Multi-MNO Predictive-QoS for Vehicular Applications

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Abstract: There are more and more 'connected' vehicles on the streets, and they run increasingly more safety critical applications. To meet the connectivity requirements of these vehicles, network providers need to not only ensure the quality of service (QoS) but also to predict any upcoming changes in the QoS and inform the vehicle(s) about it. This concept is called predictive-QoS (P-QoS) and is being heavily discussed in various organizations, e.g. 3GPP, 5GAA.

To allow a seamless service to vehicles, some issues such as handling multiple mobile network operators (MNOs), while roaming for example, need to be addressed. For example, if prediction about QoS is available for multiple MNOs simultaneously for a specific area, this could be beneficial for the vehicle in selecting an MNO for further operation in specific scenarios, e.g. roaming, driving through an area where the current MNO is predictive to have poor QoS.

In this paper, we introduce an entity, that takes the QoS prediction about multiple MNOs and makes decision about how to manage the connectivity in a vehicle, e.g. selecting a set of MNOs for further connectivity including a preference for each, making an "MNO usage timeplan" based on the QoS comparison etc.

1 INTRODUCTION

Connectivity is becoming increasingly important for automotive applications that serve many functions in vehicles such as infotainment, safety, automation etc. The number of vehicles that rely on connectivity is on a constant rise. Therefore, the reliability as well as predictability of the whole connectivity ecosystem, especially the communication technology itself, is a major consideration for vehicle manufacturers. That is why, the automotive and telecommunications industry have been placing emphasis on increasing the reliability and coverage of the connectivity and additionally, on predicting any upcoming degradations or changes to better prepare the vehicles as well as the entire system.

Communication in vehicles comes in many forms. This includes the traditional cellular mobile connectivity utilizing 3GPP (3rd Generation Partnership Project) technologies 2G, 3G and 4G LTE. During the past decade, vehicles now also include direct connectivity, known as vehicle-to-everything (V2X) which enables them to communicate with other road participants (other vehicles, pedestrians etc).

For cellular mobile connectivity, prediction of the 'quality of service' (P-QoS) has been an active topic of research and discussions for past several years, in the context of 5G and beyond technologies. It is addressed in public-funded research projects in EU, such as 5G-NetMobil (Hofmann et al., 2019) and 5G-CroCo (Hetzer et al., 2019), as well as in organizations like 5GAA (5G Automotive Association) (5GAA, 2020) and 3GPP (3GPP, 2019d; 3GPP, 2019c; 3GPP, 2019a; 3GPP, 2019b).

Typically, a mobile network operator (MNO) has all control over which services are provided to a network user and how are they provisioned. The roaming scenarios, i.e. when a user of MNO1 is being served by MNO2, are well defined in terms of technical (how is the connectivity handled technically in the respective networks) and business solutions (roaming charges, if any). But for vehicular network users, the roaming scenarios are not easily implemented. Firstly, the movement between the coverage areas of different MNOs is fast and frequent, and secondly, the applications can be highly demanding (e.g. in terms of network resources) or even safety critical.

In this paper, we focus on the problem of managing P-QoS in an multi-MNO environment. We introduce a novel multi-MNO approach to P-QoS provision that utilizes QoS predictions about multiple cellular mobile networks (managed by different MNOs) at the same time. The approach makes decision about how to manage the connectivity in a vehicle, e.g. se-

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lecting a set of MNOs for further connectivity including a preference for each, making an “MNO usage timeplan” based on the QoS comparison etc. This approach puts the vehicle’s interest at the centre of the P-QoS provision. Apart from the general problems of multi-MNO scenarios stated above, providing P-QoS can be especially tricky. This is because it additionally requires knowledge of the cellular network performance and the capability of making predictions of high reliability. While one MNO may be capable enough to assess its own network and make predictions about the QoS, it may not be fit to do the same for networks operated by other MNOs.

The remainder of this paper is organized as followed. In the next section, we briefly discuss related work. We introduce our Multi-MNO P-QoS approach in Section 3, followed by a discussion of advantages and issues in Section 4. Finally, we present conclusions and an outlook to future work in Section 5.

2 RELATED WORK

The P-QoS research has focused on many different aspects of P-QoS.

Making prediction for end-user mobility is one approach that can be taken to managing and/or predicting connectivity (and subsequently QoS) requirements for a mobile network. The authors of (Fazio et al., 2017) demonstrate how this mobility prediction can be used for in-advance bandwidth reservations in order to achieve service continuity, avoiding call droppings during active sessions. In a similar vein of work (Abdalla and Ariffin, 2019), Abdalla et al. discuss a scheme to make more accurate predictions for end-user mobility and corresponding future cell. Both works lay the groundwork for one of the most important elements of P-QoS, namely prediction of mobility and thus connectivity of an end-user.

The authors of (Hofmann et al., 2019) evaluated QoS adaptation for platooning scenario. They reported improved planning towards an optimum efficiency for the platooning application in trucks when they are informed, in advance, of the possible upcoming changes in end-to-end latency and packet delivery rate.

In (Hincapie. et al., 2019), the authors focused on the software implementation of P-QoS in a vehicle. They introduced a collaborative and distributed QoS manager in the vehicle that seeks to increase and diversify the sources of information for P-QoS parameters and the selection of further configuration settings for the vehicular connectivity.

Torres-Figueroa et al. apply various machine learning mechanisms to recorded data sets of multiple MNOs for generating respective QoS predictions (Torres-Figueroa et al., 2020). They deem the prediction results to not be sufficient for highly reliable safety-critical and propose a combined network- and user-based P-QoS prediction to achieve more reliable predictions.

Closest to the scope of our paper is the research done within the 5G-CroCo project where the researchers defined multiple deployment options for a P-QoS service (5G-CroCo, 2021). This approach allows the vehicle navigate a multi-MNO environment but in each deployment option, the vehicle is, in effect, served by a single MNO at a time.

To the best of our knowledge, no research has been done on the specific scenario of managing P-QoS for multiple MNOs at the same time by a single entity in order to cherry-pick the best available QoS for a user.

3 MULTI-MNO P-QoS MANAGEMENT

3.1 Multi-MNO Environment

In a typical connected vehicle scenario, there a number of vehicles on the roads that have network connectivity provided by a set of MNOs. Different MNO networks have different capabilities, coverage, data-traffic at any given time, and different roaming and service-level agreements (SLAs) with other MNOs.

A multi-MNO environment, such as the one depicted in Figure 1, presents a number of challenges when a connected vehicle is to be served. One such challenge is to provide a service that runs seamlessly across network coverage boundaries. This is especially difficult to achieve for users with high mobility, such as vehicles traveling at a highway. The difficulty of this challenge is further escalated when the road segment traveled by the said vehicle crosses over national boundaries and thus requiring not only inter-MNO SLAs but also international agreements and/or requirements.

Through the network connectivity, the vehicles are not only connected to the serving MNO but also to other entities in the cloud, e.g. OEM backend, third party service providers. It is this connectivity that we intend to leverage for the idea presented in this paper, through a so-called ”Communication Decision Entity (CDE)”.

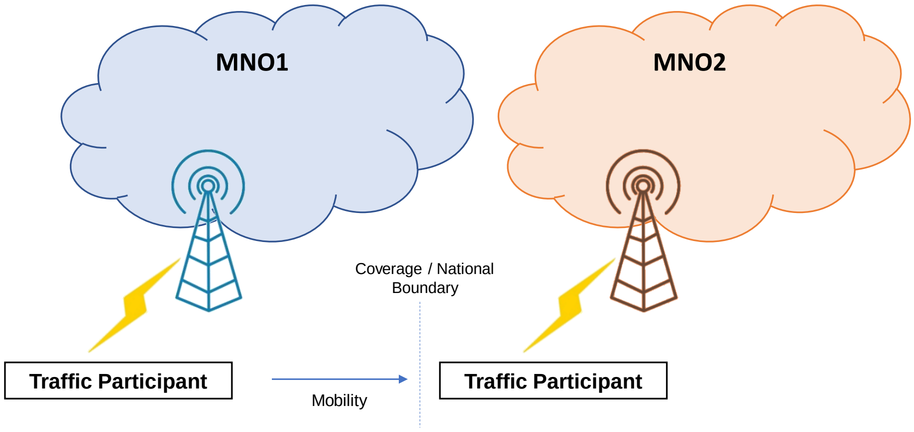

Figure 1: Typical Inter-MNO Mobility Scenario.

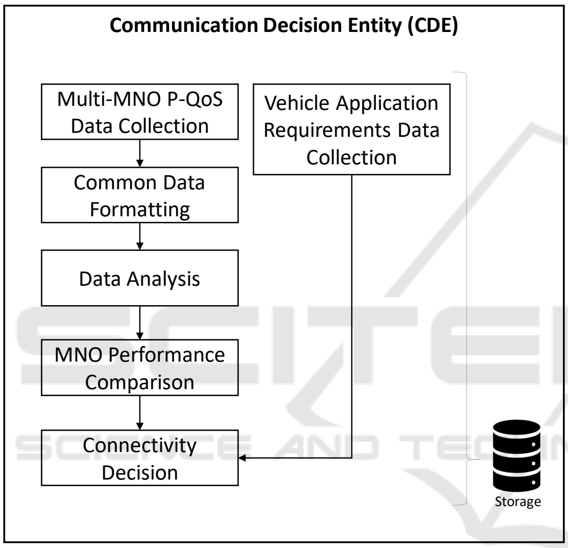

Figure 2: Functions of Communication Decision Entity.

3.2 Communication Decision Entity (CDE)

The "Communication decision entity (CDE)" acts as aggregator of P-QoS related information from multiple MNOs. It then analyzes the P-QoS data to make decisions about the network connectivity for a vehicle or a whole fleet of vehicles.

3.2.1 CDE Functions

The CDE accomplishes its objectives by performing following functions (shown in Figure 2) –

- Collect P-QoS data about multiple MNOs (multiple embodiments are possible as described later): this data includes the current provided QoS of each MNO and any predictions about it, e.g. predicted degradation in the bandwidth in a specific timeslot due to a network maintenance event
- Obtain application requirements of the vehicle: these requirements can be expressed in terms of bandwidth, (tolerable) latency, reliability etc
- Bring the prediction data of multiple MNOs into a common format, if required
- Gather insights about connectivity both spatial and temporal, e.g. the expected QoS in a certain geographic area in a certain time-period (say 5 to 6 o'clock in the evening on a weekday) is below the requirements of a safety application running on a vehicle
- Consider which parameters to compare and produce a quantitative output from the comparison. The parameters are chosen based on application(s) requirements in a vehicle. An example parameter for comparison can be latency and the quantitative output can be an index, e.g. a 0.8 and 1.1 for MNO1 and MNO2 respectively could mean that the MNO1 provides a latency of 0.8 times the latency required by the application and MNO2 provides 1.1 times the latency.
- Make decision about further connectivity, e.g.
  - Which MNO to select when roaming to make sure that an application can continue to run in a vehicle even when the parent MNO is not available any more (hence the roaming on another MNO)
  - Which MNO to select when current MNO's performance falls below a certain threshold
  - A timeplan of usage such as use MNO1 for the next 10 minutes and then switch to MNO2. This is to (1) ensure seamless execution of an application in a vehicle, (2) ensure an efficient usage of MNO resources, and (3) possibly keep the cost to a minimum (due to roaming agreements and corresponding charges)

3.2.2 CDE Configurations

The CDE can reside in the backend (e.g. a third party service provider or an MNO's core network) or in the vehicle itself. Each approach comes with its own set of advantages.

- Backend-based CDE: can make decisions tailored to one vehicle but also for an entire fleet (e.g. an OEM-backend-based CDE making decisions for all connected vehicles of the said OEM).
- Vehicle-based CDE: offers an advantage of more efficient decisions that are highly tailored to that vehicle and has an additional advantage of making decisions even when there is no connectivity (e.g. based on historical data).

Furthermore, multiple configurations for the CDE are envisioned.

- Configuration 1 (Figure 3): the CDE collects the QoS prediction data directly from MNOs.
- Configuration 2 (Figure 4): the CDE collects the data from a 3rd party server which in turn collects it from the MNOs.
- Configuration 3 (Figure 5): the CDE collects the data from an MNO which provides not only its own data but also the data about other MNOs.

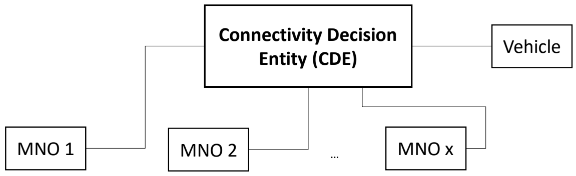

Figure 3: CDE Configuration 1.

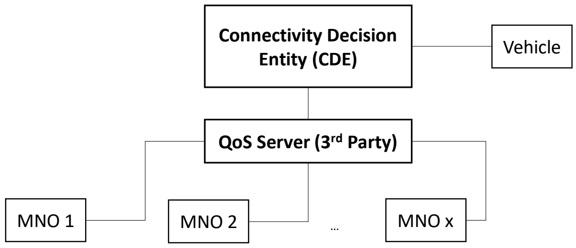

Figure 4: CDE Configuration 2.

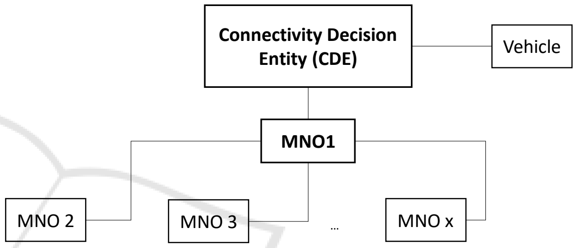

Figure 5: CDE Configuration 3.

Each configuration offers a set of advantages and disadvantages. For instance, in configuration 1 and 2, the MNOs provide P-QoS data about their respective networks to a third party entity (that they trust). This frees them for performing vehicle related.

3.2.3 CDE Working Example

The following example illustrates functioning of the CDE as proposed in this paper. A vehicle is driving automated while the CDE (in the vehicle or in the backend) receives a prediction about decline in the QoS of the primary mobile network (let's call it MNO1). Based on the predicted QoS of other mobile networks (let's call them MNO2, MNO3, ...), the CDE determines that based on the connectivity requirements of the automation application running on the vehicle, it is better to switch to MNO3 after a certain period of time (say 5 minutes) and then remain on MNO3 for 15 minutes before switching back to MNO1.

4 DISCUSSION

The multi-MNO P-QoS management we proposed in this paper offer multiple advantages. Firstly, the vehicle gets the best service possible based on QoS prediction data of multiple MNOs operating in its range. This is highly beneficial and even necessary for safety-critical and/or high-demanding (in terms of communication network resource usage) applications such as remote driving. Secondly, there is a natural 'load-balancing' among multiple MNOs, i.e. instead of a large number of vehicles overloading one MNO (e.g. either because they are all contractees of the said MNO or because the said MNO has SLAs with their original MNO(s)), the vehicles choose or are assigned the best possible service at any given time. Thirdly, connectivity decision can be made not only one single vehicle but for a whole fleet of vehicles. This is especially useful if CDE is operated by a vehicle OEM or a fleet owner such as a logistics company.

The advantages are of course not without their disadvantages. There are many roadblocks for the proposed approach. From a technical point of view, the very first demerit is having to process a much larger amount of data, which in turn may have been formatted differently (e.g. formulated using different KPIs) by different MNOs. Secondly, the proposed approach may increase the frequency of handovers. This not only means more complex roaming agreements among the MNOs but also the additional overheads in terms of amount of control data and the more frequent periods of service outage (if any). Concerning the business aspects of this approach, for example, the MNOs need to share their QoS prediction data either to each other or to a third party. Additionally, an MNO might not be forthcoming with our proposed idea due to data trust or privacy concerns. Even if this could be resolved by SLAs or similar, the agreements might be quite complicated, and so will be the service tariffs and business models.

5 CONCLUSIONS

Making predictions about the performance and hence the available QoS for a cellular mobile network is a challenging task because a network serves thousands of users at a time and the users have varying mobility and network usage. This task becomes even more complex if one tries to make similar predictions about a multitude of such networks because each network has its own characteristics (e.g. capacity, topology, maintenance schedule, roaming agreements) as well as its own set of users. Thus, providing predictive-QoS in a multi-MNO environment is very challenging.

In this paper, we propose a novel approach for multi-MNO P-QoS management that focuses on providing a vehicle with best possible QoS from multiple MNOs operating within vehicle's range. This approach also ensures a more uniform data-traffic load distribution among the MNO networks. This is achieved by introducing a dedicated 'Communication Decision Entity' (CDE) for a vehicle or fleet of vehicles that collects QoS relevant data for multiple MNOs and makes the connectivity decisions for the vehicle(s). On one hand, this approach acts in the best interest of the vehicle(s), on the other hand, it can alleviate over-loading problems for the involved MNOs. We envision multiple configurations for CDE to suit different network configurations or business paradigms.

In future, we plan to provide simulation-based evidence for this approach. We also intend to work on analyzing the challenges of adopting such an approach in real-life environment.

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