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5G for Vehicular Use Cases: Analysis of Technical Requirements, Value Propositions and Outlook

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ABSTRACT The fifth generation (5G) of wireless networks promises to meet the stringent requirements of vehicular use cases that cannot be supported by previous technologies. However, the stakeholders of the automotive industry (e.g., car manufacturers and road operators) are still skeptical about the capability of the telecom industry to take the lead in a market that has been dominated by dedicated intelligent transport systems (ITS) deployments. In this context, this paper constructs a framework where the potential of 5G to support different vehicular use cases is thoroughly examined under a common format from both the technical and business perspectives. From the technical standpoint, a storyboard description is developed to explain when and how different use case scenarios may come into play (i.e., pre-conditions, service flows and post-conditions). Then, a methodology to trial each scenario is developed including a functional architecture, an analysis of the technical requirements and a set of target test cases. From the business viewpoint, an initial analysis of the qualitative value perspectives is conducted considering the stakeholders, identifying the pain points of the existing solutions, and highlighting the added value of 5G in overcoming them. The future evolution of the considered use cases is finally discussed.

INDEX TERMS Vehicular, 5G, technical requirements, value propositions.

I. CONTEXT/MOTIVATION

CONNECTED, cooperative and automated mobility (CCAM) is one of the key enablers to enhance road safety, traffic efficiency and to improve environmental and information flows [1]. In this context, the fifth generation (5G) of wireless networks is expected to significantly enhance wireless connectivity, support automation and provide a broad range of digital services to the vehicles, which will support various advanced vehicular use cases and pave the way to fully connected mobility and autonomous driving. As such, the automotive vertical industry has been one of the main targets of recent 5G deployments [2].

A. RELATED WORK

On the industrial side, given that the automotive sector was not historically targeted by the cellular networks community, some effort has been made in the last few years to bring together the telecom and automotive stakeholders. In this respect, the 5G Automotive Association (5GAA) was formed

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in September 2016 as a global, cross-industry organisation of companies from the automotive technology, and information and communication technology (ICT) industries, working together to develop end-to-end solutions for future mobility and transportation services [3]. The 5G Infrastructure Association (5G-IA), representing the private side of the 5G Infrastructure Public Private Partnership (5G PPP), has established a Vertical engagement Task Force (VTF) to coordinate and monitor activities related to working with various vertical sectors, including automotive, manufacturing, public safety and smart cities [4]. To further boost the progress on the automotive sector, the European Commission (EC) has funded various CCAM projects in the context of 5G PPP with an initial focus on cross-border trials along highways (aka 5G corridors) [5]. The findings of these projects are currently being extended and generalized to cover other (e.g., urban/suburban) areas to achieve an economy of scale. Recognizing the increasing demand for vehicle-to-everything (V2X) communications, the third-generation partnership project (3GPP) established a cellular V2X (C-V2X) standard to provide improved range and reliability for enhanced vehicular services beyond the basic safety applications traditionally supported by the IEEE 802.11-based standards (e.g., ITS-G5 and dedicated short-range communication (DSRC) in Europe and USA, respectively) [6]. The C-V2X basic functionality was initially defined in 3GPP Release (Rel)-14 [7] before being refined in Rel-15 [8]. Its full potential is expected to be exploited with 5G New Radio (NR) technologies which will be introduced from 3GPP Rel-16 onwards [9].

In the literature, various surveys have compared the various access technologies that may be used by V2X communications and have highlighted the advantages of 5G C-V2X (e.g., additional bandwidth, extended coverage and slicing support) compared to its cellular (i.e., fourth generation (4G) C-V2X) and non-cellular (e.g., DSRC) predecessors [6], [10]–[12]. While these surveys provided useful insights into the general capabilities of 5G C-V2X, they are not use case-centric, i.e., have not discussed the added value of 5G to support different use cases. At the same time, few recent works focused on specific use cases, including remote driving [13], platooning [14] and collision avoidance [15], but their methodologies remain very much dependent on their target scenarios and cannot be easily applied to examine others.

More recently, few use case-centric studies have been conducted to analyse the potential of 5G to support a plethora of vehicular use cases. In this context, the 3GPP has focused on the network side and analysed the requirements each use case is putting on 5G [16]. In turn, the 5GAA has paid more attention to the user side (i.e., automotive industry) with a focus on the business roles definition and value analysis [17]. These studies, albeit useful, remain fragmented. First, they looked at different angles by focusing on the network and user perspectives, respectively. Second, they either targeted different use cases (e.g., vehicle quality of service (QoS) support and automated valet parking for 3GPP and 5GAA, respectively) or considered different scenarios of the same use cases (e.g., situational awareness). This means that, if someone is interested in a given use case, he would need to dig into different reports to get the full picture. Also, the lack of a common methodology makes it difficult to examine any emerging (i.e., unexplored) use case as choosing the most suitable approach may not be a trivial task.

To overcome these limits, this paper builds upon these previous studies to construct a framework, where the potential of 5G to support different vehicular use cases is analysed under a common format from both the technical and business perspectives.

B. SCOPE OF THIS PAPER

This paper aims at bringing together the telecom and automotive industries by developing a common understanding of few illustrative use cases, their technical requirements and the value 5G would bring to each of their stakeholders.

More specifically, this paper makes the following contributions:

- Construct a framework where the potential of 5G to support different vehicular use cases is thoroughly examined under a common format from both the technical and business perspectives.
- Based on the constructed framework, analyse a non-exhaustive list of four illustrative use cases, namely:
  - ✓ T1 – "*Platooning*" that considers vehicles forming a tightly coordinated "train" with significantly reduced inter-vehicle distance, thus increasing road capacity and efficiency.
  - ✓ T2 – "*Autonomous/assisted driving*" that involves semi- or fully-automated driving to achieve safer traveling, collision avoidance, and improved traffic efficiency.
  - ✓ T3 – "*Support for remote driving*" that enables a human operator or cloud-based application to operate a remote vehicle.
  - ✓ T4 – "*Vehicle data services*" that focuses on collecting actionable information from all the relevant entities (e.g., vehicles and road users) to provide various services via the available 5G infrastructure.

  Each of these use cases entails a few scenarios, where the focus is on a specific service or functionality. For each of these scenarios, the technical and business merits of 5G are analysed using a unified approach.
- From the technical standpoint, a storyboard description is developed following the 3GPP methodology to explain when and how each scenario may come into play (i.e., pre-conditions, service flows and post-conditions). Then, a methodology to trial each scenario is devised including an indicative functional architecture, an analysis of the resulting technical requirements and a set of target test cases.
- From the business standpoint, an initial analysis of the qualitative value perspectives for each use case scenario is conducted. The conducted analysis follows the

5GAA methodology to identify the pain points of the existing solutions for each of the relevant stakeholders and the added value of 5G in overcoming them. The list of stakeholders has been identified based on the expertise and views of the partners of the Horizon 2020 consortium 5G-HEART which include a mixture of all relevant stakeholders (e.g., automotive industry, telecom industry, local authorities, service providers and research institutes).[1] To avoid biasedness, only the inputs that reached a minimum level of consensus across all consortium partners have been kept.
- The possible evolution and future applicability of each of the considered use cases are finally discussed.

To the best of the authors' knowledge, this is the first user case-centric comprehensive analysis, where the potential of 5G to support different vehicular use cases is thoroughly examined under a common format from both the technical and business perspectives.

C. DEFINITIONS

The following terminology and definitions are consistently being used across this paper:

- *Road Side Unit (RSU):* A stationary infrastructure entity equipped with V2X capabilities. It can exchange messages with other entities supporting V2X applications. The RSU may be implemented in a 4G evolved NodeB (eNB), 5G next generation NodeB (gNB), or in a stationary user equipment (UE) [18].
- *Vehicle-to-Infrastructure (V2I):* UEs equipped with V2I capabilities can exchange relevant information with the infrastructure (e.g., an RSU or local application server).
- *Vehicle-to-Network (V2N):* UEs supporting V2N applications can communicate with an application server via a 3GPP packet network.
- *Vehicle-to-Pedestrian (V2P):* UEs supporting the V2P functionality can transmit relevant information to pedestrians. These UEs may be situated in vehicles (e.g., sending warning to pedestrians), or associated with a vulnerable road user (VRU) (e.g., sending warning to vehicles). The 3GPP transport of this information could be direct between UEs and/or via an infrastructure supporting V2X communication (e.g., on-board unit (OBU), RSU and application server).
- *Vehicle-to-Vehicle (V2V):* UEs supporting the V2V functionality can transmit relevant information (e.g., location, dynamics and attributes) to other vehicles. The 3GPP transport of this information is predominantly broadcast-based. It may be direct between UEs and/or via an infrastructure supporting V2X communication (e.g., OBU, RSU and application server).
- *Vehicle-to-Everything (V2X):* V2X is an umbrella term that covers all 4 types mentioned above (i.e., V2I, V2N, V2P and V2V).
- *SAE levels:* The Society of Automotive Engineers (SAE) defines the following six levels of automation (LoAs) [19]:
  - ✓ 0 – No automation,
  - ✓ 1 – Driver assistance,
  - ✓ 2 – Partial automation,
  - ✓ 3 – Conditional automation,
  - ✓ 4 – High automation,
  - ✓ 5 – Full automation.

  The above classification is based on the degree of human involvement. For the lower automation levels (i.e., 0-2), the human operator is the main responsible for the monitoring of the environment and the subsequent adjustment of the driving behavior. For higher automation levels (i.e., 3-5), the automated system takes over the control of these tasks and the human operator becomes less involved.

The remainder of this paper is organized as follows. Sections II–V provide an analysis of the selected use cases from the technical and business perspectives. The analysis is provided per use case scenario, highlighting the motivation, technical requirements and target test cases from the technical viewpoint, and the value proposition for the different stakeholders from the business standpoint. The conclusions and future directions are provided in Section VI.

II. USE CASE T1: PLATOONING

Platooning allows vehicles to form a tightly coordinated "train" with significantly reduced inter-vehicle distance. The term was originally coined, with a specific control algorithm, for truck platooning in the advanced driver-assistance system (ADAS) domain, with the aim to increase energy efficiency and to reduce fuel consumption. Recently, the term has also been used for passenger cars, focusing mostly on the issue of traffic congestion, and without much distinction from the aims and control algorithms of other ADAS functions, such as Cooperative Adaptive Cruise Control (CACC) and Stop-&-Go [20]. The vehicles in a platoon receive a continuous data stream from the lead vehicle for carrying out the platoon operations. This information allows the time headway between vehicles to become extremely small, even less than a second. The following vehicles in a platoon can drive (more or less) automatically, which may create economic, environmental and safety benefits, increase driving comfort by freeing up drivers to perform other tasks (for passenger cars), and reduce the need for professional drivers (for commercial vehicles).

A. SCENARIO T1S1: HIGH BANDWIDTH IN-VEHICLE SITUATIONAL AWARENESS AND SEE-THROUGH FOR PLATOONING

This scenario involves support for high bandwidth in-vehicle streaming serving situational awareness/collision warning and see-through applications for platooning. When driving in a platoon with reduced distances between vehicles, the

1. https://5gheart.org/

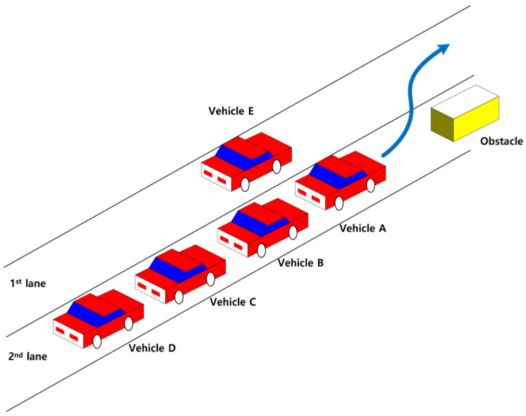

FIGURE 1. Relevance of see-through for changing driving mode.

passengers will feel more secure when they can see what is happening ahead of the platoon leader. One way of facilitating this is by providing an augmented reality (AR) video stream from the lead vehicle to the other members. This can also extend the object/event detection to the trailing vehicles for increased safety (via redundancy) or comfort by anticipating maneuvers of the lead vehicle in response to the driving conditions.

1) MOTIVATION

While situational awareness and see-through have been previously applied to warn individual drivers about hazardous driving situations ahead [21], [22], they have not been considered to support the switch between platooning and individual driving modes. As partial automation levels (e.g., SAE Level 3) may govern the operation of platoons, the human driver of a platooned vehicle would need to be updated to get ready to take over the control of the vehicle whenever needed. The identified objects ahead and/or real-time video representing the front scene could be used as a visual alert that a given platoon may be about to be split for safety and/or efficiency reasons before the actual instruction is received, thus, keeping the anxiety levels of drivers low. Fig. 1 presents an illustrative example of this scenario.

In the following section, an illustrative storyboard of this scenario is provided based on Fig. 1.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
   - A platoon of vehicles A, B, C and D is established. The lead vehicle (i.e., vehicle A) is guiding the actions of the following vehicles according to a conditional automation level (i.e., SAE Level 3).
   - It is assumed that the vehicles are not well equipped to cope with complex situations by themselves. The considered conditional automation level (i.e., SAE Level 3) is only possible within platoons (i.e., with the help of the platoon leader).
2) Service flows:
   - The video captured by the front camera of vehicle A (i.e., the real-time video representing the front scene) is transmitted to the following vehicles.
   - All passengers sitting in vehicles B-D exhibit lower anxiety levels and feel more ready to take over the control of the vehicle if needed.
   - An unexpected obstacle appears in front of vehicle A, which makes the conditional automation level (i.e., SAE Level 3) no longer possible.
   - The platoon operation is split. An instruction to switch to driver-assisted mode (i.e., SAE Level 1) is sent to vehicles B-D.
   - The drivers of Vehicles B-D take over the control.
3) Post-conditions:
   - The switch between platooning and individual driving modes is performed smoothly with a prior visual notification to the platoon members.

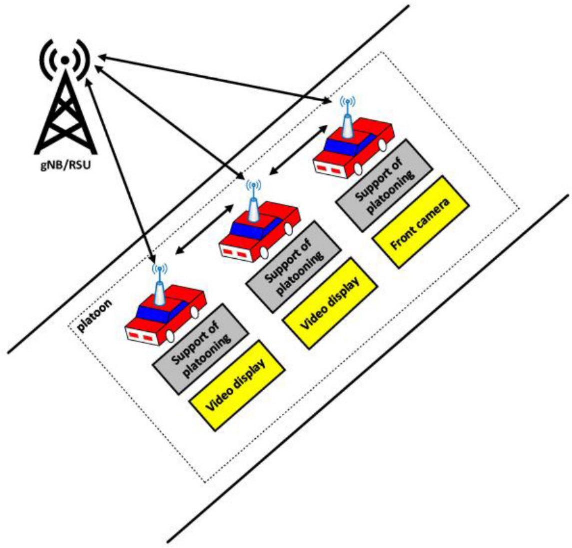

FIGURE 2. See-through for platooning.

3) ARCHITECTURE

The basic principle of this use case is depicted in Fig. 2. For improved reliability, this scenario relies on object and event detection capabilities through on-board sensors together with V2V and V2I communications over 5G. The V2V link is used to share the processed videos and/or identified objects with the next vehicles, whereas the V2I link is used to communicate with the platoon members that are out-of-reach of the platoon leader (i.e., via V2I-to-vehicle (V2I2V)). The V2I link can also be used to upload raw video and offload heavy computation tasks (e.g., video rendering) to the edge of the network.

TABLE 1. Technical requirements for T1S1.

Technical requirement	Target values
Downlink (DL) throughput[2]	High (25-80 Megabits per second (Mbps))
Uplink (UL) throughput	High (25-80 Mbps)
Latency	Low automation level: Low (25 ms) High automation level: Medium (10 ms)
Reliability	Low automation level: Low (90%) High automation level: Medium (99.99%)
Mobility	Medium (50-200 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	4.3×10^3 platoon members/km^2 (peak)[3] <50 platoon members/km^2 (typical)
Interactivity	Medium (100 transactions/s)
Area traffic capacity	0.344 Mbps/m^2 (DL peak) 0.004 Mbps/m^2 (DL typical) 0.344 Mbps/m^2 (UL peak) 0.004 Mbps/m^2 (DL typical)
Security / privacy	Low (Public)

TABLE 2. Requirement definitions and ranges.

Technical requirement	Definition	Ranges
DL throughput	Cumulative throughput on the DL.	Low ≤ 1 Mbps 1 < Medium ≤ 10 Mbps 10 Mbps < High
UL throughput	Cumulative throughput on the UL.	
Latency	The time it takes for a transmitted data packet to reach its destination.	Low ≥ 25 ms 5 ≤ Medium < 25 ms High < 5 ms
Reliability	The success probability of transmitting a small data packet (i.e., from the radio protocol layer 2/3 ingress point to the radio protocol layer 2/3 egress point of the radio interface) within a certain delay [24].	Low ≤ 99% 99% < Medium ≤ 99.999% High > 99.999%
Mobility	The maximum user speed at which a defined QoS can be achieved.	Low ≤ 50 km/h 50 < Medium ≤ 200 km/h 200 < High ≤ 500 km/h
Location accuracy	The accuracy with which location information is provided to the end device/user.	Low > 25 m 1 < Medium ≤ 25 m High ≤ 1 m
Connection (device) density	The total number of devices fulfilling a specific QoS level per unit area.	No specific range. 40×10^3 devices/km^2 (peak)[3]
Interactivity	The number of transactions per unit of time	Low ≤ 1 transaction/s 1 < Medium ≤ 100 transactions/s 100 < High ≤ 1000 transactions/s
Area traffic capacity	Total traffic throughput served per geographic area.	No specific range. 10 Mbps/m^2 (peak)
Security / privacy	The protection of the usability and integrity of user data, equipment and network, as well as the privacy of user identity and information.	Low: Public Medium: Restricted High: Confidential

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 1 summarizes the resulting list of technical requirements with the associated definitions and ranges given in Table 2.

The T1S1 requirements are mainly characterised by high (i.e., DL and UL) throughput, medium latency and high location accuracy to support the demanding situational awareness functionalities on top of the basic platooning operation.

5) TEST CASES

This use case scenario could be trialed based on the following test cases:

- *Phase 1:* See-through and situational awareness for better driving experience
  - ✓ The see-through and situational awareness functionalities are used to inform the passengers of the platoon members of what is happening ahead of the lead vehicle, thus, resulting in a better driving experience.
- *Phase 2:* Initial see-through and situational awareness for smooth switch between driving modes
  - ✓ An initial assessment of the effectiveness of see-through and situational awareness in ensuring a smooth switch between platooning and individual driving modes is trialed at small scale. The transmitted video of the front scene serves as a prior visual notification to allow the drivers of the platoon members to expect the maneuvers of the lead vehicle and get ready to take over the control of the vehicle.
- *Phase 3:* Final see-through and situational awareness for smooth switch between driving modes
  - ✓ A more detailed assessment of the effectiveness of see-through and situational awareness in ensuring a smooth switch between platooning and individual driving modes is trialed at scale.

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted by 5GAA in [17], the key stakeholders are identified together

2. This also captures the throughput requirement on the V2V link.
3. Example estimate is for worst case US Freeway scenario that does not include arterial roads (i.e., onramps): 5 lanes in each direction or 10 lanes total per highway, for up to 3 highways intersecting = 3,100 to 4,300 cars per square kilometer [24].

TABLE 3. Value proposition for the stakeholders of T1S1.

Stakeholders	Pain points	Current solutions	The benefits
Vehicle manufacturers	Need to support adaptive video streaming depending on the available bandwidth. To this end, the bandwidth estimation methods and video quality adaptation logics that have been developed to support the dynamic adaptive streaming over HTTP (DASH) standard [25] could be leveraged and adapted to the V2X context.	The video camera captures the front scene according to a preset video quality that the network may not be able to sustain. As such, the displayed video inside platoon members may stall.	The proper video quality/resolution is selected depending on the available bandwidth. The displayed video inside platoon members is smooth and does not stall.
Mobile network operators	Support of quality-of-service/experience (QoS/QoE) over V2V/V2I links is needed.	The V2V/V2I links do not support delivery of high-definition (HD) video stream with QoS/QoE guarantees.	The video stream can be delivered with some QoS/QoE guarantees.
	Multicasting the video stream to the platoon members can increase the usage efficiency of radio resources.	The communication between platoon members is currently based on periodic broadcasted messages to share status information (e.g., speed and heading) with some event-triggered announcements (e.g., braking and acceleration).	The enhanced multicast broadcast multimedia system (eMBMS) feature does support a combined usage of unicast, multicast and broadcast modes. Applying it on V2X links would result in a more efficient usage of radio resources.
Users (i.e., passengers and drivers)	Need to comfort the passengers by informing them of what is happening ahead of the platoon lead.	The passengers sitting inside the platoon members feel anxious. As such, the acceptance and penetration of platooning applications remains low.	The anxiety level of the passengers sitting inside the platoon members decreases, which results in higher acceptance/penetration of platooning applications.
	Need to warn the drivers before changing the driving mode.	The human drivers are not prepared to take over the control of the vehicle if needed (e.g., in SAE Level 3).	The drivers feel more ready to take over the control of the vehicle.

with the pain points of the existing solutions and the added value of 5G in overcoming them. Table 3 summarizes the outcome of this exercise.

7) FUTURE EVOLUTION

The proposed features (i.e., situational awareness and see-through) are expected to significantly increase the acceptance/penetration of platooning applications. Drivers would feel more ready to take over the control of the vehicle whenever needed (e.g., SAE Level 3), and passengers would feel less anxious about what is happening ahead. The increased penetration of platooning would in turn result in a statistical gain in terms of increasing road capacity due to reduced inter-vehicle distances, improving fuel efficiency, reducing accident rate and enhancing productivity by freeing up drivers to perform other tasks.

B. SCENARIO T1S2: DYNAMIC CHANNEL MANAGEMENT FOR TRAFFIC PROGRESSION

This scenario proposes to optimise the assignment of radio channels to the V2I and V2V links used by the platoons operating in a given area. To this end, a centralised architecture is considered, where a V2X application analyses the speed, location and destination of the platoons before assigning the best radio channels to each of them. Based on this analysis, a radio environmental map (REM), combining geo-location information with the best radio channels, is generated and continuously updated. The area of interest may cover a single (e.g., junctions) or multiple (e.g., highways) RSUs. Distributed architectures may also be considered in other scenarios where cooperative sensing (i.e., with other vehicles and/or RSUs) is deemed more appropriate to determine the best radio channels in a given neighbourhood.

1) MOTIVATION

Cooperative intelligent transport systems (C-ITS) solutions typically use one radio channel for broadcasting messages about vehicle position updates, warning messages or traffic control information. With the introduction of automated vehicle platoons on the road, there is a need for low latency, high reliability and frequent communication. Due to their localised nature, the same radio channels can be used at different locations. As the various platoons are moving, assigning a fixed radio channel to a platoon will not be efficient. Fig. 3 presents an illustrative example of this scenario.

In the following section, an illustrative storyboard of this scenario is provided based on Fig. 3.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
- The blue vehicles shown on the top left of the figure are in platoon 1 and use channel A.
- Platoons 2 (i.e., dark green) and 3 (i.e., blue) are coming from the south-west.

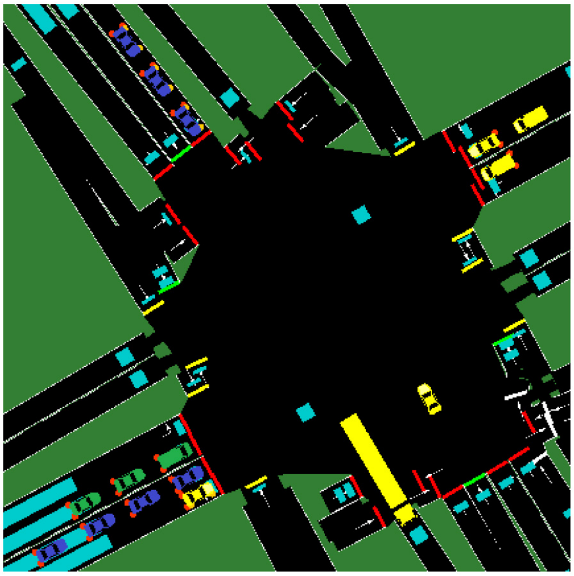

FIGURE 3. Illustrative example of dynamic channel management.

- The other yellow vehicles in Fig. 3 operate individually (i.e., do not belong to any platoon) and use the broadcast channel.

2) Service flows:
   - The RSU application analyses the speed, location and destination of the platoons and assigns the best radio channels to each of them.
   - The blue vehicles in platoon 1, using channel A, will get a green light first.
   - Afterwards, the platoons coming from the south-west will get a green phase, while the dark green vehicles in platoon 2 will overtake the blue platoon 3 right after the intersection.
   - With platoon 2 assigned channel C and platoon 3 again assigned channel A, the geographical spacing of the channels will be A-C-A.
   - Platoons driving in the opposite direction (not shown in the figure) will be assigned channels B and D.
3) Post-conditions:
   - All nearby platoons are using different radio channels. Thus, the communication reliability within all platoons is maintained and their operation remains safe and smooth.

3) ARCHITECTURE

Fig. 4 describes the considered architecture for dynamic channel management for traffic progression.

The modules of the centralised and distributed implementations are coloured in blue and yellow, respectively. In the centralised solution, the various platoon members send their speed, location and destination to their serving gNBs/RSUs. In a given area possibly spanning various RSUs, a V2X application (not shown in the figure for the sake of simplification) gathers and combines all received inputs to determine the optimum channel assignment for the active platoons. A hierarchical optimisation is considered, where a local REM, combining geo-location information with the best radio channels, is generated and continuously updated in each neighbourhood. Note that a form of collaboration between the locals REMs is required to minimise the border effects (e.g., facilitate handovers and minimise co-channel interference). In the distributed solution, the best radio channels are directly determined based on a collaborative sensing jointly performed by the platoon members.

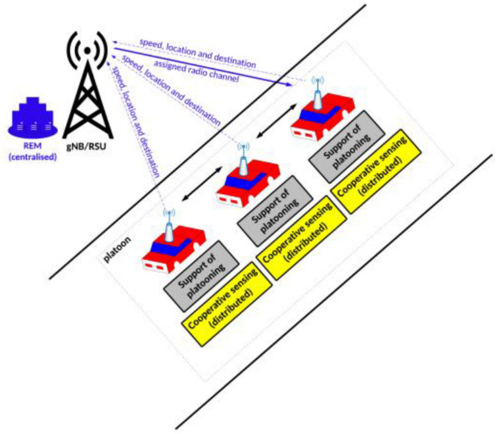

FIGURE 4. Considered architecture for dynamic channel management for traffic progression.

TABLE 4. Technical requirements for T1S2.

Technical requirement	Target values
DL throughput[2]	High (10-65 Mbps)
UL throughput	High (10-65 Mbps)
Latency	Low automation level: Low (25 ms) High automation level: Medium (10 ms)
Reliability	Low automation level: Low (90%) High automation level: Medium (99.99%)
Mobility	Medium (50-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	4.3×10^3 platoon members/km^2 (peak)[3] <50 platoon members/km^2 (typical)
Interactivity	Medium (100 transactions/s)
Area traffic capacity	0.2795 Mbps/m^2 (DL peak) <0.00325 Mbps/m^2 (DL typical) 0.2795 Mbps/m^2 (UL peak) <0.00325 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 4 summarizes the resulting list of technical requirements.

Similarly to T1S1, the T1S2 requirements are mainly characterised by high (i.e., DL and UL) throughput, medium

2. This refers to the footnote on p. 5.
3. This refers to the footnote on p. 5.

latency and medium location accuracy to support the changes of assigned radio channels on top of the basic platooning operation.

5) TEST CASES

This use case scenario could be trialed based on the following test cases:

- *Phase 1:* Extensive simulation campaign
  - ✓ The system is initially simulated to compare different REM implementations and architectural (i.e., centralised and distributed) options.
- *Phase 2:* Small-scale trials
  - ✓ A trial of optimising channel assignment within the coverage area of one single RSU is conducted with a focus on intersections/junctions.
- *Phase 3:* Large-scale trials
  - ✓ Large-scale trials are conducted in areas spanning the coverage area of various RSUs. This would require a form of collaboration between the various RSUs to efficiently deal with border effects (e.g., avoid co-channel interference along borders and perform handovers at the right time and location).

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted in [17], the key stakeholders are identified together with their pain points and the added value of 5G in overcoming them. Table 5 summarizes the outcome of this exercise.

7) FUTURE EVOLUTION

The dynamic channel management functionality could be applied to other V2X use cases and eventually be integrated into a more general framework, where the radio channel assignment is jointly optimised for different verticals (e.g., automotive, e-health and public safety) to enable a more efficient usage of radio resources in a given area. This could first leverage the new spectrum usage models that have recently emerged and gained momentum across the world (e.g., licensed shared access (LSA) and spectrum access system (SAS) in Europe and the U.S, respectively [26]), and then adapt them to the V2X context.

III. USE CASE T2: AUTONOMOUS/ASSISTED DRIVING

Autonomous/assisted driving covers a large number of functionalities and services in the automotive industry. In this context, there has been an increasing trend towards developing connected automated vehicles and services supporting autonomous driving and on-board driving assistance systems. The support comes in the form of extra information provided to the vehicles (via the available 5G infrastructure) regarding its operational environment and the other road users (e.g., vehicles, pedestrians and bicycles) in the area.

TABLE 5. Value proposition for the stakeholders of T1S2.

Stakeholders	Pain points	Current solutions	The benefits
REM providers	A REM, combining geo-location information with assigned radio channels, is highly needed.	No active role in the current situation.	The REM captures the best radio channels to be used by the various platoons operating in a given area. Thus, the various platoons would be subject to less interference and could operate safely.
Spectrum regulators	A regulatory framework is needed to govern the dynamic channel assignment i.e., to use the same radio channels at different locations and/or times. If the same spectrum is shared between various technologies (e.g., cellular and non-cellular), a technology-neutral regulation would be preferred.	The platoons use fixed broadcast channels. No need for regulation.	The area spectrum efficiency is significantly increased.
Vehicle manufacturers	The OBUs should support the dynamic selection of radio channels. If distributed solutions are implemented, cooperative sensing should be also supported.	Vehicles usually come equipped with a single radio access technology (RAT) interface without support of dynamic channel selection.	The various platoons can change their radio channels on-the-fly without impacting the platoon operation.
Mobile network operators	The network should guarantee that the used radio channels by a given platoon are not used by other users in the same time and location.	The network is providing a best effort service to the various platoons. The broadcasted channels may get highly loaded in dense areas, which would strongly hurt the platooning performance.	Radio channels are efficiently reused along the time and space dimensions. As such, the operation of the various platoons can be kept smooth and safe, potentially with less radio channels.

A. SCENARIO T2S1: SMART JUNCTIONS

A high percentage of all traffic accidents occur at intersections, where there is a high density of vehicles and VRUs (e.g., cyclists and pedestrians). The smart junction scenario, also known as "*Intersection Safety Information System*", provides network-assisted safety information towards vehicles to prevent traffic accidents and assist cooperative automated driving functions when the vehicles pass through an intersection. As described in the generic example of Fig. 5, this safety information may involve the exchange of precise traffic signal status information, vehicle information (e.g. location, speed and trajectory), as well as location information of VRUs.

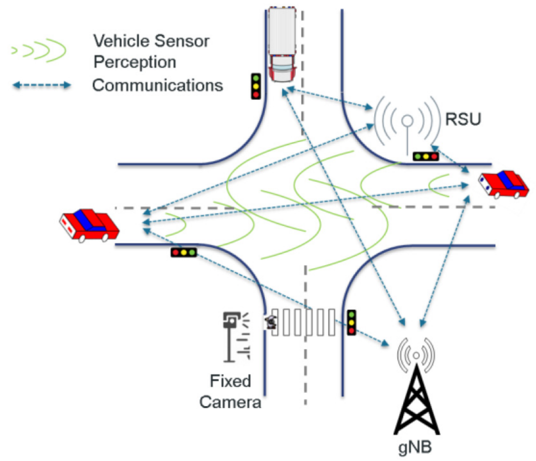

FIGURE 5. Example of a smart junction with traffic lights.

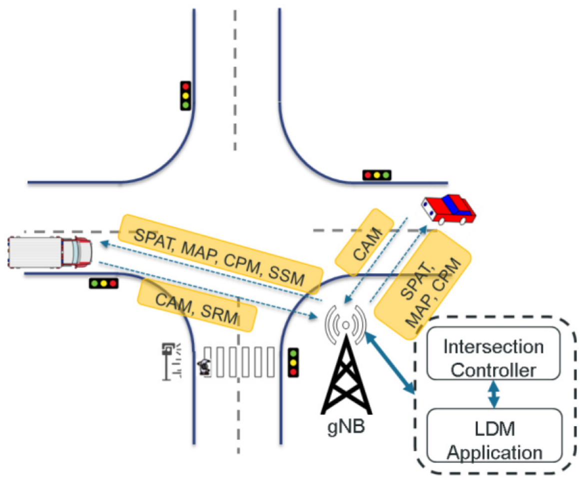

FIGURE 6. Emergency vehicle requesting green wave priority.

The smart junction scenario can be implemented in multiple ways. For instance, the safety information can be stored in a local dynamic map (LDM) running at the RSU, while the intersection controller can be hosted separately from the RSU and be, amongst others, responsible for controlling the traffic lights at an intersection. Under this setting, the LDM information will be sent to the vehicles periodically or on demand using European Telecommunications Standards Institute (ETSI) collective perception messages (CPM) [27]. This information will be needed both in the vehicles and at the intersection controller to know the current intersection situation and control or convey messages to automated vehicles (AVs) (e.g., according to SAE Levels 1 to 3). Next to providing this safety information, smart junctions could also help in improving the overall traffic flow in various situations, e.g., for multiple adjacent junctions on the same corridor. That way, they would be able to improve the traffic flow by creating a green light wave or by giving priority to certain types of vehicles. A special case is when an individual vehicle, for example an ambulance on its way to an accident, requests priority. This would disrupt the default operation of dynamically creating green waves for the larger traffic flow.

Fig. 6 gives a high-level overview of the messages being exchanged (i.e., CPM [27], cooperative awareness message (CAM) [28], MAP [29], signal phase and timing (SPAT) [29], signal request message (SRM) [29], [30] and signal state message (SSM) [29], [30]) in the illustrative scenario of a green wave priority request. The vehicle sends an SRM to request priority, which will be answered by the RSU with an SSM.

1) MOTIVATION

The concept of smart junctions has been developed and trialed over the past years with different setups and implementations (e.g., in the earlier European project InterCor[4] as well as with the Dutch initiative TalkingTraffic)[5]. These implementations are based on current state-of-the-art (SotA) technologies at the time of the trials, where 4G long term evolution (LTE) was used for V2I communication and ITS-G5/DSRC for V2V and V2I communications.

During these trials, an end-to-end (E2E) communication latency of around 20 ms is observed for ITS-G5, while for LTE, the observed latency increases to an average of 150 ms with outliers up to 2 s (e.g., between the physical traffic light and vehicles) [31], [32]. Furthermore, the current LTE technologies cannot scale to support an increasing number of connected entities, each requesting higher network bandwidth with low latency together with a large amount of exchanged information. The promise of 5G is to combine these different and separate technologies into one solution, facilitating high bandwidth and low latency V2X communication through C-V2X and 5G NR.

In the following section, an illustrative storyboard of this scenario is provided based on Fig. 6.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
- The road radio detection and ranging (Radar) and/or cameras are installed at the intersection to detect the movement of vehicles and VRUs.
- The *Intersection Safety Information System* will
  - ✓ host an LDM Application that will receive the status of the traffic lights and location information of the vehicles to store in the LDM,
  - ✓ and/or receive information about VRUs from infrastructure sensors to store in the LDM,

4. https://intercor-project.eu/

5. https://www.talking-traffic.com/nl/

- ✓ and/or host an Intersection Controller capable of granting green priority to requesting vehicles via SRM/SSM,
- ✓ send LDM related information to vehicles via CPM messages.

- The LDM Application and RSU are connected.
- The RSU transmits LDM information via ETSI CPM and/or ETSI SPAT messages on-demand or via broadcasting.
- The UE or *Intersection Safety Information System* may initiate radio link setup.
- The UE may
  - ✓ request LDM information,
  - ✓ request Green Priority,
  - ✓ send location information.

2) Service flows:

- The UE in the (emergency) vehicle initiates radio link setup to the *Intersection Safety Information System.*
- The UE in the (emergency) vehicle continuously sends CAM messages, at a maximum rate of 10 messages/s depending on the vehicle speed, towards the roadside infrastructure over 5G/V2X.
- The intelligent traffic controller continuously sends ETSI MAP messages containing the topology of the intersection and ETSI SPAT containing the current (and upcoming) status of the traffic lights.
- The UE in the (emergency) vehicle requests LDM information from the *Intersection Safety Information System.*
- The *Intersection Safety Information System* sends LDM information to the UE in the (emergency) vehicle.
- The UE in the emergency vehicle sends an SRM message towards the roadside infrastructure, containing a request for green priority for the upcoming intersection(s) and the direction that the emergency vehicle will follow.
- Upon receiving the SRM message, the intersection controller calculates whether the emergency vehicle is able to gain green priority or not, and at which time window. After that, it updates the SSM messages accordingly.
- The UE within the vehicle terminates radio link setup to the *Intersection Safety Information System*.

3) Post-conditions:

- The UE receives the LDM and Green Priority information and generates a warning message for the vehicle driver and/or AV when applicable.

3) ARCHITECTURE

Fig. 7 illustrates the considered high-level architecture for the Smart Junctions use case. The ambulance is equipped with a 5G-capable UE connected to the 5G radio access network (RAN), through which it communicates with the different intelligent traffic controllers that are responsible for controlling the traffic lights at the intersections. The LDM application is running in the edge with a local instance of the user plane function (UPF). User data are handled in the local UPF if multi-access edge computing (MEC) is used, otherwise forwarded to a remote UPF located in the 5G Core Network (5GC). Thanks to this setup, the ambulance can receive real-time status information about the current status of the intersection and request green wave priority if needed.

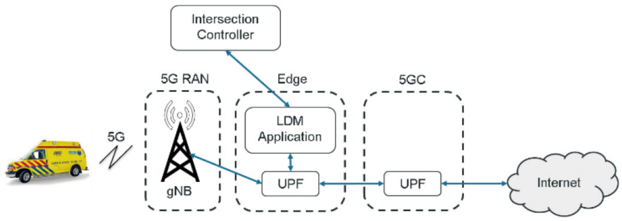

FIGURE 7. Network architecture for T2S1.

TABLE 6. Technical requirements for T2S1.

Technical requirement	Target values
DL throughput	Medium (10 Mbps)
UL throughput	Medium (10 Mbps)
Latency	Medium (10 ms)
Reliability	Medium (99.99%)
Mobility	Medium (max 160 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	Low <4.3×10^3 devices/km^2 (peak)[3] typical: N.A.
Interactivity	High (1000 transactions/s)
Area traffic capacity	0.043 $Mbps/m^2$ (DL peak) 0.043 $Mbps/m^2$ (UL peak)
Security / privacy	Low (Public)

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 6 summarizes the resulting list of technical requirements.

The T2S1 requirements are mainly characterised by medium latency, medium reliability, high location accuracy and strong interactivity requirements. This scenario involves providing network-assisted safety information towards vehicles to prevent traffic accidents and assist cooperative automated driving functions when the vehicles pass through an intersection. Although the provided safety information (e.g., precise digital maps of intersections, status of traffic signals and locations of vehicles and VRUs) does not require high throughput, it is time-critical and dense within a short period of time.

5) TEST CASES

This use case scenario could be trialed based on the following test cases:

- *Phase 1:* Implementation testing of individual modules

3. This refers to the footnote on p. 5.

- ✓ The interaction between the individual modules within the architecture is tested based on the SotA 4G/LTE. This would provide the baseline for the next phases.
- *Phase 2:* Implementation and integration of individual modules
  - ✓ The individually tested modules are integrated with a 5G-capable UE. After that, the connectivity and functionality of the individual modules are tested.
- *Phase 3:* Demonstration of integrated modules
  - ✓ The integrated system is tested, evaluated and demonstrated.

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted in [17], the key stakeholders are identified together with the pain points of the existing solutions and the added value of 5G in overcoming them. Table 7 summarizes the outcome of this exercise.

7) FUTURE EVOLUTION

The smart junction scenario can be realised with existing V2X solutions based on 3GPP specifications or other competing technologies. However, building the required communication infrastructure on top of a 5G network-as-a-slice opens new possibilities for improvements in the technological performance as well as in the deployment flexibility and cost efficiency of the overall service.

B. SCENARIO T2S2: HUMAN TACHOGRAPH

This scenario focuses on a wearables-based human tachograph, which provides a direct measurement/assessment method and technology to assess the driver's physiological status. Wearable sensor devices are typically worn continuously, thus also providing important information from the time spent outside the vehicle. The driver's alertness and fitness-to-drive can be determined from sleep history, recovery status, stress levels and physical activity or lack thereof during the day. For example, prolonged sitting is a health risk for professional drivers. This history data can then be used to assess the current state of the driver more accurately. In addition, wearable sensors can provide real-time status information about the driver in the car while driving. For example, heart rate, heart rate variability, body temperature and skin conductivity are metrics that would be challenging to measure indirectly by on-board systems.

This scenario proposes to collect data monitoring the driver's condition status throughout the day and define the most useful data sets for different driver safety applications. The technologies and methods enabling detailed monitoring of the driver's status, before and during driving, could be exploited as wearable solutions and services aimed towards professional drivers. For instance, different fatigue risk management strategies could provide tools to improve the driver's physiological status related to driving.

TABLE 7. Value proposition for the stakeholders of T2S1.

Stakeholders	Pain points	Current solutions	The benefits
Human drivers	Drivers cannot anticipate a possible problem if they do not physically see it.	Adapt driving speed and respect safety distances.	Improve the level of safety by a warning or proposed trajectory.
	Traffic accidents increase travel times by adding traffic delays due to jams.	Possibly re-route to your destination	Optimised traffic patterns and lesser accidents improve travel times.
Vehicle manufacturers	Vehicles need to be equipped with V2X communication systems.	No exchange of (sensor) information between vehicles.	Higher awareness of surrounding vehicles and entities and their intentions improves the safety level.
	Vehicles need to be equipped with more advanced sensors, such as Radar or light detection and ranging (LiDAR), cameras.	Current sensors are only used within vehicle systems to avoid collisions, e.g., Emergency Brake Assist.	Sensors can be used to avoid collisions in a cooperative way improving the safety level.
	Vehicles should be equipped with LDMs to keep track of object detections.	n/a	Sharing map information allows to warn for possible danger and/or offer safe trajectories for autonomous cars improving the safety level.
Road network manager/city/state	Equipping intersections with intelligent traffic light controllers	Static control algorithms	Improve the traffic flow with tailored traffic light Green/Red phases.
	Equipping intersections with road detection systems	Overall situation monitoring with cameras.	Send detections of e.g., VRUs towards vehicles to improve safety and awareness
	Equipping road sections and intersections with V2X communication equipment.	Traffic regulations and road signs.	Exploiting V2X communication reduces the number of accidents.
Mobile network operators	Sufficient coverage at road sections and intersections	n/a	Potential for new services offered to road network maintenance providers.

1) MOTIVATION

Wearables-based driver condition monitoring can provide useful data for the active safety systems utilised in cars and other vehicles, such as trucks and engines. However, this information will be especially useful for future connected automated vehicles, where accident prevention can be aided by sharing information between vehicles and other systems. If the monitoring data, typically restricted to the current state of the driver, is extended to include the potential risk factors identified from the driver's history data (e.g., sleep deprivation and high stress), more proactive measures can be taken to improve the safety of drivers, passengers and other road users. Wearables, when coupled with high-performance connectivity and service platforms, can furthermore provide driver condition monitoring capabilities to vehicles that do not have an on-board system installed or function as part of network-assisted warning and safety systems.

Currently, a tachograph is a European Union (EU) regulated device to assess that professional drivers have enough rest between drives to prevent fatigue, ensure minimum working conditions standards and guarantee road safety. However, the tachograph is not based on the actual physiological status of the driver. An approach based on the measurement of the actual driver's bio-signals would enable a more personalised tachograph application that takes into account many relevant factors (e.g., the driver's heavy physical activities or accumulated sleep debt during past days), and adjusts the proposed break times and recovery tips accordingly. The information from the tachograph application could also be shared with other drivers and vehicles. After all, a more accurate assessment of the driver's condition is important not only for the driver himself, but also to the other traffic actors.

An emerging trend is to integrate cellular low power wide area (LPWA) connectivity (e.g., LTE Category M1 (LTE-M) and narrowband Internet of things (NB-IoT)) to wearables that could also be used for driver monitoring. However, based on previous measurements [33], the latency of cellular Internet of Things (IoT) technologies is too high, e.g., for warnings towards other road users. In addition, the battery lifetime of wearables easily becomes too short for the driver monitoring if the reporting interval is frequent. For these reasons, this scenario assumes that, at least in the early stages of 5G evolutions, a smartphone or a vehicle on-board system acts as a gateway (GW) node for the wearables. This kind of architecture also enables data fusion of the driver's physiological measurement and history data together with the vehicle on-board sensor data at the GW.

The utilisation of driver monitoring data could be investigated with both long- and short-term data sets. The collected history data based on long-term wearable sensor measurements can be analysed for guidance on how to prevent fatigue and facilitate recovery before and after driving, respectively. Short-term live measurement data can be rather utilised for guidance, warning during driving and potential data fusion with other systems. The driver monitoring data collected with wearable sensors are delivered to the application servers (residing in the local edge or distributed cloud environment) through a 5G network as described in Fig. 8.

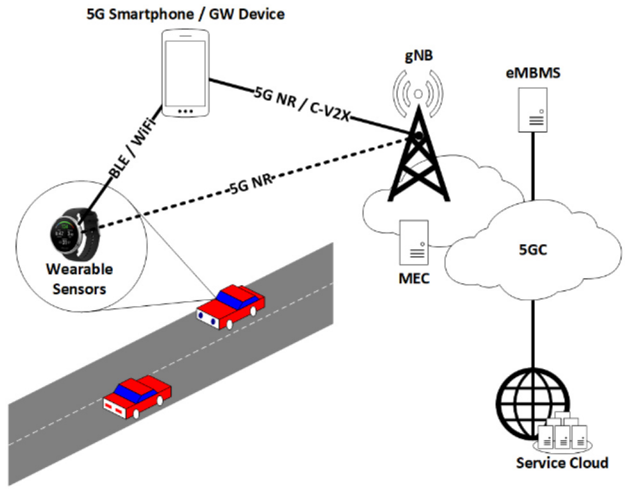

FIGURE 8. Human tachograph scenario schema.

Data fusion with the vehicle on-board sensor data (e.g., speed, location, route, driving time and breaks) or with infrastructure-based vehicle data and warning services (e.g., collision avoidance and environmental services) is expected to open up opportunities for new and more accurate services for automated and assisted driving.

In the following section, an illustrative storyboard of this scenario is provided.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
   - The sensor data from the wearable devices are communicated to the network over a 5G NR link.
     - ✓ Wearable devices have 5G connectivity through a GW node (e.g., smartphone) and/or the vehicle on-board system.
     - ✓ Wearable devices have short-range connectivity (e.g., Bluetooth low energy (BLE) or WiFi) to the GW node and/or vehicle on-board system.
2) Service flows:
   - Vehicle A is considered, where wearable devices send sensor data to the GW node and/or vehicle on-board system via a BLE or WiFi link.
     - ✓ The GW node or vehicle on-board system sends sensor data from Vehicle A to the network via a 5G NR link.
   - Vehicle A receives additional information and other feedback messages based on the sensor data (processed in the network) via a 5G NR link or C-V2X broadcast service.

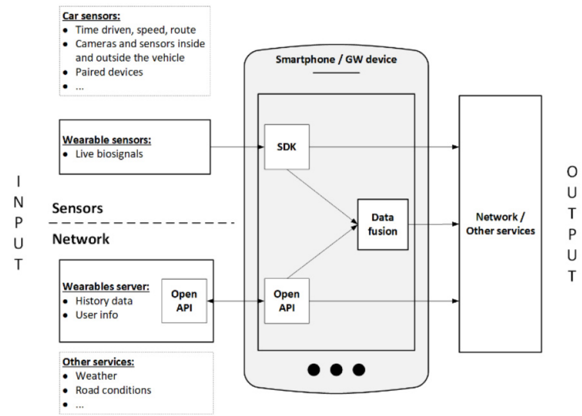

FIGURE 9. User side architecture and data fusion inside a smartphone.

TABLE 8. Technical requirements for T2S2.

Technical requirement	Target values
DL throughput	Low to Medium (<10 Mbps)
UL throughput	Low to Medium (<10 Mbps)
Latency	Medium (5 ms)
Reliability	Medium (99.99%)
Mobility	Medium (50-200 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	4.3×10^3 devices/km^2 (peak)[3] 0.43×10^3 devices/km^2 (typical)
Interactivity	High (1000 transactions/s)
Area traffic capacity	<0.043 Mbps/m^2 (DL peak) <0.043 Mbps/m^2 (UL peak) <0.0043 Mbps/m^2 (DL typical) <0.0043 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

  ✓ The source of the additional information can be a wearables application service (e.g., analysing history data) or an external system (e.g., monitoring weather information and road conditions).
- Vehicle B receives warning messages triggered by the analysed sensor data from Vehicle A (processed in the network) via a 5G NR link or C-V2X broadcast service.

3) Post-conditions:
- Wearable devices display suggestions/warnings to the drivers based on the messages received from the network.
- The GW node utilises the additional information received from the network and combines it with the live measurement data from the wearable devices.
  ✓ Local data fusion can be used for more accurate assessment of the driver status.
- Vehicles A and B generate and display vehicle control information for automated driving based on the additional information and warning messages received from the network.
  ✓ Vehicles A and B adjust driving parameters (e.g., speed or distance to other vehicles) based on the generated vehicle control information.

3) ARCHITECTURE

This use case scenario is built around wearable sensor devices with short range connectivity and standard-compliant 4G/5G network components (i.e., 5G UEs, 5G gNBs, 5G 5GC and eMBMS). Smartphones act as GW nodes between the wearable sensors and 5G network, and perform data fusion tasks, as illustrated in Fig. 8 and Fig. 9, respectively. As 5G technologies continue to evolve, it is expected that in the future, the delivery of the sensor data to the network can be realised directly from the wearable device and data fusion tasks can be efficiently handled at the network edge.

In the GW node (i.e., a smartphone in this example), a mobile software development kit (SDK) enables the service developer to read live data directly from the sensors, including electrocardiogram (ECG) data, acceleration data and heart rate broadcast. For history information, an application programming interface (API) provides a direct information sharing link between the backend data server in the wearables' ecosystem and GW node.

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 8 summarizes the resulting list of technical requirements.

The T2S2 requirements are mainly characterised by medium latency, high interactivity and high location accuracy to support the real-time delivery of the wearable sensors' data to capture the driver's status information in the car while driving. As the human tachograph service supports and complements the on-board driving systems, the reliability requirement is not as strict as in safety-critical standalone services.

5) TEST CASES

This use case scenario could be trialed based on the following test cases:
- *Phase 1:* Initial trial implementation
  ✓ Measurement of the driver's bio-signals with wearable sensor devices. Collection of the sensor data and analysis of the driver's physiological parameters related to fatigue, such as sleep metrics, recovery status and physical activity. Unicast sessions between users and the application service.
- *Phase 2:* Large-scale field trial implementation
  ✓ Trigger of warning messages based on the post-processed and analysed sensor data. Unicast from user to application server with broadcast from application server to all users in the area.
- *Phase 3:* Multi-site trial implementation

3. This refers to the footnote on p. 5.

- ✓ Data exchange and fusion between wearable devices and other (on-board or online) automated driving support systems. Sensor data include both analysed history data and live bio-signals like heart rate.

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted in [17], the key stakeholders are identified together with the pain points of the existing solutions and the added value of 5G in overcoming them. Table 9 summarizes the outcome of this exercise.

7) FUTURE EVOLUTION

Parts of this use case scenario, namely the utilisation of post-processed history data, can be realised already with current 4G technology. With the integration of direct cellular connectivity to wearable sensor devices, the energy efficiency of 4G and 5G chipsets is expected to remain a limiting factor. However, the future evolution of 5G is expected to bring various improvements, including low latency communication for reactive driver safety services, enhanced support for large number of connected wearable devices in crowded environments (e.g., city centres and highways during rush hour) and longer battery life for connected wearables. With these enhancements, the trial architecture presented for the human tachograph service can be streamlined by removing the GW node and moving the data fusion capability to the network edge. The enhanced wireless communication reliability and security are also key factors that will help the new combined services to gain market acceptance.

TABLE 9. Value proposition for the stakeholders of T2S2.

Stakeholders	Pain points	Current solutions	The benefits
Professional drivers	Need to do their jobs successfully and safely. Need for general well-being despite work with irregular and long hours, rush, and changing environments. Professional drivers pose a higher risk in traffic than others (e.g., heavy trucks, existence of passengers around and need to drive in all weather conditions).	Digital tachograph (based on law) with fixed times to ensure enough rest.	More personalised tachograph application to adjust break times, recovery tips, fatigue prevention/management strategies. Drivers are more capable to improve their well-being at work. Drivers acknowledge the role of healthy lifestyle and safe driving for their well-being at work.
Other actors in traffic	Need to drive/cycle/jog safely together with other drivers and AVs.	Visual inspection of other drivers.	Alerts and warnings when an elevated risk in the traffic arises due to driver fatigue or drowsiness.
Transport companies	Ensure minimum working conditions. Ensure healthy labour force in the future.	Digital tachograph.	Health promotion is needed to enhance employee well-being and guarantee enough labour force in the future.
Occupational health care	Support professional drivers' well-being and safety at work.	Regular medical check-ups to ensure fitness-to-drive.	Improved tools for continuous driver condition assessment. Day-to-day objective feedback on the sleep and recovery and other health aspects such as physical activity. This information augments medical check-up data and helps to deliver important preventive screenings.
Policy makers (i.e., communities and governments)	Have minimum working conditions standardised.	Law and regulations.	Guarantee better road safety and less accidents.
Car safety system developer	Reliable and up-to-date information on the driver's health status and fatigue is missing.	Systems detecting eye blinking and irregularities in driving exist, but no reliable preventive methods based on e.g., driver's sleep history.	The fusion of wearable, in-car safety and external road safety data can increase the traffic safety and provide opportunities for new safety services.

IV. USE CASE T3: SUPPORT FOR REMOTE DRIVING

Remote driving is a concept in which a vehicle is controlled remotely by either a human operator or cloud computing software. While autonomous driving needs a lot of sensors and sophisticated algorithms like object identification, path planning and vehicle control, remote driving with human operators can be realised using less of them, provided that ambient information is properly transferred and visualised to the remote vehicle operator. Remote operators may additionally need to react to more diverse scenarios, e.g., passengers getting on/off a bus.

In what follows, only the case of human operators will be considered.

A. SCENARIO T3S1: TELE-OPERATED SUPPORT

In the tele-operated support (TeSo) use case scenario, a vehicle, bearing HD video cameras (i.e., front, right-left side and rear) and perhaps various sets of instrumentation sensors, is traveling in an urban/suburban street or highway. With the aid of vehicle's instrumentation data and video streaming, a remote human operator can track the car and control its course and speed. Tele-operation may be considered throughout the vehicle course, or on-demand upon the request of the driver for remote assistance. All instrumentation data and video streams are communicated to the remote location of the human operator, namely the remote operations centre (ROC) that is either accessed through the core or located at the edge of the network. The instrumentation data and video feed represent ambient information that would strengthen situation awareness, and in turn allow prompt reaction to emerging hazards (e.g., collision avoidance). Furthermore, such TeSo capability enables a single human operator to potentially control more than one vehicle remotely, thus providing additional levels of protection and efficiency.

1) MOTIVATION

The benefits of realising such scenario will be multi-fold for the automotive industry, its professionals and the society in general. Allowing tele-operated (i.e., semi-automated) driving support can be a first cost-feasible step for the realisation of the broader vision for purely automated driving. This means a feasible solution for realising lower-cost professional transportations and public support vehicles (e.g., tele-operated gritters controlled by human operators), and thus avoiding the cost of a rather expensive sophisticated artificial intelligence (AI) computing system. In addition, it will provide the desired advanced security level since societies currently trust more the human-supervised tele-command than complete automated driving. Finally, this will mean coming a step closer to the envisioned desired scenario of humans operating such vehicles remotely in case of critical/emergency conditions. For example, a remote human operator could undertake the driving of the vehicle in case of driving software failure, human driver emergency sickness, or extreme weather conditions.

Given that remote driving is expected to significantly reduce the need for numerous sensors and sophisticated algorithms, it has gained a lot of interest in both academia and industry. In this context, few works have focused on experiments and trials based on existing technologies. Among them, the authors in [34] have set up a real-time streaming testbed, evaluating frame latency with different parameter settings using LTE and Wi-Fi networks. They concluded that significant new design of the communication infrastructure is both necessary and possible. The authors in [35] have investigated the human behavior in a remote driving setup reaching the notable conclusion that remote driving over LTE is not immediately feasible, primarily caused by network delay variability rather than delay magnitude. Motivated by these identified limits, this paper aims at assessing the feasibility of using 5G to support remote driving from both the technical and business perspectives.

In the following section, an illustrative storyboard of this scenario is provided.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
   - The vehicle has established reliable connectivity to the edge/core of the network.
   - The vehicle supports some level of autonomous-driving capabilities (SAE Levels 1-4).
   - The remote vehicle and ROC can establish an authenticated and secure communication channel, and thus exchange information (e.g., instrumentation data, video streaming and driving commands).
   - The vehicle bears the appropriate sets of instruments, sensors and HD video cameras to ensure the human operator has acceptable view to execute control functions.
   - There is an available human operator in the ROC who may undertake the control of the remote driving vehicle.
2) Service flows:
   - The driver of the vehicle asks a remote driving service to undertake the control of the vehicle and drive safely. The data flow from the vehicle to the remote service (e.g., sensor data and video) may be established in the beginning and maintained throughout the vehicle course, or later upon request of the vehicle.
   - The remote operator checks the status of the requested remote driving vehicle (e.g., instrumentation data and video) and decides to activate remote driving function from the ROC.
   - The remote human operator undertakes the control of the vehicle.
   - The vehicle transmits video stream and useful instrumentation data to the remote driver, which helps him to identify road conditions, neighbouring vehicles, and objects on the road.
   - Based on the perceived environment, the remote driver controls the vehicle with maneuver commands transmitted from the ROC to the vehicle via the network.
   - The network monitors and estimates any potential degradation of the network conditions that will not allow to keep the current guaranteed QoS for the communication between the ROC and the vehicle.
   - The network notifies the remote driving application about the expected degradation of the QoS. Based on that, the vehicle falls back to a safe state, or it is decided to adapt the speed by the remote driver.
3) Post-conditions:
   - The remote driving service terminates when no further support or control is needed from the remote human operator.

3) ARCHITECTURE

In the TeSo scenario, the remote human operator would control the vehicle by utilising live data feeds from vehicle instrumentation sensors (e.g., steering angle, gear position and throttle pedal position) and global navigation satellite system (GNSS), as well as from HD on-board cameras over a V2N connection between the vehicle and the ROC.

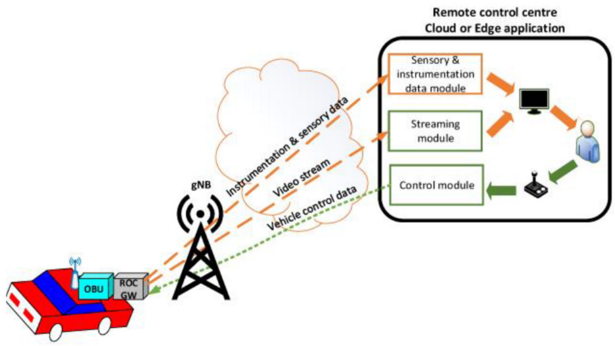

FIGURE 10. V2N communication between the ROC and remotely-operated vehicle.

Fig. 10 depicts the established UL and DL communication links, the data sent from the vehicle to the ROC and vice versa, as well as the sensors and controls involved in such an operation.

In the deployment scenario for the remote driving use case, TeSo is enabled by a V2N connection between the vehicle OBU and a remote server hosting the TeSo application. The OBU transfers through the UL connection the instrumentation data feed (high resolution perception data) from the vehicle to the remote human operator. The instrumentation sensor data provide the human operator the "driver's view" in that particular vehicle and allow the human operator to send appropriate command messages (e.g., command trajectories and possibly voice commands/communication between tele-operator and actual human driver) back to the vehicle (through the DL connection). The E2E delay would result accumulatively from: instrumentation sensors reading, instrumentation data processing, UL, data visualisation, manual control, control signal reading, DL, and control signal processing.

As far as the used instruments are concerned, the vehicle needs to share with the remote operator not only driving information, such as speed, position and videos from cameras (front, right and left sides, and rear), but also vehicle status information, such as steering angle, gear position, throttle pedal position, handbrake position, turn and alarm signals, lights and fuel consumption. Furthermore, specific controls are used so as for the remote driving service to be able to control the different actuators of the car, such as steering wheel, brake, handbrake, gear, throttle, turn and alarm signals and lights to maneuver the vehicle.

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 10 summarizes the resulting list of technical requirements.

The T3S1 requirements are mainly characterised by medium-to-high location accuracy to track the car in real-time, medium latency and medium reliability on the DL to control the course and speed of the car and high throughput on the UL to sustain the delivery of instrumentation data and video streams the ROC.

TABLE 10. Technical requirements for T3S1.

Technical requirement	Target values
DL throughput	Low to Medium (1-5 Mbps)
UL throughput	High (16-20 Mbps)
Latency	DL: Medium (5-20 ms) UL: Low (100 ms)
Reliability	DL: Medium (99.999%) UL: Low (99%)
Mobility	Urban: Low (0-50 km/h). Suburban: Low to Medium (0-100 km/h). Highways: Low to High (0-250 km/h).
Location accuracy	Urban: High (0.5 m). Suburban and highways: Medium (4 m).
Connection (device) density	4.3×10^3 vehicles/km^2 (peak)[3] 0.86×10^3 vehicles/km^2 (typical)
Interactivity	Medium (50 transactions/s) High (200 transactions/s)
Area traffic capacity	0.0215 Mbps/m^2 (DL peak) 0.0043 Mbps/m^2 (DL typical) 0.086 Mbps/m^2 (UL peak) 0.0172 Mbps/m^2 (UL typical)
Security / privacy	High (Confidential)

5) TEST CASES

This use case scenario could be trialed based on the following test cases:

- *Phase 1:* Testing of individual modules
  - ✓ The first phase aims at testing each of the architectural modules of the remote driving application.
- *Phase 2:* Demonstration of the integrated modules – standalone demonstration of the scenario
  - ✓ After testing the functionality of each distinct module, the integrated modules are jointly demonstrated. This phase targets to execute step-by-step the use case/service flow described in Section IV-A.2.2 and thus, successfully accomplish vehicle tele-operation.
- *Phase 3:* Comparison with 4G counterpart trials already demonstrated.
  - ✓ In the last phase, a comparison is conducted between capabilities of the 4G and 5G networks. Specifically, the use case/service flow is executed under the same circumstances, however, under different network capabilities, namely the legacy 4G and the emerging 5G network.

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted in [17], the key stakeholders are identified together with the pain points of the existing solutions and the added value of 5G in overcoming them. Table 11 summarizes the outcome of this exercise.

3. This refers to the footnote on p. 5.

TABLE 11. Value proposition for the stakeholders of T3S1.

Stakeholders	Pain points	Current solutions	The benefits
Public administration (i.e., counties and prefectures)	It is costly to maintain separate drivers for seasonally used vehicles.	Employ different drivers for each vehicle, and possibly additional personnel.	Have more flexibility in the management of public vehicles, conserving resources and adapting them seasonally. Reduce functional costs with less personnel to operate the vehicles.
	It can be risky to send drivers in hazardous conditions.	Obliged to send drivers to hazardous situations for the broader public safety.	Reduce risk for its personnel in hazardous situations.
Mobile network operators	Accommodate critical data transfers for potentially multiple and scattered vehicles. Distinguish TeSo data from ordinary vehicle data.	Currently they have no special business relevant to this application.	Become able to differentiate critical traffic streams. Provide differentiated services at different costs.
Human drivers (of legacy vehicles)	Adjust to the tele-operated vehicles driving around them.	Prefer predictable driving behaviours. Trust more human drivers than automated, or semi-automated driving.	Trust more assisted-driving vehicles, and shift their caution to human-driven vehicles. TeSo will create better driving conditions and prevent hazardous situations for human drivers. Ultimately, TeSo will assist passengers in case of an emergency (e.g., sickness of the driver or extreme weather conditions).

7) FUTURE EVOLUTION

Considering the TeSo evolution, a piece of software could undertake the task of remotely driving the vehicles. To comply with the legal and safety constraints, the remote driving software should be supervised by a remote human operator located at the ROC. The benefit in this case would be that a single remote human operator could supervise the TeSo service of multiple vehicles concurrently, which reduces the number of required drivers and thus the cost of the service. Ultimately, TeSo will enable the envisioned scenario of remotely operated vehicles as an alternative/complementary service to self-driving cars, enabling transportation of passengers who cannot drive themselves (e.g., elderly and disabled persons), or to cut down human driving costs.

V. USE CASE T4: VEHICLE DATA SERVICES

This use case focuses on collecting actionable information from all the relevant entities (e.g., vehicles and road users) to provide various services via the available 5G infrastructure.

A. SCENARIO T4S1: SMART TRAFFIC CORRIDORS

This use case scenario looks at how historical and real-time data from vehicles can be used to intelligently control the routes that a vehicle is recommended or mandated to take to reduce pollution or congestion. The selection can be based either on historical or real-time data collected from the road infrastructure and vehicles. This may include among others:

- Monitoring of emissions and guidance of individual, or groups of, vehicles to be routed based on locally implemented emissions corridors. Vehicles such as lorries or older vehicles with high emissions may be guided through a high emissions corridor whilst low emissions or electric vehicles may be given more flexibility on the routes they may take to their destinations.
- Logistics and delivery vehicles may be routed based on the time-of-day to reduce congestion. This is currently being explored by numerous local authorities to relieve congested areas during peak traffic times during the day.

1) MOTIVATION

Empowering cities with IoT infrastructure to turn them into “smart cities” has gained growing interest in the past years. The main reason is that the upcoming 5G technologies enable bandwidth and connectivity speeds that allow multi-source and large-scale information transactions, which are necessary to provide a real-time service in a system consisting of a vast number of sensors and simultaneous end-users. In particular, by 2025, cities that will deploy smart mobility applications, such as smart traffic corridors, could potentially reduce commuting times by an amount of 20% on average [36]. In this context, this scenario focuses on leveraging real-time air quality and traffic information to offer the most ‘livable’ route in the context of saving as much time as possible for the driver, while simultaneously minimizing the environmental impact. As the traffic congestion is a dynamic phenomenon, with a continuously changing behavior, a real-time assessment of the situation and a continuously updated navigation offer are important for the efficiency of the service, which could be facilitated by 5G. Moreover, such a service, would be most applicable to an urban environment with high vehicle density, where congestion is more of a major problem. This would result in a high number of potential end-users and simultaneously will impose a high demand of sensor information to cover the large extent of the urban area of interest, which would require a level of scalability not achievable by current 4G systems. Moreover, the future integration of additional information into the service (e.g., weather conditions, pedestrian flow or the integration with other complementary services) would increase vastly the corresponding DL and UL bandwidth needs for a real-time service.

In the following section, an illustrative storyboard of this scenario is provided.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
- IoT infrastructure, supported by sensors gathering traffic and environmental information, is installed.
- A cloud service analyses the gathered data and predicts the congestion loads and vehicle emission levels.

2) Service flows:
- The driver asks for a route recommendation based on the profile of the vehicle.
- The profile information is sent to the cloud service. Based on it together with the recent and historical data, the optimal/recommended route and departure/arrival times are determined.
- The calculated route and time as well as other information (e.g., alternative routes and statistics) and metadata are sent to the user.

3) Post-conditions:
- The driver receives all relevant information and schedules his journey accordingly.

3) ARCHITECTURE

An overview of the considered architecture is described in Fig. 11.

The considered architecture consists of a 5G GW node collecting the air-quality sensors information, 5G RAN and 5GC. The end-user mobile application, with a direct connection to the OBU of the vehicle, has access to the service provided through the Cloud. The vehicles are connected to the 5G RAN for transmission of related data. The collected data is then transferred through the CN to the cloud for further analysis and selection of the most appropriate route/path for each of the vehicles. It is worth pointing out that this use case scenario could also be supported by 4G, but the level of scalability needed to support a high density of vehicles (e.g., in urban areas) could only be achieved by 5G as mentioned earlier.

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 12 summarizes the resulting list of technical requirements.

The T4S1 requirements are mainly characterised by high connection density and medium location accuracy to optimise routing based on the historical and real-time data provided by the vehicles.

5) TEST CASES

This use case scenario could be trialed based on the following test cases:

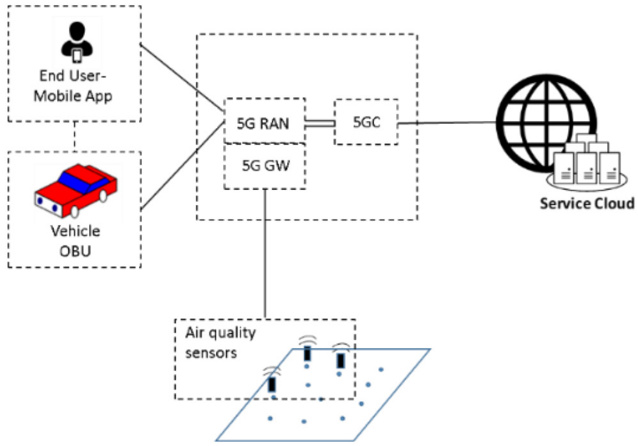

FIGURE 11. Indicative architecture for smart traffic corridors.

TABLE 12. Technical requirements for T4S1.

Technical requirement	Target values
DL throughput	Medium (1-10 Mbps)
UL throughput	Low (≤1 Mbps)
Latency	Low (25 ms)
Reliability	Medium (99.99%)
Mobility	Medium (50-200 km/h)
Location accuracy	Medium (4 m)
Connection (device) density	4.3×10^3 devices/km^2 (peak)[3] 0.5×10^3 devices/km^2 (typical)
Interactivity	Medium (< 100 transactions/s)
Area traffic capacity	0.043 Mbps/m^2 (DL peak) 0.005 Mbps/m^2 (DL typical) 0.0043 Mbps/m^2 (UL peak) 0.0005 Mbps/m^2 (UL typical)
Security / privacy	Low (Public)

- *Phase 1:* Installation and configuration of the available equipment and preparation to gather and process information from the sensors installed on the vehicles and/or from the RSUs.
- *Phase 2:* Implementation, creation, and storage of the dynamic heatmaps based on optimised discretisation levels in the spatial and time domains. Implementation of the decision-making entity that exploits the produced heatmaps, vehicle profile and user preferences to select the optimal route and time of journey based on some predefined rules.
- *Phase 3:* Testing according to the outcome of the available routes connecting two points, taking into consideration the vehicle profiling information and possible restrictions associated with it (e.g., some routes may be prohibited for high-emission vehicles).

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted in [17], the key stakeholders are identified together with the pain

3. This refers to the footnote on p. 5.

TABLE 13. Value proposition for the stakeholders of T4S1.

Stakeholders	Pain points	Current solutions	The benefits
Vehicle manufacturers	Ensure all required data are collected accurately in a timely manner. Develop appropriate interfaces.	Usage of common maps for finding a route between the origin and destination.	Recommending routes/corridors based on various parameters and constraints (e.g., pollution levels and traffic loads).
Mobile network operators	Accommodate data transfers for multiple and scattered vehicles.	n/a	Provide differentiated services at different costs.
Technology providers	Provide services for selection of routes/corridors	n/a	Developing services for recommending routes/corridors based on various parameters and constraints (e.g., pollution and traffic).
Users (i.e., vehicle owners and drivers)	Adjust to route/corridor suggestions.	Usage of common maps for finding a route between origin and destination.	Usage of advanced services for recommending routes/corridors based on various parameters and constraints (e.g., pollution levels and traffic).

points of the existing solutions and the added value of 5G in overcoming them. Table 13 summarizes the outcome of this exercise.

7) FUTURE EVOLUTION

Different algorithms for interpolating scattered data could be evaluated, and the performance sensitivity to the spatial density and distribution of sensors could be assessed. A combination of this analysis with further data sources, such as road traffic and weather information, could eventually be utilised and tested from both the application and network perspectives. Once a high level of maturity is reached, the smart corridors scenario could scale up to support a high number of users.

B. SCENARIO T4S2: VEHICLE-SOURCED HD MAPPING

AVs do not only require on-board sensors to perceive the world around them, but also HD maps to aid their decision making. HD maps of roads and infrastructure will take years to capture and consolidate. There is the added issue of dynamic changes to these maps over time. As such, an innovative means to collect and maintain up-to-date data would be to crowdsource this information 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.

1) MOTIVATION

As one of the most important of human inventions, maps have been made for millennia. People have created and used these maps to help them define, explain, and navigate their way through the world and beyond. These maps initially were in the form of two-dimensional drawings and eventually took the form of three-dimensional globes. Modern maps of the old and new worlds were developed during the age of discovery. The last century has ushered in the information age where the power of computing, connectivity and storage has allowed us to digitise maps and transmit real-time location information via satellite technology. These maps are commonly used in smartphones through the use of applications such as Google Maps and also in vehicles (e.g., TomTom and Garmin for road vehicles).

For instance, for Lyft, maps are a key component to building self-driving technology [37]. Unlike regular Web map services which are in wide use today for turn-by-turn navigation, AVs require a new class of HD maps. Current maps and mass market location-based tracking using GNSS technology provide accuracy within a range of ten meters. HD maps for AVs need to represent the world at a centimeter-level resolution, which is orders of magnitude greater than the resolution that map services offer today.

AVs demand such a high resolution because they need to routinely execute complex maneuvers such as nudging into a bike lane to take a turn and safely passing cyclists. For example, marked bike lanes in Europe are typically 1.2 – 1.5 m wide at a minimum, but are recommended to be between 1.5-2.5 m in width. Other factors, such as the type of road or junction, distance from the kerb, road signage as well as other considerations impact the design of these lanes. Centimeter-level accurate maps are a must for an AV to be able to confidently reason about its position within a lane, assess distance from vehicles, cyclists, road infrastructure and potentially unique road features (e.g., potholes or other road conditions) to confidently take action.

Several mapping and self-driving companies have already started to produce and consume HD maps. However, it is still early days in terms of how these maps are being built, the richness of information they contain, and how accurate they are. Companies are iterating quickly on making these HD maps better, and as such, there is little standardisation between the various providers and consumers. Therefore, the creation and management of HD maps form a specialised function in the autonomy stack of AVs.

In the following section, an illustrative storyboard of this scenario is provided.

2) DESCRIPTION

This section provides a storyboard description of this use case scenario following the methodology adopted by 3GPP in [23]. It specifies a list of pre-conditions, service flows and post-conditions to explain when and how this scenario may come into play.

1) Pre-conditions:
- The site and area are identified for HD mapping.
- The identified sites must have 5G coverage and required features available.
- A group of contributing vehicles, each equipped with one or more sensors (e.g., optical, LiDAR, Radar and

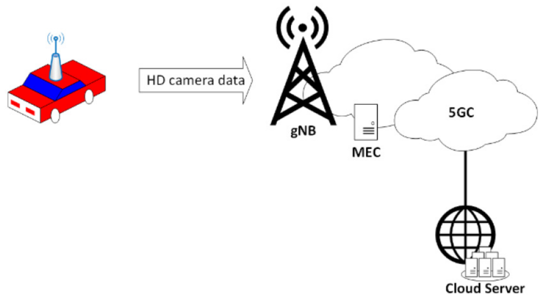

FIGURE 12. Indicative architecture for vehicle-sourced HD mapping.

inertial measurement units) connected to an OBU, are available.
- A mapping application creates, and updates HD maps based on real-time data.
- All participating vehicles have 5G connectivity to roadside infrastructure and/or cloud servers with the mapping application.
- A route plan is available for capturing map data.

2) Service flows:
- A given vehicle, tasked with mapping a specific route, begins its journey.
- The RSU does local processing and updates the information to the cloud mapping application.
- The other contributing vehicles repeat the same task as the first vehicle but only send updates of additional map data.
- All updates are consolidated and shared with all vehicles.

3) Post-conditions:
- All the key elements (i.e., cloud mapping application, RSUs and vehicles) have the latest HD map data based on the latest journeys taken by the contributing vehicles.

3) ARCHITECTURE

The HD mapping application should be implemented on both the OBU and cloud server, with possibly a local instance running on the local MEC facilities. An indicative architecture for the implementation is depicted in Fig. 12.

4) TECHNICAL REQUIREMENTS

The expectations of this use case scenario have been analysed as per the 3GPP methodology described in [24]. Table 14 summarizes the resulting list of requirements.

The T4S2 requirements are mainly characterised by high UL throughput and high location accuracy to collect the required data to initially establish and subsequently maintain HD maps.

TABLE 14. Technical requirements for T4S2.

Technical requirement	Target values
DL throughput	Low ≤ 1 Mbps
UL throughput	High (100 Mbps)
Latency	Low (100 ms)
Reliability	Medium (99.99%)
Mobility	Low to Medium (0-200 km/h)
Location accuracy	High (0.5 m)
Connection (device) density	200 devices/km^2 (peak) 100 devices/km^2 (typical)
Interactivity	Medium (< 100 transactions/s)
Area traffic capacity	0.0002 Mbps/m^2 (DL peak) 0.0001 Mbps/m^2 (DL typical) 0.02 Mbps/m^2 (UL peak) 0.01 Mbps/m^2 (UL typical)
Security / privacy	Low (Public)

5) TEST CASES

This use case scenario could be trialed based on the following test cases:
- *Phase 1:* Test setup
  - ✓ Prepare the test setup with HD mapping application in a distributed or centralised deployment across cloud servers. Vehicles are prepared, and testing is conducted focusing on the 5G connectivity for the overall scenario.
- *Phase 2:* HD map creation
  - ✓ Use one or more in-vehicle sensors to create an HD map from scratch using one or more vehicles.
- *Phase 3:* HD map maintenance
  - ✓ Test the dynamic update of the HD map across all elements (i.e., cloud mapping application, RSUs and vehicles).

6) STAKEHOLDER ANALYSIS

This section conducts an initial analysis of the qualitative value propositions for each of the stakeholders of this use case scenario. Following the methodology adopted in [17], the key stakeholders are identified together with the pain points of the existing solutions and the added value of 5G in overcoming them. Table 15 summarizes the outcome of this exercise.

7) FUTURE EVOLUTION

HD Maps are a critical component of the software and hardware requirements for autonomous driving. These maps need to be created for practically all public roads and paths where AVs are expected to operate safely and efficiently. The task of creating these maps is enormous, but the proposed novel concept of building them using vehicle-sourced data will aid in reducing the time, cost and required effort.

This use case scenario could eventually be tested at a larger scale and consider:
- Integration with automotive OEM platforms.
- Creation of standards to allow any vehicle to contribute to map making.
- Exploring how 5G providers may enable services in the 5G MEC to facilitate the creation and distribution of HD map data.

TABLE 15. Value proposition for the stakeholders of T4S2.

Stakeholders	Pain points	Current solutions	The benefits
Vehicle manufacturers	Need HD maps to build safe AVs.	Relying on 3rd parties.	Gain some independence from map makers and speed up process.
Map makers	Need to quickly build HD maps to offer to vehicle operators and original equipment manufacturers (OEMs).	Process of map building is excruciatingly slow.	Allow existing traffic to help build maps.
Users (i.e., passengers and drivers)	Need to feel safe.	n/a	Complete a critical piece of the autonomy puzzle.
Local authorities	Need to ensure local infrastructure supports HD mapping.	Collaboration limited.	Work jointly with map makers and OEMs in ensuring maps are up-to-date.

- Study how infrastructure sensors may be used to support the map creation and maintenance processes.

As we move beyond AVs and towards autonomous systems (e.g., planes, boats, and drones), the HD mapping requirement will go beyond just the road networks at ground level. Point clouds will be required for numerous new systems that will emerge and consideration will need to be given to how these systems ‘see’ each other and how they interact.

VI. CONCLUSION AND FUTURE WORK

The fifth generation (5G) of wireless networks promises to meet the stringent requirements associated with various advanced vehicular use cases that cannot be fully supported by previous (i.e., cellular and non-cellular) technologies. However, the stakeholders of the automotive industry (e.g., car manufacturers, road operators and governments) are still skeptical about the capability of the telecom industry to take the lead in a market that has been dominated in the last few decades by dedicated intelligent transport systems (ITS) deployments. In this context, this paper constructs a framework where the potential of 5G to support different vehicular use cases is thoroughly examined under a common format from both the technical and business perspectives. From the technical standpoint, an analysis of the need for 5G is made together with a storyboard description to explain when and how different use case scenarios may come into play (i.e., pre-conditions, service flows and post-conditions). A methodology to trial each scenario is developed, including an indicative functional architecture, an assessment of the resulting technical requirements and a set of target test cases. From the business viewpoint, an initial analysis of the qualitative value perspectives is conducted considering the stakeholders of each use case scenario, identifying the associated pain points and assessing the added value of 5G in overcoming them. The future evolution of the considered use cases is finally discussed.

TABLE 16. List of acronyms.

Acronym	Full form
3GPP	Third-generation Partnership Project.
4G	Fourth Generation.
5G	Fifth Generation.
5G PPP	5G Infrastructure Public Private Partnership.
5G-IA	5G Infrastructure Association.
5GAA	5G Automotive Association.
ADAS	Advanced Driver-assistance System.
AI	Artificial Intelligence.
API	Application Programming Interface.
AR	Augmented Reality.
AV	Automated Vehicle.
BLE	Bluetooth Low Energy.
C-ITS	Cooperative ITS.
C-V2X	Cellular-V2X.
CACC	Cooperative Adaptive Cruise Control.
CAM	Cooperative Awareness Message.
CCAM	Connected, Cooperative and Automated Mobility
CPM	Collective Perception Message.
DASH	Dynamic Adaptive Streaming over HTTP.
DL	Downlink.
DSRC	Dedicated Short-range Communication.
E2E	End-to-end.
EC	European Commission.
ECG	Electrocardiogram.
eMBB	Enhanced Mobile Broadband.
eMBMS	Enhanced Multicast Broadcast Multimedia System.
eNB	Evolved NodeB.
ETSI	European Telecommunications Standards Institute.
EU	European Union.
gNB	Next generation NodeB.
GNSS	Global Navigation Satellite System.
GW	Gateway.
HD	High-definition.
ICT	Information and Communication Technology.
IoT	Internet of Things.
ITS	Intelligent Transport Systems.
LDM	Local Dynamic Map.
LiDAR	Light Detection and Ranging.
LoA	Level of Automation.
LPWA	Low Power Wide Area.
LSA	Licensed Shared Access.
LTE	Long Term Evolution.
LTE-M	LTE Category M1.
Mbps	Megabits per second.
MEC	Multi-access Edge Computing.
NB-IoT	Narrowband IoT.
NR	New Radio.
OBU	On-board Unit.
OEM	Original Equipment Manufacturer.
QoE	Quality of Experience.
QoS	Quality of Service.
Radar	Radio Detection and Ranging.
RAN	Radio Access Network.
RAT	Radio Access Technology.
Rel	Release.
REM	Radio Environmental Map.
ROC	Remote Operations Centre.
RSU	Road Side Unit.
SAE	Society of Automotive Engineers.
SAS	Spectrum Access System.
SDK	Software Development Kit.
SotA	State-of-the-Art.
SPAT	Signal Phase and Timing.
SRM	Signal Request Message.
SSM	Signal State Message.
TeSo	Tele-operated Support.
UE	User Equipment.
UL	Uplink.
UPF	User Plane Function.
V2I	Vehicle-to-Infrastructure.
V2I2V	V2I-to-Vehicle.
V2N	Vehicle-to-Network.
V2P	Vehicle-to-Pedestrian.
V2V	Vehicle-to-Vehicle.
V2X	Vehicle-to-Everything.
VRU	Vulnerable Road User.
VTF	Vertical engagement Task Force.

As part of future work, it is intended to further elaborate on the initial analysis of the qualitative business value perspectives conducted in this paper by collecting all the necessary inputs using scientifically sound surveys whose results will be fed into viability simulations for national transport systems. This could be complemented by revealed-preferences methods providing quantitative information to assess the viability for profit margins in a solid business case assessment.

ACRONYMS

The list of the acronyms used in this paper can be found in Table 16.

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