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Potential 5G Applications for Connected Vehicles: Use Cases, Opportunities and Challenges

M. Lu¹, F. Bouali²

1. Dynniq Nederland B.V., Basicweg 16 3821 BR Amersfoort, The Netherlands

2. University of Surrey, Guildford, GU2 7XH, UK

[meng dot lu at dynniq dot com](mailto:meng.dot.lu@dynniq.dot.com)

Abstract

The fifth generation of wireless networks (5G) is not just an evolutionary upgrade of the previous generations of cellular communications, but rather a revolutionary technology envisioned to meet the access, bandwidth, performance, and latency requirements associated with various vertical industries. In this context, this paper makes an analysis of the capability of 5G systems to support various advanced use cases of the Intelligent Transport Systems (ITS) industry. First, the most representative ITS use cases and associated scenarios are selected and described together with their key challenges. To efficiently trial the considered use case scenarios, a three-step method is proposed, where the focus will be initially on performing local tests and eventually evolve towards interconnected multi-site setups. Finally, the technical opportunities and business challenges associated with the future application of 5G to intelligent road transport are discussed and some of the future directions are highlighted.

Keywords: ITS, use cases, V2X; 5G

Introduction

Intelligent Transport Systems (ITS) is a domain of substantial development since more than 30 years. Nearly 15 years ago, the development of cooperative systems started. Short-range communication would provide connectivity between neighbouring vehicles to exchange their own positions and velocities together with the information observed by vehicle sensors, e.g. concerning obstacles on the road or road surface conditions. The idea was that this would enable a whole range of new safety and driver comfort applications. Furthermore, other road users, especially vulnerable road users (VRUs), such as pedestrians and cyclists, could further strengthen such applications, now that smartphones had become widespread. Deployment of cooperative systems has been less rapid than that of autonomous systems, partly due to the higher level of complexity of the technology. Communication technologies, the essential component of Cooperative Intelligent Transport Systems (C-ITS), also called Connected Vehicles outside Europe, include direct vehicular communication based on IEEE 802.11p and cellular network communication. Careful selection of eventual technologies and business models will substantially influence the further development towards connected, cooperative and automated road transport, and determine its success. Appropriate cooperation between authorities, industry and academia in countries worldwide is a must for the successful implementation of high-level automated road transport, with harmonisation and interoperability as key determinants. [Lu (Ed.) 2019]. In this context, this paper makes an analysis of the potential of 5G to support ITS applications with a focus on connected and automated vehicles, which would be a complementary option to the current mature communication technologies for V2X applications, e.g. ETSI ITS-G5 and 4G.

The remainder of the paper is structured as follows. The first section introduces the background of the 5G research activities in Europe, as well as the purpose of the considered 5G trials of the ITS vertical

industry. Next, the selected use cases and their associated scenarios are described together with their key challenges and expected added value of 5G. A method to efficiently trial the considered scenarios is proposed in the following section. Moreover, business opportunities and challenges are discussed. Finally, the key conclusions are drawn and some of the future directions are provided.

Background

Together with the launch of the 5G Infrastructure Public-Private Partnership (5G PPP) in 2013, a large-scale European 5G research programme with a huge funding budget was initiated. 5G PPP is a joint initiative between the European Commission (strongly supported by DG Connect), and the European telecom industry. The 5G collaborative research program is organised as part of the EC Horizon 2020 Programme for Research and Innovation and aims to foster "*industry-driven research, monitored by business-related, technological performance and societal KPIs*". According to the 5G Infrastructure Association (5G IA), in 2017 the EC "*is investing 700 million € and the industry will leverage this investment by at least a factor of 5*". The 5G PPP consists of three phases of collaborative research: Phase 1 (2015-2018) performed fundamental research for 5G networks, with 19 projects funded by the EC; Phase 2 (2017-2020) used those technologies for the digitisation and integration of vertical industries, with 21 projects funded under Horizon 2020; and Phase 3 (2019-2022) has been addressing the development and rollout of 5G platforms across Europe, with around 26 projects funded so-far by the EC. For all these phases. great achievements have been made. [5G IA, 2017; 5G PPP: <https://5g-ppp.eu/>]

Advanced 5G validation trials across multiple vertical industries are especially addressed in Phase 3. One of the EU-funded projects launched in 2019 is 5G-HEART, targeting healthcare, aquaculture and road transport sectors. The needs and requirements of vertical industries are the key drivers for the next-generation wireless mobile telecommunications technology. There are also huge challenges for the network and connectivity, especially concerning e.g. latency, reliability, throughput (peak data rate) and connection density. The 5G validation trials focus on 5G applications in the three vertical industries especially for improving utility, efficient processes, and safety. It defines vital vertical use cases of healthcare, aquaculture and transport respectively by using the fifth-generation of wireless mobile telecommunications technology. The project investigates the possible architectures and approaches for the validation of the trials of the three target vertical industries from both the technological and business perspectives. In addition, it explores business opportunities for future 5G applications in these industries as per the European vision of "5G empowering vertical industries". This eventual objective of getting the 5G vision closer to deployment with innovative digital use cases involving cross industry partnerships is quite challenging. It requires technological and business validation of 5G end-to-end connectivity and associated management from two perspectives: i) within the set of specific requirements from one application domain; ii) across all sets of heterogeneous requirements stemming from concurrent uses of network resources by different vertical domains [5G-HEART Consortium, 2019].

In this context, 5G-HEART intends to address how 5G may empower the healthcare, transport and aquaculture industries. These vertical industries and related connectivity use cases pose diverse technical requirements on (wireless) network connectivity. These focus on the validation of a mixture of enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC) services. The resulting ecosystem and technological solutions for 5G validation across multiple vertical industries is illustrated in Figure 1. The project will in particular provide showcases of how a single network infrastructure may be able to serve eMBB, mMTC and URLLC services belonging to different verticals, which have completely different associated requirements, in a cost-effective manner. For larger impact of the project, the developed technical solutions could be also applicable to other 5G use cases with the same or similar technical requirements. As such, the project contributes to the overall strategy and roadmaps of 5G PPP. It focuses on the most representative use cases from the requirements perspective, and the resulting technical challenges for the provision of high user **throughput** (for eMBB), high **connection density** (mMTC) and high-**reliable**, low-**latency** (URLCC) communications.

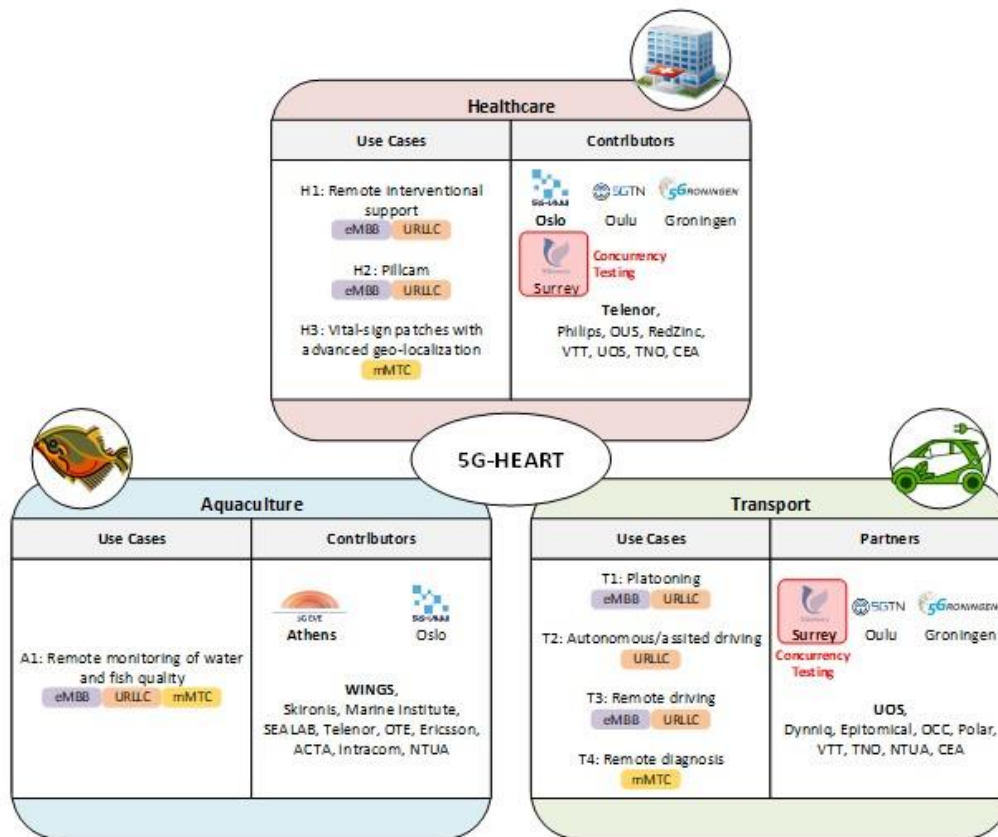


Figure 1 - An ecosystem for 5G validation across multiple vertical industries [5G-HEART Consortium, 2019]

This paper focuses on one of the vertical industries, i.e. ITS, and especially on the validation of automated, assisted and remote driving together with various vehicle data services.

Use Cases in ITS and Trials Development

According to the vision of 5G-HEART, leveraging 5G capabilities to support advanced ITS use cases is expected to be of great benefit. To select the most representative use cases, the recommendations and reports issued by the key standardisation bodies (e.g. [3GPP 22.886, 2018]) and associations (e.g. [5G Automotive Association, 2019]) have been analysed. Enlightened by this analysis, the following use cases, for which the expected added value of 5G is the highest, have been selected:

- 1) Platooning: Vehicles move like a train with virtual strings attached between vehicles. This would reduce the inter-vehicle distance, overall fuel consumption and number of needed drivers.
- 2) Autonomous/assisted driving: Sensor data and communication capabilities are combined to support driving,
- 3) Support for remote driving: A vehicle is controlled remotely by either a human operator or cloud computing application whenever and wherever relevant (e.g. access to hazardous areas, efficient road construction and snow plowing). This could be a cost-effective step towards pure automated driving.
- 4) Vehicle data services: The network collects and processes actionable information from all the relevant entities (e.g. vehicles and road users) to provide various services.

The practical aspects and key challenges of the above use cases have been captured through a set of representative scenarios. Table 1 summarises the list of the considered scenarios together with their associated motivations.

Table 1 - Use cases and scenarios of ITS industry [5G-HEART Consortium, 2020]

Use case	Scenario description
Use case 1: Platooning	<ul style="list-style-type: none"> - <i>High bandwidth situational awareness and See-through for platooning</i> - High bandwidth in-vehicle streaming serving situational awareness/collision warning and see-through applications for platooning scenarios. - <i>Dynamic channel management for traffic progression</i> - Optimisation of the assignment of radio channels to the vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) links used by the platoons operating in a given area.
Use case 2: Autonomous/assisted driving	<ul style="list-style-type: none"> - <i>Smart Junctions and network assisted & Cooperative Collision Avoidance (CoCa)</i> - Delivery of network assisted safety information (e.g. precise digital maps of the intersection, traffic signal status, vehicle location and vulnerable road user location) towards vehicles to prevent traffic accidents and assist cooperative automated driving functions when the vehicles pass through an intersection. - <i>QoS for advanced driving</i> - Proactive provisioning of QoS for advanced driving supporting e.g. the dynamic selection of the appropriate driving mode based on the context at-hand. - <i>Human tachograph</i> - Assessment of the driver's physiological status and delivery of related trigger messages to on-board or online driving assist systems based on live and history data measured with wearable sensor devices.
Use case 3: Support for remote driving	<p><i>Tele-operated Support (TeSo)</i> - Connected vehicle travelling on a highway, or other public street, bearing various sets of sensors, radars/lidars, and high-definition video cameras, based on which a remote human operator is able to track the car, and control its course and speed.</p>
Use case 4: Vehicle data services	<ul style="list-style-type: none"> - <i>Vehicle prognostics</i> - A roadside unit (RSU) application, having the capability to access the Internet will enable any passing vehicle to report its current functional state to a local/remote diagnosis service and to receive "Just in time repair notification". - <i>Over-The-Air (OTA) updates</i> - Over-the-air updates for the Engine Control Unit (ECU) without the need for the vehicles to be recalled by a manufacturer or service centre. - <i>Smart traffic corridors</i> - Collection of historical and real-time data from vehicles to be used to intelligently control the routes that a vehicle is recommended or mandated to take in any given journey. - <i>Location based advertising</i> - With vehicle and passenger information readily available, location-based servers are implemented to stream content, local advertising or traffic guidance to vehicles and road users. - <i>End to end (E2E) slicing</i> - E2E slicing allowing to concurrently support the heterogeneous requirements associated with multiplicity of use case scenarios that may run simultaneously inside the same vehicle. - <i>Vehicle sourced HD mapping</i> - Crowdsourcing of the HD mapping information collection and maintenance through on-board cameras and sensors which would stream back to a regional or central service, firstly to establish baseline maps and subsequently to manage change detection. - <i>Environmental services</i> - Creation of hyper local weather maps based on vehicles' on-board sensors aiding drivers and automated vehicles in day-to-day driving but also to assist local authorities to improve road maintenance.

To efficiently trial the considered use case scenarios, a three-step method is proposed, where the focus will be initially on validating individual components and performing local tests and will eventually

evolve towards advanced interconnected multi-site setups. Table 2 presents a brief description of each of the considered phases.

Table 2 - Trial development steps

Phase	Description
Phase 1: Individual transport scenarios	The capability of 5G to support each of the considered scenarios will be individually trialled and benchmarked against 4G.
Phase 2: Co-located concurrent transport scenarios	Once the individual scenarios have been trialled, a set of combined trials will be conducted to stress test the 5G network with different transport scenarios associated with heterogenous requirements. The network slicing paradigm will be particularly applied to create various slices to simultaneously support a set of applications running inside the same vehicle, while ensuring a minimum level of isolation between them (e.g. the performance of a given application does not affect the others).
Phase 3: Multi-site multi-vertical concurrent slices	Concurrently trials multiple slices associated with different vertical industries across different sites. Cross-domain orchestration and management solutions will be developed and used to efficiently manage and execute trials involving various transport and healthcare scenarios.

Business Validation, Business Models and Discussions

5G is expected to be the ultimate converged network, to which the road is typically gradual and most likely long. Unlike the core network, there is less convergence in the current access and application layer infrastructure of today's telecom networks. For instance, most 2G and 3G networks are separate from their 4G/LTE counterparts. The new radio (NR) access, expected to be much more efficient thanks to various enablers such as small-cells, massive-MIMO, beamforming and full-duplex, is expected to become the only radio access for both fixed wireless and mobile wireless access. At the same time, ubiquitous use of VoIP in both fixed and mobile networks (voice-over-LTE (VoLTE) and voice-over-Wifi (VoWiFi)) will drive out the TDM (i.e. GSM) based on voice / telephony. Together with the introduction of software-defined networking (SDN) / network function virtualisation (NFV) and the softwarisation of traditional network functions, legacy telephony networks will eventually evolve to mere applications within the new converged network architecture. This convergence has been reflected by the latest IP multimedia subsystem (IMS) and Cloud-IMS based platforms and the on-going evolution of data and video/TV distribution networks to a single IP-based network platform. Individual applications all move to the cloud together with the control and management plane of the network.

The very dissimilar requirements of different services are now being satisfied with various network mechanisms that are based on Quality of Experience/Service (QoE/QoS), Virtual Private Networks (VPNs) and Service-level Agreement (SLA) monitoring tools. As a result, the KPI validation is currently fragmented and service- or network layer-focused, which strongly depends on the use cases. To overcome this fragmentation, the 5G network envisions to accommodate and converge all the above mechanisms under the slicing paradigm to serve the increasingly and extremely variable requirements of the different vertical industries.

The simultaneous support of various heterogeneous requirements (e.g. eMBB, URLLC and mMTC) by a single infrastructure is the unique feature that differentiates 5G from its predecessors. The main 5G achievement is the introduction of an all-encompassing single network that will "absorb" and evolve existing networks (e.g. 2G, 3G and 4G). 5G will definitely come at a cost, but this would be offset by the expected benefits of the converged network, which are the following: i) Long-term savings due to a single network that serves everybody and everything, ii) Flexibility in introducing new services and applications, iii) Scalability in expanding and vi) Simplicity. Even though 5G will introduce a level of

complexity, its architecture will be eventually simplified after "absorbing" the existing network functionalities and becoming the single network that serves all traffic.

The 3GPP has proposed an alternative short-distance protocol named LTE-V2X or PC-5 whose mature version is expected to coincide with the rollout of 5G networks. The first official release is foreseen for late 2021. PC-5 focuses on direct communication and works without interference from the (provider-bound) cellular 5G network. A cellular 5G network requires additional transmission masts and this, in turn, requires a significant investment from the telecom industry. LTE-V2X and the cellular 5G network are often placed under the same header 5G, and this complicates the discussion. The paper does not discuss the details of the Rel-14 LTE-V2X PC5 mode 4, which requires more thorough evaluation and analysis of different configurations in relation to different scenarios (particularly, congested scenarios) to determine the most appropriate configurations and congestion control schemes [Shimizu, et al., 2019], and the best deployment options for ETSI ITS-G5 and LTE-V2X [Dyన్ని Press Release, 2019].

From the business perspective, the ITS sector is full of opportunities to be explored by new technologies. For instance, the advanced features of 5G networks have a strong potential to contribute to the robust and reliable communication technologies required by various intelligent road transport use cases. At the same time, 5G is not expected to initially drive any (new) application [Schulzrinne, 2019] until a clear business model is developed.

To further elaborate on these observations, business validation and business models in the ITS sector have been initially studied through a workshop held on 5 February 2020 in Athens by the 5G-HEART consortium. In general, the business validation process starts with the identification of a specific problem (i.e., pain point) that the prospective customers of a given business are experiencing. Any viable product should achieve a real business value from solving that specific problem. In the case of the ITS sector, the aforementioned use cases and associated pain points have been mainly put forward by the telecom sector (i.e. 3GPP), which do not necessarily capture the specific needs of the automotive industry (i.e. the key stakeholders in the road transport sector).

5G does not seem to be critical for any particular application in intelligent road transport. For instance, there is no simple solution for low latency and high density. If the telecom sector intends to enter a new market, it could, instead of using marketing push, first cooperate with the automotive industry to identify the pain points on connectivity, and make an effort to convincingly present the current status of the 5G development from a technical perspective. In addition to the fact that a target pain point for the offered solution seems to be missing, it is very difficult to identify the benefits and impact from an economic perspective. Furthermore, the estimated investment for a sufficient coverage of all European roads will be huge (e.g. 5G gNBs, on-board units (OBUs) and/or road-side units (RSUs)). From a pragmatic business perspective, who will invest and when is still not clear.

Motivated by these facts, the Service Dominant Business Model Radar (SDBM/R) tool, described in Figure 2, will be exploited to develop a business model for each of the considered use case scenarios. This method, recently proposed and used for business model development, is based on the framework of BASE/X (Business Agility through Service Engineering in a Cross-Organizational Setting) [Grefen 2015], which has been successfully used in transport and logistics domains [Grefen et al. 2015, 2016; Sambeek et al. 2015; Traganos et al. 2015; Turetken & Grefen 2017; Grefen & Turetken 2018; Turetken, et al., 2019]. For each of the considered scenarios, a service-dominant business model will be developed to identify the added value and cost associated with to each party participating in the model (e.g. user and ITS stakeholders).

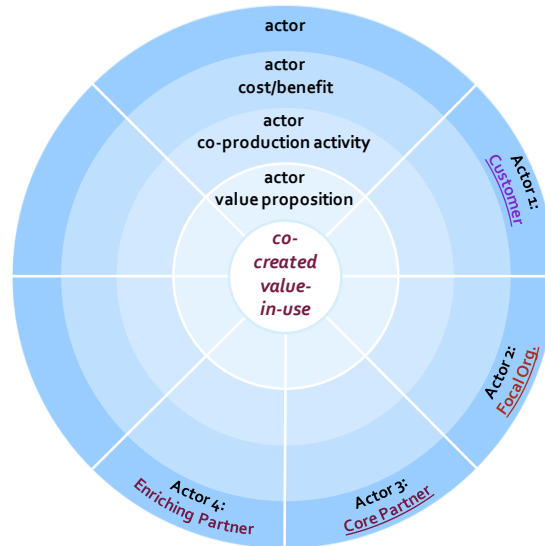


Figure 2 - Service-Dominant Business Model Radar (SDBM/R) template

Conclusion and Further Research

The paper presents four intelligent transport use cases: i) Platooning (scenarios: high bandwidth in-vehicle situational awareness and see-through for platooning; dynamic channel management for traffic progression). ii) Autonomous / assisted driving (scenarios: smart junctions and network assisted & Cooperative Collision Avoidance (CoCA); QoS for advanced driving; human tachograph). iii) Support for remote driving (scenario: Tele-operated Support (TeSo)). vi) Vehicle data services (scenarios: vehicle prognostics; Over-The-Air (OTA) updates; smart traffic corridors; location-based advertising; End to end (E2E) slicing; vehicle sourced HD mapping and environmental services).

From a technical perspective, the selected use cases are relevant to further investigate. However, from a business perspective, the case of 5G for intelligent road transport still needs to be strengthened. No convincing business model is shown, especially due to the fact that a huge investment is needed and that it will take considerable time to sufficiently cover the road network. There is also no guarantee from a specific public or private sector to cover the costs of the development and deployment of 5G for intelligent road transport. Reasons for this could be that the current 5G standard (i.e., R15) is not critical for any particular application, and it is just a means of general connectivity. For the application of 5G in the intelligent road transport sector to be successful, it is needed to convincingly demonstrate cost-effective solutions beyond what current mature technologies can achieve, and to determine real and meaningful gaps in this sector that the next generation technology must be able to accommodate.

As part of future work, it is envisaged to:

- 1) Conduct the three phases of planned trials to showcase the added-value of 5G versus previous cellular (e.g. 4G) and non-cellular technologies (e.g. ETSI ITS-G5).
- 2) Extend the trials to accommodate all road users (e.g. legacy vehicles and non-connected Venerable Road Users).
- 3) Study and compare the performances of multiple communication technologies (e.g. IEEE 802.11p, LTE V2X, 5G-V2X), development business models, and develop a migration path towards future Cooperative, Connected and Automated Mobility (CCAM).
- 4) Extend and adapt the trials to cover other use cases in other sectors (e.g. railway).

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