Top Level Newsletter: Connected Vehicle

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Vol 21 comprises:

(1) 5G New Radio for Automotive Applications

(2) A Definition and Framework for Vehicular Knowledge Networking

(3) Energy-Efficient Connected and Automated Vehicles

(4) Autonomous Bus Driving

(5) Activities on Legislation for Autonomous Vehicles Take Off

(6) Position Location for Futuristic Cellular Communications

(7) A Qualitative Analysis of Vehicle Positioning Requirements for Connected Vehicle Applications

(8) Security and Privacy Issues in Intelligent Transportation Systems

General Notes

This series of newsletters is intended to provide the IEEE member with a top level briefing of the many different subjects relevant to the research, development and innovation of the connected vehicle. This newsletter additionally takes an early peek at 6G and ways in which its development will differ from 5G.

A note on the Connected Vehicle Newsletter development: Volume 20 departs from the norm and includes a complete article. Volume 19 returned to the usual format. Volume 18 was a top-level synopsis of the 74 most recent entries from the twelve previous volumes (vol 17 to vol 6) since March 2020.

The objective is to provide a platform for fast learning and quick overview so that the reader may be guided to the next levels of detail and gain insight into correlations between the entries to enable growth of the technology. Intended audiences are those that desire a quick introduction to the subject and who may wish to take it further and deepen their knowledge. This includes those in industry, academia or government and the public at large. Descriptions will include a range of flavors from technical detail to broad industry and administrative issues. A (soft) limit of 300 to 600 words is usually set for each entry, but not rigorously exercised.

As descriptions are not exhaustive, hyperlinks are occasionally provided to give the reader a first means of delving into the next level of detail. The reader is encouraged to develop a first level understanding of the topic in view. The emphasis is on brief, clear and contained text. There will be no diagrams in order to keep the publication concise and podcast-friendly. Related topics in the case of Connected Vehicle technology, such as 5G cellular and the Internet of Things will be included. The terms Connected Vehicle and Automated Driving will be used inter-changeably. Articles from other published sources than IEEE that add to the information value will occasionally be included.

This newsletter forms part of the regional Advanced Technology Initiative (ATI) of which connected vehicles form a constituent part. Technical articles solely from IEEE journals/magazines are referred to by their Digital Object Identifier (DOI) or corresponding https link. The link for each article is provided. Those readers who wish to delve further to the complete paper and have access to IEEE Explore (www.ieeexplore.ieee.org) may download complete articles of interest. Those who subscribe to the relevant IEEE society and receive the journal may already have physical or electronic copies. In case of difficulty please contact the editor at kaydas@mac.com. The objective is to provide *top level guidance* on the subject of interest. As this is a collection of summaries of already published articles and serves to further widen audiences for the benefit of each publication, no copyright issues are foreseen.

Readers are encouraged to develop their own onward sources of information, discover and draw inferences, join the dots, and further develop the technology. Entries in the newsletter are normally either editorials or summaries or abstracts of articles. Where a deepening of knowledge is desired, reading the full article is recommended.

1. 5G New Radio for Automotive, Rail, and Air Transport, by Gabor Fodor et al.

Published: IEEE Communications Magazine (Volume: 59, Issue: 7, July 2021, pp 22-36)

Abstract/ Introduction: Recent advances in wireless communications, real-time control, sensing, battery technologies, and artificial intelligence are enabling the transport sector to become more cost efficient, secure, and sustainable. Due to new requirements arising in road, railway, and air transport, cellular connectivity is becoming an essential part of cooperative intelligent transportation systems (C-ITSs) and smart cities. The authors review the most important characteristics and requirements of a wide range of services that are driven by the desire to help the transport sector to become more sustainable, economically viable, safe, and secure. These requirements will be supported by the evolving and entirely new features of 5G NR systems.

As the number of vehicles operational worldwide has surpassed one billion, and is expected to reach two billion by 2035, there is great interest in making road transport more safe, sustainable, and much more cost-efficient and energy-efficient. Digitalization and increasing connectivity in the transport sector are driven by three key factors. First, there are increasing demands imposed by virtually all stakeholders - passengers, cargo companies, vehicle manufacturers, public transport and rail operators, and infrastructure (road, rail, airport) providers. This broad set of requirements includes being always connected to the Internet and enterprise networks, safe and secure journeys, and minimizing environmental impacts. At the same time, reducing capital and operational expenditures necessitates digitalization, automation, and always-on connectivity. Third, the rapid deployment of 5G networks and the recent advances in 6G research provide a technology push toward digitalized and connected transport services.

In parallel with the above trends in the transport industry, Release 15 of the 3rd Generation Partnership Project (3GPP) specifications in 2016 marked the birth of the new cellular radio interface for the fifth generation (5G) cellular systems, commonly referred to as New Radio (NR). Although mobile broadband (MBB) services continue to be the main driver for NR, this new radio technology generation inherently has much stronger support for verticals such as the transport industry as compared to Long Term Evolution (LTE). Additionally, already in Rel-16, new technical features were introduced specifically for supporting critical machine-type communications including ultra-reliable low-latency communications (URLLC) vehicle-to-everything (V2X) services for automotive. Compared to 4G systems, 5G NR adopts a new design philosophy and novel technology components, which significantly benefit connected transport use cases. The core NR features include flexible numerology and waveform design for lower and millimeter-wave frequency bands minimizing control signaling overhead, multi-hop support by integrated access and backhaul relay, enhanced positioning, and quality of service (QoS) handling mechanisms. Also, further enhanced multiple-input multiple-output (MIMO) techniques enable 5G networks to acquire accurate channel state information (CSI) for beamforming and spatial multiplexing applications, which are important for maintaining high spectral efficiency even in high-speed road and rail transport scenarios. Furthermore, recent 3GPP releases of NR pave the way for advanced radio-based positioning techniques that efficiently complement and improve pure satellite-based positioning techniques, which are highly useful for automotive and drone use cases.

The article serves two purposes. First, we summarize the technical foundations of 5G NR that can fulfill basic requirements imposed by emerging use cases in the transport sector. Second, based on an in-depth review of special connectivity requirements of transport use cases, we highlight several important new technology enablers that will play key roles in meeting the most stringent requirements. In particular, we focus on the following:

- Positioning techniques that take advantage of combining onboard sensors and cellular network measurements
- Reference signal design and selecting the appropriate multi-transmission and reception point (TRP) option for operations of other high-speed user equipments (UEs)
- Novel QoS prediction techniques useful in driverless and driver-assisted transport use cases (595 words)

DOI: org/10.1109/MCOM.001.2001106

2. A Definition and Framework for Vehicular Knowledge Networking, by Duncan Deveaux et al

Published: 2019 IEEE Vehicular Technology Magazine (Volume 15, Number 2), pp 57 – 67

Abstract: The authors define a structure for vehicular knowledge description, storage, and sharing. To operate intelligent vehicular applications such as automated driving, mechanisms including machine learning (ML), artificial intelligence (AI), and others are used to abstract knowledge from information. Knowledge is defined as a state of understanding obtained through experience and analysis of collected information, and it is promising for vehicular applications. However, to achieve its full potential, it requires a unified framework that is cooperatively created and shared. This article investigates the meaning and scope of knowledge as applied to vehicular networks and defines a structure for vehicular knowledge description, storage, and sharing. Through the example of passenger-comfort-based automated driving, we expose the potential benefits of such knowledge structuring for network load and delay.

Background: Over the last decade, we have witnessed the evolution of vehicular networking from vehicular ad hoc networks that enable spontaneous, direct communications among vehicles to connected vehicles generalizing information exchange among vehicles and infrastructure. Vehicular networking has developed as an enabler of innovative applications intended to improve traffic safety, reduce congestion, and even provide infotainment on board. Early applications were designed to provide information only to drivers, delegating any decision making to them.

However, in recent ambitious applications, such as automated driving or platooning, simple information treatment and forwarding mechanisms are no longer sufficient. Instead, decision making is based on models of the environment built from much more sizable sets of input information. Models are designed to learn from experience rather than react to static input signals. In this context, models have the potential to reduce the load and delay in vehicular networks, as key content is extracted from larger sets of input information. What is more, by favoring the distribution of models over static content, information privacy is improved. However, unlike with static content sharing, mechanisms to name, localize, and network/offload the knowledge creation capacities of models in vehicular networks are lacking.

Various techniques, such as AI, ML, or formal language, have been used to extract knowledge in vehicular contexts through the analysis of various sources of information. Regardless of the technique, extracting knowledge from information is a complex and expensive process, but the generated knowledge may be beneficial to other vehicles. So far, each vehicle remains autonomous for its knowledge building, requiring highly specialized algorithms and a large amount of input information, which could potentially be sourced from multiple different vehicles. This can be seen as a significant overhead, considering that knowledge can be shared but not individually recreated. As a reaction, research has recently focused on defining a knowledge-centric approach to networking, where information would no longer be the main focus. Instead, knowledge would be created by nodes in the network and directly stored and shared among them.

Vehicular Knowledge Representation: We understand knowledge as an abstract content obtained from the analysis of larger sets of information. Knowledge can be extracted from information using ML algorithms and divided into three classes:

1. SL: Supervised learning applies to classification or regression. A model is trained based on a number of samples of the form (information, class) for classification or (information, value) for regression. Knowledge is extracted as the relationship between the information and its associated class, i.e., the function that takes information as an input and returns its estimated class.
2. UL: Unsupervised learning extracts clusters of similar items in a set of information. It creates knowledge by exposing the relationships among information items and sorting them into different clusters.
3. RL: Reinforcement learning, finally, can be used by an agent to learn the optimal behavior to adopt in a context of interaction with an environment to maximize a user-defined reward. (609 words)

DOI: https://doi.org/10.1109/MVT.2021.3066376

3. Energy-Efficient Connected and Automated Vehicles, by Yunli Shao et al.

Published: 2019 IEEE Vehicular Technology Magazine (Sept 2021, Volume 16, Number 3), pp 47 – 56.

Connected and automated vehicles (CAVs) can bring energy, mobility, and safety benefits to transportation. This article presents a unified control framework that integrates real-time traffic prediction with the co-optimization of vehicle motion and powertrain operation.

The CAV is an emerging technology to benefit the energy, mobility, and safety aspects of transportation. Vehicles with connectivity are equipped with communication devices to access real-time information that has not been available before, such as the speed and position of preceding vehicles, signal phase and timing (SPaT), road curvature and slope, and so on. Vehicles with partial or full automation are equipped with control systems to precisely control their motion as well as onboard sensors to perceive the environment and surrounding objects. The new information provides an opportunity to effectively predict future traffic conditions. Therefore, a CAV can be controlled proactively in an optimal fashion to achieve objectives such as minimizing energy consumption, control effort, and travel time. An optimal control strategy can be obtained by solving a mathematical optimization problem for a look-ahead horizon. When minimizing the energy consumption of CAVs, energy savings can be obtained at two levels: the vehicle and the powertrain levels. At the vehicle level, the vehicle speed trajectory and car-following distance can be optimized to operate the vehicle with the most efficient power request. A powertrain is an assembly of every component that pushes the vehicle forward. A vehicle's powertrain creates power from the engine and delivers it to the wheels on the ground. The key components of a powertrain include an engine, transmission, driveshaft, axles, and differential.

At the powertrain level, for a given vehicle power demand, powertrain systems can be further optimized to operate in the most energy-efficient regions. The co-optimization of vehicle motion and powertrain operation maximizes the potential for energy savings. For vehicles with varying powertrain types, different optimization problems need to be formulated and solved. (312 words)

DOI: https://doi.org/10.1109/MVT.2021.3085999

4. Autonomous Bus Driving, by Rui Oliviera et al.

Published: 2019 IEEE Vehicular Technology Magazine (Sept 2021, Volume 16, Number 3), pp 29 – 37.

Abstract: In this article, we present a motion-planning framework that leverages expert bus driver behavior, increasing the safety and maneuverability of autonomous buses. Autonomous vehicles will increase the safety, quality, and efficiency of transportation systems. However, to deploy this technology in urban public transport, many challenges related to self-driving buses still need to be addressed. Unlike passenger cars, buses have long and wide dimensions and a distinct chassis configuration, which significantly challenges their maneuverability. To deal with their special dimensions, we introduce a novel optimization objective that centers their whole body as they travel along a road. Furthermore, we present new environment classification schemes that enable self-driving buses to take advantage of their distinct chassis configuration, namely, the elevated overhangs, to increase maneuverability. Finally, we offer a novel collision checking method that explicitly considers a bus's front wheels and how they can protrude from beneath the chassis when maneuvering near stops. We demonstrate the benefits of our framework through experiments using an autonomous bus in real road scenarios**. (**167 words)

DOI: https://doi.org/10.1109/MVT.2021.3086438

5. Activities on Legislation for Autonomous Vehicles Take Off, by Katrin Sjoberg.

Published: 2019 IEEE Vehicular Technology Magazine (Sept 2021, Volume 16, Number 3), pp 149.

Abstract: The COVID-19 pandemic is still holding the world in a strangle- hold. Large-scale vaccination is in different stages throughout nations globally, and countries that have come far in terms of vaccinating the population are slowly beginning to open up. The commercial vehicle industry sells more vehicles than it can produce for the moment—a sort of rebound effect from when the world was put on hold last spring. At the same time, the automotive industry is experiencing semiconductor shortages, resulting from unfortu- nate occurrences such as fires in semiconductor factories, but also because semiconductor companies' order intakes from the automotive industry declined substantially last spring, and the companies turned to other customers. Delays in production in Europe have also been experienced due to the cargo ship *Ever Given*'s blocking of the Suez Canal for a week during the spring. The storage of

automotive components is on the road to cut costs, and the manufacturing of vehicles is sensitive to hiccups in the delivery chain.

Despite the challenging times with the COVID-19 pandemic, there is more activity than ever in the field of connected and automated driving. Much funding has been invested in start-ups aiming to bring zero-emission connected and automated vehicles to market for enabling the safe and sustainable transport of people and goods. Autonomous vehicles need new types of initiatives to create appropriate legislation for putting safe autonomous vehicles on the streets are underway. It is challenging when the driver is removed from the loop! (246 words)

DOI: 10.1109/MVT.2021.3091393

6.Position Location for Futuristic Cellular Communications: 5G and Beyond, by Ojas Kanhere et al

Published: IEEE Communications Magazine (Volume: 59, Issue: 1, January 2021, pp70-75**)**

Abstract/ Excerpt:

With vast mmWave spectrum and narrow beam antenna technology, precise position location is now possible in 5G and future mobile communication systems. This is of particular interest to the growth of autonomous/ connected vehicles, amongst other applications. In this article, we describe how centimeter-level localization accuracy can be achieved, particularly through the use of map-based techniques. We show how data fusion of parallel information streams, machine learning, and cooperative localization techniques further improve positioning accuracy.

With the rapid adoption of Internet of Things (IoT) devices, a variety of new applications that require centimeter-level precise positioning shall emerge, such as automated factories that require precise knowledge of machinery and product locations to within centimeters. Geofencing is the creation of a virtual geographic boundary surrounding a region of interest to monitor people, objects, or vehicles, and by using sensors on a moving object, the location of the object may be continually and adaptively "geofenced" to trigger a software notification immediately when the object enters or leaves the virtual geographic boundary. Position location to within 1–2 m will enable accurate geofencing, such that users entering/leaving a room or equipment and people may be tracked in hospitals, factories, within and outside buildings.

Today's fourth generation (4G) cellular networks rely on LTE signaling and the global positioning system (GPS) (which is accurate to within 5 m). However, in indoor obstructed environments, or in underground parking areas and urban canyons, GPS signals are attenuated and reflected such that user equipment (UE) cannot be accurately localized. To further refine the positioning capabilities of GPS indoors and in urban canyons, SnapTrack "wireless assisted GPS" (WAG) improved the sensitivity of GPS receivers. Additionally, databases of geo-tagged Wi-Fi hotspots have been used by companies such as Apple and Google. The UE may be localized using the known positions of all Wi-Fi hotspots that the UE can hear, where the UE position estimate is formed from the weighted average of the received signal strengths, providing an accuracy of tens of meters. Although FCC requirements specify a horizontal localization error of less than 50 m for 80 percent of enhanced 911 (E911) callers, a localization error less than 3 m will be required for positioning applications of the future.

In addition to infrastructure-based positioning systems, other sensor-based technologies such as vision-based localization using cameras (commonly utilized by drones) can provide accurate positioning capabilities when fused with inertial sensors. However, in low-visibility environments, localization systems at cellular frequencies work better since they are not blocked when visibility is hampered. Ultrasound indoor positioning systems such as Forkbeard are able to achieve a precision level of 10 cm within an office environment. Autonomous vehicles utilize light detection and ranging (LIDAR) to estimate the relative distances to other vehicles with sub-millimeter accuracy, while factory-based systems using infrared have shown good accuracy.

Position location solutions are being developed using other media such as ultra wideband (UWB), RFID, visible light, and Bluetooth. UWB signals, in the 3.1-10.6 GHz band, have a bandwidth of more than 500 MHz. Rapid strides in utilizing UWB for localization are expected, with the iPhone 11 currently carrying UWB chips that are typically capable of achieving a ranging accuracy on the order of centimeters.
The advent of millimeter-wave (mmWave) communications enables a paradigm shift in localization capabilities by allowing joint communication and position location, utilizing the same infrastructure. As shown in this article, the massive bandwidths, coupled with the high gain directional, steerable multiple-input multiple-out-put (MIMO) antennas at mmWave frequencies, enable unprecedented localization accuracy in smartphones of the future. We demonstrate how the utilization of cooperative localization, machine learning, user tracking, and multipath enables precise centimeter-level position location. (607 words)

DOI: https://doi.org/10.1109/MCOM.001.2000150

7. A Qualitative Analysis of Vehicle Positioning Requirements for Connected Vehicle Applications, by Matthew Bart et al.

Published: IEEE Intelligent Transportation Systems Magazine (Volume: 13, Issue: 1, Spring 2021, pp225 - 242)

Abstract/Excerpt:

Many Connected Vehicle (CV) applications, including safety-critical ones such as collision warning, require lane-level positioning accuracy to function correctly. However, differential GNSS, the primary positioning method used by CVs in current deployments across the U.S., cannot always provide this level of accuracy. This is particularly true in urban environments. Alternative positioning methods or strategies must be developed to fill this gap. To determine what strategies are appropriate, we first identify the

positioning requirements of each CV application listed in the USDOT's Connected Vehicle Reference Implementation Architecture (CVRIA). These requirements include accuracy, integrity, update rate, and type of positioning (relative or absolute). Based on our overall analysis, we recommend two general positioning strategies: 1) utilize other sources of positioning information whenever possible (particularly at intersections), and 2) estimate the uncertainty of the positioning solution and use this uncertainty as an input to CV applications themselves.

If the GNSS receiver's view of the sky is blocked (by objects such as buildings, foliage, and terrain), the positional accuracy may be degraded. Errors of ten meters or more are not uncommon in the so-called "urban canyons" of large cities and are hard to predict. Such large errors are unacceptable for some applications (e.g., cooperative adaptive cruise control). Therefore, the first objective of this paper is to qualitatively identify the positioning requirements of CV applications, namely the required accuracy, integrity, positioning type (relative or absolute), and update rate. All of these are explained below. For the purposes of our analysis, we separate accuracy into four levels, which are described below.

1. None: No positioning required.

2. Coarse ("Where-on-road"): Accuracy sufficient to determine which roadway segment the vehicle is traveling on, and approximate location on it. Positioning accuracy is typically 5-10 meters. If the position error exceeds 10 meters, that location may be discarded (i.e., the accuracy drops to "None").

3. Lane-level: Which lane the vehicle is in (the "absolute positioning" case, explained below) or the number of lanes between vehicles ("relative positioning" case, explained in article). Given that a typical passenger car is 1.8 m wide, the position error must be less than 0.9 m. This way, the measured position will fall within the correct lane, even if one side of the vehicle is on the lane edge. Submeter accuracy is also declared necessary for correct lane assignment.

4. Where-in-lane: Where-in-lane accuracy is important for automated driving functions such as stopping at a stop bar and lane keeping. While 0.9 m accuracy may be sufficient for lane placement, it is not sufficient for these tasks. Therefore, we define 0.1 m as the required accuracy. This is also the required accuracy for collision avoidance applications. (440 words)

DOI: : https://doi.org/10.1109/MITS.2019.2953521

8. Security and Privacy Issues in Intelligent Transportation Systems: Classification and Challenges, Dalton Hahn et al.

Published: IEEE Intelligent Transportation Systems Magazine (Volume: 13, Issue: 1, Spring 2021, pp 181- 196)

Abstract: Intelligent Transportation Systems (ITS) aim at integrating sensing, control, analysis, and communication technologies into travel infrastructure and transportation to improve mobility, comfort, safety, and efficiency. Car manufacturers are continuously creating smarter vehicles, and advancements

in roadways and infrastructure are changing the feel of travel. Traveling is becoming more efficient and reliable with a range of novel technologies, and research and development in ITS. Safer vehicles are introduced every year with greater considerations for passenger and pedestrian safety. Nevertheless, the new technology and increasing connectivity in ITS present unique attack vectors for malicious actors. Smart cities with connected public transportation systems introduce new privacy concerns with the data collected about passengers and their travel habits. In this paper, we provide a comprehensive classification of security and privacy vulnerabilities in ITS. Furthermore, we discuss challenges in addressing security and privacy issues in ITS and contemplate potential mitigation techniques. Finally, we highlight future research directions to make ITS more safe, secure, and privacy-preserving. (161 words)
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