Performance and Service Continuity of HD Map Downloads in MEC-Enabled Cross-Border Mobile Radio Networks

Mazen Abdel Latif, Maciej Muehleisen
Ericsson GmbH
Herzogenrath, Germany

Magnus Castell, Roland Gustafsson,
Daniel Mcgillivray
Ericsson AB
Gothenburg, Sweden

Ulf Larson, Johan Löfhede, Mikael Nilsson,
Henrik Segesten, Hongxia Zhao
Volvo Car Corporation
Gothenburg, Sweden

***Abstract*—Cooperative, Connected and Automated Mobility (CCAM) will enrich assisted and automated driving by exchange of information among vehicles (V2V), as well as between vehicles and the network, commonly also called ”cloud” or ”backend”, (V2N). HD Mapping is such a V2N use case where vehicles obtain up-to-date information about the roads they drive on. This includes lane markings and dedication of lanes, to e.g. better distinguish between parking vehicles and vehicles waiting at a traffic light, and road signs like speed limits. Such information can become outdated, e.g. due to road constructions, and vehicles therefore download it on-the-fly before entering corresponding areas.**

Such HD map tile downloads must be seamlessly enabled and especially should not be interrupted when crossing a country border and with that also switching between different Mobile Network Operators (MNOs). It is furthermore a candidate service for Mobile Edge Cloud (MEC) deployment, as it might benefit from faster HD map tile transmissions from reduced round trip times (RTTs) enabled by MEC-hosting.

This paper evaluates the performance gain MEC-hosting has over hosting on the public Internet and shows how seamless cross-MNO service continuity is achieved by enabling handover across different MNOs. Results from corresponding trials at the AstaZero automotive test ground are presented showing no noticeable effect on use case performance when handing over between the two mobile networks. Furthermore, it is shown that bulk-data transmission use cases like HD Mapping, using webserver download with TCP, benefit from reduced RTT from MEC-hosting through shorter HD map tile download times. In our setup 15 ms reduced RTT resulted in 15% shorter download times.

***Index Terms*—MEC, Edge Computing, HD Mapping, Inter-PLMN handover, cross-border, cross-MNO, trial results, CCAM**

I. INTRODUCTION

High-Definition (HD) maps provide valuable extra information to support the processing of on-board sensor readings used for assisted and automated driving decisions. Such maps contain lane-accurate road representations and further information like road signs to be obeyed on the road segment. With this, simple tasks like determining the speed limit, and more complex ones, like distinguishing between parking cars and cars waiting for a light to turn green, can be supported. Such information is semi-static as, for example, lanes get repainted or changed by road construction works. It is therefore common that up-to-date HD map content is downloaded before entering the corresponding area.

The 5GCroCo project [1] focuses on Cooperative, Connected and Automated Mobility (CCAM) provided through 5G networks with seamless continuity across country borders and Mobile Network Operators (MNOs) serving each country. This implies that downloading up-to-date HD map content must also work when traveling across a country border and connecting to a different MNO in the visited country.

This paper presents results from HD Mapping use case trials conducted at the AstaZero test site in September 2020 in context of the 5GCroCo project. Besides seamless service continuity across two networks that could be in two different countries, the performance difference between public Internet and Mobile Edge Cloud (MEC) server hosting was also evaluated.

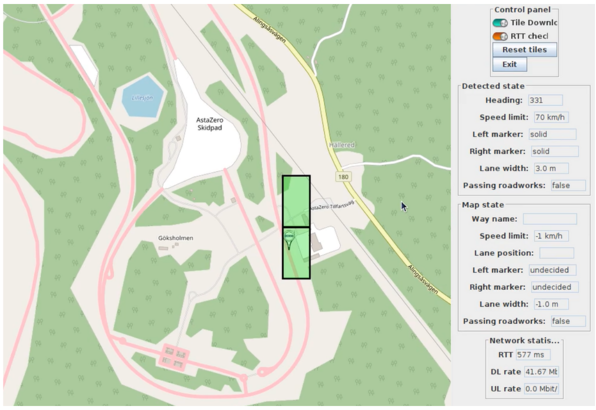
This paper is organized in the following way: Section II presents and discusses relevant work in the field of MEC and Inter-Public-Land-Mobile-Network (Inter-PLMN) handover. Section III provides more details about the HD Mapping use case and its implementation used for these trials. Section IV describes the effects that determine the performance results which are presented in Section V together with a description of the scenarios in which they were obtained. Section VI concludes this paper.

II. RELATED WORK

Technically, HD map delivery is realized through webservices using TCP. This section therefore focuses on related work on TCP performance in edge-enabled mobile radio networks. In [2] a comprehensive overview of effects determining TCP performance in 5G networks is studied. These networks are characterizes by their low end-to-end delay, also achieved through edge computing, and, in case of high frequency bands, of small cells causing fast throughput fluctuations for mobile users. In [3] edge vs. central server TCP performance is evaluated in simulations with realistic scenarios. It is confirmed that the reduced latency of edge hosting has a positive effect on TCP performance. The focus was on performance impairments due to fluctuating TCP throughput where lower latencies allowed faster adaptation. Studies mentioned before put their focus on long-lived TCP flows resulting from transmission of files that are large compared to available maximum throughput. Such TCP flows spent most of the time in Congestion Avoidance Phase. In [4] short-lived TCP flows are analyzed, as applicable for HD maps that consist of small to medium sized files compared to the high maximum throughput provided by 5G networks. In this case TCP Slow Start Phase behaviour dominates the overall performance. The study confirms our finding that reduced end-to-end latencies improve performance of short-lived TCP flows by comparing file download times in different scenarios. Varying latencies were achieved by comparing 3.5G to 4G network performance and introducing different amounts of background traffic. Our work builds upon the studies mentioned above, but to the best of our knowledge none of them has systematically evaluated TCP performance for short-lived flows with focus on the impact the reduced latency of edge hosting in 5G networks has on file download times. We are not aware of any performance evaluation studies of TCP performance with handover between two mobile radio networks, as done in our study. We currently have no reason to believe that the impact on TCP performance from intra-network handover differs from the one encountered during normal inter-network handover, as studied in [5].

III. HIGH-DEFINITION MAP SYSTEM

Maps used in vehicles are divided into different layers. No commonly accepted naming conventions for these layers exist. This paper follows the terminology from [6] where Map Layer 1 contains road-accurate information enabling navigation while HD maps (Map Layer 2) also contain lane and road sign information. This especially includes centimeter-level accurate information about lane markings and curbs to precisely define the area a vehicle may drive on and the dedication of each lane (e.g. turning or going straight). Such information can become outdated quicker than SD maps, e.g. due to repainting or road works, and is therefore typically updated on-the-fly before entering the corresponding area. Different data formats for HD maps exist. It is common to divide it into rectangular tiles a few kilometers in size. Each tile is stored in a file with Uniform Resource Identifier (URI) to access it, e.g. through webservers or webservices. There is a lack of publicly available information about HD map tile files sizes. It especially depends on the covered area, amount of roads in that area and resolution of lane markings on these roads. Following [7] we estimate it to hundreds of kilobytes to tens of megabytes per tile and expect it to grow in the future.



Detected state
Heading: 331
Speed limit: 70 km/h
Left marker: solid
Right marker: solid
Lane width: 3.0 m
Passing roadworks: false

Map state
Way name:
Speed limit: -1 km/h
Lane position:
Left marker: undecided
Right marker: undecided
Lane width: -1.0 m
Passing roadworks: false

Network statis...
RTT 577 ms
DL rate 41.67 Mb
UL rate 0.0 Mbit/

Fig. 1. Graphical User Interface of HD Mapping Client Application

Within the 5GCroCo project a custom-made HD Mapping application was developed to allow different parametrizations for trials. The system includes a backend that contains the HD maps and is responsible for delivering them to clients and keeping them up-to-date, and a client that runs in the vehicle that can request map data related to the driving route and upload data if needed. Uploads are done to allow crowd-sourcing to keep HD map information up to date. Furthermore, is is also possible to inform a vehicle if another vehicle in front had just uploaded a HD map update so the following vehicle can immediately download the updated HD map tile. This paper only focuses on HD map tile downloads.

Tiles can be individually requested by the client based on its driving direction. Figure 1 shows the Graphical User Interface (GUI) of the developed HD map client and highlights the requested and downloaded map tiles. The map tiles must be delivered within a certain time limit, as the client must receive the requested tile before the car reaches that specific tile. However, the client should not request too many tiles in advance, because the planned route might change and that would result in too much unused downloaded data and wasted network resources. Therefore, the parameters visualized in Figure 2 can be configured at the client to influence HD map data delivery. The pin in the figure indicates the vehicle location. The parameters are:

- Tile size factor: dimensions of the requested tiles. Changing this parameter scales inversely with the tile dimensions
- Tile horizon: number of tiles requested ahead of current location
- Tile data padding: adds additional random bytes to the file containing the tile to emulate future increase of tile size e.g. due to higher resolution

IV. NETWORK FEATURES AND THEIR PERFORMANCE IMPACT

A. Role of Round Trip Time (RTT) for TCP Performance

HD map tile information is stored in files that are requested and provided using the Hypertext Transfer Protocol (HTTP) using the Transmission Control Protocol (TCP). Linux with Kernel version 4 was used on client and server with TCP

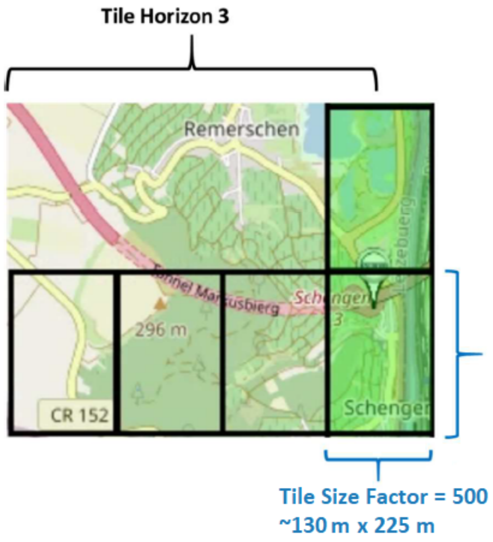


Fig. 2. Visualization of HD Mapping Client Application Parameters

CUBIC [8]. The basic behaviour of the Slow Start Algorithm of TCP CUBIC follows other TCP flavours. For every received acknowledgement the Congestion Window (CWND) size is increased by the amount of acknowledged data. For file downloads all except for the last packet carry Maximum Segment Size (MSS) amount of data, which is typically 1500 bytes with all headers on all layers. Linux sets the initial CWND size to 10 MSS meaning that 10 x 1500 B = 15 kB are initially transferred. Roughly after one round trip time (RTT) the acknowledgements for the 15 kB are received and the CWND size is increased to 20 MSS and 20 packets carrying 30 kB are sent and corresponding acknowledgements are received roughly after one RTT. This shows the large impact the RTT has during Slow Start Phase. With maximum throughputs in the range of tens or hundreds of megabits per second, the Slow Start Phase dominates the transmission time for files that are only few megabytes in size, as common for HD map tiles. A reduced RTT should therefore lead to reduced file download time as the instantaneous throughput, which directly corresponds to the CWND size, increases faster until the maximum throughput of the bottleneck link along the communication path is reached. The radio link is typically the bottleneck link. Its capacity is larger for 5G than 4G thanks to higher spectral efficiency and potentially more available spectrum. The smaller the file, the more impact the Slow Start Phase, and therefore the RTT, has on the time it takes to download the whole file. A MEC-hosted server normally provides a lower RTT than one hosted on the public Internet which should translate to shorter file transmission times. The RTT decides how fast the maximum throughput is reached. The magnitude of this maximum throughput per client, corresponding to the capacity of the bottleneck link, typically the radio link, is determined by spectrum bandwidth, spectral efficiency, radio channel quality, traffic from other clients and radio scheduler policy how to distribute the capacity among the clients.

B. *Cross-border Handover*

Besides evaluating the impact reduced RTT from MEC hosting has on TCP performance, we also evaluate service continuity across country borders. Some of the authors of this paper live in a border region and know from daily experience that it can take many seconds or even minutes to have acceptable cellular network quality when crossing a border. When crossing a border, the end-device usually holds on to the mobile radio network of the previous country for a long time resulting in a performance so bad, that not even a voice call is possible. At some point the end-device will finally lose connectivity to the mobile radio network of the previous country and start scanning in the current country and then register to a selected network according to selection policies. Such cross-border challenges and potential solutions are further described in [9].

A key solution is cross-border handover, given that cell deployment and radio configuration is done in a way that there is no radio coverage gap in the border region. Already the 3GPP requirements for 4G [10] stated that such Inter-PLMN handover should be possible. The S10 interface of the Evolved Packet Core (EPC) is normally used to enable handovers across different Mobility Management Entities (MMEs) of the same mobile radio network. Corresponding radio handovers are so-called S1-handovers in contrast to X2-handovers which cannot be used when the MME is changed during handover. The same procedure that is used within the same mobile radio network can also be used for Inter-PLMN handover across two mobile radio networks operated by different Mobile Network Operators (MNOs). The prerequisite is, that the roaming interfaces S6a between visited MME and Home Subscriber Server (HSS) and S8 between visited Serving Gateway (S-GW) and home Packet Data Network Gateway (P-GW) are in place. In addition to those, the S10 interface is established between the MMEs of the two mobile radio networks, as shown in Figure 3. While technically feasible, several operational challenges prevent this feature to be widely enabled. Within the same network the Operations Support System (OSS) is typically used to automatically discover and configure neighbor relations between cells to support the handover procedures. OSSs are currently not able to obtain such information across multiple MNOs. S6a and S8 interfaces are widely deployed for roaming using IP eXchange (IPX) networks intended for that purpose. Corresponding experience with S10 interfaces does not yet exist and especially security issues when connecting two MMEs, that each process potentially privacy-related information, must be evaluated before commercial operation.

After the Inter-PLMN handover, the P-GW of the previous mobile radio network is still used, corresponding to Home Routing if the previous mobile radio network was the home network of the end-device, according to its subscription on the SIM.

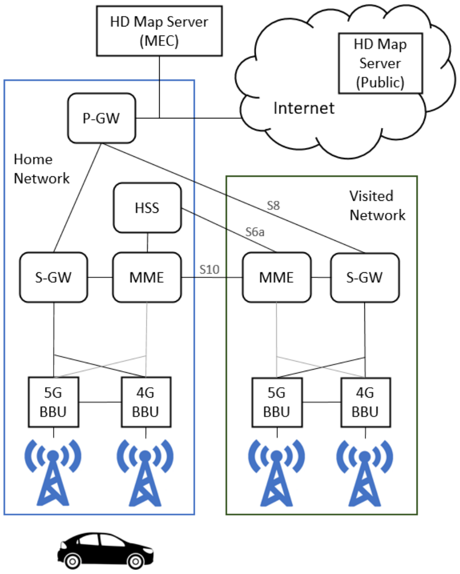


Fig. 3. Network Architecture Used for HD Mapping Trials

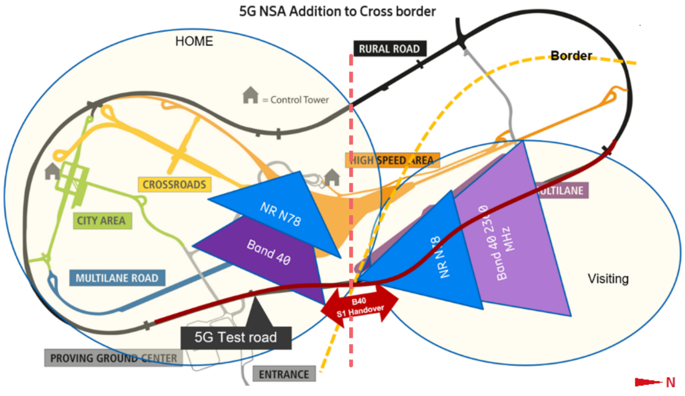


Fig. 4. AstaZero Test Track Topology and 5G Network Coverage

V. SCENARIO AND RESULTS

A. *Scenario*

Trials to test the performance of the HD Mapping use case were carried out in the AstaZero test ground close to Gothenburg, Sweden, where two non-standalone 5G networks were deployed. Figure 4 shows the road topology and network coverage of the test site. Band n78 (3.7 GHz) is used with 100 MHz bandwidth and Time Division Duplex (TDD) $2:1$ downlink to uplink ratio. Band B40 (2.3 GHz TDD) is used as 4G anchor with 20 MHz bandwidth and 1:1 downlink to uplink ratio. The core network connected to the site is located in an Ericsson lab in Gothenburg. An instance of the HD map server is deployed on a MEC host collocated with that core. For performance comparison, a public Internet hosted HD map server was deployed on Amazon Web Services (AWS) located in Frankfurt, Germany.

The performance was tested for both servers. During the test, a car drove back and forth at 70 km/h in the area where radio handover between the two networks takes place. HD Mapping client application parameters were configured as listed in Table I.

TABLE I
HD MAPPING CLIENT APPLICATION PARAMETERS FOR TRIALS

Parameter	**Value**
Tile Size Factor	500 (approx. 130 m x 225 m)
Tile Horizon	1
Download Tile Size [MB]	6.7

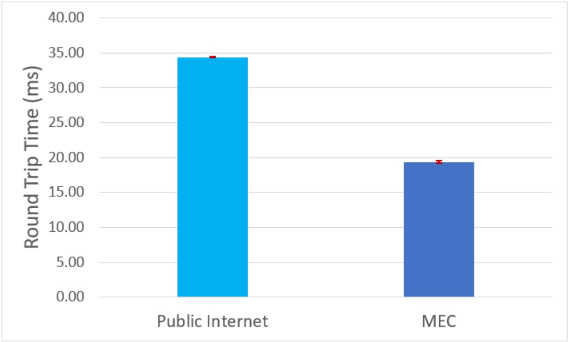


Fig. 5. Mean Values with 95% CIs of Ping RTT for Server Hosted on MEC and Public Internet

B. *Round Trip Time Tests*

As discussed in Section IV, the RTT has a large influence on the performance of HD map delivery over TCP. Therefore, to prepare for the performance tests, the mean RTT value of the network was measured. This was just done for one of the two networks, as they are identical. The RTT was measured using Internet Control Message Protocol (ICMP) Echo Messages from the *Ping* command. Measurements were conducted towards the MEC and a public Internet host used for HD map server hosting, as shown in Figure 3.

Figure 5 shows the mean values of the RTT measurements, along with 95% confidence interval (CI) for the mean based on repeating the test ten times. The mean RTT to the MEC server (19.4 ms) is on average 15 ms lower than the public Internet server (34.4 ms), due to the difference in the network distance between servers and client. The red caps in the figure indicate the 95% CI for the means. As seen, the caps are very small as they fell below 1% of the mean for both hosts. This indicates that the path on the public Internet does not introduce substantial further variance. A significant portion of the variance spans across a 5 ms interval according to the configured 2.5 ms duration of a download-upload passage of the TDD configuration with three 0.5 ms long Transmission Time Intervals (TTIs) for downlink, followed by one special TTI mostly used for downlink and then one TTI for uplink.

C. *Results*

HD map download was not interrupted along the entire run. Figure 6 shows the download throughput along the run and the recorded latitude of the car from GPS measurements.

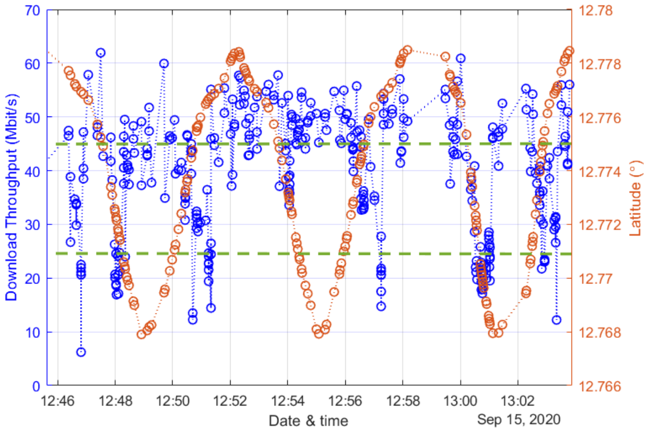


Fig. 6. HD Mapping Downlink Throughput and Geographical Latitude; Inter-PLMN Handovers Occurring Around 12.771° and 12.775° (Hysteresis)

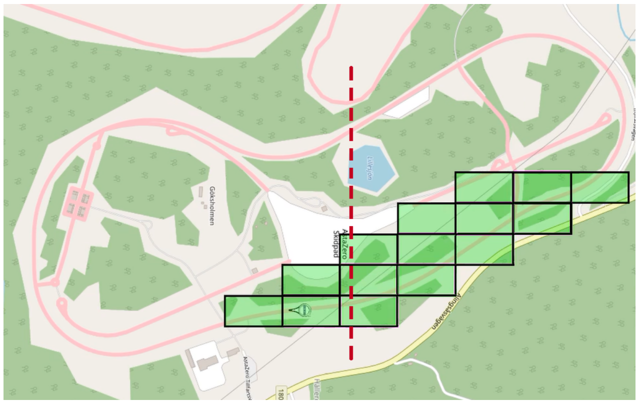


Fig. 7. Uninterrupted HD Map Tile Download Across two PLMNs

This throughput was measured for each downloaded HD map tile (marked by a circle in the figure) and corresponds to the 6.7 MByte tile size divided by the time required to download the tile. Throughput was higher than zero for the entire test duration showing that no download failed. The fluctuations correspond to changing radio channel conditions as the distance from the serving cell increases and decreases. Figure 7 shows a GUI screenshot from a run and highlights the successfully downloaded map tiles (green) along the run.

For comparison, Figure 8 shows the GUI from a trial run in a different test site of the 5GCroCo project in Luxembourg, close to the German border, where the Inter-PLMN feature can be disabled temporarily. The red tiles indicate that the download failed because the radio channel quality of the previously serving network (Luxembourg) was too bad to download the tile within acceptable duration of 10 s while the modem did not yet register with the new network (Germany). Interruption lasted for approximately 500 meters, which corresponds to one minute at 30 km/h.

Figure 9 shows the Cumulative Distribution Function (CDF) of the tile download times collected during the test runs at AstaZero, for MEC and public Internet server hosting. Mean values and their 95% CIs (5 runs) are also shown. The download time values and distribution show that the MEC-hosted server offers 15% lower average tile download time than the public Internet hosted one. This performance gain, as expected, is a consequence of the, on average, 15 ms lower RTT towards the MEC host. It allows the TCP Slow Start Algorithm to converge faster towards the maximum throughput, resulting in shorter tile download times.

Fig. 8. Interrupted HD Map Tile Download Across two PLMNs Recorded at Trial Site in Luxembourg with Inter-PLMN Handover Disabled Temporarily

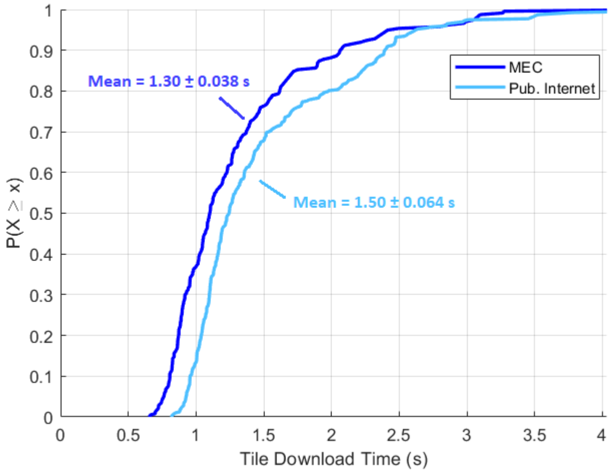


Fig. 9. Tile Download Duration

VI. Conclusion

On-demand download of HD map information plays an important role to support purely sensor based decisions for assisted and automated driving and should therefore not be interrupted at country borders. Solutions for seamless service continuity across country borders, namely Inter-PLMN handover, were therefore presented and evaluated in this paper. Corresponding trials were conducted at the AstaZero test track with a HD Map application developed in the 5GCroCo project. It was shown that Inter-PLMN handover can enable seamless service continuity across two mobile radio networks to allow uninterrupted download of HD map content. This scenario is particularly relevant for Europe, where borders can be passed without having to stop at checkpoints, but different MNOs operate the networks in adjacent countries.

Besides cross-border service continuity, it was also shown that bulk-download based applications, like HD map tile downloading, can benefit from the reduced RTT of MEC-hosting, as TCP can faster approach the maximum throughput during its Slow Start Phase.

This trial was done on a closed automotive test field and used Home Routed Roaming meaning that when served by the visited network, the MEC host of the home network was still used. This had no visible impact for this small-scale trial as the MEC host was very close to both networks. In reality, transition from Home Routed to Local Breakout Roaming would be used to assure MEC facilities in the serving network can be used. As a next step, trials will be done on public roads at the border between Luxembourg and Germany as well as France and Germany. Furthermore, a transition from Home Routed Roaming to Local Breakout Roaming will be done. We will also evolve the HD Mapping use case to obtain throughput predictions from the network to improve scheduling of HD map downloads.

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