Eleonor Sjödin Turah
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1. Summary

The 5G Ride project is a collaboration between several companies that are at the forefront of their industries. The project partners were Ericsson AB, Keolis AB and Urban ICT Arena/Kista Science City AB. Telia Company AB, Intel AB and T-Engineering AB contributed in-kind.

In 2020, we performed various tests with a self-driving vehicle, connected to a control tower via 5G. As 5G provides new opportunities to send real-time information, a Control Tower could provide driverless vehicles with support for both increased safety and a more efficient traffic flow.

The tests included communication between the self-driving vehicle and the control tower in critical situations, cybersecurity, network stability among other things.

This was the first time that tests of this kind were conducted in Sweden.

One important technical lesson learned from the project is that the end-2end solution for self-driving vehicles, which are connected to the control tower, must be robust and stable. The whole process must therefore be developed in close collaboration with various partners and tested in a real urban environment in order to continue the technical development.

2. Swedish Summary

Projektet är ett nära samarbete av flera företag, som ligger i framkant i sina industrier. Projektparterna var Ericsson AB, Keolis AB, Urban ICT Arena/Kista Science City AB. Telia Company AB, Intel AB och T-engineering AB bidrog in kind.

Vi har under 2020 genomfört tester med ett självkörande fordon, uppkopplat mot ett kontrolltorn via 5G. Då 5G ger nya möjligheter att skicka realtidsinformation skulle ett kontrolltorn kunna ge förarlösa fordon ett stöd för både ökad säkerhet och ett bättre trafikflöde.

Testerna innefattade bla kommunikationen mellan det självkörande fordonet och kontrolltornet i kritiska situationer, nätsäkerhet och stabiliteten av 5G nätverket under dessa förhållanden.

Detta var första gången liknande tester genomfördes i Sverige.

En viktig lärdom från projektet var att end-2-end lösningen för självkörande fordon, uppkopplade mot kontrolltorn via 5G, måste vara robust och stabilt. Hela processen måste utvecklas i nära samarbete mellan de olika parterna och testas i verklig miljö för att komma vidare.

3. Background

Today, self-driving vehicles cannot cope with all situations they encounter along a route. That forces the self-driving vehicles to stop, for security reasons, in situations that are hard to manage by the vehicle itself. With a connected self-driving vehicle, via 5G, the control tower can gather real-time information and provide necessary information and give commandos in the form of various actions to the vehicle. This results in a safer journey and makes the traffic-flow smoother and more efficient.

Problem to be solved: Smart & safe public transportation through connectivity & automation; basic development of 5G connected autonomous vehicles with support of control tower function, public acceptance of autonomous vehicles (AVs), last mile solution.

The 5G network will enable real-time communication between an AV and control tower and give the possibility for the passenger to communicate with the control tower if needed. The traffic flow can get more efficient by gathering traffic-information in real time and adjust route and speed. That will contribute to a safe and sustainable transport.

Utility & Impact:
1. Introduction of connected autonomous vehicles with control tower as a part of smart public transportation
2. Traffic safety assurance without driver onboard
3. 5G connectivity testing
4. Receiving direct public opinion on appeal of AVs is vital for next implementation phase

4. Project set up

4.1 Purpose

Main ambition with 5G Ride was to connect autonomous vehicles, via 5G, to the Control Tower to take another step to transfer the driver to an outside position of the vehicle, for improved public transport.

The project partners had all advanced technologies already developed, Traffic control tower, self-driving vehicle, AI, 5G Network. The 5G Ride project made it possible to integrate these technologies and test the whole process and solution in a real environment, on a public road in an urban area.

4.2 Objectives

The objective of the project was to integrate 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 [1].

- Testing and verification of 5G connectivity
- Knowledge of how Control Tower should assist self-driving vehicle in specific situations
- Design standards for Control Tower
- Public opinion on the overall appeal of the service

Due to the pandemic we could not obtain the amount of data needed in order to properly analyze the public opinion on the overall appeal of the service. Nevertheless, we still managed to gather valuable feedback from the passengers that used 5G Ride during the trial at Djurgården.

4.3 Project period

March 2020 – January 2021 (March 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.

Intel provided, in-kind, an edge-node which handled, and increased, the security for the communication from the vehicle via 5G and 4G. The edge-node analyzed the information from all sensors in and outside the vehicle and could therefore provide correct information to the control tower with high cyber-security in place.

Telia rolled out the 5G network, in-kind, in the geographical area of Djurgården island to enable these tests and gather learnings as to how the 5G network could be used and where it should be tuned.

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. Together with T-Engineering, providing the autonomous vehicle itself in-kind, they ensured the pre-testing of the route and made sure all the necessary permissions were in place for the trial.

The control tower, developed by Ericsson, provides information and commands to the vehicle in critical situations.

The project was also supported by KDI (Royal Djurgården society), KDF (Royal Djurgården Administration), Region Stockholm and the City of Stockholm.

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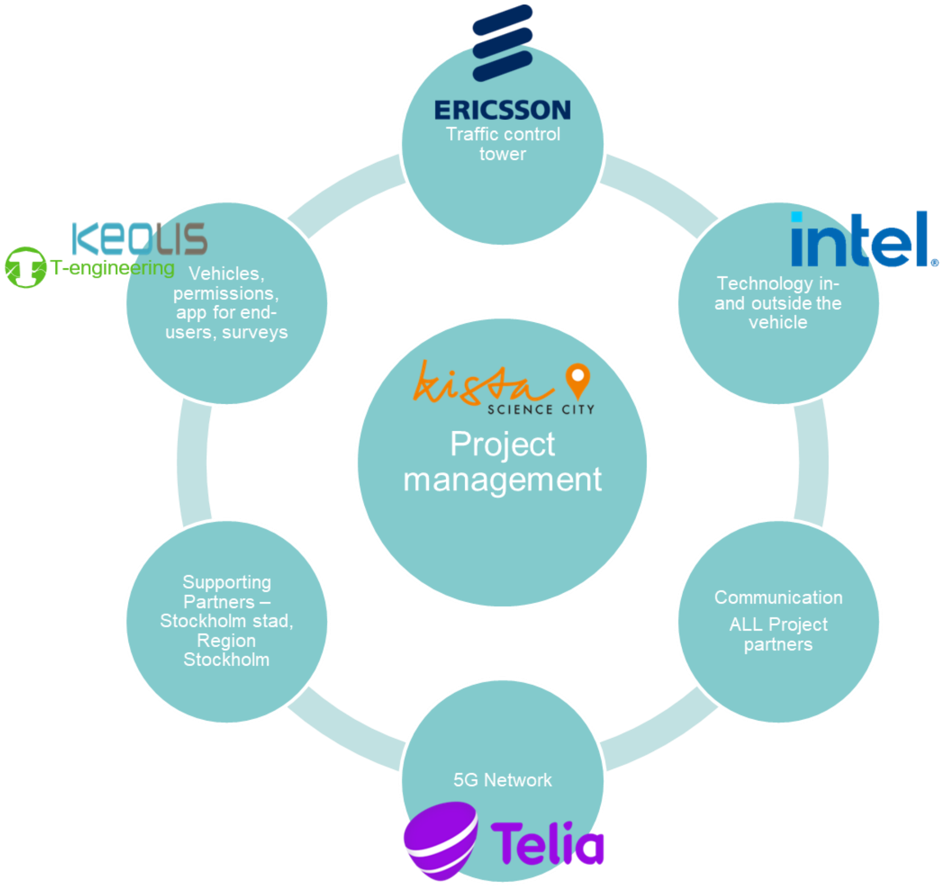
[1] Se bilaga A

Project organization



5. Method and activities

During the spring 2020, the project partners created the use cases and designed the architecture to communicate the needed information. Around May-July, tests of devices and the system itself were conducted in a test environment indoors and in a fenced area.

The project, together with KDI (Royal Djurgården society) and KDF (Royal Djurgården Administration), carefully selected a route at Djurgården, where both pedestrians, horses and cars were often spotted on the route. In this way, the system could face real-life challenges of urban environment, while at the same time it was possible to run tests in a safe and controlled way.

The route was scanned and mapped for the self-driving car before it was tested, equipped with project specific technology, and connected to the control tower via 5G.

Telia rolled out three 5G sites on a test frequency from PTS on the 3.5 GHz band, ready to be used for tests by the project in the end of August 2020. The project was running tests from August to mid-October 2020 where an inauguration was held on September 24th. From that day travelers visiting Djurgården could take a ride with our self-driving vehicle.

The 5G Sites were connected to the public mobile core network which is common to 4G and 5G.

The connectivity was measured via *bredbandskollen.se* along the route.

All the pre-defined use-cases [2]were carried out in the beginning of the project and were therefore a ground base for additional tests in later stages of the project.

Even though the pandemic affected the project in many ways, we managed to test the technical solutions through the whole process and to get feedback from a number of passengers. We offered the visitors of Djurgården to take a ride along the test route with appropriate corona restrictions in place, so that only one person/family could take the ride at the same time. Each passenger could scan a QR code to answer a survey, made by a researcher within the project.

6. Results and Deliverables

The tests have been very fruitful to all the parties involved, and we gained a valuable understanding of what is important and what consequences the control tower system has both for the passenger and from a technical perspective. Sixteen of the passengers gave us concrete feedback through surveys especially designed for the project. However, due to the restricted number of passengers, the findings were not of a scale large enough in order to analyze and use for further research.

The results are compiled in the attachment of the 5G Ride passenger survey [3].

Overall, the passengers who took a ride in the automated vehicle felt safe and experienced that the journey was reliable. None of them felt unsecure during the ride and the vast

[2] Attachment A

[3] Attachment B

majority of passengers would be willing to take the ride even with the driver outside the vehicle as the next step.

The passengers showed both curiosity and willingness to try autonomous vehicles.

Testing and verification

The urban environment on Djurgården island, combined with the unique challenges along the route (visitors, horses etc.) led us to choosing the following set-up during the project:

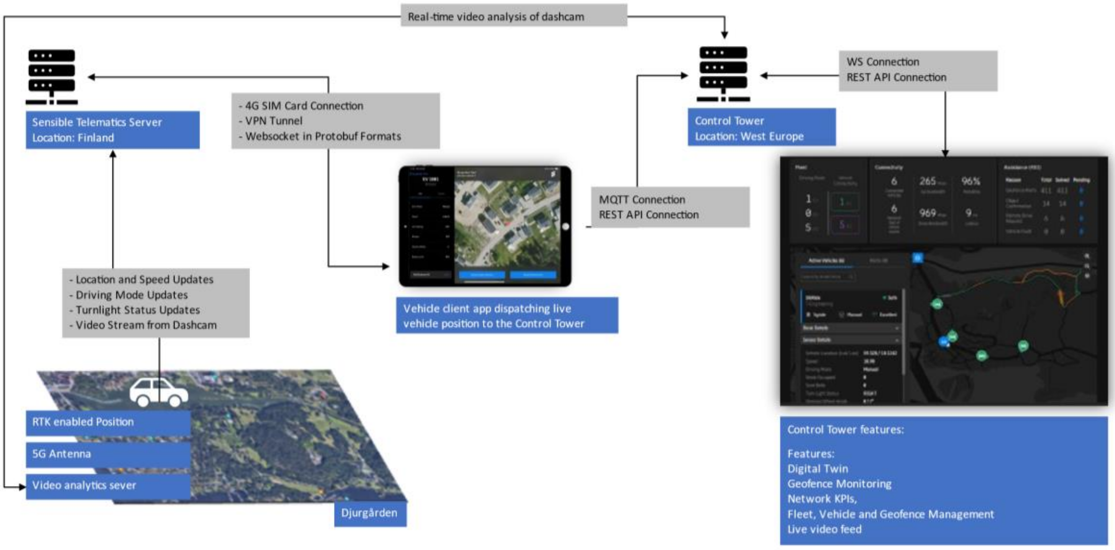


Figure: Data Flow Model

The digital infrastructure involves a centrally located cloud service (Control Tower Server) that enables connections and data-exchange with various other clients and the dashboard. The Control Tower Server exposed multiple service endpoints for facilitating the communication with the connected-vehicle-client (iPad), and with the Control Tower Dashboard. The services exposed by the Control Tower are:

1. MQTT Broker Connection
   For facilitating real-time sensor data-exchange with the Control Tower. All the data-exchange was done using MQTT Protocol and predefined data-formats.

2. REST APIs
   For exchanging latest application / device data, and for creating assistance / service requests in the Control Tower Portal.

3. WebSocket APIs

For real-time exchange of application data and service notifications that are generated on the Control Tower dashboard.

All the services were protected by authentication and authorization modules, and thus, securing the data. Communication happening over these channels.

The data-flow model represented in above figure, summarizes the different devices / services involved in the Demo.

1. The sensor-data generated from the vehicle was shared over proto-buf messages to a telemetry server located in Finland.
2. An iOS Application, hosted in an iPad, was connected to the telemetry server to fetch the sensor-data updates and translated them into messages that were recognized by the Control Tower Server.
3. After translation, the sensor data messages are forwarded to the Control Tower over MQTT Protocol and thus the relevant data is reflected on the Control Tower Dashboard.
4. Similar data pipeline is involved in sending back the data to the connected vehicle, whenever a geofence-notification / alert message is generated on the Control Tower side.

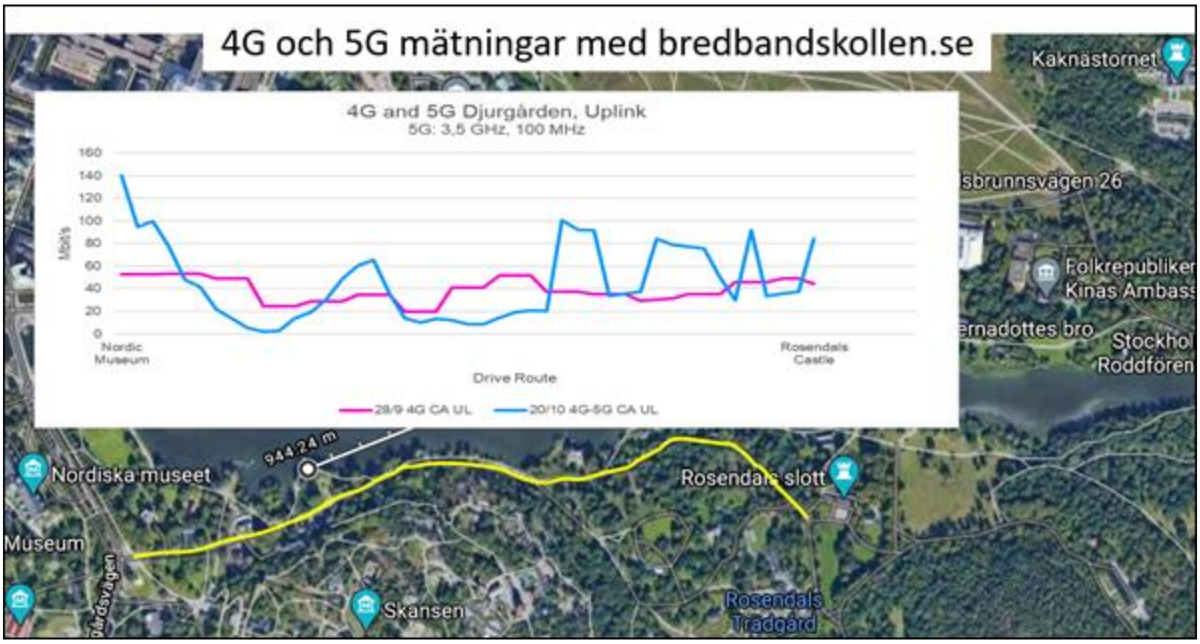
One of the technical challenges we experienced was caused by the very big amount of data from the continuous streaming of video from the vehicle to the control tower, up to 300 GB per day.
This caused the abuse filters in the mobile core network to activate and throttle the data speeds. This was the case also with subscriptions with unlimited data. Therefore, we solved this by changing the continuous video streaming to video streaming activation when support from the operator in the control tower was requested.

Another technical challenge was the connection between the vehicle and the Control Tower, which was secured with VPN tunnels. In the beginning, these VPN tunnels were not completely stable. This issue turned out to be caused by IP address changes, initiated from the mobile network. To solve this, the 5G subscriptions were converted to subscriptions with fixed public IP addresses. This is an area which must be further explored in order to find long term solutions.

5G Connectivity

The connectivity was measured via *bredbandskollen.se* both on 5G and 4G. The main findings are concluded below:

Firstly, we proved that higher frequencies are more sensitive to "obstacles on the road" between mast and terminal, which can be seen in the picture below, of the 5G measurements made with *bredbandskollen.se* along the route. There were large variations between measured maximum and minimum uplink speeds. The uplink is also more critical than the downlink for connected vehicles due to the video streams and other data to be sent from the vehicle to the control tower.



Secondly, the public 4G network consists of aggregated frequencies between 800 - 2600 MHz. 4G had a smoother and more stable level on the uplink than 5G, the 4G uplink was in some cases better than the 5G test network and in other cases worse than the 5G test network.

Thirdly, in commercial 5G production, 5G will be run on several frequency bands and with careful network planning so that deficiencies in coverage are avoided. Nevertheless, there will always be geographical locations in a public mobile network where coverage and capacity will be worse. Hence, it is important that the end-2-end solution AV-CT is built robustly and can withstand dips in coverage and speed.

Control Tower

Control Tower is a concept designed to help connectivity service providers serve the future of automated transportation and remotely operated fleets of vehicles.

The Control Tower concept captures the requirements to:

- Execute on the transportation use cases of today and prepare for the demands of tomorrow
- Provide flexible services and secure infrastructure for automated transportation
- Play a crucial role in supporting a more sustainable transport ecosystem

The control tower has been developed and tested during the project. As a result, it now has a standard format for data streaming between to and from the control tower. Also, cyber security is well tested and standardized both for the control tower and the edge-node.

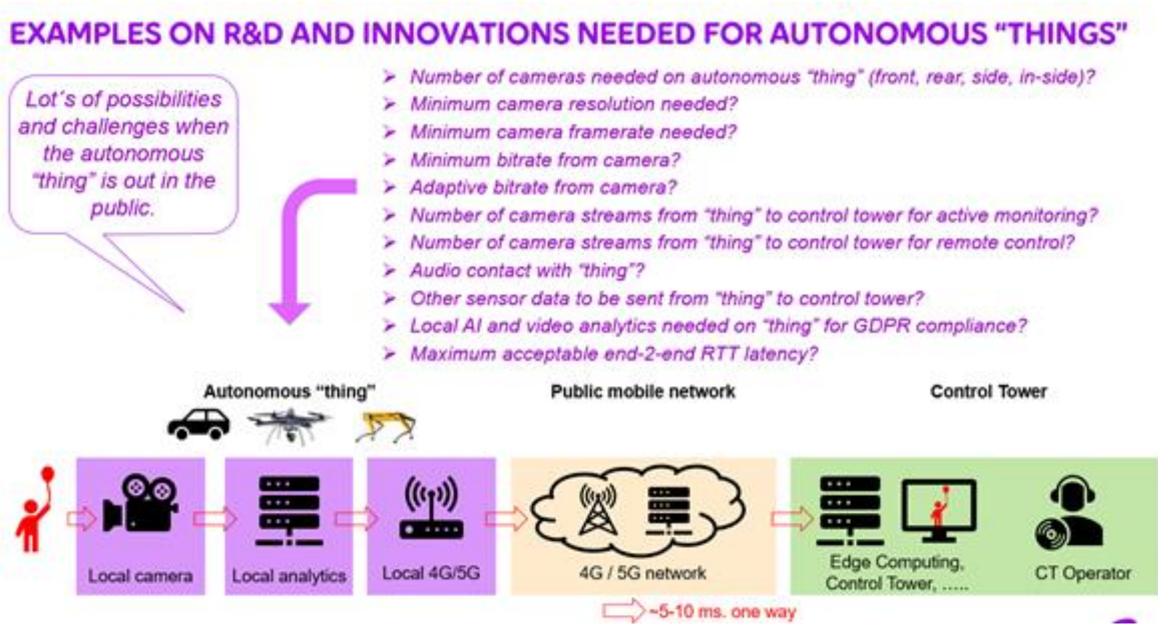
7. Conclusions, Lessons Learned and Next Steps

After the project had been successfully completed, all the project partners highlighted the importance of further testing with real self-driving vehicles as opposed to merely radio-controlled mini cars, both in this and the upcoming phase of the 5G Ride project. The overall experience and understanding of the impact of connected self-driving vehicles to the surroundings will not be possible to obtain from testing indoors nor in gated test-sites, which is one of the many reasons why the trial was widely appreciated by all the project partners and associated stakeholders.

One important technical lesson learned from the project is that the end-2end solution for self-driving vehicles, which are connected to the control tower, must be robust and stable. The whole process must therefore be developed in close collaboration with various partners and tested in a real urban environment in order to continue the technical development.

After completion of the 5G Ride project, we can state that the extended Control Tower functionality will be key to enable:

- Higher levels of automation
- Larger fleets and other types of automated vehicles
- Higher driving speed



We have now developed a Traffic control tower, ready to connect to bigger fleets and different kinds of vehicles.

User-cases will be created to find out what kind of data and when it is most efficient and important to transfer the data. This to be able to adjust the 5G network accordingly.

Next steps

- Checklist in the traffic control tower, measuring more data from vehicles and sensors around the route, to a safer way of traffic management and a safer (passenger-) experience of the ride.
- Integrate Traffic Control Tower directly to different kinds of vehicles
- Run use-case with different kinds of vehicles

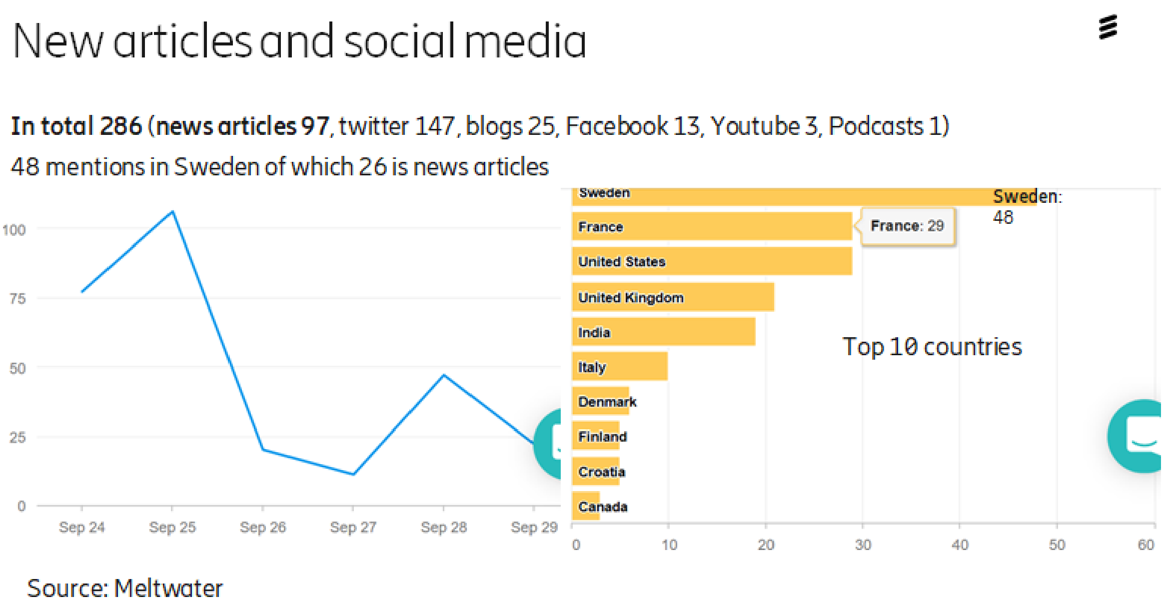
The project partners gained valuable knowledge from the project and will continue the joint journey towards a safe implementation of autonomous vehicles in public transport.

8. Dissemination and Publications

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

- Kista Mobility Day, June 16th, 2020
- Public inauguration at Djurgården, September 24th, 2020
- Drive Sweden annual forum, January 28th, 2021

The media interest, statistics from Melwater on September 29th 2020, is shown in the following graph.



Some of the articles linked below.

- https://uk.reuters.com/article/uk-ericsson-autonomous/swedens-ericsson-telia-present-self-driving-bus-ahead-of-5g-spectrum-auction-idUKKCN26F2WN
- https://www.zfk.de/mobilitaet/oepnv/artikel/8c641bd6accf1615fa2ebec5db5ca1e7/5g-lenkt-einen-bus-autonom-durch-stockholm-2020-09-25/

- https://www.vanillaplus.com/2020/09/25/54968-ericsson-telia-partners-test-driverless-5g-enabled-electric-minibus-stockholm/
- https://www.telecompaper.com/news/ericsson-telia-run-trial-of-5g-connected-electric-mini-bus-in-central-stockholm--1355440
- https://iotnowtransport.com/2020/09/25/76465-ericsson-telia-and-partners-test-driverless-5g-enabled-electric-minibus-in-stockholm/
- https://www.telecomtv.com/
- https://www.fiercewireless.com/5g/ericsson-telia-take-5g-for-a-royal-ride
- https://www.usine-digitale.fr/article/ericsson-intel-et-keolis-testent-une-navette-autonome-supervisee-a-distance-via-la-5g.N1009104
- https://telecomlive.com/web/swedens-ericsson-telia-present-self-driving-bus-ahead-of-5g-spectrum-auction/

Swedish Media

- https://www.svd.se/sjalvkorande-5g-buss-invigd-pa-djurgarden
- https://www.svtplay.se/video/28327705/lokala-nyheter-stockholm/svt-nyheter-stockholm-24-sep-18-33-1
- https://www.kungahuset.se/kungafamiljen/aktuellahandelser/aktuellt/prinsdanieldeltogvidjungfrufardforsjalvkorandefordonpadjurgarden.5.735103e8174b4ddd7f81b66.html
- https://www.expressen.se/tv/ditv/motor/telias-vd-vi-kommer-ta-5g-till-hela-landet-inom-nagra-ar/
- https://etn.se/index.php/nyheter/67222-djurgardens-sjalvkorande-minibuss-invigd.html
- https://www.fplus.se/nu-har-5gbussen-borjat-kora-i-stockholm/a/39jdKA
- https://www.nyteknik.se/fordon/nu-borjar-5g-bussen-kora-i-stockholm-7001704
- https://www.bussmagasinet.se/2020/09/har-aker-prinsen-utan-nagon-som-kor/
- https://www.di.se/nyheter/kungligt-varre-nar-sjalvkorande-buss-invigdes-pa-djurgarden/
- https://www.svt.se/
- https://iotnowtransport.com/2020/09/25/76465-ericsson-telia-and-partners-test-driverless-5g-enabled-electric-minibus-in-stockholm/
- https://www.bussmagasinet.se/2020/09/har-aker-prinsen-utan-nagon-som-kor/
- https://www.nyteknik.se/premium/kontrolltorn-hjalper-stockholms-forsta-sjalvkorande-5g-buss-7001929

Drive Sweden is one of the Swedish government's seventeen Strategic Innovation Programs (SIPs) and consist of partners from academia, industry and society. Together we address the challenges connected to the next generation mobility system for people and goods. The SIPs are funded by the Swedish Innovation Agency, Vinnova, the Swedish Research Council Formas and the Swedish Energy

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