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Pastor Figueroa, Giancarlo; Mutafulungwa, Edward; Costa Requena, Jose; Li, Xuebing; El Marai, Oussama; Saba, Norshahida; Zhanabatyrova, Aziza; Xiao, Yu; Mustonen, Timo ; Myrsky, Matthieu; Lammi, Lauri; Hamid, Umar Zakir Abdul; Boavida, Marta; Catalano, Sergio; Park, Hyunbin; Vikberg, Pyy; Lyytikäinen, Viljami

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*Published in:*

Proceedings of IEEE 93rd Vehicular Technology Conference, VTC 2021

*DOI:*

[10.1109/VTC2021-Spring51267.2021.9448788](https://doi.org/10.1109/VTC2021-Spring51267.2021.9448788)

Published: 15/06/2021

*Document Version*

Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

*Please cite the original version:*

Pastor Figueroa, G., Mutafulungwa, E., Costa Requena, J., Li, X., El Marai, O., Saba, N., Zhanabatyrova, A., Xiao, Y., Mustonen, T., Myrsky, M., Lammi, L., Hamid, U. Z. A., Boavida, M., Catalano, S., Park, H., Vikberg, P., & Lyytikäinen, V. (2021). Qualifying 5G SA for L4 Automated Vehicles in a Multi-PLMN Experimental Testbed. In *Proceedings of IEEE 93rd Vehicular Technology Conference, VTC 2021* Article 9448788 (IEEE Vehicular Technology Conference). IEEE. <https://doi.org/10.1109/VTC2021-Spring51267.2021.9448788>

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# Qualifying 5G SA for L4 Automated Vehicles in a Multi-PLMN Experimental Testbed

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**Abstract**—National roaming, multi-SIM and edge computing constitute key 5G technologies for the cooperative perception and remote driving of L4 (automated) vehicles. To that end, this article reports our progress to trial these technologies at the multi-PLMN experimental 5G SA testbed of Aalto University, Finland. Overall, the objective is to qualify 5G as a core connectivity for connected, cooperative and automated mobility.

**Index Terms**—5G SA mode, L4 vehicle, national roaming, multi-PLMN, edge computing

## I. INTRODUCTION

In 2018, the European Commission opened the ICT-18-2018 call for funded projects. The challenge of this call was to qualify 5G as core technology for the higher automation levels, L4 and L5, defined by the SAE International [1]. Moreover, the funded projects should demonstrate the benefits of 5G in support to new business models that would encourage private investments. Overall, the funded projects, via cross-border trials, should support the realisation of the European Commission’s strategic objective of having all major transport paths covered by 5G in 2025.

One of the funded projects is 5G-MOBIX, which brings two cross-border corridors (Spain-Portugal and Greece-Turkey) and six (local) trial sites (Finland, the Netherlands, Germany, France, South Korea and China) [2]. This work reports the progress of the Finland trial site, which builds on top of the 5G testbed by the national 5G-FORCE project [3].

The 5G-FORCE project develops and evaluates cutting-edge 5G technologies on radio, networking, machine learning and security to facilitate experiments targeting at various verticals. The project is led by Aalto University in cooperation with local telecom operators and vendors, SMEs (small and medium-sized enterprises), research and academic institutions, and the frequency and road regulator of Finland. In the Otaniemi campus area, Aalto University holds licenses to manage up to ten public land mobile networks (PLMN), of which two will be used in 5G-MOBIX.

The paper is organized as follows. Section 2 introduces our two use cases with requirements, which will motivate the key



Fig. 1: The pre-trials of the Finland trial site: 5G enabling automated driving in open roads with mixed traffic under challenging Nordic winter conditions, Otaniemi, February 2021.

5G technologies discussed in Section 3. Finally, Section 4 will brief our coming trialing plans with a timeline.

## II. TRIALING OVERVIEW

As one of the designated trial sites for the 5G-MOBIX project, the Finland trial site is evaluating 5G technologies within the context of two use cases [4]. These are described briefly below (see also Fig. 1).

### A. Remote Driving in Redundant Network Environment

The remote driving of an L4 (automated) vehicle (see Fig. 2(a)) is enabled by a Vehicle-to-Network (V2N) connection between the vehicular On-Board Unit (OBU) (see Figs. 2(b)-(c)) and a remote server hosting remote driving applications used by the remote human operator at the Remote Control Centre (RCC) [5]. The V2N connection transfers the vehicular sensor data and video feed from the vehicle to the remote human operator (in the uplink direction). The video and sensor data provides the human operator a “driver’s view” allowing the human operator to send appropriate command messages (e.g., command trajectories) back to the L4 vehicle (in the downlink direction). The remote control or driving of a vehicle presents stringent requirements on connection between the vehicle and the RCC. It is essential to ensure availability of the V2N and the uplink capacity is guaranteed for the transmission of the data feeds from the vehicle for demanding streams including LIDAR (Light Detection and Ranging) and high definition (HD) video. Furthermore, the whole control loop needs to be kept tight. To that end, the accumulated



(a) Automated test vehicle. (b) 5G mobile multi-channel router. (c) 5G antennas on the vehicle's roof.

Fig. 2: The automated test vehicle “AVA” by Sensible 4, the 5G mobile multi-channel router w24h-S (OBU) by Goodmill Systems, and the installation of the four 5G antennas on the roof of the automated test vehicle.

delay from: sensor reading, sensor data processing, uplink, data visualization, manual control, control signal reading, downlink, and control signal processing to control must be kept low for direct control (depending on speed and dynamics of the vehicle). In the Finland trial site, the remote driving use case leverages the fact that the L4 vehicle trajectory is in an area with overlapping coverage of multiple PLMNs that emulate a multi-network environment in a same country or in cross-border areas. In practice, a vehicle's home PLMN (original serving network) may have locations with poor or non-existent coverage, or then experience V2N connection degradation or failure due to overloading, network failure and so on. The remote driving trials in the Finland site will test remote driving in an environment with two 5G networks to analyse the impact on remote driving use case when the vehicle seamlessly switches (or simultaneously utilises) both networks (see Fig. 3(a)).

#### B. Cooperative Perception of the Environment

Automation is about independence. To that end, cooperative perception of the environment expands the awareness thus automation level of vehicles via enhanced positioning, localization and labeling [5]. Typical data to achieve such cooperation includes HD video and LIDAR from the surrounding vehicles and road infrastructure. On the other hand, the common computing tasks consist of computer vision, data aggregation and map building. Therefore, cooperative perception demands major computing resources from the network. However, vehicles will cross multiple PLMNs, and computing systems within these. Moreover, each operator could deploy its own policies and technology stack. Consequently, services migration is critical. In the Finland trial site, the cooperative perception is trialed as part of an extended sensors user case that constitutes two developments, namely, a crowdsourced HD mapping application and edge service discovery system that enables a UE (user equipment, e.g., vehicle) to discover a Multi-access Edge Computing (MEC) resources in a visited 5G network (see Fig. 3(a)). The HD mapping application is designed to create and efficiently update the 3D map of the road environment in a timely manner. This HD mapping applications runs on the MEC to ensure timely updating and sharing of the maps. This places demand on capacity and

latency in both uplink and downlink directions. Moreover, it introduces requirement for flexible availability of edge computing resources even when vehicle is in a visited PLMN.

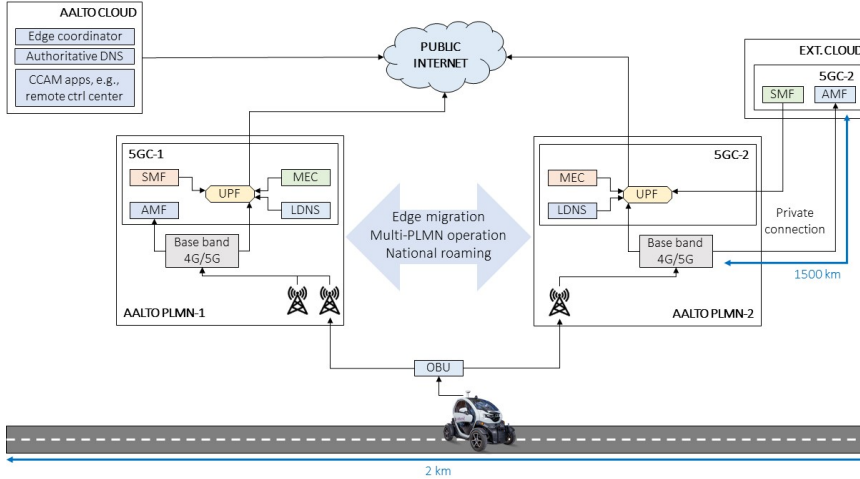
### III. KEY 5G TECHNOLOGIES AND EARLY RESULTS

#### A. National Roaming (5G SA Mode)

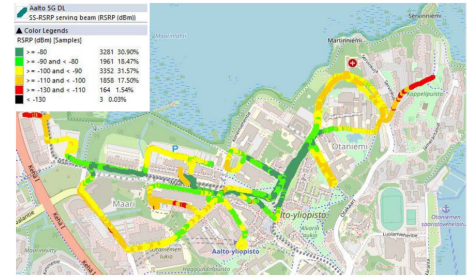
The 5G-MOBIX project is evaluating different network interconnectivity architectures and roaming approaches for 5G Non-Standalone (NSA) networks in realistic cross-border environments with interfacing network operators from different countries. The target is to identify architectures and solutions that are most suited for the stringent performance (e.g., latency) and service continuity demands of connected, cooperative and automated mobility (CCAM) applications in a cross-border environment. As complement to this, the Finland trial site of Fig. 3(a) consisting of two PLMNs provides an environment for early evaluation of interconnection and roaming approaches for 5G Standalone (SA) networks which are still at a nascent phase [6]. Additionally, the Finland trial site allows for research on the benefits of the 5G Service Based Architecture (SBA), in this case investigating the benefits of local User Plane Function (UPF) breakout for a 5G Core (5GC) with the UPF deployed on the edge (close to the road) and control plane network functions (NFs) deployed in remote servers (more than 1500 km away).

#### B. Multi-PLMN Operation

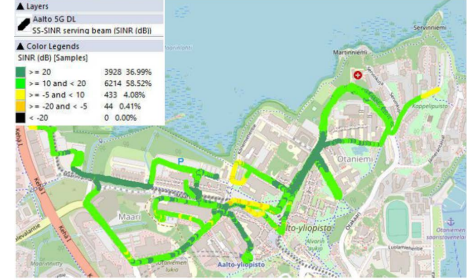
Vehicles typically traverse areas with overlapping coverage from multiple PLMNs (e.g., by operators in the same country) or transit between two PLMN coverage areas (e.g., cross-border). In the multi-PLMN scenario, the vehicle's home PLMN (original serving network) may have areas with poor QoS (Quality of Service), performance degradation or outage due to overloading, network failure, and so on. To that end, the Finland trial site of Fig. 3(a) with two PLMNs offers an environment for evaluation of multi-PLMN connectivity approaches, whereby, the vehicle utilises OBUs with multiple SIMs (subscriber identification modules) or multi-SIM ports (one for attaching to each PLMN). This enables the vehicle to either selectively and seamlessly switch between two PLMNs or leverage bonding through dual (simultaneous connectivity) over two PLMNs. Experimental benchmarking is targeted



(a) Two PLMNs, each configured in 5G SA mode and equipped with edge computing in 5GC. The UPFs are deployed on the edge (close to the road). However, the control plane NFs are deployed one locally and the other remotely (in a third-party cloud). The testbed also includes a cloud, which hosts the RCC and the edge migration coordination.



(b) Drive test result: coverage.



(c) Drive test result: signal quality.

Fig. 3: The Finland trial site.

to compare performance conventional roaming approaches (including 5G SA roaming mentioned previously). Proprietary multi-SIM UE-side solutions have been well established, the interest in multi-SIM approaches in this case is further motivated by 3GPP Release 17 work items on standardised RAN support for multi-SIM UEs [7], [8] and increased use of embedded SIMs (eSIMs) in vehicles with support of GSMA's specifications for Remote (OTA) SIM Provisioning of MNO (mobile network operator) profiles to eSIMs [9].

### C. Edge Computing in 5GC

The automated vehicles may need to continuously offload demanding computing tasks to the network. While traversing areas with multiple PLMNs, besides the network performance variability, the offloaded tasks may require different levels of computing resources or the computing servers in the network may be overloaded. To that end, the Finland trial site of Fig. 3(a), with each PLMN being equipped with its own edge computing server in the 5GC, offers an environment for experimental benchmarking of service migration approaches. In the Finland trial site, the proposed solution is a DNS-based service migration protocol which includes dynamic registration of automated vehicles and LDNS-based discovery of MECs. The service migration enables a smart coordination, whereby, the computing tasks (and data) to seamlessly switch between two MECs. The typical computing tasks consist of generation and sharing of HD maps based on HD video and LIDAR data. Overall, the goal is to perform a cooperative perception of the environment for safety purposes [5]. Moreover, the interest in edge computing in 5GC is motivated by 3GPP Release 17 work on enhancement of support [10] and associated security aspects [11].

### IV. NEXT STEPS

The Finland trial site is currently being upgraded and configured to SA, and the developed solutions are being tested. Figs. 3(b)-(c) depict some of the drive test results for PLMN-1 on the roads designated for the trials. The next steps include the local trials to be completed by Q1 2021. The early results and measurements collected from these trials will be publicly presented in a demo video. Future work includes the integration and evaluation of some of the developed solutions in two 5G cross-border corridors by Q4 2021, one between Spain and Portugal, and the other between Greece and Turkey.

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