# Demonstration and Evaluation of Cross-Border Service Continuity for Connected and Automated Mobility (CAM) Services


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***Abstract*—Connected and Automated Mobility (CAM) services like Tele-operated Driving, High-Definition (HD) Mapping, and Anticipated Cooperative Collision Avoidance (ACCA) require uninterrupted network connectivity. This is a particular challenge in Europe where national borders can be passed without stopping while Mobile Network Operators (MNOs) usually only serve a single country. Today, vehicles keep the connection to the MNO of the country they come from until the signal is lost and then search and register with an MNO in the country they enter. This causes several minutes of service interruption, which is not acceptable for the aforementioned CAM services.**

**Therefore, 5GCroCo, together with the other Horizon 2020 ICT-18 and ICT-53 projects, conducts research on cross-border/-MNO handovers to enable seamless service continuity when crossing borders. For this purpose a large-scale test and trial network was deployed in the Metz-Merzig-Luxembourg 5G Corridor. This paper presents results from that setup where the HD Mapping and ACCA use cases experienced hardly any service degradation when transitioning between the two networks.**



***Index Terms*—Cross-border handover, Cross-MNO handover, MEC, trial results**


## I. Introduction

Mobile radio network service interruption when crossing country borders in Europe is unpleasant as it causes, for example, voice calls to be dropped. For future CAM services like Tele-operated Driving, HD Mapping, and ACCA such interruptions are unacceptable as, especially for Tele-operated driving, they would lead to an immediate abort of the service, bringing the vehicle to a safe stop and potentially preventing its journey to continue. For HD Mapping, it would result in areas where the driving vehicle's assistance or automation system could not exploit the benefit of up-to-date HD maps which would provide precise geo-referenced information about lane markings to support interpretation of on-board sensor readings. Developers would need to implement functionalities to detect such areas of interrupted coverage to trigger downloads before the area is entered. Such QoS prediction algorithms are also in scope of the 5GCroCo project, but not of this paper. For ACCA, a lack of cross-border service continuity would mean that a service that is deployed to improve the safety of vehicles of any level of automation cannot be used in border regions as vehicles are prevented from sending or receiving warnings about road hazards. Details of the three use cases are described in [1] and [2], and their Key Performance Indicator (KPI) requirements in [3]. Enabling cross-border/-MNO handover between networks in different countries ensures that the aforementioned and other CAM services can be delivered in border regions of which many are present in Europe.

In this paper, we present the results of trials carried out near Remerschen, Luxembourg, that tested the performance of CAM service continuity across two different Public Land Mobile Networks (PLMNs), with cross-border/-MNO handover enabled between them. These trials were conducted in the European 5GCroCo project [4].

Following this introduction, Section II presents a technical overview of cross-border/-MNO handover. Section III discusses the trial scenario and collected results, and the paper is concluded with Section IV.

## II. Cross-border/-MNO Handover

When moving between two PLMNs, vehicles can experience connection interruptions that can last up to minutes until the modem finds and attaches to a new network and the data connections are restored [5]. Several solutions exist to provide service continuity across different mobile networks, and in this study we deploy one in particular, that is cross-border/-MNO handover, by establishing the S10 interface between Mobility Management Entities (MMEs) of different MNOs [6]. Cross-border handover should be expected to achieve service continuity if there are no radio coverage gaps between mobile networks across different countries. Figure 1 shows the architecture of this solution, in which two networks, Home and Visited, support cross-MNO handover. The MMEs of the two networks are connected through the S10 interface, and the roaming interfaces S8 between Packet Data Network Gateway (P-GW) in the Home network and Serving Gateway (S-GW) in the Visited network, and S6a between the Home Subscriber Server (HSS) in the Home network and the MME in the

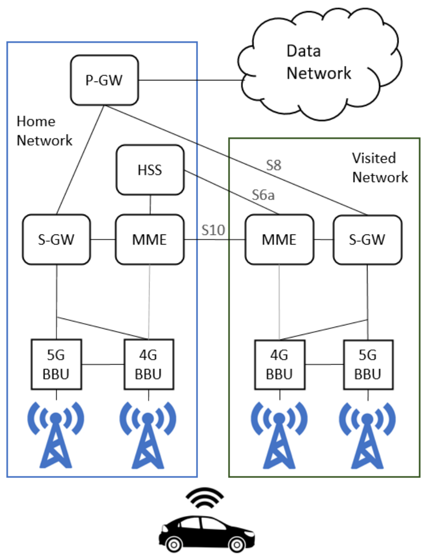



Fig. 1: Architecture of Two Networks with Supported Cross-MNO Handover

TABLE I: Network Radio Configurations for Trials

| Configuration | 5G | 4G |
|---|---|---|
| Band (frequency) | n78 (3.7 GHz) | B28 (700 MHz) |
| Duplex mode | TDD 4:1 (DDDSU) | FDD |
| Bandwidth | 40 MHz | 2 x 10 MHz |
| Effective DL bandwidth | $\sim$ 32 MHz | 10 MHz |

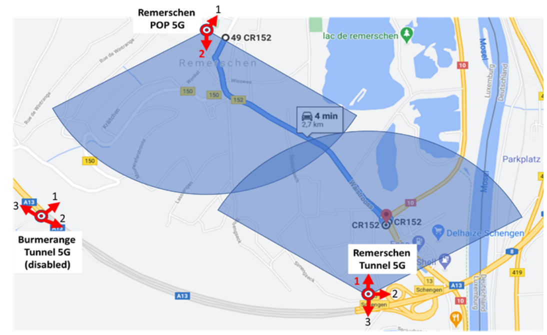



Fig. 2: Radio Coverage of Deployed Networks in Test Site

Visited network are established. With these connections in place, a user can be handed over between the networks, as in a handover between two MMEs in the same network. Home-routed roaming is used in this architecture, which results in maintaining the same P-GW connection from the home network to a data network after the handover is completed. It should be noted that in real-world scenarios this solution can face operational challenges, particularly in exposing the required information and configurations between involved MNOs to enable the handover procedure between cells in two different networks. Furthermore, legal requirements like lawful interception might require further attention.

## III. Scenario and Trials Results

### A. Scenario

The trials were conducted on a rural road between the towns of Remerschen and Schengen in Luxembourg, near the border between Luxembourg and Germany. Two non-standalone (NSA) 5G networks were deployed with neighbouring radio coverage as shown in Figure 2. The user plane nodes of the Evolved Packet Core, namely the S-GW and P-GW, of the two networks are deployed in Luxembourg City, and the control plane nodes are located in an Ericsson lab in Aachen, Germany. The radio configurations for both networks are identical and provided in Table I. The n78 (3.7 GHz) band is used for 5G coverage with 40 MHz bandwidth, and Time Division Duplex (TDD) with 4:1 ratio between downlink and uplink, resulting in a 32 MHz effective bandwidth for downlink. Band B28 (700 MHz) is used for the 4G anchor cells, with Frequency Division Duplex (FDD) using 10 MHz bandwidth for each direction.

Figure 3 shows the network architecture used for the trials. For comparison of Mobile Edge Computing/Cloud (MEC) hosting versus public Internet hosting, all backend services are deployed in both. Cross-border/-MNO handover does not trigger a change of the used MEC host. This will be evaluated at a later project stage. For each experiment, the vehicle drove along a 1.4 km route as shown in Figure 2, back and forth multiple times at 30 km/h.

### B. Results

The radio channel quality during handover was measured. Figure 4 shows the signal-to-interference-plus-noise ratio (SINR) of the 5G and 4G anchor connections and the serving network reported by the modem for both connections. The figure shows that the 5G SINR fluctuates more than the 4G anchor, which is expected as the 3.7 GHz band has higher

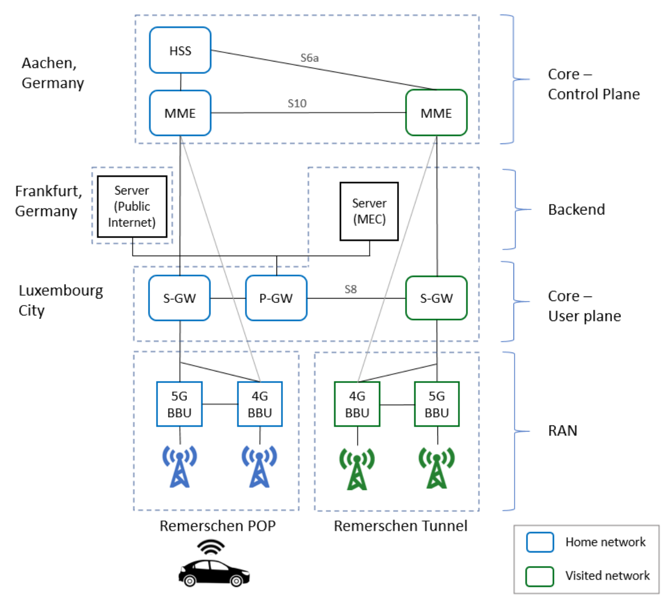



Fig. 3: Architecture of Deployed Networks for Trials

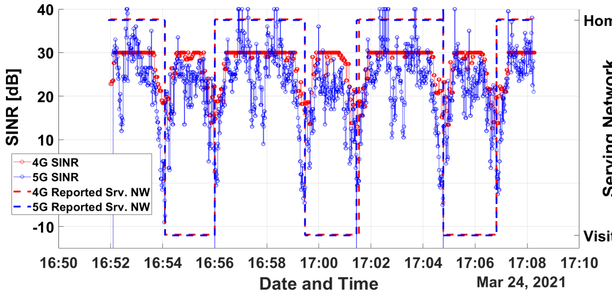
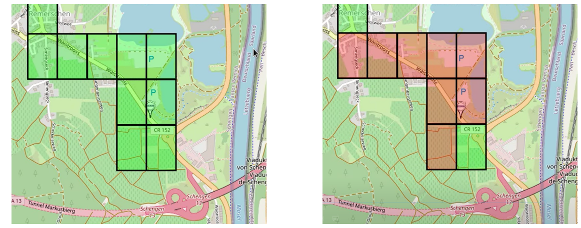



Fig. 4: SINR of 5G and 4G Anchor During Handover



(a) Cross-MNO Handover Enabled

(b) Cross-MNO Handover Disabled

Fig. 6: HD Map Service Continuity across PLMN Borders

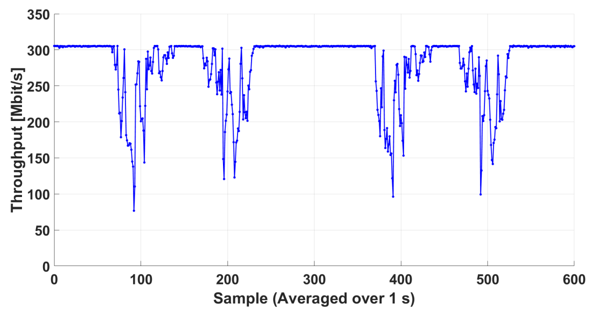



Fig. 5: Maximum 5G Throughput When Driving Two Times Back and Forward

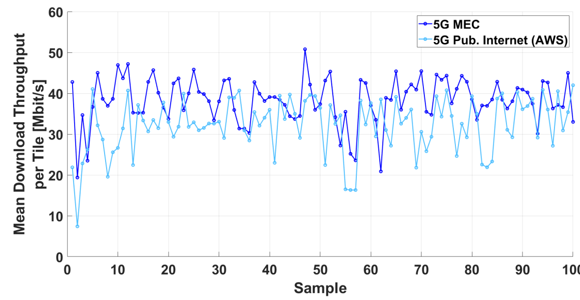



Fig. 7: Mean Throughput for each of 100 Downloaded Tiles from MEC Host and Public Internet Host in Frankfurt

attenuation than the 700 MHz band. It is also seen that there are no 4G interruptions during the handovers and only very short ones for 5G (indicated by large negative values in SINR near the handover points). The minimum recorded SINR value during handovers for 5G was $-5$ dB and $12.5$ dB for 4G. The two cell sectors involved are operating at exactly the same frequency and bandwidth which can be the situation as different countries usually provide all available spectrum to MNOs. In reality, bandwidths on both sides of the border could be different, so that one MNO in one country interferes with multiple MNOs in the other one.

Figure 5 shows the maximum download throughput measured for the 5G connection by sending User Datagram Protocol (UDP) traffic at higher rate than the maximum downlink channel capacity. The maximum measured capacity of 305 Mbit/s corresponds to 9.5 (bit/s)/Hz peak spectral efficiency according to 32 MHz in Table I. At the cell edge the throughput drops to values between 100 Mbit/s and 125 Mbit/s. This is expected for every cell edge regardless if it is between two cells in the same or in different PLMNs. The cross-border/-MNO handover stops the decrease of channel quality and throughput as the distance from the serving cell increases. After the handover is completed, like with every other handover, radio channel quality and throughput will start increasing again as the vehicle moves towards the new serving cell.

Cross-border handover allowed for seamless service continuity for HD map download, as can be seen in Figure 6a. The green tiles indicate successful downloaded, as true for all tiles when cross-border/-MNO handover was enabled. When cross-border handover was disabled, the resulting service interruption lasted for up to a minute, resulting in several tile downloads to fail, as shown in Figure 6b, where a red tile indicates a failed download.

The mean throughput for each HD map tile download was calculated by dividing the tile size by the download time, and the results are shown in Figure 7 for both MEC- and public Internet hosted content. The tiles are all around 6.7 MBytes large and their download is completed way before the maximum throughput of 305 Mbit/s is reached. The highest measured mean throughputs of 50 Mbit/s correspond to approximately 1 s tile download time. The average over all samples is 37.6 Mbit/s and 32.3 Mbit/s for MEC and public Internet hosting, respectively. The difference results from 5 ms lower delay towards the MEC host allowing the Transmission Control Protocol (TCP) to converge faster towards the maximum throughput. The effect of changing radio channel condition, shown in Figure 5, is not directly visible in the mean tile throughputs. It is masked by other effects like the number of concurring tile downloads and variations in TCP performance for short-lived data flows [7] [8].

Figure 8 shows the average throughput over all mean throughputs for all downloaded tiles. Besides previously described 5G results, also 4G results are shown for comparison. The 4G network operates at 10 MHz bandwidth which is around a factor of three lower than that for 5G. The maximum throughput for 4G measured with UDP traffic is 46 Mbit/s and therefore more than six times lower. The improvement in tile

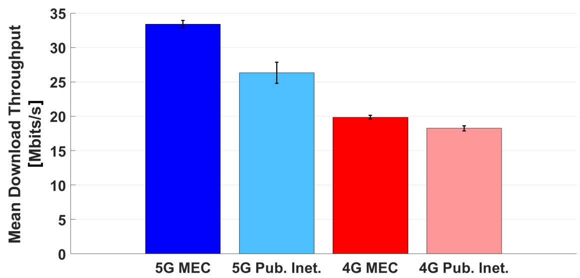



Fig. 8: Mean Tile Download Throughput over 5G and 4G with MEC- and Public Internet Hosting

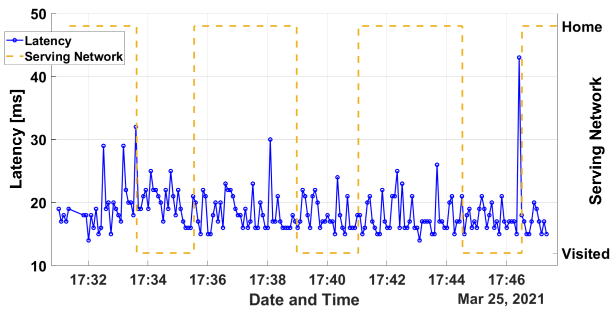



Fig. 9: Latency of ACCA Messages Delivery

download throughput is only around 80% as the maximum throughput is not reached before finishing the tile download and the reduced round trip time is the main factor resulting in improved 5G performance.

In the ACCA use case, hazard warning messages are sent from the car to a server approximately every 5 seconds. Some randomness was added to prevent unwanted correlation to periodic network processes like the TDD frame. The server processes the messages and relays them back to the same car that sent them, which then measures the Application Level Latency by calculating the difference between the time when each message was sent and the time when it was received. Figure 9 shows the measured Application Level Latency values between sending and receiving a message. It is seen that most messages did not experience any noticeable delay from the handover, with an average latency value of 18.4 ms, except for two messages which were sent during the handover procedure, for which the latency was 32 ms and 43 ms. This is only slightly higher than some other packets that experienced 5 ms extra delay from retransmissions and well below the 1 s KPI requirement specified in [3]. Cross-border/-MNO handover allowed hazard warning messages to be delivered reliably even when moving between networks multiple times. In this single vehicle scenario it was a rare event to have a message transmission happening at the same time as a handover, but once many vehicles use the system it becomes likely that at least some vehicles are conducting a handover during transmissions.

Further details about the presented results and the analysis of KPIs can be found in [9].

## IV. Conclusion

CAM services can not tolerate long service interruptions as they could lead to operational and safety problems. Such interruptions can be experienced when a UE leaves the coverage area of a network, which presents a challenge for CAM services as vehicles can frequently move between PLMNs operated by different MNOs, particularly at country borders. This paper showed that cross-border service continuity was successfully demonstrated for the HD Mapping and ACCA use cases in the 5GCroCo project by deploying cross-border/-MNO handover. Service interruption in the range of minutes was successfully prevented by enabling such handover. The impact of the handover on the evaluated use cases HD Mapping and ACCA is very small. For the HD Mapping use case it cannot be distinguished from other effects leading to varying throughput performance. For ACCA, increased delays can occur in the unfortunate but also unlikely event that messages are sent or received exactly at the time when handover occurs. As a next step, Tele-operated Driving use case trials will be conducted to assess the impact of cross-border/-MNO handover on video streaming.

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