5G Network Requirement Analysis and Slice Dimensioning for Sustainable Vehicular Services

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***Abstract*—The Fifth Generation (5G) mobile communications together with software defined networking (SDN) and network function virtualization (NFV) are expected to enable a wide range of vertical use-cases. Different vertical industries with diverse service streams and sets of requirements should leverage the advanced capabilities of 5G networks through a single infrastructure to support the desired Quality of Service/Experience (QoS/QoE). In this paper, we focus on the Transport vertical and we study four novel service categories, each one consisting of one or more related scenarios, within the framework of the 5G Health, Aquaculture and Transport (5G-HEART) 5G PPP Phase 3 project. The first pass analysis of the envisioned vehicular services and their underlying operation, combined with the mapping of the mostly high-level functional user requirements to quantitative network Key Performance Indicators (KPIs) via a thorough and concise methodology, is essential for future testing with real pilots. Furthermore, our work paves the way towards efficient network slicing by exploring the interrelations between the identified KPIs and the respective target values that must be simultaneously satisfied over the same physical network infrastructure, in the context of the three 5G generic services.**

***Keywords*-5G mobile communications, network requirements, key performance indicators, transport vertical, network slicing.**

I. Introduction and Motivation

The Fifth Generation (5G) mobile communications, which are under continuous development by the standard bodies [1], foster the growth of individual vertical sectors via the provisioning of network connectivity services tailored to each sector's needs. In order to provide customized vertical services, the overall system architecture should be inevitably reconsidered, and the underlying network infrastructure should shift from a single unpartitioned entity to a network of logical partitions. In this context, novel efficient monitoring solutions that take into consideration the diverse requirements of a variety of traffic types originating from different applications are emerging in a wide range of scenarios, spanning from virtual to vehicular networks [2]. Accordingly, the established 5G generic network services—namely, the enhanced Mobile Broadband (eMBB), the Ultra-Reliable Low Latency Communications (URLLC), and the massive Machine Type Communications (mMTC)—may prove to be inappropriate to cumulatively support the diverse requirements of each vertical sector on their own. Hence, a holistic approach targeting the requirement analysis, the architectural design, the development and the final trialing of the envisioned services, considering multiple vertical sectors, is an imperative.

The "5G HEalth, AquacultuRe and Transport (5G-HEART) Validation Trials" Horizon 2020 project [3] aims to define and validate the cost-efficient 5G-converged network concepts that will enable an intelligent hub, supported by multiple vertical industries. As one of the 5G Infrastructure Public Private Partnership (5G PPP) phase 3 projects [4], 5G-HEART will deploy an extended set of innovative use-cases and perform validation trials related to the Healthcare, Aquaculture and Transport verticals. This includes the design, development, integration, testing and trialing of multiple concurrent and co-located vertical applications, resulting to the delivery of end-to-end network-enabled vertical services operating over the same network infrastructure. In this way, 5G-HEART will achieve its ultimate goal, which is the empowerment of different vertical industries

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and the flexible support of their distinct requirements under a service-aware network infrastructure of elastic, software-driven and programmable capabilities.

In this paper, we focus on the Transport vertical industry, which enabled by the 5G communications systems is expected to drive transformational changes and bring social, economic and industrial benefits to the economies that will take the lead in adopting the latest virtualization and programmable technologies. Specifically, the advantages and benefits of using 5G technology to enable Vehicle-to-Everything (V2X) services compared to existing alternatives, such as Fourth Generation (4G) cellular communications and non-cellular Dedicated Short-Range Communications (DSRC), have been extensively explored so far [5]–[7]. In [8], the authors discuss the main use-cases of 5G V2X and analyze their requirements, aiming to identify the gaps of the existing communication technologies. In this context, the 3rd Generation Partnership Project (3GPP) examines the network requirements that are imposed to the 5G infrastructure by a set of enhanced V2X scenarios [9]. Finally, in [10], the authors focus on the latency-critical V2X use-cases. Compared to these "fragmented" studies, in this paper, we present a common methodology that apart from the explicitly examined use-cases can be readily applied to other unexplored emerging scenarios, while at the same time we perform a comprehensive end-to-end analysis starting from the requirements gathering process and leading to validation trials with real pilots.

In our current work, we seek to assess the benefits brought by the 5G technology to the Transport vertical via scrutinizing four major vehicular service categories, namely "Platooning", "Autonomous/Assisted Driving", "Support for Remote Driving" and "Vehicle Data Services", each of which brings its own perspective and specific requirements to the design of the overall system. First, the mapping of the qualitative user requirements to the quantitative network Key Performance Indicators (KPIs) is performed, while a preliminary dimensioning of the potential network slices required to serve the different vehicular services complements the work. The outcome of the study conducted in this paper is the groundwork for the subsequent phases of the network architectural design and the planned trials with real pilots.

The main contributions of this paper are summarized as follows:

- We study four vehicular service categories of the Transport vertical, each one consisting of one or more related scenarios. In particular, we perform a first-pass analysis of the desired functionality, the operational environment, and the user requirements of each scenario within each major vehicular service category.
- We define and analyze the network Key Performance Indicators (KPIs) emerging in the considered scenarios of each vehicular service category. To that end, we map the mostly high-level functional user requirements to more network-specific KPIs and we explore their interrelations. The output of this effort is expected to be used for the evaluation of the forthcoming 5G-HEART trials.
- We pave the way towards network slice dimensioning. Namely, we determine and present the values of the network KPIs that will be required to be concurrently satisfied by the multiplexed virtualized and independent logical networks on the same physical network infrastructure, as allocated by the providers/operators to each specific scenario.
- Finally, we discuss the impact of the derived network KPIs to the underlying physical infrastructure, providing insights for future enhancements to the employed architecture and the services currently foreseen in the 3GPP Release 15 and 16.

The remaining of this paper is structured as follows. Section II provides the technical background and methodology pertaining to the network KPIs requirement analysis. The examined vehicular service categories are presented in detail in Section III. Section IV identifies the most stringent KPIs for the Transport vertical as a whole, and explores how they can be fulfilled in the context of the generic 5G services. Section V highlights considerations regarding the overall infrastructure requirements and the envisioned network slices. Finally, Section VI concludes the paper, identifying future research directions.

II. Technical Background and Methodology

In this section, we present the systematic methodology followed for realizing the requirement analysis of the examined vehicular service categories and the initial network slicing. To that end, we first introduce the employed KPIs and we briefly overview the three generic 5G services that span the 5G use-case space, emphasizing on different sets of requirements.

A. Quantitative Assessment via Key Performance Indicators

In the following, the definition and explanation of the employed network KPIs, which form the basis for the assessment of the underlying network infrastructure of 5G-HEART, are given in accordance with the latest standardization efforts [11], [12] and 5G-PPP activities. Each of the network KPIs can be mapped to one or more high-level operational requirements from the perspective of the stakeholders and vice-versa:

- *Throughput Downlink (DL) / Uplink (UL) [Mbps]*: the number of correctly received bits over a certain period of time (application layer), at the respective direction.
- *Latency [ms]*: the time needed for a data packet sent from a source to be received at the destination.
- *Reliability [%]*: the success probability of transmitting a packet within a certain maximum time.
- *Mobility [km/h]*: the maximum user speed achieving a defined QoS.
- *Location Accuracy [m]*: the accuracy with which location information is provided to the end device/user.

• *Connection Density [devices/km^2]*: the total number of devices fulfilling a target QoS per unit area (per km^2).
• *Interactivity [transactions/s]*: the number of issued commands/requests and received acknowledgements per device, within a short period of time.
• *Area Traffic Capacity [Mbps/m^2]*: the total traffic throughput served per geographic area.
• *Security/privacy*: the level of integrity of user data and privacy of user identity and information.

Table I below, presents the qualitative characterizations of the KPIs values' ranges in terms of "Low", "Medium" and "High" that are used and referred to in the remainder of the paper.

B. 5G Generic Services

There are three 5G mobile use-case driven sets of services considered as cornerstones that a 5G network aims to provide. These are the following [13]:

• *enhanced Mobile Broadband (eMBB)*: This service aims at scenarios that are data-driven and require stable connections with high peak data rates across a wide coverage area, as well as moderate data rates for cell-edge users. Representative examples of bandwidth-intensive services and applications include new immersive experiences such as Augmented Reality (AR) and Virtual Reality (VR), and access to resource-intensive multimedia content and data like Ultra High Definition (UHD) video sharing (i.e., 4K, 8K). The targeted KPIs' values are determined as follows: up to 20 Gbps for *peak data rate* in DL and 10 Gbps in UL, 10 Mbits/s/m^2 for *area traffic capacity* in DL, down to 4 ms for *latency* in both UL and DL, and up to 500 km/h for *mobility*.
• *massive Machine Type Communications (mMTC)*: This service aims at scenarios characterized by a massive number of low-power devices in a small area, required to sporadically transmit a relatively low volume of non-delay-sensitive data. mMTC regards mainly applications in wearables and sensor networks. The main KPIs for the mMTC services involve increased connection density, expanded coverage, and extended battery life. Taking into account the proliferation of IoT terminals, a target value for *connection density* of 1,000,000 devices/km^2 (or equivalently 1 device/m^2) is set for urban environments [12]. Regarding *battery life*, mMTC devices are required to operate for 10 to 15 years without changing or charging batteries. The *coverage* target of mMTC is defined in terms of 164 dB of Maximum Coupling Loss (MCL). Finally, *latency* for the infrequent small packets shall be down to 10 ms in the UL.
• *Ultra-Reliable and Low Latency Communications (URLLC)*: This service aims at supporting low-latency transmissions with extremely high reliability. Indicative examples of applications with such requirements include the remote control of critical infrastructure, transportation safety, and remote medical procedures. Specifically, in URLLC, the critical KPIs include *latency* and *reliability* with target values of 1 ms and 99.999% respectively. URLLC enablers related to latency include edge computing, flexible numerology, and mini-slots, among others. Such capabilities along with increased synchronization and location accuracy, provided by URLLC, can be utilized in high mobility usage scenarios regarding transportation safety, where high data rates can be less or more important on a case-by-case basis.

Table I
KEY PERFORMANCE INDICATORS VALUES' RANGES

Network KPI	**Definition**
DL throughput	Low $\leq$ 1 Mbps 1 Mbps < Medium $\leq$ 10 Mbps 10 Mbps < High
UL throughput	Low $\leq$ 100 Mbps 100 Mbps < Medium $\leq$ 1 Gbps 1 Gbps < High $\leq$ 20 Gbps
Latency	Low $\leq$ 5 ms 5 ms < Medium $\leq$ 25 ms High > 25 ms
Reliability	Low: 99.99 % Medium: 99.999 % High: 99.99999 %
Mobility	Low $\leq$ 50 km/h 50 km/h < Medium $\leq$ 200 km/h 200 km/h < High $\leq$ 500 km/h
Location accuracy	Low > 25 m 1 m < Medium $\leq$ 25 m High $\leq$ 1 m
Connection density	Low $\leq 40 \times 10^3$ vehicles/km^2 40×10^3 < Medium $\leq 10^6$ vehicles/km^2 High > 10^6 vehicles/km^2
Interactivity	Low $\leq$ 1 transactions/s 1 < Medium $\leq$ 100 transactions/s 100 < High $\leq$ 1000 transactions/s
Area traffic capacity	Maximum: 10 Mbps/m^2
Security/privacy	Low: Public Medium: Restricted High: Confidential

C. Methodology

As previously mentioned, the main objective of this work is the specification and analysis of the network Key Performance Indicators (KPIs) emerging in the considered scenarios/use-cases of the Transport vertical. To achieve this goal, the key stakeholders involved in the vertical—namely, vehicle drivers/passengers, road network managers, and policy makers—determine a number of high-level operational requirements, which ultimately impose specific network KPIs for each use-case. Eventually, these KPIs are the ones that the underlying network infrastructure, the control/management planes, orchestration planes and possibly slices will be called upon to fulfill. Requirements from the side of the stakeholders mostly follow a qualitative approach focusing on the desired type and quantity of information that will be exchanged over the network. Accordingly, the quantitative requirements per scenario are defined based on the analysis of the features of each related architectural solution, taking into account the qualitative stakeholders requirements and aiming to fulfil the QoS/QoE that a user perceives for the provided services [14]. To characterize the requirements of the innovative 5G-HEART use-cases, which form the basis for the assessment of the underlying network infrastructure, we use the performance metrics presented in Section II-A. Each of the network KPIs can be mapped to one or more high-level operational requirements from the perspective of the stakeholders and vice-versa.

The corresponding analysis is performed individually for each use-case, indicating their striking differences in terms of network resource needs. Then, the cumulative network requirements for the whole vertical are extracted, in order to ultimately proceed to a basis for the definition of the overall 5G-HEART network infrastructure building blocks. As previously mentioned in Section II-B, there are three 5G mobile use-case driven sets of services, each of which highlights a common set of capabilities and requirements [13], defined by different indicative values of characterizing KPIs [11], [12]. In order to provide a comprehensive overview of the considered use-cases and an educated comparison among them, a set of multi-axes radar charts is provided as the final step of our analysis, depicting selected network KPIs and the mapping to the 5G generic services and current slice templates.

III. Next-Generation Vehicular Services: The 5G-HEART Perspective

This section presents four major vehicular service categories that shape the frontier of the new transportation era, enabled by the powerful connectivity and networking capabilities of the 5G networks. Targeting at a plethora of distinct functionalities, the different use-case specific scenarios pertaining to each one of the four vehicular service categories scrutinized within the scope of 5G-HEART are introduced. Fig. 1 provides a graphical illustration of some representative use-case scenarios, which are advocated by the 5G-HEART efforts.

A. Platooning (T1)

Platooning conforms to the vehicular services that leverage the future vehicles' ability to operate autonomously, by allowing a group of vehicles to form a tightly coordinated "train" with significantly reduced inter-vehicle distances. To keep the vehicles of a platoon as close as possible with safety assurance, periodic status information, i.e., speed, heading, and driving intention data (braking, turning) is shared from the platoon leader to the following platoon vehicles. Such a coordinated traveling results in increased aerodynamic drag that improves the fuel efficiency. Also, by smartly managing the amount of drivers needed, the accident rates are reduced and the productivity is enhanced.

Within the concept of platooning, the contribution of 5G-HEART is twofold. First, as a means of serving enhanced situational awareness and collision avoidance, the 5G-HEART project capitalizes on the potential of Augmented Reality (AR) and targets at promoting the specific functionality of high-bandwidth in-vehicle real-time streaming. The real world view is captured from the leading platoon vehicle and is instantaneously constructed and projected via the following platoon vehicles' auditory and visual material to the passengers. Secondly, a dynamic radio channel management paradigm is also pursued to allow for the efficient utilization of the scarce radio resources, while at the same time accounting for the platoon's mobility. A V2X application analyzing indicative platoon status information along with a Radio Environmental Map (REM) is developed, which optimally assigns in real-time radio channels to the platoons, in order to satisfy the need for localized, low-latency, high-reliability and frequent communication.

B. Autonomous/Assisted Driving (T2)

Autonomous/assisted driving encompasses a wide variety of technologies and use-case specific vehicular scenarios. In 5G-HEART, the primary focus is paid on the development of on-board network-assisted collision warning and avoidance systems to support the automated vehicles' operation. Such services provide information to the vehicles and their drivers about imminent dangers and help them take corrective actions, e.g., lane changing and deceleration. The information derives from the vehicles' surrounding environment, such as the status of traffic signals and the locations of vehicles and of vulnerable road users, and is communicated to the vehicles in the form of a Local Dynamic Map (LDM). Complementarily to this, the power of wearable devices and their ability to accurately assess the drivers' alertness and fitness-to-drive is also exploited to prevent hazardous situations. Both use-case specific scenarios described constitute part of the 5G-HEART's trialing mission.

Apart from the basic vehicle services that deal with safety data fusion between the network and the vehicles, providing predictive Quality of Service (QoS) alerts is also another responsibility of the network. In the cases when the service continuity and the quality of connectivity are controversial, appropriate metrics should indicate the need for the vehicle's level of automation change, ranging from fully autonomous to manual driving modes. This will enable the drivers to timely take control of the vehicles and avoid the activation of pre-programmed emergency routines during the autonomous driving mode. This use-case scenario complements the 5G-

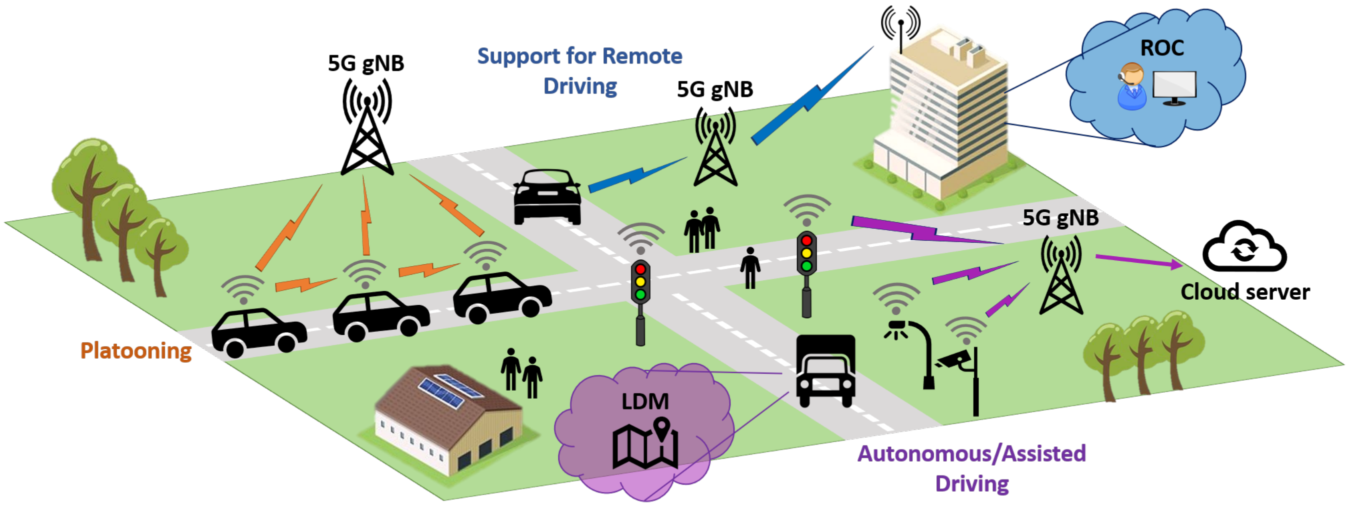

Figure 1. High-level overview of the advanced use-cases expected to be supported by 5G V2X.

HEART's threefold contribution across the domain of autonomous/assisted driving.

C. Support for Remote Driving (T3)

Contrary to the autonomous/assisted driving services, which are established on the vehicles' capabilities to sense the surrounding environment, remote driving refers to the use-cases where an operator remotely controls a vehicle provided that ambient information from its surrounding environment is available in real time. Indeed, remote driving can be utilized as a standalone service to support various use-case scenarios, ranging from mission critical situations under harsh environmental conditions to every-day automated transportation services. More importantly though, the application of remote driving can serve as a predecessor or a back-up service of the autonomous/assisted driving mode.

In this context, the development and delivery of the pure functionality of tele-operated support constitutes an integral part of the 5G-HEART's trialing plan. A Vehicle-to-Network (V2N) connection, established between a remotely-controlled vehicle and the Remote Operations Center (ROC), allows the secure transmission of real-time data feed from the on-board vehicle's instrumental sensors and High Definition (HD) cameras, as well as the Global Navigation Satellite System (GNSS) position. This data is eventually utilized by a remote human operator to properly manoeuvre the vehicle, by transmitting appropriate control commands via the V2N connection in the opposite direction. As a consequence, a high bandwidth availability and increased achieved throughput is required for the uplink (UL), while a low latency requirement is imposed by the downlink (DL) communications of this specific scenario.

D. Vehicle Data Services (T4)

This service category studies a variety of distinct scenarios that aim at interconnecting potential third-party data sources, such as centralized online databases or distributed sensor networks, and the connected automated vehicles via the available 5G infrastructure. Within this scope, the specific scenarios and envisioned provided services by 5G-HEART are as follows. A V2X application linked to a local repair center allows any passing vehicle to report its current functional state and receive a "Just in time repair notification" regarding any identified functional issue, after the analysis of the reported data. Apart from mechanical functional repairing, the scenario of future autonomous vehicles' software updates is applicable under the concept of "Vehicular Data Services". In more detail, the service of Over-the-AIR (OTA) software updates provisioning is considered, according to which the vehicles' Engine Control Unit (ECU) can be updated via the vehicles' network connectivity in a transparent, though secure, manner.

With respect to the environmental benefits brought by the collection and analysis of the vehicles' historical route data, the scenario of smartly controlling the vehicles' routes to relieve congested areas and reduce the emissions is examined. At the same time, environmental data collected by the vehicles are utilized by the local authorities to improve the road maintenance. Additional benefits can be also provided to the entertainment industry by the deployment of location-based servers that stream content and local advertisements to the passengers of self-driving vehicles, which, in turn, form a geo-targeted group. Last, crowd-sourcing from the vehicles and maintaining up-to-date data can be used to further corroborate any autonomous driving-related service of the Transport vertical, in terms of accurate and dynamically configured HD maps of roads and transportation infrastructure.

IV. Network Key Performance Indicators Analysis

Each of the previously presented vehicular services/use-cases has its own focus and provides requirements for the overall system architecture. This section concerns the mapping of the more qualitative user/stakeholder requirements to measurable network KPIs with specific target values, following the methodology presented in Section II-A. The results of the requirement analysis for the examined use-cases are presented in Table II and summarized in the form of a radar chart (Fig. 2) depicting the most stringent values of the selected KPIs, followed by a brief explanation and interpretation of the outcome based on each use-case's main objective/functionality and user expectations upon usage.

As can be seen in Fig. 2, use-cases T1 and T4 have generally similar requirements with some differences in the most stringent values required. Compared to them, use-case T3 is primarily differentiated by the significantly lower values of UL/DL throughput and area traffic capacity. Finally, use-case T2 is similar to T3 with the key difference of requiring very high interactivity and higher DL throughput. In greater detail, the Augmented Reality (AR) features along with the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications required for see-through and situational awareness in platooning (use-case T1) impose the need for increased UL/DL throughput (up to 80 Mbps). Similar increased UL/DL throughput values are found in use-case T4, dictated primarily by the transmissions involved with vehicle sourced HD mapping for uplink and location-based advertising and over the air updates for downlink. The use-case T2 demands high DL throughput (up to 50 Mbps) due to the vehicle-to-everything (V2X) application employed in QoS for advanced driving, while the instrumental sensor data and video streams that are communicated to the remote operations center in use-case T3 justify the required low UL throughput (up to 20 Mbps).

The safety information (e.g., the exchange of precise digital maps of intersections, the status of traffic signals and locations of vehicles and vulnerable road users, the drivers' physiological status, etc.) related to the smart junctions and network assisted & cooperative collision avoidance (CoCA) scenario and to the human tachograph scenario consists of payloads that do not require high UL throughput, but are time critical and dense within a very short period of time. As a consequence, use-case T2 is the only one with a demand of high interactivity (up to 1000 transactions/s). Furthermore, all examined use-cases exhibit the need for high mobility (up to 250 km/h), high location accuracy (down to 0.5 m), low latency (down to 5 ms) and medium to high reliability (99.999% for the majority of scenarios, reaching up to 99.99999% for the platooning use-case and the QoS for advanced driving scenario of T2), imposed by the desired real-time, continuous operation and the envisioned provision

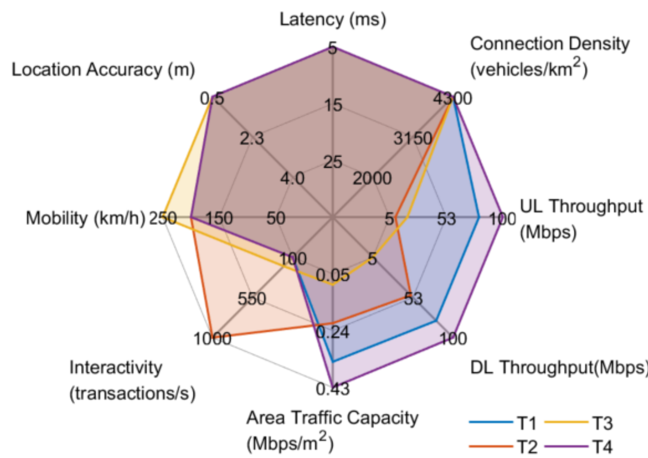

Figure 2. Radar Chart of Transport use-cases.

of personalized location-based services.

The peak connection density for the vertical (4300 vehicles/km^2) observed in all use-cases corresponds to a worst-case scenario with 5 lanes in each direction or 10 lanes total per highway, for up to 3 intersecting highways [15]. Accordingly, the stringent area traffic capacity value is 0.43 Mbps/m^2 for use-case T4, calculated based on the respective throughput requirement. Finally, high security/privacy is required for all use-cases, given that a large part of the envisioned functionality involves confidential/sensitive data of both drivers/passengers and vehicles, as well as commands and instructions critical for the real-time (remote) operation.

V. Unified Physical Network Infrastructure

The 5G technology is envisioned to support a wide range of verticals with a diverse set of performance and functional requirements under the same physical network infrastructure. In order for the unified 5G network to offer the desired QoS/QoE to the various vertical industries, it is necessary to understand and quantify their particular needs and expectations. In this context, requirement analysis becomes crucial for the provision of tailored 5G services following a more user-centric design. To that end, in this section, we extend the mapping of the user qualitative requirements to network-specific KPIs for the transport vertical and its provided vehicular services, by considering the particular network configurations and selection of enabling technologies that are needed to achieve the desired enhanced performance and flexibility, reaching eventually the determined target values in a cost-efficient manner.

The fundamental enablers of 5G for supporting the heterogeneous KPIs of the emerging vertical use-cases include end-to-end network slicing, service-based architecture, Software-Defined Networking (SDN), and Network Functions Virtualization (NFV) [16]. Focusing on network

Table II
5G-HEART Vehicular Services' Network Key Performance Indicators.

Network KPI	Units	Platooning	Autonomous/Assisted Driving	Support for Remote Driving	Vehicle Data Services
DL throughput	Mbps	80	50	5	100
UL throughput	Mbps	80	10	20	100
Latency	ms	5	5	5	5
Reliability	%	99.99999	99.99999	99.999	99.999
Mobility	km/h	200	200	250	200
Location accuracy	m	0.5	0.5	0.5	0.5
Connection density	vehicles/km^2	4300	4300	4300	4300
Interactivity	transactions/s	100	1000	200	100
Area traffic capacity	Mbps/m^2	0.344	0.215	0.086	0.43
Security/privacy	Public/Restricted/Confidential	Confidential	Confidential	Confidential	Confidential

slicing, we perform a first assessment of the implementation needs and a preliminary dimensioning of the network slices needed for serving the examined transport use-cases over a unified physical network infrastructure. Each slice can be considered as an end-to-end isolated logical network involving a specific collection of network functions and resource allocation modules [17], accommodated over the shared network infrastructure.

Fig. 3 presents the aggregated KPIs of the entire transport vertical, which are obtained by combining the more stringent target values of the four individual vehicular services, together with the three main 5G service types. As can be seen, a combination of eMBB, URLLC and mMTC is required for simultaneously fulfilling the aggregated network KPIs across the entire vertical. In particular, the target values of latency, mobility, UL/DL throughput and reliability suggest a combination of URLLC and eMBB. Furthermore, the demand for high location accuracy and the use of a potentially large number of multiple sensors indicate as well the need for mMTC.

The eMBB slice requires considerable bandwidth to support high-data-rate services, such as high-definition video streaming at varying mobility levels. A caching function together with data and cloud units are also needed to assist control functions in implementing eMBB slicing services. Reliability, low latency, and security are crucial for the URLLC slice in order to provide services that are extremely sensitive to delays, such as autonomous driving, V2X communications, and Remotely Operated Vehicles (ROVs). To facilitate this, all dedicated functions can be instantiated at the edge cloud. Regarding the mMTC slice, which serves a large number of devices (e.g., sensors, wearables), a high level of connection density is required, with low demands in data rate and high energy/power efficiency.

The stringent requirements regarding the end-to-end latency and reliability of the transport vertical's vehicular

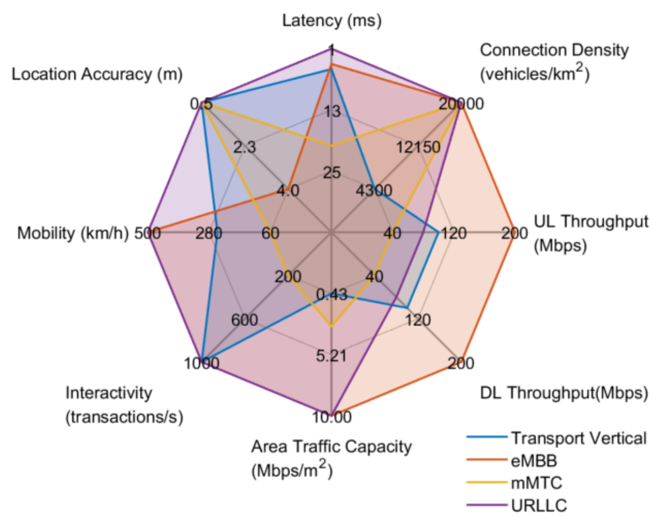

Figure 3. KPIs of the Transport vertical and related 5G service types.

services can be addressed by the use of Multi-Access Edge Computing (MEC), which promotes the utilization of storage and computational resources residing in close distance to the network edge and the end-users. Application-specific Virtualized Network Functions (VNFs) deployed at the edge can dynamically migrate to optimal locations to increase performance and reduce congestion. Moreover, the experienced throughput and location accuracy can be heavily affected by the user's mobility. As a result, seamless connectivity and service continuity is crucial considering access to communication, information and processing resources in order to successfully serve use-cases with high users' mobility.

Apart from fulfilling the QoS of the emerging vehicular services, context awareness and particularly continuous outdoor high-accuracy localization can also enhance the intelligence of the existing applications, such as user monitoring, guiding and navigation, network management, and load balancing among others. The large number of stakeholders involved in the transport vertical further highlights the importance of efficient end-to-end security solutions that must be integrated into the network infrastructure. Finally, reliability strongly depends on the number and type of employed antennas, which directly affect the energy consumption and spectrum efficiency. The latter are especially important for battery-powered and wearable devices. Thus, a balance between these two contradicting aspects should be targeted.

VI. Conclusion

5G mobile communications promise to fulfill the stringent requirements imposed by the envisioned advanced vehicular use-cases that cannot be supported by the previous technologies. In this paper, we focused on the desired functionality, operational environment, and user requirements of four novel vehicular service categories examined within the context of the 5G-HEART project. The presented methodology constitutes a clear and concise way to quantify the requirement analysis and map the high-level functional requirements to network-specific KPIs. Furthermore, by examining the identified target values of the network KPIs that must be concurrently satisfied in light of the three 5G generic services (i.e., eMBB, mMTC, and URLLC), we performed an initial network slice dimensioning. Finally, considerations regarding the required underlying infrastructure were also discussed and will be used as an input for the evaluation of the forthcoming validation trials.

As the standardization of 5G specifications is still under way, this paper is one of the first attempts to address such challenges more concretely and can be utilized to facilitate the evolution and implementation of various use-cases of the Transport vertical, in terms of architecture and implementation. Future research directions will focus on further tailoring the network deployment and configuration towards a flexible solution that would efficiently accommodate customized 5G mobile network services for simultaneously supporting several vertical industries.

References

[1] A. Morgado, K. M. S. Huq, S. Mumtaz, and J. Rodriguez, "A survey of 5g technologies: regulatory, standardization and industrial perspectives," *Digital Communications and Networks*, vol. 4, no. 2, pp. 87–97, Apr. 2018.

[2] G. Kakkavas, A. Stamou, V. Karyotis, and S. Papavassiliou, "Network tomography for efficient monitoring in SDN-enabled 5G networks and beyond: Challenges and opportunities," *IEEE Communications Magazine*, vol. 59, no. 3, pp. 70–76, Mar. 2021.

[3] 5G-HEART Project. [Accessed: May 10, 2020]. [Online]. Available: https://5gheart.org/

[4] 5GPPP The 5G Infrastructure Public Private Prtnership. [Accessed: May 10, 2020]. [Online]. Available: https://5g-ppp.eu/5g-ppp-phase-3-projects/

[5] S. A. A. Shah, E. Ahmed, M. Imran, and S. Zeadally, "5g for vehicular communications," *IEEE Communications Magazine*, vol. 56, no. 1, pp. 111–117, Jan. 2018.

[6] Y. Yang and K. Hua, "Emerging technologies for 5g-enabled vehicular networks," *IEEE Access*, vol. 7, pp. 181 117–181 141, 2019.

[7] S. Gyawali, S. Xu, Y. Qian, and R. Q. Hu, "Challenges and solutions for cellular based v2x communications," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 1, pp. 222–255, 2021.

[8] M. Boban, A. Kousaridas, K. Manolakis, J. Eichinger, and W. Xu, "Connected roads of the future: Use cases, requirements, and design considerations for vehicle-to-everything communications," *IEEE Veh. Technol. Mag.*, vol. 13, no. 3, pp. 110–123, Sep. 2018.

[9] *3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Service Requirements for Enhanced V2X Scenarios (Release 16)*, 3GPP Std. 3GPP TS 22.186 V16.2.0, Nov. 2020.

[10] Z. Amjad, A. Sikora, B. Hilt, and J.-P. Lauffenburger, "Low latency V2X applications and network requirements: Performance evaluation," in *2018 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, Jun. 2018, pp. 220–225.

[11] *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Scenarios and Requirements for Next Generation Access Technologies; (Release 16)*, 3GPP Std. 3GPP TR 38.913 V16.0.0, Jul. 2020.

[12] *Minimum requirements related to technical performance for IMT-2020 radio interface(s)*, International Telecommunications Union (ITU) Std. Report ITU-R M.2410-0, Nov. 2017.

[13] *IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond*, International Telecommunications Union (ITU) Std. Recommendation ITU-R M.2083-0, Sep. 2015.

[14] D2.1: Use case description and scenario analysis. [Accessed: Sep 28, 2020]. [Online]. Available: https://5gheart.org/wp-content/uploads/5G-HEART_D2.1.pdf

[15] *3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on enhancement of 3GPP Support for 5G V2X Services (Release 16)*, 3GPP Std. 3GPP TR 22.886 V16.2.0, Dec. 2018.

[16] S. Redana, O. Bulakci, C. Mannweiler, L. Gallo, A. Kousaridas, D. Navrátil, A. Tzanakaki, J. Gutiérrez, H. Karl, P. Hasselmeyer, A. Gavras, S. Parker, and E. Mutafungwa, "5G PPP Architecture Working Group - View on 5G Architecture, Version 3.0," Jun. 2019.

[17] H. Zhang, N. Liu, X. Chu, K. Long, A.-H. Aghvami, and V. C. Leung, "Network slicing based 5G and future mobile networks: Mobility, resource management, and challenges," *IEEE Commun. Mag.*, vol. 55, no. 8, pp. 138–145, Aug. 2017.