. We wanted to explore how onboard automation could communicate safety issues to the remote human operator through haptics, while the human operator is controlling the vehicle. This creates a challenging requirement on the latency of the network where the interaction between the remote human and the onboard automation will deteriorate if the communication is too slow. Second, we extended the first use case and explored the possibility of remote driving a vehicle with no sensing capabilities but has received safety information from another vehicle nearby who does have sensing capabilities. This further explores the use of the 5G network to share safety information between vehicles in real time and allows us to understand whether 5G networks can support fellow vehicles enriching each other’s safety information.

5.3 Safe ride

The question is how to make public transport and especially buses attractive even after removing the driver. This could be a showstopper for the new technology. By testing AI detecting deviations in the vehicle such as illness, forgotten bags etc., we have found the first steps on the road to making the passenger even more safe in the new driverless vehicles. Outgoing from these findings we can start interacting with passengers proposing technology for safety and making new trials.

6. Results and Deliverables

The 5G Ride autonomous vehicle was upgraded with a new embedded computer with connected camera and audio stream devices. Purpose of this computer is to handle all the control tower interfaces via 5G and communicate with the VCU (vehicle control unit) via CAN. The software in the VCU was updated to handle the new remote drive mode with the existing implemented safety features for safe operation. The embedded computer based software was developed fully during the project in close cooperation with Ericsson. All parts were then integrated and tested together with the control tower functionality via 4G/5G connections. This enabled new functionality like remote monitoring, remote driving, two way audio stream and low latency video streaming.

The installed Intel edge node communicated with the control tower with its own modem; it was basically working completely independent from the other vehicle systems. The edge node was used for the implementation of the use-cases “passenger safety monitoring” and “lost item detection”.

Of the ten planned use cases eight were demonstrated during an event 28 Oct in a cordoned off parking lot. The indirect driving case was not demonstrated, the focus was not autonomous performance, but the low latency communication and the direct driving station was used for that. We also need further development on the indirect control to be able to suggest different maneuvers and not just one (like overtake obstacle approve yes/no that we demonstrated in Djurgården 5G ride project Oct 2020)
The passenger safety monitoring received great feedback from the participants at the event and we realized that this could be implemented also in the existing bus fleet to increase comfort and safety. One learning from the development was that the annotation of the video stream to teach the algorithm requires a lot of time.

The updated vehicle is available after the project for continued demonstrations, testing and further development. The result of this project was not only learnings like vehicle integration knowledge together with the control tower functionality; and remote operation technical demands; but also exploring further cooperation benefits between the companies also after this project has ended.

Testing and verification

The specification of functionality and test approach for the project was made in three levels.

- Use-cases
- Functions
- Sub-functions

Highest level was to define the use-cases, how should the control tower and the vehicle work together. For instance, “Auto mission activation” or “Vehicle request remote assistance” were high level use-cases. The use-cases were then divided into the mid-level functions needed, like “send vehicle sensor status”, “enable remote mode” etc. These functions were further divided into needed sub functions, like “transmit data on CAN bus”, “calculate steering angle” etc.

The testing was then performed starting on the lowest level on a testbench to confirm each sub function. Then moving up to a higher level to build working functions mostly testable in our testbench or otherwise in the vehicle itself, and finally confirm the functionality on complete use-cases level with the entire vehicle and over 5G connected control tower system.

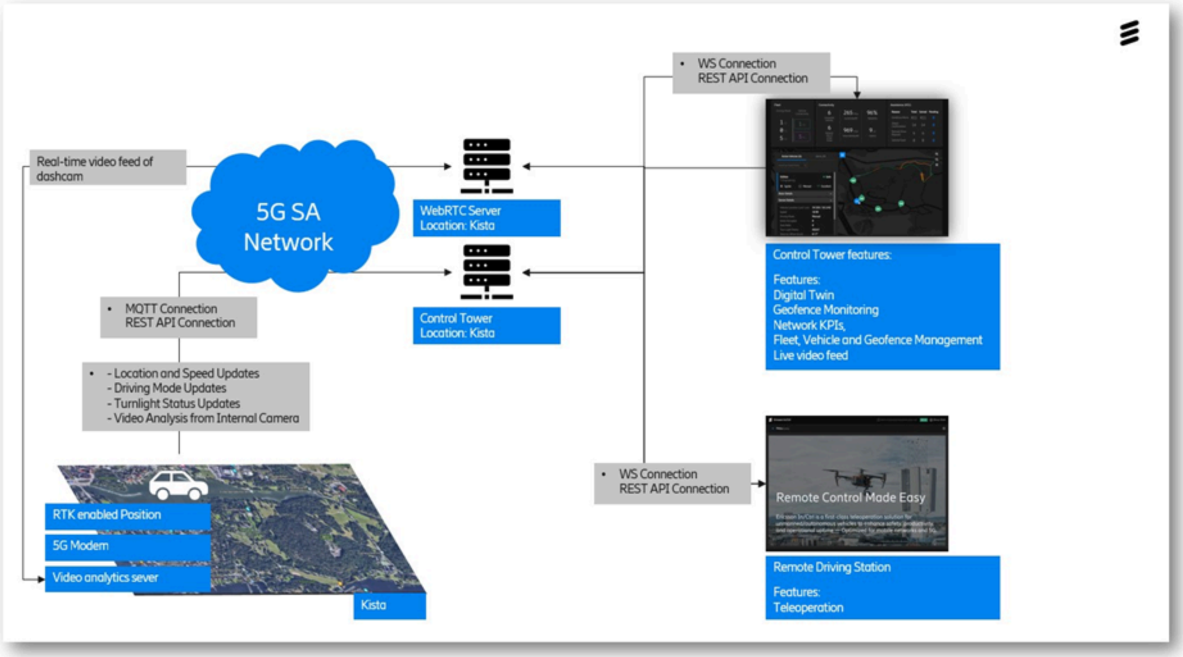


Figure: Data Flow Model

We think the demonstration at the end of the project has multiple important purposes, one of course to show the result of the project to invited visitors. But it also serves as a hard planned milestone when all testing and verification must be finished, and the robustness of the complete system has been proven.

6.1 Control Tower

The control tower was designed to support the sensor-data exchange, remote-assistance and vehicle monitoring use-cases during the trial run in Kista. The control tower application supported the 5G Ride Demo through the following services:

- Fleet Management
- Digital Twin Representation
- Live video feed of Vehicle
- Sensor data-sharing and visualization
- Handling vehicle assistance requests
- Handling remote-operation requests
- Geofence Alerts

In addition to the afore-mentioned services / features, the control tower application also contained a security module for maintaining the authentication and authorization aspects during the demo. Through this security module, only registered and authorized clients were able to establish connection and exchange data with the application.

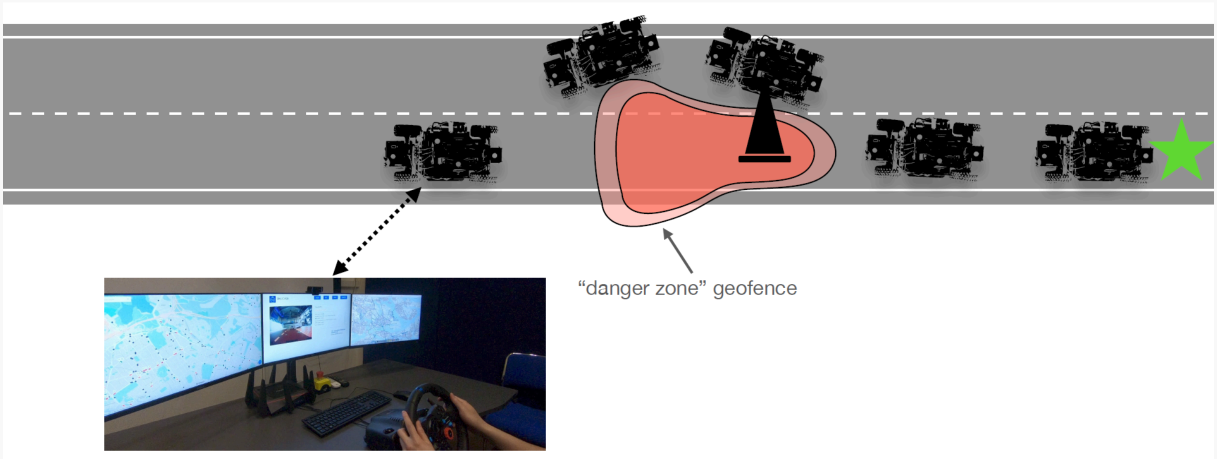
The control tower was also responsible for forwarding the requests for remote-operation that were generated by the vehicle in certain scenarios where the vehicle was unable to navigate due to obstructions. The remote-operation requests were first verified by the control-tower operator and then forwarded to a remote driving station that was available to handle such a request. These requests were handled by the control-tower in real-time.

Reachability analysis[1] is used to compute regions around the obstacles that a vehicle must avoid at all costs to stay safe. These regions are presented as geofences for the vehicle. We draw examples of the geofences in the figure below. Using this technique, we are able to develop an autonomous agent that can control the vehicle to avoid the geofence with guarantees on safety. This safety controller only activates when the vehicle is about to endanger itself.

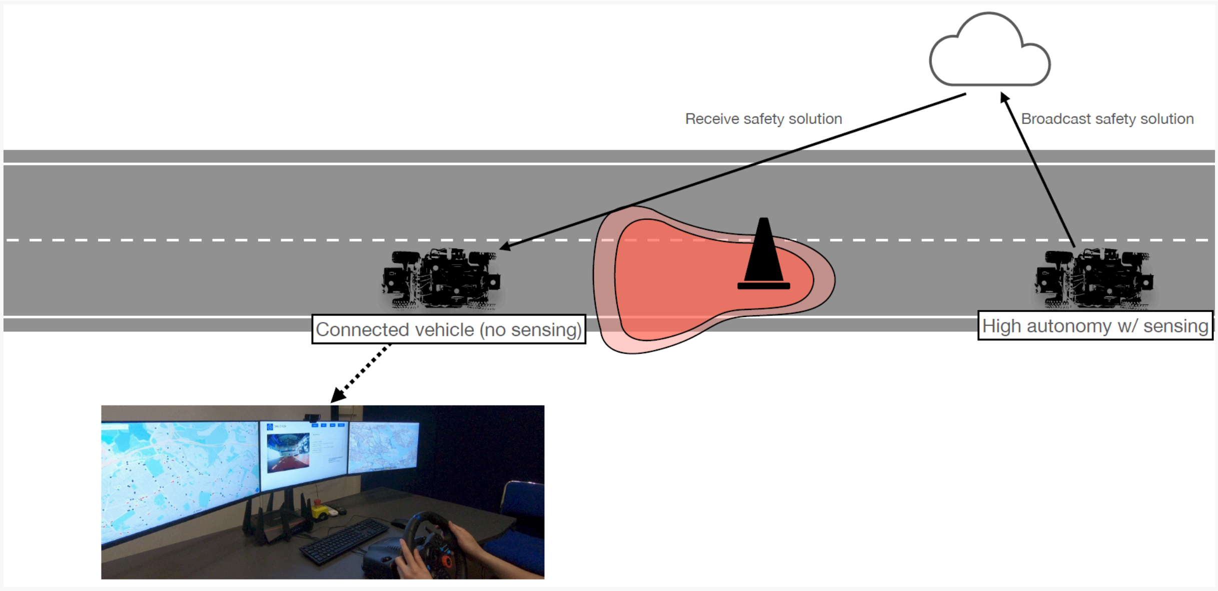
[1] Reachability analysis is a method for computing the set of states (e.g., position/pose and velocity) that a system (the vehicle) can reach in a certain time span, given a model of the dynamics and possible constraints on the movement.

In the first use case, we run the safety-guaranteeing automation onboard the vehicle, and when there is a safety issue about to occur, we give control to it and design it to provide haptic cues to the remote operator to inform the operator about the safety control. In the second use case, the geofence is computed by one vehicle (as in the first use case), and then communicated with another vehicle who is about to encounter the same obstacle, and who lacks the required sensing capabilities to compute the geofence itself. When the second vehicle approaches the region where the obstacle sits, the geofence is received and a remote operator is able to perform the same interaction with that vehicle. The two use cases were implemented and evaluated on a small-scale vehicle platform (the Small-Vehicles-for-Autonomy platform[2]) in the Integrated Transport Research Lab at KTH.

From analyzing the two use cases, it becomes clear that, while the safety requirements on the 5G network can be softened by having a safety guaranteeing automation onboard a vehicle, the interaction between the remote operator and the onboard automation is extremely sensitive to latency. Especially through modes like haptic feedback, when latency is increased, the remote operator has poor awareness about the safety situation. The second use case creates an even further demand on the latency requirements on the 5G network, since safety information needs to be communicated in real-time if you want to guarantee the safety of vehicles that do not have rich sensing capabilities.



[2] https://svea.eecs.kth.se/



6.2 Quality of service

The project developed functionality to request Quality of Service (QoS) from the mobile network when needed for critical communication, e.g. when there is a high number of users in the system making it difficult to maintain a good video quality or a low latency signaling. QoS in the mobile network could then be requested from the control tower when the operator needs a high quality video to determine action to take, or from the control tower when a high resolution video is needed to execute direct remote control of the vehicle. The interaction with the mobile network for QoS was performed using the 3GPP specification for exposure.

6.3 Real time communication

Communication between the car and the driving station is handled by a custom implementation based on WebRTC. In short, an encrypted direct connection between the car and driving station is established where video/audio and control signals are streamed.

To create this direct connection a signaling server hosted on innovation cloud is used. All vehicles will connect and register on the signaling server, where the registration process will include an authentication process to ensure only allowed vehicles are registered.

The driving stations will also connect and register to the signaling server and will then be presented with a list with all connected vehicles that are registered.

The driving station will initiate the direct connection by selecting a vehicle which will start SDP/ICE negotiation (part of the WebRTC standard) using the signaling server as a relay. Once the negotiation concludes a direct connection can be established and video and audio will start streaming.

After the connection is established, an additional stream is added for arbitrary data where the control signals are sent between the car and driving station. All control signals are packaged as Protobufs.

Gender equality and safety

To increase the level of safety and comfort for the passengers, we have implemented a solution that detects different kinds of events in the bus. If a passenger gets sick and lays down, we immediately inform the traffic control tower, who can first talk to the passenger and also alert 112. We know that public transit is seen as a less safe situation for women, but with AI we will be able to detect signs of unusual or concerning activity and respond immediately- just like we would on a subway train. We have also implemented detection of forgotten belongings. In the case of a forgotten bag, we detect that the passenger is walking away from the bag and then informs the passenger via a voice in the bus. That's an easy scenario to encounter if you're a parent juggling active children, a briefcase, a stroller, and grocery shopping all at the same time. We know we must work diligently to earn the public's trust in our future mobility plan; that means it's imperative to think of all the casual and extreme scenarios and be prepared.

Technically this was solved by implementing a very capable EDGE Node in the vehicle where we can analyze data with artificial intelligence from all internal and external sensors without any delay and rapidly send the results to the control tower and other receivers. By doing the analytics in the vehicle and using data protection technologies such as software guard extensions we are able to provide a very high level of data integrity and security. We can select to just send the results of the analytics and the large amount of raw data never has to leave the vehicle. In special situations we can stream the raw data to receivers. Those receivers have to be authenticated and we can adopt the data based on the receivers' need to know and authority. Outgoing from this technology support we will be able to create an awareness by the travelers that if something happens like illness you will be taken care of in the best manner. Developing this means very good chances to reach our goal that Public transport will be the safest travel there is.

We succeed to test IRL the abilities of AI as a means of safety. Good to verify that it works in real life, end to end. We learned that the use of AI could bring in terms of safety and as a spinoff this could to some extent be used in today's operations. Safety vs cost for installation is a thrilling exercise. In long term we will verify use cases where AI could bring safety to public transport safety and how to interact with the control tower. Probably one of the most important parameters when passengers start to ride Autonomous vehicles

The next step is to find more use cases with AI and control tower, test them possibly in other vehicles, challenge the public transport authorities of technology bringing safety, strive for several common projects. We also would like to have a vehicle more adapted to "normal public transport". That will make us come closer to the daily safety problems. The test vehicles we used are in this sense confined.

7. Conclusions, Lessons Learned and Next Steps

Just as after the first phase of 5G Ride all project-partners, in the consortium, agreed that we never would have been able to find out all the challenges nor solutions if the technology had been developed and tested individually.

To develop in close collaboration and test the whole chain end-to-end is a key for success to taking this complex and security-intensive technology forward.

After completion of this phase of the 5G Ride project, we can state that the extended Control Tower functionality will be key to enable a safe journey.

The consortium will continue the collaboration, now also together with Scania and Viscando, and has both financially and content of the project confirmed for the next few years.

We will take the next step to

- Measure more data from and to the vehicles
- Develop and test smart sensors in the infrastructure, to a safer way of traffic management and a safer (passenger-) experience of the ride.
- Integrate the Traffic Control Tower directly to different kinds of vehicles
- Run use-case with different kinds of vehicles

The project partners gained valuable knowledge from the project and will continue the joint journey towards a safe implementation of autonomous vehicles in public transport.

8. Dissemination and Publications

The project and its findings were presented at two public events, namely:

- Kista Mobility Day, June 1st, 2021
    - https://urbanictarena.se/kista-mobility-day-2021/
- Public Demo in Kista, November 28th, 2021
    - https://youtu.be/SBxF6TFBd7A

- Drive Sweden, yearly forum, January 26th, 2022

Some of the articles linked below.

https://insideautonomousvehicles.com/safety-features-tested-on-swedish-5g-self-driving-bus/

https://upjobsnews.com/ericsson-backed-self-driving-bus-project-tests-new-safety-features/

https://getproductguide.com/ericsson-backed-self-driving-bus-project-tests-new-safety-features/

http://maxiviewblindspotmirrors.com/ericsson-and-partners-test-new-safety-features-on-5g-self-driving-bus/

https://www.fiercewireless.com/5g/ericsson-revs-safety-trials-for-5g-self-driving-bus-project

https://telecomdrive.com/ericsson-partners-test-new-safety-features-on-5g-self-driving-bus/

https://www.devdiscourse.com/article/technology/1788082-ericsson-backed-self-driving-bus-project-tests-new-safety-features

https://www.telecompaper.com/news/ericsson-says-5g-ride-trial-brings-driverless-buses-closer-to-public-operation--1402602

https://telekomidag.se/5g-ride-fordon-smartare/

https://www.bussmagasinet.se/2021/10/har-kor-keolis-fjarrovervakade-buss/