(INVITED) 5G-MOBIX: The Greece-Turkey Cross-Border Corridor

Nazlı Güney
5G Research & Development
Turkcell Teknoloji
Istanbul, Turkey
nazli.guney@turkcell.com.tr

Konstantinos Trichias
Research & Development
WINGS ICT Solutions
Athens, Greece
ktrichias@wings-ict-solutions.eu

Dries Naudts, Vasilis Maglogiannis
IDLab, IMEC
Antwerp, Belgium
{Dries.Naudts, vasilis.maglogiannis}@imec.be

Tahir Sarı
Connected and Autonomous Vehicles
Ford Otosan
Istanbul, Turkey
tsari1@ford.com.tr

Serhat Çöl
Network Design and Optimization
Ericsson Turkey
Istanbul, Turkey
serhat.col@ericsson.com

Ioannis Zompas
Customer Unit South East Europe
Ericsson Greece
Athens, Greece
ioannis.zompas@ericsson.com

***Abstract*—The potential benefits of 5G for connected and automated mobility are investigated in a cross-border setting, between Kipoi (Greece/GR) and Ipsala (Turkey/TR), based on the user stories developed and implemented to target the specific characteristics of the route to be followed. The heavy commercial traffic at Ipsala-Kipoi, created by the long queues attributable to a large number of goods-carrying trucks, may be alleviated by resorting to platooning, truck routing and assisted-border crossing as to be trialed in that region. Focusing on the technological, regulatory and business needs of the network infrastructure investments at currently underserved areas, the gaps that exist in the standards, the business models and the regulations to support pan-European mobility for 5G-enabled automated driving are analyzed in the 5G-MOBIX project, where the GR-TR corridor constitutes one of the two main cross-border trial site locations.**

Keywords—5G, Connected and Automated Mobility (CAM), C-V2X, vehicular communications, platooning, extended sensors, tele-operated/remote driving

I. Introduction

An autonomous vehicle, in its most advanced form, is expected to be capable of sensing its environment and making maneuver decisions without the intervention of a human, but the road to achieving this level of mobility is long as depicted by the 6-level taxonomy of the Society of Automotive Engineers (SAE), which corresponds to a step-by-step evolution of automated driving (see [1]). In particular, for achieving higher levels of commercial-grade automated mobility and wide-spread adoption by the public, extensive trialing in both controlled and open road environments is required as well as a careful design of the interaction between the various stakeholders that make up the complete ecosystem of mobility, in order to grant vehicles, access to a plethora of information about their surroundings.

For exchange of data between broad categories of traffic/road entities such as vehicles, road side infrastructures, pedestrians/cyclists and cloud applications, two modes of communication are foreseeable: (1) direct or short-range and (2) network-based or long-range communications. Depending on the specific use case, either one or both of these options may have to be preferred, where the pros and cons of employing a certain option need to be carefully studied.

In this paper, the focus is on 5G network communications for Connected and Automated Mobility (CAM) at cross-border settings, with an ultimate goal to describe and discuss the work carried out at the Ipsala-Kipoi corridor between Greece and Turkey in the scope of 5G-MOBIX, which is a project funded by the Horizon2020 research and innovation program. Next, following a brief overview of the project in Section II, the trial/test location and the main elements of the test environment of the GR-TR corridor are introduced in Sections III-VI, along with some preliminary results and achievements of the partners in Section VII.

II. The 5G-MOBIX Project

The H2020 ICT-18-2018 5G-MOBIX Innovation Action project [3], which is partially funded by the European Commission, is tasked with the realization of advanced cross-border CAM trials, using 5G connectivity. The trials will be conducted in two major European Cross-Border Corridors (CBCs), between Spain-Portugal (ES-PT) and Greece-Turkey (GR-TR), as well as four national Trial Sites (TS), in Finland, France, Germany and The Netherlands. The CBCs and TSs are covered with 5G using 3GPP Rel.15 Non-Stand Alone (NSA) networks, while some TSs will also use Stand Alone (SA) networks. The 5G networks are provided by the two major European vendors (Nokia for ES-PT and Ericsson for GR-TR), while the existing infrastructure and networks of four major European Mobile Network Operators (MNOs) are used to cover the two CBCs, namely Telefonica and NOS for the ES-PT, and COSMOTE and Turkcell for the GR-TR CBC.

The goals of the trials, which will begin in April 2021 and last until March 2022, are i) to showcase the capabilities of 5G connectivity and its suitability for CAM applications even in extreme conditions, ii) to identify the issues and difficulties that arise from CAM operation in cross-border environments and to investigate several 5G-based solutions and iii) to explore appropriate deployment options and business models for the successful adoption and penetration of the relevant 5G technologies in cross-border areas. During the trials the five most prominent CAM Use Case Categories (UCC), as defined by 3GPP [4], will be implemented, namely Advanced Driving, Vehicles Platooning, Extended Sensors, Tele-operated (Remote) Driving and Vehicle Quality of Service (QoS) Support.

III. The Greece-Turkey Corridor

The GR-TR cross-border corridor lies within the south-eastern border of the European Union providing a challenging geo-political environment due to the existence of actual, physical borders, where customs agents perform rigorous border checks. The heterogeneity of traffic going through these borders, i.e. trucks with commercial goods, tourists, as well as the co-existence of multiple differentiated vehicles with pedestrians (security personnel, customs agents, etc.)

provide ideal conditions for the execution of diversified trials to showcase the advantages offered by the 5G connectivity to CAM use cases.

A. *The Trial and Test Locations*

The GR-TR trials will take place on the most commonly used border crossing between Greece and Turkey in the area of Kipoi (GR) - Ipsala (TR) where the E90 (GR) highway becomes the E84 (TR) highway when crossing into Turkey. Figure 1 depicts the exact location of the GR-TR cross-border trials and the route to be followed by the participating vehicles when executing the scenarios described in Section IV. Besides the trials at the GR-TR border, initial tests will also be carried out at the Ford Otosan Inonu test track (see Figure 2) where development of functionality and testing will take place to support the cross-border trials. The knowledge and technology transfer from this test location will enable the advanced trials taking place at the border, while the site also provides an area for long-term development and testing (such long-term activities are prohibitive at the border location).

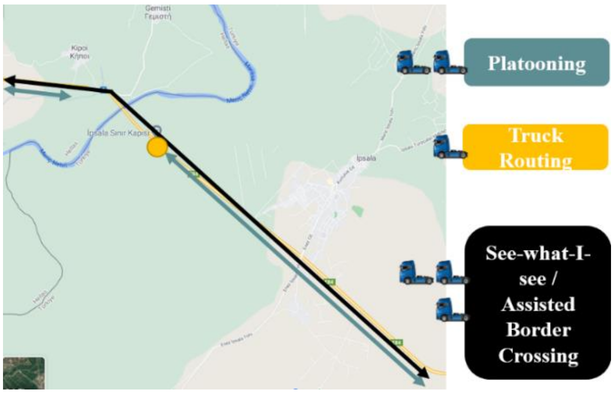

Figure 1: GR-TR border-crossing trial location

Figure 2: Ford Otosan test site to be used for long-term functionality development and testing

B. *Partners and Supporting Public Authorities*

The GR-TR cross-border corridor consists of the following partners from the 5G-MOBIX consortium: Mobile Network Operators (MNOs) - COSMOTE (GR), Turkcell (TR); 5G Equipment Vendors - Ericsson (GR and TR); Vehicle Manufacturer - Ford Otosan (TR); OBU Developers - IMEC (Belgium) and WINGS (GR); RSU Developer - IMEC (Belgium); CAM Application Developers - WINGS, ICCS (GR), Ford Otosan, TÜBİTAK BİLGEM (TR), also Aalto University (Finland).

To perform trials for autonomous driving at public roads using 5G, permissions are required from a number of public authorities. The ones that have declared their support to the trial activities are The Information and Communication Technologies Authority (TR) – also part of the advisory board, Hellenic Ministry of Infrastructure and Transport (GR), Ministry of Digital Policy, Telecommunications and Media (GR) and the customs agencies (both GR and TR).

IV. User Stories

In the GR-TR CBC, four different User Stories (US) will be implemented, belonging to two UCCs defined by 3GPP [4].

A. *Truck Platooning*

The Truck platooning US will demonstrate the efficient travelling pattern, during which the first truck leads the way, and the following trucks follow in extremely close distance, allowing for reduced drag and more fuel efficiency. This is possible via the autonomous driving of the follower trucks, enabled through cellular communication technologies. During the GR-TR platooning trials all stages of platooning will be tested (joining, driving, dissolving) and the performance will be evaluated using both network-based 5G communication (over the Uu interface) and Vehicle-to-Vehicle (V2V) communication (over the PC5/sidelink interface). The concept of this US is depicted in Figure 3.

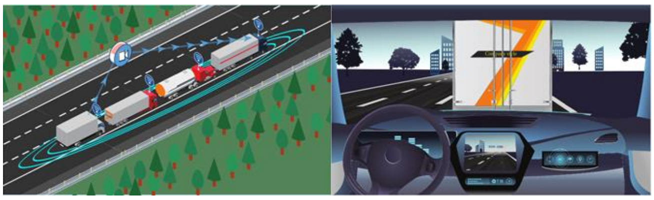

Figure 3: Depiction of the "Platooning" and "See-What-I-See" User Stories implemented in the GR-TR CBC

B. *See-what-I-see*

The See-What-I-See US is also linked to the Platooning UCC, and it addresses the anxiety induced to the truck drivers of the follower vehicles, when driving in a platoon formation, caused by the obstructed view to the road. Thanks to 5G capabilities, an HD camera mounted in the front of the leading truck of the platoon, will transmit Ultra high-quality video of the road ahead to all of the following trucks, thus alleviating the issue. This concept, which is also depicted in Figure 3, should remain operational even when the platoon is crossing national borders, causing multiple switches of IP addresses.

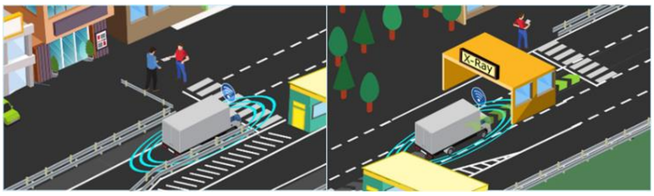

Figure 4: Depiction of the "Truck Routing" User Story implemented in the GR-TR CBC

C. *Truck routing*

The Truck Routing US is part of the Extended Sensors UCC, and refers to the autonomous driving of a truck within the customs area of the GR-TR borders, based on information from on-board sensors (e.g., Lidar, GNSS) as well as surrounding sensors (e.g., cameras) mounted on Road-Side Units (RSU). As part of the scenario that will be demonstrated in the GR-TR trials, the truck driver will be able to get off the truck to e.g., fill-out the necessary paper-work for crossing the border, while the truck will be autonomously driven and guided to proceed to the necessary customs checks (e.g., going through an X-Ray machine). This functionality, which is depicted in Figure 4, depends on Cloud/Edge based fusion and processing of all relevant information, and ultra-fast and ultra-reliable communication of the autonomous driving commands from the cloud platform to the truck, over 5G.

D. Assisted border crossing

The Assisted –zero touch– Border Crossing US, is also part of the Extended Sensors UCC, and will demonstrate remote vehicle inspection and predictive risk assessment for all trucks coming into the customs area of the GR-TR borders. Based on information from on-board and road-side sensors, a cloud/edge-based platform performs data ingestion, fusion and processing (based on Machine Learning techniques) and assess whether an incoming truck presents a risk of smuggling attempts. If a truck is deemed of "low risk" then it experiences a zero-touch border crossing, as the border gate automatically opens and the truck passes with no manual inspection, while if a risk is detected then the truck is autonomously guided and stopped for further manual inspection. The whole process is directly linked to the smartphones of customs agents on both sides of the border, who can intervene at any time and remotely stop the truck. This concept, which is depicted in Figure 5, also comprises increased protection for the customs agents, as any truck is autonomously stopped, if it is detected to be driving towards a customs agent.

Figure 5: Depiction of the "Assisted –zero touch– Border Crossing" User Story implemented in the GR-TR CBC

V. 5G Network

The requirements and specifications of the user stories described have some serious implications on the architecture and design of the 5G network to be deployed for the corridor: service disruption during handover from one operator to another (Turkcell to COSMOTE, and vice versa) or large end-to-end latencies while performing any of the GR-TR user stories is likely to have detrimental and vital consequences. However, the availability of equipment and features from the vendor (i.e., Ericsson) further restricts the options. In 2020, when the 5G network deployment took place, the Ericsson core network with roaming functionality/features already implemented offered only the NSA option 3x architecture [5] – the 5G Core to support the standalone network was still under development, lacking the seamless handover functionality for inter-operator connectivity. This set of considerations led to the 5G architecture for the GR-TR corridor shown in Figure 6.

While three sites cover the road going to the Ipsala border gate on the Turkish side, one base station at Kipoi is used to give 5G service in Greece, as an upgrade of the existing LTE commercial network site. In order to start development and early testing, an additional 5G/LTE test site is installed close to the Ford Otosan plant to serve the test track shown in Figure 2. The core network locations, on the other hand, are Istanbul and Alexandropolis that are chosen to confine the end-to-end latency as much as possible.

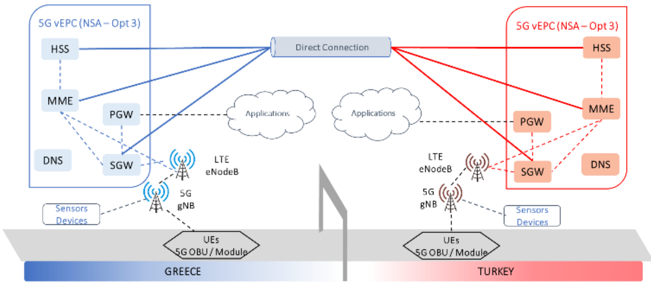

Figure 6: The GR-TR 5G network architecture

A further note on the 5G architecture is that as demonstrated in Figure 6, the inter-connection between the two networks is based on a direct link between COSMOTE and Turkcell as opposed to the commercial practice of using a GRX roaming partner, since this introduces extra delays beyond what can be tolerated by the latency-critical applications envisioned in the user stories.

VI. Vehicles and Equipment

A. Autonomous vehicle

Ford Otosan provides two Ford F-MAX trucks for the defined user stories, where the high-level architecture of the trucks can be seen in Figure 7. These trucks are equipped with a front radar and a front camera for object detection, an electronic steering wheel controller, a real-time kinematics - Global Navigation Satellite System (RTK-GNSS) unit for cm-precise positioning, a rapid prototyping unit for autonomous vehicle controller (dSpace MicroAutoBox II – "MABX") and an on-board unit (OBU) for connectivity. Additionally, clients (for video encoding, decoding) and one 4K camera (only for the front vehicle) will be used for the "see-what-I-see" video streaming application. The rapid prototyping unit collects all related data from the other units, acts as a gateway unit to exchange messages between the other vehicle control units and sensors, and holds the autonomous application algorithms that are developed by Ford Otosan engineers.

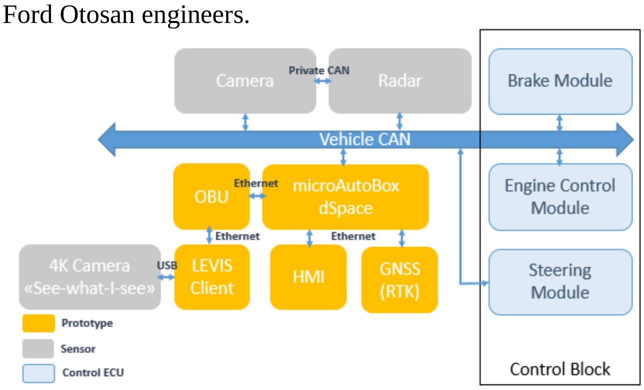

Figure 7: High Level Ford F-MAX Truck Architecture

B. On Board Units (OBUs)

The OBU developed by IMEC is installed on the roof of the vehicle and is connected to the Ford MABX with an Ethernet connection, and with a 4K camera via the video streaming client. The OBU contains all the V2X communication hardware that is needed to foresee the connectivity over 5G (Quectel RM500Q) and C-V2X PC5 (Cohda MK6c). A 4G modem is included for remote configuration and monitoring. For positioning and time synchronization purposes a GNSS unit is integrated. An overview of the hardware components of the OBU is shown in Figure 8.

The software architecture of the IMEC unit is based on the in-house developed CAMINO framework [2]. CAMINO is the core platform for managing the V2X communication technologies of the GR-TR corridor and the services running on top of them. The framework enables integration with existing and future short- and long-range V2X technologies such as ITS-G5, C-V2X PC5 and C-V2X Uu (5G/4G).

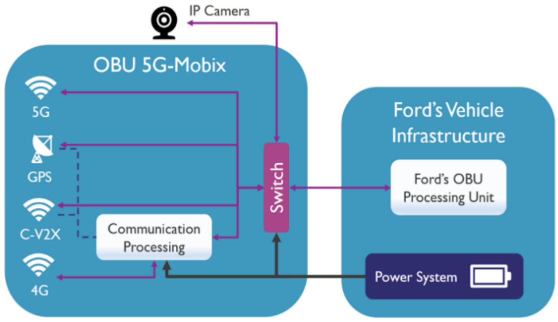

Figure 8: IMEC OBU Architecture

Besides the IMEC OBU which is used for the Platooning, See-what-I-see and Truck routing USs, a second OBU developed by WINGS ICT Solutions is employed and integrated with the Ford truck for the Assisted border crossing US. The WINGS OBU, is equipped with chipsets supporting 3G/4G/5G and IoT communications and is connected with the multiple on-board sensors needed for the realization of this US. It is seamlessly integrated with the Ford MABX and the IMEC OBU via ethernet, and remotely connected with the cloud-based platform, and is thus capable of supporting the necessary autonomous functions of the truck.

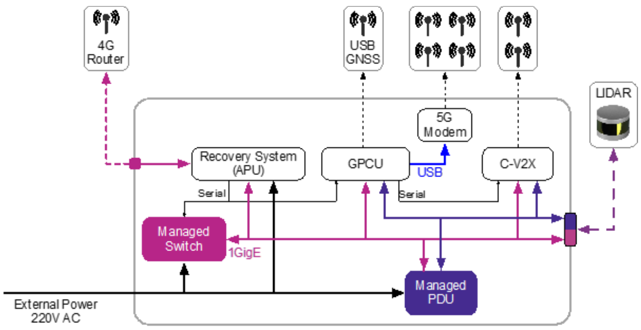

Figure 9: IMEC RSU Architecture

C. *Road Side Unit*

In the context of the GR-TR corridor, IMEC provides three RSUs with 5G and C-V2V PC5 connectivity. The Velodyne VLP-16 Light Detection and Rangings (LiDARs), provided by Ford Otosan, are integrated within the RSUs. These LiDARs will be used to increase perception capabilities of the TUBITAK cloud application, which is performing truck routing in customs zone. The RSU allows minimal local processing of the data, e.g., converting data formats before sending it to the cloud. Hence, the heavy computations are done in the cloud. For this purpose, the RSU must be able to relay data received from the LiDAR and/or OBU to the cloud over a 5G Modem. The architecture of the RSU in Figure 9 shows that the RSU contains a GPCU that acts as the main controller and it is directly connected to the 5G modem (Quectel RM500Q), and this provides a 5G Uplink for the rest of the components.

VII. Initial Results and Trial Planning

In order to assess the limits of the 5G network deployed at the Ford Otosan plant, Ipsala and Kipoi, several visits were made to investigate the statistics of the throughputs and latencies achievable at these locations by stationary and moving users. Some of the figures obtained during these test sessions are given in Table 1 below.

The 5G connectivity testing of the IMEC OBUs/RSUs and WINGS OBU were carried out in Istanbul and Athens, respectively. Due to the characteristics of the hardware used (2x2 MIMO), the IMEC OBUs/RSUs have a peak downlink (DL) throughput of 587 Mbps and an uplink (UL) throughput of ~80-85 Mbps, whereas the WINGS OBU cap at around 400 Mbps on the DL.

The next step for the GR-TR is to complete the integration of the individual components and the end-to-end connectivity of the 5G networks of the two MNOs in order to be able to begin the early trials in the controlled environment provided by the Ford Otosan plant. Once the initial set of tests demonstrate promising results, the trials will commence at the border region.

Table 1: 5G network performance results for stationary users

LOCATION	**Peak DL/UL**	**DL/UL Statistics [X% of total samples > Y Mbps] OR [Average]**	**Latency**
Ford Otosan	638 Mbps / 97 Mbps	DL: 90% >100Mbps UL: 87% >25Mbps	Min 16msec Avg 24msec
Ipsala	862 Mbps / 159 Mbps	DL: 88% >100Mbps UL: 94% >25Mbps	Min 12msec Avg 21msec
Kipoi	716 Mpbs/ 71 Mbps	DL: Avg: 553Mbps UL: Avg: 44 Mbps	Min 15msec Avg 21msec

VIII. Summary and Future Work

As of Q2 2021, 5G networks have been deployed at the Ipsala-Kipoi border, which have been validated to offer the performance required for the user stories. Following the integration between the vehicles, the OBUs/RSUs and the applications, the corridor is ready for the trial phase, which will end in Q1 2022, with possibly a large demo event to showcase the results and achievements of the activities.

Acknowledgement

This work has been supported by the European Union's Horizon 2020 5G-MOBIX project under the Grant Agreement No 825496. The authors also would like to thank *Emanuel Sousa* from Centro de Computação Gráfica (CCG of Portugal) for Figure 3-5.

References

[1] https://www.sae.org/standards/content/j3016_201806

[2] Naudts, D., Maglogiannis, V., Hadiwardoyo, S., Van den Akker, D., Vanneste, S., Mercelis, S, Hellinckx, P., Lannoo, B., Marquez-Barja, J., Moerman, I. "Vehicular Communication Management Framework: A Flexible Hybrid Connectivity Platform for CCAM Services". MDPI Future Internet, 13(3), pp. 81, 2021.

[3] H2020 ICT-18-2018 5G-MOBIX, https://www.5g-mobix.com/

[4] 3GPP TS22.186, Technical Specification, "Enhancement of 3GPP support for V2X scenarios; Stage 1", v16.2.0, June 2019.

[5] 3GPP TDoc RP-161249: Architecture configuration options for NR