**Top Level Newsletter:** **Connected Vehicle**

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Systems Research Development and Innovation

**(Vol 4.0 progress: An important paper reviewing current sensor technology has been added)**

This publication is intended to provide the reader with a top level briefing of the subject under review. There are two sections:

- ***Concepts:*** Background information for a first level comprehension of new concepts

- ***Publication Briefs:*** Summary of material of deeper interest in selected dated publications

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 200 to 300 words is usually set for each topic, 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. However, it is not the intent to make this a forest of hyperlinks. 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. Related topics in the case of Connected Vehicle technology, such as 5G cellular and the Internet of Things will be included. Publications from 2017 onwards will only be included. The publication will be updated periodically. This Vol 2.0 edition has new publication summaries.

This newsletter forms part of the Advanced Technology Initiative (ATI) in the region. Technical articles solely from IEEE journals/magazines are referred to by their Digital Object Identifier (DOI). Those readers who wish to delve further to the complete paper and have access to IEEE Explore may download a complete article of interest directly by inserting the DOI. Those who subscribe to the relevant IEEE society and receive the journal may already have physical or electronic copies in their possession. In case of difficulty please contact the editor at [kaydas@mac.com](mailto: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.

New: Here is a Youtube summary presentation by Prof. Amnon Shashua of Mobileye/Intel addressing some key issues: <https://youtu.be/y6i8T49Xz5U>

Readers are encouraged to develop their own onward sources of information, discover and draw inferences, join the dots, and further develop the technology. A small quiz is included at the end of this publication.

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**Concepts (in alphabetical order)**

Artificial Intelligence (AI) is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience. Since the development of the digital computer in the 1940s, it has been demonstrated that computers can be programmed to carry out very complex tasks—as, for example, discovering proofs for mathematical theorems or playing chess—with great proficiency.

Big data has spawned the current interest and increased investment in artificial intelligence. The availability of large volumes of data—plus new algorithms and more computing power—are behind the recent success of deep learning, finally pulling AI out of its long “winter.” More broadly, the enthusiasm around big data (and the success of data-driven digital natives such as Google and Facebook), has led many enterprises to invest heavily in the collection, storage, and organization of data. (170)

Building Blocks of Connected Vehicle Technology**:** Mimicking themany things humans do while driving requires a complex blend of technologies. Several sensors are required to analyse inputs and make decisions about steering, braking, speed…and routing. OEMs, Tier1s, start-ups etc are all involved in this disruption. Key areas are (47):

- Processing Power*:* a range of technologies from NXP. Infineon, Renesas, STMicroelectronics, Intel etc. Joined by (1) Nvidia with its GPUs which excel at performing multiple tasks simultaneously, like analyzing the many pixels streaming in from cameras. Nvidia’s recent platform for SAE level 3 to 5 is the size of a car license plate delivering 320Moperations per sec. (2) Mobileye/Intel with its dedicated video processor EyeQ3. Conventional CPUs will not disappear as the need to make sequential decisions remains.

Specialised parallel devices can be made from FPGAs from Xylinx, Altera/Intel, Lattice and Microsemi. The fusion of sensors and localized processors will continue. The likely progression will be that a major control unit will collect all relevant data and make decisions. That will push the demand for more cores, lower latency/higher clock rates, and lower power consumption. Another development is driver alertness monitoring for SAE 2 upwards. The driver’s face angle is perceived to determine drowsiness. (155)

- Sensors*:* Radar, Video, Lidar: Humans need two eyes and some mirrors to drive well but vehicles will need upto 30 sensors to match. The radar component is dominated by NXP, STMicroelectronics, Analog Devices and Renesas who are pairing controllers and radar. Start-ups/others include Oculii, Omniradar, Artsys360, Bosch, Delphi. Cameras and radar currently work together and overlap to identify objects and it is likely that lidar will be added when solid state devices meet automotive requirements. The shift to 77 GHz radar from 24 GHz permits more bandwidth. Advanced techniques for sending and receiving signals are helping radar identify objects instead of simply providing range information. In video, 8-10 Mpixels will supersede today’s 2-4 Mpixel cameras. Increased data will require innovative latency management.

Various smaller companies now make electro-mechanical lidar systems but all are developing solid state versions. Some lidar systems are ready but only for short distance usage like lane departure. High resolution at distances of 200 to 300 ft is required. (162)

- Architecture and SW/HW interfaces*:* The architecture is of prime importance in achieving quality of performance. Amongst many responsibilities, it determines how sensor data is collected and fused to create a single and dynamic view of the surroundings, how data is shared throughout the vehicle, how decisions are made, and how efficiently data is cross-checked. Software will play a key role as electronic controls determine actions in reponse to what is happening around the vehicle. Hardware must be powerful enough to make computations in time to avoid danger. Today software and hardware are often made by the same supplier, though the Automotive Open System Architecture (AUTOSAR) has enabled some separation. However, a continued necessity for abstraction between the two prevails in order to bring in third party software. One critical aspect is whether the processing power needs to be centralized or distributed (ADAS favours the latter). There is evenly divided opinion on this. Some OEMs opt for a mix of the two approaches. It is difficult to create software that will respond correctly to all the possibilities that autonomous vehicles will see while in operation. This is sparking a huge investment in creating AI programs that ‘learn’ as vehicles are in operation. (202)

- Communications*:* If vehicles can communicate, they can get information their onboard sensors cannot get, such as emergency braking, blind spot activity etc. V2I communications to roadside beacons can also aid in safety and in traffic flow. The NHSTA is advocating the use of Dedicated Short Range Communication (DSRC), though the uptake has been slow in some sectors of the industry. DSRC promises low latency. There are some spectrum issues to be resolved. Cadillac has been the first to adopt V2V. On highway tests have already proven DSRC’s performance. While some 5G proponents feel that cellular, already embedded in the industry, can displace DSRC, many feel that both systems can share roles and co-exist. It will take time for V2X vehicles to displace older cars. Aftermarket systems cannot offer many safety features since it is difficult to verify that messages are coming from a verified source and not a hacker! (151)

Caching:  a hardware or software component that stores data so that future requests for that data can be served faster; the data stored in a cache might be the result of an earlier computation or a copy of data stored elsewhere. A *cache hit* occurs when the requested data can be found in a cache, while a *cache miss* occurs when it cannot. Cache hits are served by reading data from the cache, which is faster than recomputing a result or reading from a slower data store; thus, the more requests that can be served from the cache, the faster the system performs.

To be cost-effective and to enable efficient use of data, caches must be relatively small. Nevertheless, caches have proven themselves in many areas of computing, because typical computer applications access data with a high degree of locality of reference. Such access patterns exhibit temporal locality, where data is requested that has been recently requested already, and spatial locality, where data is requested that is stored physically close to data that has already been requested. (177)

Cloud Computing is the on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. The term is generally used to describe data centers available to many users over the Internet. Large clouds, predominant today, often have functions distributed over multiple locations from central servers. If the connection to the user is relatively close, it may be designated an edge server. Clouds may be limited to a single organization (enterprise clouds) or be available to many organizations (public cloud,) or a combination of both. (92)

Computer Vision is an interdisciplinary field that deals with how computers can be made to gain high-level understanding from digital images or videos. Computer vision is concerned with modeling and replicating human vision using computer software and hardware. It is a discipline that studies how to reconstruct, interrupt and understand a 3D scene from its 2D images in terms of the properties of the structure present in scene.

From the perspective of engineering, it seeks to automate tasks that the human visual system can do. Computer vision is concerned with the automatic extraction, analysis and understanding of useful information from a single image or a sequence of images. It involves the development of a theoretical and algorithmic basis to achieve automatic visual understanding. As a scientific discipline, computer vision is concerned with the theory behind artificial systems that extract information from images. The image data can take many forms, such as video sequences, views from multiple cameras, or multi-dimensional data from a medical scanner. (164)

Connected Vehicle: Although many terms are in use such as Autonomous Vehicle, Connected Car, and others, we choose this nomenclature to include partially and fully autonomous vehicles of all descriptions, for example, including two-wheel machines.

Co-ordinated Multipoint (CoMP) When a UE is in the cell-edge region, it may be able to receive DL signals from multiple cell sites and the UE’s UL transmission may be received at multiple cell sites regardless of the system load. Given that, if the signaling transmitted from the multiple cell sites is coordinated, the DL performance can be increased significantly. This coordination can be simple as in the techniques that focus on interference avoidance or more complex as in the case where the same data is transmitted from multiple cell sites. For the UL, since the signal can be received by multiple eNBs, if the scheduling is coordinated from the different cell sites, the system can take advantage of multiple reception to significantly improve the link performance. A UE at the edge of a cell is able to be served by two or more eNBs to improve reception / transmission and increase throughput particularly under cell edge conditions.

An advantage of intra-site CoMP is that significant amount of exchange of information is possible since this communication is within a site and does not involve the backhaul (connection between base stations). Inter-site CoMP involves the coordination of multiple sites for CoMP transmission. Consequently, the exchange of information will involve backhaul transport. This type of CoMP may put additional burden and requirement upon the backhaul design. (221)

Dedicated Short Range Communications [DSRC](https://whatis.techtarget.com/definition/dedicated-short-range-communication-DSRC) allows high-speed communications between vehicles and the roadside, or between vehicles. It has a range of up to 1,000 meters. DSRC applications for public safety and traffic management include intersection collision avoidance and many others. DSRC applications now in use include electronic toll collection, and electronic credentialing and monitoring of commercial vehicle operations. Current applications operate at 915 MHz utilizing a bandwidth of 12 MHz and primarily use proprietary technology,although some standards- compliant devices have been developed. The new 5.9 GHz frequency permits much higher data-transmission rates than the lower-frequency 915 MHz bandand provides 75 megahertz of spectrum for DSRC applications. In the case of 5.9 GHz, other users in the band include military radars and satellite communications systems.

DSRC has low [latency](https://whatis.techtarget.com/definition/latency) and high [reliability](https://whatis.techtarget.com/definition/reliability), is secure, and supports [interoperability](https://searchmicroservices.techtarget.com/definition/interoperability). It receives very little interference, even in extreme weather conditions, because of the short range that it spans. This makes it ideal for communication to and from fast-moving vehicles.

DSRC technology can be used in either a vehicle-to-vehicle ([V2V](https://internetofthingsagenda.techtarget.com/definition/vehicle-to-vehicle-communication-V2V-communication)) or vehicle-to-infrastructure ([V2I](https://whatis.techtarget.com/definition/vehicle-to-infrastructure-V2I-or-V2X)) format, and communicates using transponders known as on-board units (OBUs) or roadside units (RSUs). (192)

Deep Learning: This is a class of [machine learning](http://en.wikipedia.org/wiki/Machine_learning)algorithms that use multiple layers to progressively extract higher level features from raw input. For example, in image processing, lower layers may identify edges, while higher layers may identify human-meaningful items such as digits/letters or faces. In deep learning, each level learns to transform its input data into a slightly more abstract and composite representation. In an image recognition application, the raw input may be a matrix of pixels; the first representational layer may abstract the pixels and encode edges; the second layer may compose and encode arrangements of edges; the third layer may encode a nose and eyes; and the fourth layer may recognize that the image contains a face. Importantly, a deep learning process can learn which features to optimally place in which level *on its own*.

It is predicted that by 2020, deep learning will have reached a fundamentally different stage of maturity. Deployment and adoption will no longer be confined to experimentation, becoming a core part of day-to-day business operations across most fields of research and industries. This is because advancements in the speed and accuracy of the hardware and software will have made it both viable and cost-effective. Much of this added value will be generated by deep learning inference - that is, using a model to infer something about data it has never seen before. Models can be deployed in the cloud or data center, but more and more we will see them on end devices like cameras and phones. (254)

Device-to-Device (D2D) This mode of communication is expected to play a significant role in upcoming cellular networks as it promises ultra-low latency for communication among users. This new mode may operate in the licensed or unlicensed spectrum bands. It allows UEs in close proximity to communicate using a direct link rather than having their radio signal travel all the way through the base station or the core network. One of its main benefits is ultra-low latency in communication due to a shorter signal traversal path. Various short-range wireless technologies like Bluetooth, WiFi Direct and LTE Direct can be used to enable D2D communication.

In a typical cellular network, UEs achieve time and frequency synchronization using periodic broadcasts from the BS. Devices in D2D communication can also synchronize with the same broadcasts so long as they belong to the same BS. The situation gets complicated in the following cases: (1) UEs belong to different BSs that may not be themselves synchronized, or (2) some of the UEs are in the coverage of the network and some outside the coverage, and (3) all UEs lie outside network coverage [9]. Synchronization among UEs is beneficial for D2D communication because it helps a UE use the right time slot and frequency for discovering and communicating with its peer and thus engage in more energy-efficient communication. Note that *global* synchronization among all UEs in a network may not be required for D2D communication; rather *local* synchronization among neighboring devices is sufficient. (243)

Fog Computing **:** An architecture that uses edge devices, which provide entry points into enterprise or service provider core networks, to carry out a substantial amount of computation, storage, with local communication and routed over the internet backbone. It can be perceived both in large cloud systems and big data structures, making reference to the growing difficulties in accessing information objectively, resulting in a lack of quality of the obtained content. Fog networking consists of a control plane and a data plane. On the data plane, fog computing enables computing services to reside at the edge of the network as opposed to servers in a data-center. Fog computing emphasizes proximity to end-users and client objectives, dense geographical distribution and local resource pooling, latency reduction, and backbone bandwidth savings. Fog networking supports the Internet of Things (IoT) concept, in which most of the devices used by humans on a daily basis will be connected to each other. (156).

Fronthaul and Backhaul are an essential component of the 5G radio access infrastructure. They provide connectivity and data transport in the 5G radio access network. The fronthaul connects 5G antennas with base stations and the backhaul connects base stations with the operator's core network. The term Xhaul refers to the integrated combination of fronthaul and backhaul. (56)

Internet of Things (IoT)is the extension of Internet connectivity into physical devices and everyday objects. Embedded with electronics and other forms of hardware (such as sensors), these devices can communicate and interact with others over the Internet, and they can be remotely monitored and controlled. The definition of the IoT has evolved due to convergence of multiple technologies such as real-time analytics, machine learning, commodity sensors, and embedded systems. In the consumer market, IoT technology is most synonymous with products pertaining to the concept of the "smart home", covering devices and appliances (such as lighting fixtures, thermostats, home security systems and cameras, and other home appliances) that support one or more common ecosystems, and can be controlled via devices such as smartphones and smart speakers like Alexa from Amazon.(130)

Machine Learning is the scientific study of algorithms and statistical models that computer systems use in order to perform a specific task effectively without using explicit instructions, relying on patterns and inference instead. It is seen as a subset of artificial intelligence. Machine learning algorithms build a mathematical model based on sample data, known as "training data", in order to make predictions or decisions without being explicitly programmed to perform the task. Machine learning algorithms are used in a wide variety of applications, such as computer vision, where it is infeasible to develop an algorithm of specific instructions for performing the task. (102)

Near Far Effect : Consider a receiver and two transmitters, one close to the receiver, the other far away. If both transmitters transmit simultaneously and at equal powers, then due to the inverse square law the receiver will receive more power from the nearer transmitter. Since one transmission's signal is the other's noise, the SNR for the further transmitter is much lower. This makes the farther transmitter more difficult to understand. Possible solutions to the near–far problem:

1. Increased receiver dynamic range - Use a higher resolution ADC. This can increase the dynamic range of receiver stages that are saturating.
2. Dynamic output power control – Nearby transmitters decrease their output power so that all signals arrive at the receiver with similar signal strengths.
3. TDMA – Transmitters use a time division scheme to avoid transmitting at the same time.

(138)

Network Slicing: Use cases such as mobile broadband (MBB), the Internet of Things (IoT), and enterprise—put very different requirements on the network, but you do not want to build separate physical networks for the different services. Network slicing enables you to build multiple logical networks—network slices—on top of a common shared physical infrastructure. These network slices, one for each kind of service, are separate and independent to the extent that if something goes wrong in one slice it will not affect the other slices. This separation and independence also enable you to add new slices without impacting the rest of the network.

You can use network slicing for any access technology, and the building blocks for both building and managing a sliced network are available. Network slicing in 5G is expected to open lucrative new business opportunities for mobile operators and other newer entrants. For example, a mobile operator will be able to split its physical network resources into multiple logical slices and lease these slices out to multiple parties. Network slicing is expected to be a key component of 5G networks.

In November 2016, a [white paper](http://www.5gamericas.org/files/3214/7975/0104/5G_Americas_Network_Slicing_11.21_Final.pdf) that explores an end-to-end 5G systems framework for the creation of customised network slices was released. It also considers the application of network slicing to air-interface technologies and the long-term technology roadmap. (221)

Non-Orthogonal Multiple Access (NOMA) is a new multiple access scheme proposed. It is one of the many technologies that promise greater capacity gain and spectral efficiency than the present state of the art, and as such, is a candidate technology for 5G. Each generation of cellular technology is usually characterized by a specific multiple access scheme (FDMA/ TDMA/ WCDMA/ OFDMA). NOMA is a likely candidate in the line of succession for these technologies. NOMA goes against the present trend of transmitting information in orthogonal carriers or subcarriers. Here, the multiple users are multiplexed in the power domain, either in downlink or uplink.

In the downlink version, the Base Station (BS) transmits two signals with different powers in the same frequency band simultaneously. One message will be for a User Equipment (UE) located near the BS, while the other will be intended for a UE located a fair distance away. The UE near the base station will be allotted less power, while the far UE will be allotted more power. The UE located at the high Signal to Noise Ratio (SNR) region first decodes the message intended for the far receiver. This message is then subtracted from the received signal, and we are left with the interference-free signal that the near UE is supposed to decode. This approach requires a Successive Interference Cancellation (SIC) receiver. The non-orthogonally improves resource utilization and is found to increase the user throughput by about 38%. The tradeoff is receiver complexity.

NOMA can be extended by usage in conjunction with Massive MIMO systems. The power allocation to the antennae is based on distance and direction of the user. As a result, beams with possible slight overlaps can be directed towards different users. (A. Mohan, NOMA seminar, Govt Engg College, Trichur). (289)

**Publications 2017**

# 5G Worldwide Developments/ Gozalvez

**IEEE Vehicular Technology/March2017/p4**

* Huawei and NTT Docomo: world’s first 5G large scale field trial in 4.5GHz band in Yokohama
* NTT DoCoMo and Samsung: achieve data rate of 2.5Gbps in 5G trial, 150 kmph at 28 GHz
* Telia and Ericsson: first European 5G trial, Sweden: 15 GHz band, 800 MHz, 15 Gbps peak, 3mS latency
* NTT DoCoMo and Ericsson: first proof of concept dynamic network slicing, different types of services
* Ericsson: commercializing world’s first 5G NR (new radio) for massive MIMO
* Qualcomm: Snapdragon 5G modem chipset, MIMO with adaptive beamforming, commercial 2018
* European Commision: action plan for 5G commercial launch 2020
* Ericsson: 550m 5G subscribers 2022. N.America 25%, Asia Pacific 10%. Majority mobile broadband
* SK Telecom and Nokia: world’s first cloud-based software defined RAN
* NEC: development of a real time radio sensing system which measures usage of radio spectrum
* NEC: new geo-magnetic /deep learning technology gets locations indoors where no GPS. Geo-magnetic characteristics for each floor of building learnt. (165)

DOI: 10.1109/MVT2016.2641138

# Initial Steps Toward a Cellular Vehicle to Everything Standard/ Uhlemann

**IEEE Vehicular Technology/March2017/p14**

The V2V work item on 3GPP builds on earlier work on D2D communications and introduces a new D2D interface PC5 which is also known as the sidelink at the physical layer addressing communications at vehicular speeds. Four additional pilot signals have been added to the demodulation reference signal to improve tracking at relative speeds of upto 500 km/h and at high frequency (target is 5.9 GHz). Resource allocation based on geographical information is introduced to counter the “near-far” effect due to in-band emissions. See “near far effect”.(85).

DOI: 10.1109/MVT.2016.2641139

# New Eye on the Road/(Amnon Shashua, Mobileye)

**Automotive Engineering/March 2017/p16**

Contends that a relatively simple and cheap monocular camera and an image processing system on chip could reliably accomplish the sensing task for ADAS equipped vehicles, without need for radio ranging and for stereo cameras that find depth using visual parallax. See also “Building Blocks of Autonomous Technology”. (48)

# Eliminating Driving Distractions/ Chen et al

**IEEE Vehicular Technology/March2017/p20**

An in-vehicle interactive and intuitive user interface is described and comparison of effectiveness made for smart and traditional vehicles. A transparent windshield display is employed and gesture and voice control methods are explored. A statistical study was made to quantitatively assess each of the features.

The platform includes microphone and gesture sensing inputs. Eye-tracking and electroencephalograph (EEG) sensing are available on the platform for further research. (66)

DOI: 10.1109/MVT.2016.2625331

# Better Platooning Control Towards Autonomous Driving/ Campolo et al

**IEEE Vehicular Technology/March2017/p30**

Platooning is a pervasive use case in 5G/autonomous driving. Regulation of spacing and speed relies on up to date vehicles’ kinetic data. The potential of LTE and D2D communications for data dissemination is explored. Exploiting pooled resources and co-ordination by the in-front vehicle of the platoon is shown to fulfill the low latency requirements. Providing spatial re-use of LTE resources in the platoon membership is shown to drastically reduce the capacity demand. Each vehicle’s control system is triggered at a frequency higher than 10 Hz. Handover management and tolerating packet losses need to be further explored. A non-technical issue that requires further work is the definition of business models by mobile network operators to provide such services. (117)

DOI: 10.1109/MVT.2632418

# Using Technology to Make Roads Safer/ Al Dweik et al

**IEEE Vehicular Technology/March2017/p39**

Adaptive speed limits to make roads safer, and reduce social costs such as accidents, pollution, congestion, noise, and greenhouse gas emissions. System design framework of an ITS that comprises an interactive in-vehicle display and supporting communication units. Realizations based on cellular networks, vehicular ad hoc networks (VANETs) and a hybrid of the two are discussed. Uses standard components in the Roadside Service Unit (RSU). On board unit for receiving the transmitted speed values, observing driver behavior based on STM32 microcontroller. Extensive measurements still needed to evaluate system performance under more weather and traffic conditions. Another issue is the difficulty in dealing with closely spaced regions with different speed limits, such as car pool lanes, multi-level bridges and highways. (118)

DOI: 10.1109/MVT.2016.2634462

# Motivating Network Development/Tom McGiffen, A Paulraj et al

**IEEE Vehicular Technology/September2017/p22**

Many new and promising [vehicular communications applications](https://doi.org/10.1109/MVT.2017.2699699) are currently being developed. However, sufficient network resources to support these applications, in terms of equipped vehicles, base stations, and other infrastructure, are simply not yet available and are progressing slowly. We examine the strengths and weaknesses and uses of dedicated short-range communications (DSRC) and cellular vehicular networks. Applications are V2V, V2I, sensors on wheels, telematics, and other general applications. Telematic services are OnStar (GM), Car-Net (VW), Safety Connect (Toyota) etc.

V2V applications are control loss warning (warns surrounding vehicles of a control loss event), emergency vehicle alert, situational awareness (determines if road conditions, as measured by other vehicles, are potentially unsafe). Others are emergency electronic brake light (warns driver of a hard-braking vehicle ahead), left turn assistance (warns driver beginning to turn left of an imminent crash with a vehicle from the opposite direction) etc. We then explore strategies beyond government mandates and subsidies, the encouragement of vehicular network deployment and DSRC growth, cellular growth for vehicles, and sensors on wheels.

Vehicular communications applications, strengths of the DSRC and cellular networks, DSRC deployment in the US, comparison with Europe and Japan are explored. DSRC strengths: dedication, low latency, high security, free airtime. DSRC weaknesses: access limitations, financing, limited infrastructure, limited range, no Internet Protocol (a vehicle moving to a new base station receives a new IP address).

A weakness of cellular: higher data demand over a given area tends to occur with high-density vehicle traffic, which tends to coincide with slower vehicle motion. At many intersections governed by a traffic light, roughly half the vehicle traffic is either stopped or stopping. Cellular systems are not currently designed for high demand along busy vehicle corridors and intersections. With small cells, scenarios such as these can potentially be accommodated. (295)

DOI: 10.1109/MVT.2017.2699699

**Publications 2018**

# Reinventing Wheels

**The Economist: Special Report on Autonomous Vehicles/ 3 March 2018**

A new kind of vehicle is taking to the roads, and people are not sure what to make of it. How will it get along with other road users? Will it really shake up the way we travel? Exactly the same questions were posed when the first motor cars rumbled on to the roads. By granting drivers unprecedented freedom, automobiles changed the world. They also led to unforeseen consequences, from strip malls and urban sprawl to road rage and climate change. Now autonomous vehicles (AVs) are poised to re-write the rules of transport again. AVs are on the threshold of being able to drive without human supervision, within limited and carefully mapped areas. Waymo, the self driving car unit of Google’s parent company, hopes to launch an AV robo-taxi service in the suburbs of Phoenix AZ. GM has similar plans. There will be trade-offs in personal freedom, between goods and services, and politics will swim alongside technology. UBS, a bank, reckons that urban car ownership will fall by 70% by 2050. Today’s cars sit unused 95% of the time, so a widespread switch to robo-taxis would let urban land wasted on car parking to be re-allocated.

A century ago cars were seized upon as a solution to the drawback of horses which were clogging up the streets with manure. AVs have the potential to transform physical transport as radically as packet switching transformed the delivery of data. But as with the Internet, realizing their benefits is a matter of politics as well as technology. Lessons learnt with the horseless carriage in the 20th century applied to the driverless car of the 21st century. (273). (Some edits by author.)

# Channel Coding in 5G New Radio/Hui et al

**IEEE Vehicular Technology/Dec2018/p60**

Channel coding techniques are used in digital communications to ensure a  transmission is received with minimal errors. It is achieved by interweaving additional binary digits into the transmission. When decoded on the receiving end, the transmission can be checked for errors and repaired. Compared to 4G/LTE new error-correcting codes have been introduced. LDPC (low density parity check) replaces turbo-codes for data and polar replaces convolutional codes for control channels. LDPC gives better throughput (Gb/sec/mm2) at lower latency and reduced decoder complexity. The main idea of polar coding is to transform a pair of identical input channels into two distinct channels of different qualities: one better and one worse and thus introduce diversity in transmission. Clever bit manipulations and mappings to the channels occur at the encoder. However, complexity and dealing with re-transmissions are future research issues. Better suited to control channels. (141).

DOI: 10.1109/MVT.2018.2867640

# Fifth Generation Technologies for the Connected Car/ Mikael Fallgren

**IEEE Vehicular Technology/ September 2018/p28**

Two strong technology trends, one in the mobile communications industry and the other in the automotive industry, are becoming interwoven and will jointly provide new capabilities and functionality for upcoming intelligent transport systems (ITSs) and future driving. The automotive industry is on a path where vehicles are continuously becoming more aware of their environment due to the addition of various types of integrated sensors. At the same time, the amount of automation in vehicles increases, which, with some intermediate steps, will eventually culminate in fully automated driving without human intervention. Along this path, the amount of interactions rises, both in-between vehicles and between vehicles and other road users, and with an increasingly intelligent road infrastructure. As a consequence, the significance and reliance on capable communication systems for vehicle-to-anything (V2X) communication is becoming a key asset that will enhance the performance of automated driving and increase further road traffic safety with combination of sensor-based technologies.

We have presented a selected set of topics that are necessary for achieving the 5G connected car. A significant topic is the characteristics of the underlying V2X channels. We have also introduced the main building blocks of a cellular V2X solution. A flexible network architecture has been presented to support advanced V2X services. We have also explored the potential of using vehicles in the form of mobile base stations as part of that flexible architecture. Fog computing has been presented in the context of the connected car, and finally a business ecosystem surrounding connected cars has been explored. (262 words)

DOI: 10.1109/MVT.2018.2848400

# Connected Roads of the Future: Use Cases, Requirements, and Design Considerations/ Mate Boban

**IEEE Vehicular Technology/ September 2018/p110**

The ultimate goal of next-generation vehicle-to-everything (V2X) communication systems is enabling accident-free, cooperative automated driving that uses the available roadway efficiently. To achieve this goal, the communication system will need to enable a diverse set of use cases, each with a specific set of requirements. We discuss the main use case categories, analyze their requirements, and compare them against the capabilities of currently available communication technologies. Based on the analysis, we identify a gap and indicate possible system designs for the fifth-generation (5G) V2X to close the gap.

Furthermore, we discuss an architecture of the 5G V2X radio access network (RAN) that incorporates diverse communication technologies, including current and cellular systems in centimeter wave (cm-wave) and millimeter wave (mm-wave), IEEE Standard 802.11p, and vehicular visible light communications (VVLC). Finally, we discuss the role of future 5G V2X systems in enabling more efficient vehicular transportation: from improved traffic flow and reduced inter-vehicle spacing on highways to coordinated intersections in cities (the cheapest way to increasing the road capacity) to automated smart parking (no more visits to the parking garage!), all of which will ultimately enable seamless end-to-end personal mobility.

The most demanding use cases require high link reliability (in some cases, above 99%), low latency (below 10 ms), and high throughput (tens of megabits per second per vehicle), often concurrently. We also performed a qualitative gap analysis of the capability of existing technologies and concluded that the stringent requirements of some use cases cannot be supported by any currently available technology. We have laid out design considerations for the 5G V2X system required to enable next-generation V2X use cases.

Significant work remains ahead, ranging from the physical layer (e.g., further enhancements of MIMO, fast and reliable coding schemes, initial access and synchronization, frame structure, channel modeling, and others) to interoperation and coordination of multi-RAT systems to cross-network resource reservations through network functions virtualization. Our analysis concludes that connected transportation is one of the most stringent verticals needing support. 5G V2X needs to be at the center point of new 5G radio development. (341 words)

DOI: 10.1109/MVT.2017.2777259

**Publications 2019**

# A Wireless Localisation Algorithm..for Connected Vehicle/ Lei Chen et al

**IEEE Intelligent Transport Systems/summer2019/p96**

As one of the key technologies of connected vehicle applications, wireless localization can provide accurate and reliable location for high occupancy tolling and for collision avoidance. GPS and RSSI (Received Signal Strength Indicator) are less reliable in highly dense urban areas. Several AI methods have been employed to optimize the accuracy of path loss modelling algorithms. However, due to the stochasticity of initial weights it is difficult to reach convergence. In this study a novel double layer architecture is proposed based on optimization of the initial weights and thresholds. Also, location accuracy shows improvement with increasing the number of base stations connected to the moving vehicle. Error of less than 10 m, claimed to be sufficiently good, when connected to 7 base stations. (119)

DOI: 10.1109/MITS.2019.2903433

# Caching in Heterogeneous Ultradense 5G Networks/ Peng Lin, Jamalipur et al

**IEEE Vehicular Technology/June2019/p22**

Cache-enabled network densification is expected to be an effective approach to satisfy the explosive growth of mobile data traffic. The improvement is based on the fact that some very popular contents are transmitted from a remote server repeatedly. Equipping cache-enabled access points with prediction capabilities, context awareness, and even social networking can substantially reduce redundant traffic by proactively serving predictable user demands. Stimulated by network densification, co-ordinated multipoint (CoMP) joint transmission techniques are expected to have a significant role in 5G networks. Three co-operative cacheing schemes in cellular networks, D2D networks, and cross tier networks are examined. Cross tier networks are a feature of 5G wherein the network comprises two network hierarchies for efficient utilization and distribution of channel resources: MBSs for large macrocells (radius 1 to 16 km, transmit power 40W) and FBSs for femto-cells (radius 10 to 50m, transmit power 200mW). (143)

DOI: 10.1109/MVT.2019.2904748

# Silicon Evolution for the Automotive Revolution/2019/Andrew Hopkins

**White Paper (ARM)**

The high growth of the automotive market is attractive to semi-conductor vendors. An accompanying challenge is how to develop systems suitably, where safety is of paramount concern. One standard guiding functional safety engineering is ISO26262. It defines functional safety as ” the absence of unreasonable risk due to hazards caused by malfunctioning electrical/electronics systems”. Failures can occur in the design or implementation of a hardware component or software module, the way the pieces and sub-systems are integrated, or the conception of the overall system architecture

This means that systems must function correctly, with potentially unsafe faults detected and controlled to prevent a hazard. Predictability of failure modes is expected to enable a thorough analysis. Among the main concepts for functional safety are: determining the level of design robustness, verification and validation, performing independent assessments, and managing change and modifications. Developing and verifying software for the higher levels of integrity (ASIL D) is challenging. Practical methods include the development and execution of two different software programs to perform the same or similar system function to thus reduce the likelihood of a common cause failure. Strategies include continuous detection, run-time diagnostics. (190)

# AQUARIUS: A Proposal for Validation of Connected Vehicle Systems/ Kay Das

**IEEE VTC2019/ Connected and Autonomous Vehicles paper submission/ September 2019**

There is currently much on-going activity in the research and design of systems to enhance the safety of vehicular traffic on roads and highways. Systems will comprise a dynamically changing mix of existing and new technologies and disciplines. A range of products and systems will compete for market entry from diverse sources and nations. A significant challenge exists in validating prototypes and final systems productized for market entry.

Validation is the process of ensuring that a product, service, or system meets the operational and safety requirements of the user.The need for continued validation in the connected vehicle developments is paramount. There are two current approaches. The first involves real life-sized test beds with real vehicles. The second relies on computer modeling and simulations of use cases. While the first approach is the most accurate possible, demands on cost, real estate, and logistics are very high. The second approach is highly configurable and less expensive to develop but validation of the models themselves, with constant updating as newer systems are developed, will be a major challenge. Observing the totality of an event can also be severely limited by dependence on two-dimensional displays, even if more than one is employed. There can be no “touch and feel”. There is justification for a third approach which we shall code-name AQUARIUS. In this, a real-world test bed would be built based on actual geography, geometry and highway and town planning, but on a reduced scale. (243).

(Available with author.)

# An Overview of Automotive Electronics/ Joao Trovao

**IEEE Vehicular Technology/ September 2019/p130**

Electronic systems have become an increasingly large component of a car’s cost, increasing from approximately 1% of U.S. cars’ value in 1950 to around 35% in 2020. Some predictions suggest an impact of 50% on a vehicle’s final cost in 2030. Consumers’ constant demands for electronic gadgets, IT services, and connectivity as well as the ongoing introduction of automation in vehicles are the main reasons for this estimated impact.

Customer demands have pushed carmakers to add more intelligence. As part of this transition, new car models will have an extremely complex set of subsystems connected across different digital communication networks [a controller area network (CAN) bus, FlexRay, and others. In recent car models, different speeds, types of data, and connections across several subsystems are the main responsibilities of more than 100 onboard microprocessors. FlexRay is an automotive network communications protocol developed to govern on-board automotive computing.

Mainstream cars may have up to 10 million lines of code, and high-end luxury SUVs can have hundreds of millions (approximately a dozen times more than a Boeing 787 Dreamliner jet). To avoid potential bugs and security holes, higher levels of computer system security will be required. Several vehicular electronic components, sensors, and actuators are being developed or improved upon.

Various levels of automation of driving assistance called ASSs (Active Safety Systems) are being categorized. Some examples are: *Forward-collision warnings, Automatic emergency braking, Pedestrian detection, Lane departure warning,*

*Lane-keeping assist, Lane Centering assist, Blind Spot Warning, Rear cross traffic warning, and Adaptive cruise control* have been introduced to enhance vehicle safety. Of course, these different ASSs correspond with the level of automation in cars. Such levels are graded on a scale from zero to five, with *zero* meaning no automation and *five* signifying complete automation. The quantity of sensors, actuators, and software is in harmony with the level of automation.

Motor control, engine management, in-vehicle interfaces, and in- and out-vehicle communications need system design, modeling, and control deployment. Today, few areas of engineering share the combination of complexity and safety concerns involved in automotive electronics design. (342 words)

DOI: <https://doi.org/10.1109/MVT.2019.2923329>

# A Hierarchical Architecture for the Future Internet of Vehicles/Kai Liu

**IEEE Communications/July 2019/p41**

Recent advances in wireless communication, sensing, computation and control technologies have paved the way for the development of a new era of Internet of Vehicles (IoV). Demanded by the requirements of information-centric and data-driven intelligent transportation systems (ITS), it is of great significance to explore new paradigms of IoV in supporting large-scale, real-time, and reliable information services. In this article, we propose a hierarchical system architecture, which aims at synthesizing the paradigms of software defined networking and fog computing in IoV and best exploiting their synergistic effects on information services.

Specifically, a four-layer architecture is designed, comprising the application layer, the control layer, the virtualization layer, and the data layer, with objectives of enabling logically centralized control via the separation of the control plane and the data plane; facilitating adaptive resource allocation and QoS oriented services based on network functions virtualization and network slicing, and enhancing system scalability, responsiveness, and reliability by exploiting the networking, computation, communication, and storage capacities of fog-based services. On this basis, we further analyze newly arising challenges and discuss future research directions by presenting a cross-layer protocol stack. Finally, for the proof of concept, we implement the system prototype in a realistic IoV environment and give two case studies. The results of field tests not only demonstrate the great potential of the new architecture, but also give insight into the development of future ITS. Two case studies are presented. (234 words).

DOI: 10.1109/MCOM.2019.1800772

**Additions from VTC-Fall Honolulu/September 2019**

# VTC Fall 2019: Workshop1: 5G and Beyond Technologies for Ultra-Dense Environments/ Kim Haesik, Kenta Umeyabashi

Due to the increase in the number of mobile devices and mobile traffic, 5G and beyond architectures needs to include new requirements: scalability and flexibility. New 5G techniques like software-defined networks and network function virtualization will enable this 5G architecture, permitting more flexibility in network deployment. 5G and beyond networks will beat all predecessors and lead to a shift towards ultra-dense small cell deployments providing:

- flexible network deployment and operation

- multi-connectivity

- dynamic traffic steering and resource management

- intelligent use of network data

- user participation in storage, relaying, content delivery and computation within the network

- co-existence of heterogeneous networks and local stand-alone 5G systems

- the use of smart antennae for higher capacity

- interference mitigation

- operation in the higher frequencies

Workshop featured close collaboration between the EU and Japan under the 5GPPP initiative. (140)

# VTC Fall 2019: A Novel Simulation Framework for the Design and Testing of Advanced Driver Assistance Systems (RELEVANT)/ Florian A. Schiegg

The number and complexity of newly developed automated driving systems has been constantly rising over the past decade. Especially the introduction of vehicle-to-everything (V2X) communication is expected to further potentiate this development. In order to be deployed, the functional safety of the developed systems has to be assured previously. However, the testing in a representative number of field tests is costly and time-consuming. For this reason, virtual test drives have risen as an important option for design and testing of automated driving technologies, leaving only the final validation to test with real vehicles and thus significantly reducing the overall expenditure. The authors of the work at hand introduce a simulation framework based on the vehicle simulator CarMaker, complemented with the middleware platform Robot Operating System (ROS) and fed with real traffic data, which allows to automatically test advanced driver assistance systems for a large number of real world scenarios by varying topology, vehicle and communication parameters, among others. The simulation framework is then used to demonstrate the benefit of collective perception (i.e. sharing of on-board sensor data among nearby vehicles by V2X communication) for a vehicle merging into a freeway, with metrics such as the vehicle awareness on spot and the time it has to plan and execute its maneuver**. (186)**

# VTC Fall 2019: Real-Time Hardware-In-the-Loop Emulation Framework for DSRC-based Connected Vehicle Applications (RELEVANT!)/ Ghayoor Shah

The rapid growth of connected and automated vehicle (CAV) solutions have made a significant impact on the safety of intelligent transportation systems. However, similar to any other emerging technology, thorough testing and evaluation studies are of paramount importance for the effectiveness of these solutions. Due to the safety-critical nature of this problem, large-scale real-world field tests do not seem to be a feasible and practical option. Thus, employing simulation and emulation approaches are preferred in the development phase of the safety-related applications in CAVs. Such methodologies not only mitigate the high cost of deploying large number of real vehicles, but also enable researchers to exhaustively perform repeatable tests in various scenarios. Software simulation of very large-scale vehicular scenarios is mostly a time consuming task and as a matter of fact, any simulation environment would include abstractions in order to model the real-world system. In contrast to the simulation-based solutions, network emulators are able to produce more realistic test environments. In this work, we propose a high-fidelity hardware-in-the-loop remote vehicle emulator (RVE) framework in order to create testing environments for vehicle-to-vehicle (V2V) communication. We put particular emphasis on the real-time communication simulation module (RTCSim) within RVE. The proposed RTCSim is able to run accurately in real-time fashion in contrast to other existing systems, which can potentially boost the development and validation of V2V systems.

In this work, we propose an emulation framework for CAV applications based on the DSRC protocol stack which is able to operate in a real-time fashion. Through analysis in different channel models and vehicular topologies, we prove the high fidelity of our proposed solution with a significant improvement in the run-time as compared to that for NS-3. A main component of our RVE is the communication model that allows accurate emulation of the behavior of up to 1000 vehicles in real-time. This allows hardware-in-the-loop testing for CAV applications in scenarios with a large number of vehicles without needing to set up large field tests. Consideration of the hidden node problem and the capture effect also serve as contributions in this architecture. While simulators such as NS-3 cannot operate in real-time, the proposed RVE emulator has been tested to maintain real-time performance without a noticeable loss in accuracy.

The framework can be further extended to improve the channel performance by using distance dependent congestion control strategies based on parameters like power, rate and/or message content. Another future research direction could be modifying our proposed solution to operate on other alternative vehicular communication technologies such as C-V2X and also adding more complex applications, e.g., SAE J2945/1 to the protocol stack. (431)

# VTC Fall 2019: In Vehicle Resource Orchestration for Multi-V2X Services / Mohammad Irfan Khan

Transmit Rate Control (TRC) for V2X networks is critical for distributed channel resource allocation, limiting the channel usage per vehicle while preventing channel saturation. Similarly, efficiently distributing the limited transmit opportuni- ties among multiple services of a vehicle is necessary, but has not been sufficiently studied. In this paper, we present a multi-V2X service resource orchestrator composed of two complementary mechanisms: (i) a multi-factor prioritization function, (ii) a budgetary scheduler allowing smooth resource earning/spending. Simulation-based evaluations showed improved access time for various V2X services under restricted resources and enhanced control on resource balancing between V2X services. (96)

# VTC Fall 2019: Towards Emergency Braking as a Fail-Safe State in Platooning: A Simulative Approach/ Shahriar Hasan

Platooning is anticipated to facilitate automated driving even with semi-automated vehicles, by forming road trains using breadcrumb tracing and Cooperative Adaptive Cruise Control (CACC). With CACC, the vehicles coordinate and adapt their speed based on wireless communications. To keep the platoon fuel-efficient, the inter-vehicle distances need to be quite short, which requires automated emergency braking capabilities. In this paper, we propose synchronized braking, which can be used together with existing CACC controllers. In synchronized braking, the leading vehicle in the platoon does not brake immediately, but instead communicates its intentions and then, slightly later, the whole platoon brakes simultaneously. We show that synchronized braking can avoid rear-end collisions even at a very high deceleration rate and with short inter-vehicle distances. Also, the extra distance travelled during the delay before braking can be compensated by enabling a higher deceleration, through coordinated synchronized braking. (142)

# VTC Fall 2019: Deep Learning Tasks Processing in Fog-RAN / Sheng Hua

Recently, the demand on performing intelligent tasks for mobile devices with low latency is ever-increasing, while the requirements of intensive computation and large storage size impedes the deployment of deep learning models directly on devices. Fog radio access network (Fog-RAN) offers a promising solution by integrating the computing power and storage of edge processing nodes (e.g., base stations). In this paper, we propose a joint deep learning task selection and downlink transmit beamforming approach to improve the communication efficiency while achieving green computing, i.e., minimizing the sum of computation power consumption for deep learning tasks and downlink transmit power consumption. For efficient algorithm design, we exploit the group sparsity structure of the aggregated beamforming vector and propose a log-sum based group sparse beamforming framework. An iteratively reweighted l1 algorithm is developed to solve the nonconvex and non-smooth log-sum minimization problem. Furthermore, we derive the global convergence result of the iteratively reweighted l1 algorithm, which shows that it converges to the first-order stationary point from any feasible starting point. Simulation results demonstrate that our log-sum based group sparse beamforming approach for deep learning tasks processing is more efficient than state-of-the-art approaches in terms of power consumption. (194)

# VTC Fall 2019: Hybrid Localization: A Low Cost, Low Complexity Approach Based on Wi-Fi and Odometry/ Positioning III/ *Letizia Moro*

Robot positioning has been a major challenge in the automation industry. If accurate robot positioning can be achieved repeatedly and with economical feasibility, it would advance the automation industry a step closer to achieving a state of higher autonomy for multiple applications. Such wide deployment of robots, however, may be difficult to achieve without establishing accurate localization in indoor environments. This localization information is needed to effectively navigate the environment and to avoid any obstacles and collisions. Moreover, the next generation of wireless networks that is expected to more widely support Internet of Things (IoT) is expected to widely use millimeter- wave (mmWave) links to support indoor wireless links. Such links could use this localization information in conjunction with highly directional antennas to overcome significant pathloss at mmWave frequencies.

The topic of robot localization has been an active area of research in which various approaches have been used. These methodologies can be summarized under two categories: 1) relative positioning, e.g. odometry, inertial navigation, etc.; and 2) absolute positioning e.g., magnetic compasses, active beacons, landmark navigation, etc. We summarize the important prior work related to active beaconing and odometry.

Our findings indicate the effectiveness of combining Wi-Fi trilateration with odometry data. Furthermore, this paper proposes a reliable dynamic weight-allocation algorithm that fuses the sensory information from odometry and Wi-Fi localization to increase the overall efficiency and accuracy of robot localization in indoor environments. Our extensive experimental results indicate that the proposed method can more than halve the localization error of either odometry or Wi-Fi, when applied individually. Additionally, a comparison with prior work based on Wi-Fi fingerprinting shows that the proposed algorithm can match and even outperform these algorithms while significantly reducing the overhead associated with Wi-Fi localization.

Future research directions: the accuracy of odometry can be significantly increased by using a localization through the use of integrated mobile pedometers and gyroscopes. This also provides the dynamic weight- allocation algorithm with a more quantitative way of allocating weights to odometry measurements. (332)

# VTC Fall 2019: Investigating Value of Information in Future Vehicular Communications / Marco Giordani

In recent years, the automotive industry has evolved towards Cooperative and Intelligent Transportation Systems (C-ITSs) to offer safer traveling and improved traffic management. Connectivity among vehicles, i.e., V2X, has also emerged as a means to enable advanced automated driving applications whose unprecedentedly stringent demands, e.g., in terms of data rate, reliability and latency, may however saturate the capacity of traditional technologies for vehicular communications. The scientific community is working towards the development of new radio systems, e.g., operating at millimeter waves (mmWaves), that may cope with these challenges. This potential is however hindered by the harsh propagation characteristics of the above-6 GHz bands.

We argue that even a significant increase in the channel capacity may not be sufficient to satisfy the boldest Quality of Service (QoS) requirements of future automotive applications, in particular in scenarios with multiple active services requiring different degrees of automation. In this context, it becomes fundamental to limit the amount of information that can be broadcast over bandwidth-constrained communication channels. One approach is to set a bound on the *age of information (AoI)*, by making vehicles broadcast awareness messages that are never older than the inter-transmission period. Another approach is to discriminate the *value of information (VoI)*, to use the limited transmission resources in a way that maximizes the utility for the target applications.

This work opens up some interesting research directions. In particular, intelligent VoI-aware solutions, able to capture the evolving characteristics of the vehicular environment and to dynamically adapt the dissemination scheme accordingly (e.g., based on feedback messages from the receivers or on learning strategies), should be designed. Moreover, the algorithms should regularly forecast the future VoI of a given data for all the potentially interested destination nodes based on the knowledge that has already been acquired through previous observations. The investigation of these challenges is still an open issue and will be part of our future research. (314)

# VTC Fall 2019: VRLS: A Unified Reinforcement Learning Scheduler for Vehicle-to-Vehicle Communications /Taylan Sahin

Vehicle-to-vehicle (V2V) communications have distinct challenges that need to be taken into account when scheduling the radio resources. Although centralized schedulers (e.g., located on base stations) could be utilized to deliver high scheduling performance, they cannot be employed in case of coverage gaps. To address the issue of reliable scheduling of V2V transmissions out of coverage, we propose Vehicular Reinforcement Learning Scheduler (VRLS), a centralized scheduler that predictively assigns the resources for V2V communication while the vehicle is still in cellular network coverage.

VRLS is a unified reinforcement learning (RL) solution, wherein the learning agent, the state representation, and the reward provided to the agent are applicable to different vehicular environments of interest (in terms of vehicular density, resource configuration, and wireless channel conditions). Such a unified solution eliminates the necessity of redesigning the RL components for a different environment, and facilitates transfer learning from one to another similar environment.

We evaluate the performance of VRLS and show its ability to avoid collisions and half-duplex errors, and to reuse the resources better than the state-of-the art scheduling algorithms. We also show that pre-trained VRLS agent can adapt to different V2V environments with limited retraining, thus enabling real-world deployment in different scenarios. (202)

# VTC Fall 2019: Deep Neural Network Based Resource Allocation for V2X Communications/ Jin Gao

This paper focuses on optimal transmit power allocation to maximize the overall system throughput in a vehicle- to-everything (V2X) communication system. We propose two methods for solving the power allocation problem namely the weighted minimum mean square error (WMMSE) algorithm and the deep learning-based method. In the WMMSE algorithm, we solve the problem using block coordinate descent (BCD) method. Then we adopt supervised learning technique for the deep neural network (DNN) based approach considering the power allocation from the WMMSE algorithm as the target output. We exploit an efficient implementation of the mini-batch gradient descent algorithm for training the DNN. Extensive simulation results demonstrate that the DNN algorithm can provide very good approximation of the iterative WMMSE algorithm yet reducing the computational overhead significantly.

With the advent of autonomous driverless vehicles, transmission units mounted on vehicles will need to exchange massive amount of information signals including speed, traffic condition, direction, location, traffic incidents etc. at the frequency of ten times or even more every second through high-speed wireless links. For example, when a car pulls an emergency breaking due to an unexpected emergency situation, the signal should be transmitted to surrounding vehicles to make them aware of potential hazard built up in the vicinity. With the deployment of 5G wireless communication technology, it is no surprise that the vehicles can communicate with other communication devices, such as mobile phones and smart computers or even facilities like building, traffic lights and so on, which will enhance the proliferation and security of autonomous driving in the future.

The V2X communication systems feature several unique characteristics as opposed to conventional cellular communications including high mobility, rapid change of direction as well as location, and stringent quality-of-service (QoS) requirements. Furthermore, road safety concerns impose very strict requirements on ultra-low latency and high reliability in V2X communications. However, due to high mobility, the V2X communication channel state information (CSI) becomes outdated quite rapidly. Thus faster optimization techniques are of paramount interest for reliable V2X communications.

Furthermore, in order to improve the reliability of V2X communications, proper interference management as well as resource allocation strategies must be in place for the V2V and V2I links. Recently, machine learning approaches have gained mo- mentum in the wireless communications domain due to their inherent capability of efficiently dealing with large-scale prob- lems. Wireless channel estimation and resource allocation problems are potential examples where machine learning are increasingly exploited [6]. Once trained properly, DNN can provide real-time resource allocation solutions, which is very crucial for V2X communications. (418)

# VTC Fall 2019: Driver Drowsiness Detection through a Vehicle’s Active Probe Action/ Sen Yang

Drowsy driving is one of the major causes of traffic collisions, injuries, and fatalities. Existing literature primarily detects driver drowsiness by passively monitoring lanes, steering angles, behavioral states, and physiological states. The paper presents an approach towards enabling vehicles to detect driver drowsiness through the vehicle’s active probe action actively. To this end, we record and analyze drivers’ responses to a slight active left-lane drifting action of the vehicle in a driving simulator. According to drivers’ responses, six indicators of drowsiness are extracted and then used to detect driver drowsiness with three recognition methods, i.e., support vector machine, Gaussian kernel density estimation, and back-propagation neural networks, in comparison to traditional monitoring features regarding steering-wheel movement. Experimental results demonstrate that our proposed active probe approach outperforms the traditional monitor methods for driver drowsiness detection with an *accuracy* of 97.50%, *precision* of 95%, and *specificity* of 98.21%. The proposed active driver drowsiness detection could facilitate a new development of active safety systems. (160)

# VTC Fall 2019: V2V communications under the shadowing of multiple big vehicles/ Hieu Nguyen

Vehicle to vehicle (V2V) communications using dedicated short range communications (DSRC) are considered as promising technology for enhancing road safety. However, the V2V communications see a challenge from obstruction of big vehicle such as big bus or truck. Based on our measurement, the big vehicle can cause signal loss from 10 to 15 dB. It makes the communication range shorter and reduces the safety message dissemination capability. In this paper, we analyze the impact of multiple big vehicles shadowing on the V2V communication. We propose a model which takes into account both geometric and stochastic shadowing of multiple big vehicles. Based on the proposed model, we derive the average length of the shadow region and the shadowing loss caused by multiple big vehicles. It is revealed that when the number of big vehicles increases from 1 to 25 vehicle per km, the shadow region increases from 50 m to more than 400 m on the road. Furthermore, the shadowing loss causes the packet delivery ratio of a typical car reducing from 90% to 20% or 50%, depending on whether the big vehicles are on the same or the next lane of this typical car. (195)

# VTC Fall 2019: When Indoor Localization Meets New Communication Technologies/ Yaqian Xu

Accurate and low-cost indoor localization continues to be a research challenge. The emerging communication technologies in 5G and 802.11 standards (e.g., 802.11n and 802.11 ac), such as massive MIMO and mmWave, provide opportunities for accurate indoor localization. Meanwhile, location information is also critical for the development of new technologies, e.g., directional communication using beamforming. It leads to a synergistic relationship between localization and communication. In this paper, we review the potential benefits of the emerging communication technologies (i.e., smart antennas, Massive MIMO, mmWave, beamforming, CSI) for indoor localization. It may provide a useful guide for researchers who are interested in developing indoor localization systems based on emerging communication technologies. (109)

# VTC Fall 2019: Evaluation of Vehicle-in-the-Loop Tests for Wireless V2X Communication/ Markus Hofer

The performance of wireless communication systems is fundamentally determined by the properties of the underly- ing wireless communication channel. Vehicular communication channels exhibit time-variant multi-path propagation with non- stationary channel statistics. Thus, channel emulation tools for the reproducible test of wireless communication systems are urgently needed to enable the development of ultra-reliable low- latency communication links. In this paper we validate the vehicle-in-the-loop (ViL) test of vehicle-to-everything (V2X) communication links by means of time-variant channel emulation. The validation is performed by comparing the received signal strength indicator (RSSI) and packet error rate (PER) of measurements on a proving ground with the RSSI and PER obtained from ViL tests. For the ViL tests, the wireless communication channel is emulated using a geometry-based stochastic channel model, which is updated in real-time, dependent on the position and velocity of the vehicles. We collect results of different scenarios on the proving ground and from ViL tests. The results show a qualitative match between ViL test and measurement on the proving ground. An exact quantitative match can be obtained with the calibration parameters from the measurements. (183)

# VTC Fall 2019: Directional Analysis of Vehicle-to-Vehicle Channels with Large Vehicle Obstructions/ Mi Yang

For radio propagation, the wireless channel generally changes more significantly in the non-line-of-sight (NLOS) sce- nario compared to the line-of-sight (LOS) scenario. For vehicle- to-vehicle (V2V) communications, the most typical NLOS scene is large vehicle obstructions. Therefore, in order to understand the radio propagation mechanism and channel characteristics in V2V communication, it is necessary to carry out indepth investigations on V2V channel under the condition of large vehicle obstructions. In this paper, actual V2V channel measurements with large vehicle obstructions in the urban environment at 5.9 GHz are carried out. Based on the measured data, extraction and analysis of channel parameters are performed. Specifically, this paper focuses on the directional analysis of V2V channel in the case of large vehicle obstructions. It can be found that the occlusion of large vehicles not only causes additional attenuation of signal energy, but also significantly affects the angular distribution of multipath components in three-dimensional space, and brings larger angular dispersion. These results would be useful for establishing a more accurate channel model and serving the design of V2V communication system. (178)

# VTC Fall 2019: Smart Parking with Fine-grained Localization and User Status Sensing Based on Edge Computing / Cheonsol Lee and Soochang Park

Parking at an affordable place is the precedent task for all activities of the everyday life in urban environments such as shopping, working, exercising, etc. So, it is the most common and essential requirement of all users in a car park to fast search a preferred parking spot closely associated their current intent. Although modern parking lots have installed the sensing and display systems to inform drivers on the availability of parking areas, such systems are unable to tell drivers exact parking spots and make any recommendation to improve the traffic conditions and driver experiences. In this paper, a novel analytic-based smart parking system clustering Internet of Things, smart mobile devices and edge computing is proposed. This novel parking system aims at providing customized parking experience to users through highly accurate positioning and user status detection which are achieved by joint mobile sensing-machine learning based analytics as the edge intelligence. Based on the proof-of- concept implementation, the proposed scheme can achieve 99.1% positioning accuracy of a parking spot; in terms of user status sensing, especially getting in a car and out of a car, detection accuracy shows 96%; finally, it shows much shorter service consumption time of 15.6 times than the legacy approach. (203)

# VTC Fall 2019: Latency Analysis of LTE Networks for Vehicular Communications Based on Experiments and Computer Simulation/ Tomoki Maruko

Vehicle-to-everything (V2X) communications is vital to further developing intelligent transport systems. Network (NW) based V2X communications including the long-term evolution (LTE) is a part of the cellular V2X concept in which direct communications (sidelink) and NW-based communications (uplink and downlink) work in a complementary way. In order to design appropriate cooperation between direct and NW-based communications, it is important to identify practical performance limitations of both types of communications. While several reports indicate communication latency in commercial public NW, that in closed NW is not clearly shown. In this paper, we evaluate the latency for vehicular to vehicular communications via commercial closed LTE NW obtained through driving test in comparison to the end-to-end latency analyzed in the 3GPP report and further evaluate the impact of network congestion in terms of inter-cell interference in a system-level simulation. (136)

# VTC Fall 2019: Vehicle-to-Vehicle Millimeter-Wave Channel Measurements at 56-64 GHz/ Jiri Blumenstein

This paper presents results obtained from a vehicle- to-vehicle channel measurement campaign carried out in the millimeter-wave band around a 60GHz center frequency and with 8GHz of bandwidth. We characterize a situation of two oncoming cars on a two-lane road in the campus of the Brno University of Technology. For several vehicle passes we evaluate: (1) observed root mean square (RMS) delay spreads as a function of the received power, (2) temporal decorrelation of the channel impulse response and (3) a dependency of the Pearson correlation coefficient on the received power. For the measurement campaign, a correlative time-domain channel sounder was used.

The millimeter wave (mmwave) band has been in the focus of the research community for decades However, thanks to the inclusion of this band in the 5G standard and to the fact that mmwave bands offer several GHz of unlicensed bandwidth for industrial scientific and medical (ISM) purposes, the interest has greatly increased over the past few years. A vehicle-to-vehicle (V2V) scenario is discussed and path-loss and fading characteristics are derived; however, with a rather limited bandwidth of 400MHz at 73 GHz center frequency. A narrow-band car-to-car communication with a 1 Mb/s data transmission in the 60 GHz band was investigated already in 2001. For vehicular mm-wave channels, the number of investigations is more limited. Clearly, aiming at multi-GB/s data transmissions required for the future V2V and vehicle-to-infrastructure (V2I) links several GHz of bandwidth are needed. It is worth noting that few vehicle-to-vehicle measurements of the wide-band channel have been published due to obvious complications with a precise synchronization of the mutually moving TX and RX which cannot be done simply via a classical 10 MHz coaxial cable. In this paper we overcome this issue by means of stable local oscillators. (293)

# VTC Fall 2019: Collaborative Localization for Occluded Objects in Connected Vehicular Platform/ Rui Guo, Toyota

Localizing occluded object is a long-term challenge in Advanced Driving Assistant System (ADAS) and autonomous driving research. In this paper, we propose a novel graph-matching based approach that leverages the challenge by adopting the deep learning and multiple-view geometry analysis. Specifically, the 3D scene reconstruction is firstly built by associating the comprehensive graph representations of the multiple-view observations, incorporated with the spatial relationship of the co-visible objects so as their discriminant appearance features. Followed by, the localization for occluded object is achieved by inferring from the reconstructed 3D geometry. We conduct experiments to validate the system in connected vehicular platform in the advanced traffic simulation dataset. The experimental results convincingly indicate the effectiveness of the proposed system in real-time object detection, graph generation, matching and location inference for occluded objects.

The connected vehicle technology (CVT) has drawn sub- stantial research attentions in the intelligent transportation society by advancing connectivity among vehicles and infrastructure to improve the safety and mobility [1]. Among a variety of tasks performed by the vehicular systems to propel the intelligent driving even the autonomous driving, accu- rate localization of dynamic objects from vehicular sensory platform remains a long-term challenge. Due to the intrinsic nature of the task, the perception of individual vehicle is often confined with limited sensing range, narrow field of view (FOV) and specified sensory module/spectrum that is not able to realize the object location with high accuracy. The real-world traffic situation is even more difficult for the single vehicles traffic scene awareness, since the occlusion is always present with the natural traffic flow. Vehicles, pedestrians and other objects of interest frequently occlude each other causing the vehicular on-board sensing fail at most of the sensing time.

The objective of the paper is to present a vision technology that enables vehicular collaborative perception, specifically, collaborative localization for objects in occlusion by adopting a novel hyper-graph matching approach among connected vehicular platform. The primary idea is to associate observations from multiple nearby connected vehicles, which views are compensating to each other, to reconstruct the 3D environment for the co-visible area, and infer the location of the occluded/non-covisible objects in the view. To implement the system, we design the cascaded architecture that composes with scene representation learning, hyper- graph matching, graph re-calibration and location inference, (384)

# VTC Fall 2019: Path Loss Analysis and Modeling for Vehicle-to-Vehicle Communications in Convoys in Safety-Related Scenarios/ Pan Tang, Jianhua Zhang

Detailed understanding of vehicle-to-vehicle (V2V) channels is a prerequisite for the design of V2V communication systems. An important application of such communications systems is automated control of vehicles driving in convoy formation, which improves transportation efficiency and reduces traffic jams. In this paper, we analyze and model the path loss characteristics for V2V communications in safety-related convoy scenarios based on a series of channel measurements at 5.9 GHz. The measurements focus on two types of safety- related scenarios. In the first scenario, the convoy formation is broken due to changing traffic lights at an intersection. In the second scenario, the convoy link is obstructed temporarily by trucks or pedestrians. We analyze the signal power (pathloss and shadowing) for both of these scenarios. It is found that street signs, trunks, pedestrians or bushes can bring additional signal attenuation, with trucks providing some 15 dB attenuation and pedestrians providing 7 ∼ 10 dB attenuation. (152)

# VTC Fall 2019: Beam Design for Beam Training Based Millimeter Wave V2I Communications/ Jiahao Wang

In order to achieve high-quality entertainment services and large-capacity sensor sharing, it is imperative to improve the throughput of V2I communication systems. Millimeter wave communication is a promising technology, which is generally combined with beamforming techniques. When it comes to beam design, we need to focus on the tradeoff between system throughput and alignment overhead. However, conventional optimization schemes are limited by uniform beamwidth design. Considering the characteristics of V2I communication on the highway, this paper proposes a non-uniform beamwidth design idea. Firstly, an average throughput model based on beam training is established. Then, a recursive algorithm is used to achieve non-uniform beamwidth optimization. Finally, the simulation results prove that the non-uniform beamwidth scheme can significantly improve the throughput of the V2I system. (123)

# VTC Fall 2019: A Novel Vehicle Detection Method Based on Geomagnetism and UWB Ranging/ Liangliang Lou

With the increasing number of private vehicles, intelligent parking space management systems (IPSMS) are widely used to analyze the parking spaces status information and to improve parking efficiency. The wireless vehicle detectors (WVD) based on the magnetic sensor have been widely used in IPSMS to collect the information of parking spaces. However, due to the existence of magnetic signal blind zone between the front and rear wheels of high-chassis vehicles, the accuracy of the single magnetic sensor based detector decreases markedly in detecting high-chassis vehicles such as SUVs, MPVs, Pickups, etc. In order to improve the performance of WVDs, this paper proposes a vehicle detection method based on the fusion of the Ultra-Wideband (UWB) ranging measurements and magnetic signals to improve the vehicle detection accuracy. We have designed several WVD prototypes based on our method and deployed them in the actual parking spaces to verify and evaluate the performance of our proposed algorithm. The experimental results show that the vehicle detection accuracy of our proposed method is about 8.4% higher than that of the conventional single magnetic sensor based method. (180)

# VTC Fall 2019: Alternative Intersection Designs with Connected and Automated Vehicle/ Zijia Zhong

Alternative intersection designs (AIDs) can improve the performance of an intersection by not only reducing the number of signal phases but also change the configuration of the conflicting points by re-routing traffic. However, the AID studies have rarely been extended to Connected and Automated Vehicle (CAV) which is expected to revolutionize our transportation system. In this study, we investigate the potential benefits of CAV to two AIDs: the diverging diamond interchange (DDI) and the restricted crossing U-turn intersection. The potential enhancements of AID, CAV, and the combination of both are quantified via microscopic traffic simulation. We found that CAV is able to positively contribute to the performance of an inter- section. However, converting an existing conventional diamond interchange (CDI) to a diverging one is a more effective way according to the simulation results. DDI improves the throughput of a CDI by 950 vehicles per hour, a near 20% improvement; whereas with full penetration of CAV, the throughput of a CDI is increased only by 300 vehicles per hour. A similar trend is observed in the average delay per vehicle as well. Furthermore, we assess the impact for the driver’s confusion, a concern for deploying AIDs, on the traffic flow. According to the ANOVA test, the negative impacts of driver’s confusion are of statistical significance. (214)

# VTC Fall 2019: Towards Secure Communication for High-Density Longitudinal Platooning/ Markus Sontowski

Using V2X communication in platoons promises benefits regarding energy efficiency and fleet management. It is also a safety critical process with the potential to cause dangers to life and limb which needs to be secured against attackers. We propose two protocols for secure platoon communication and provide a comparative analysis of those protocols.

In 2016, the transportation sector was responsible for 33% of energy consumption in the European Union and 31.6% of greenhouse gas emissions. Road transportation alone was accountable for 82% of transportation energy consumption and 72% of greenhouse gas emission [1]. One technology envisioned to improve energy efficiency in heavy duty road transportation is High-Density Longitudinal Platooning (HDLP). In HDLP multiple trucks travel with short distances between them with the objective of reducing aerodynamic drag [2] and therefore achieve energy savings of up to 20% [3]. HDPL requires tight coordination of vehicles, which can be achieved by the usage of Cooperative Adaptive Cruise Control (CACC). CACC is similar to Adaptive Cruise Control (ACC) which uses sensors like cameras, radar and lidar to perceive vehicles in the vicinity and determine, e.g., distance to vehicles ahead. Additionally, CACC involves wireless communicating with nearby entities such as other vehicles or Road Side Units (RSUs). In our work we focus on 3GPP and IEEE/ITS based technologies for V2X communication, i.e., assisted (4G/5G network assisted sidelink) or non-assisted (4G/5G ad- hoc sidelink, IEEE 802.11p) direct communication. Owing to the introduction of cooperative communication and driving systems, new threats to safety, security and privacy arise. In this paper, we give an overview on data security and data protection challenges in HDLP and propose two protocols for securing platoon communication. (276)

# VTC Fall 2019: Network Driven Performance Analysis in Connected Vehicular Networks/ Manveen Kaur

As the adoption rate of connected vehicle technology and the complexity of associated vehicular applications grows, the load on the supporting connected vehicular network will also grow accordingly. Sustaining future application requirements will necessitate network optimization. To that end, a comprehensive understanding of network behavior under different operational conditions is essential. This paper studies vehicular network performance in a DSRC/IP network in terms of a set of network indicator metrics that are controllable through adjustments to lower layer parameters within the DSRC stack. We present and analyze results using DSRC enabled hardware modules that are substantiated and validated through our integrated simulator.

Advancements in vehicular technology are rapidly reshaping the human driving experience with recent manifestations including connected and autonomous vehicles (CAVs). Predictions show that 25% of all vehicles in U.S. will be fully autonomous by 2035, and 100% will be fully autonomous by 2050 [1]. Once widely deployed, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) technology will lead to more efficient use of the nation’s traffic infrastructure and to reduced energy usage. As the penetration level of autonomous vehicles grows, there will be fewer vehicular accidents and fatalities. We refer to vehicular communications either to other vehicles or to infrastructure as Vehicle-to-Everything (V2X). Today’s V2X applications provide a range of safety, mobility, and environmentally oriented vehicular applications. As market demand for vehicular entertainment features increases, a new class of data intensive content sharing and consuming applications that can be used for user-oriented event sensing and processing, locality-aware personalized suggestions, and multimedia streaming is brought forth. As society adopts autonomous vehicles, new application systems that support CAVs will need to be developed. As these systems involve the safety of humans, the underlying distributed network and compute systems will require fine-grained control of system resources. To optimize vehicular network resources and performance in the face of this impending development, a comprehensive understanding of the vehicular network behavior and factors impacting network performance is essential. (321)

In this work, we aim to provide an understanding of vehicular network behavior subject to modification of various parameters within the lower layers of the DSRC stack. We define network performance as a function of *indicator metrics* consisting of throughput, latency, channel busy ratio (CBR), and packet delivery ratio (PDR). We further posit that lower layer parameters within the DSRC stack including the modulation and coding of frame transmissions, choice of access category, and transmit power can cause performance variation reflected by the indicator metrics. We investigate this performance variation through experimental results obtained with hardware testing using DSRC enabled modules in the lab and South Carolina Connected Vehicle Testbed (SC-CVT), and validate and extend the same with simulation testing. Simulation testing is conducted via non-mobile and mobile simulation models. The non-mobile simulation model compares directly to the hardware tests and uses the discrete event network simulator ns-3. The mobile simulation model uses an integrated simulator that utilizes realistic semi-urban traffic network of the SC-SVT testbed to substantiate and extend hardware test results.

# A Review of Sensor Technologies for Perception in Automated Driving/Enrique Marti et al

**IEEE Intelligent Transport Systems/Winter 2019/p94**

After more than 20 years of research, ADAS are now common in modern vehicles available in the market. Automated Driving systems, still in the research phase and limited in their capabilities, are starting early commercial tests in public roads. These systems rely on the information provided by on-board sensors, which allow the description of the state of the vehicle, its environment and other actors. Selection and arrangement of sensors represent a key factor. This survey reviews existing, novel and upcoming sensor technologies, applied to common perception tasks for ADAS and Automated Driving. They are put in context making a historical review of the most relevant demonstrations on Automated Driving, focused on their sensing setup. Finally, the article presents a snapshot of the future challenges for sensing technologies and perception, finishing with an overview of the commercial initiatives and manufacturers alliances that will show the intention of the market in sensors technologies for Automated Vehicles.

Automated Driving systems aim to take the human driver out of the equation. This makes them a tool with the potential to reduce the number of traffic accidents. Based on recent developments and demonstrations around the world, there is a tendency to think that Automated Driving with a high level of automation will be available in a few years. This raises questions about its safety.

The architecture of Automated Vehicles is usually divided into three categories: perception of the environment, behavior planning and motion execution. Automated vehicles obtain information about their surroundings using different sensors, such as cameras, LiDARs and radars. Raw data is processed to extract relevant features which are the input to the following stages (behavior planning and motion execution), that will perform tasks such as path planning, collision avoidance or control of the vehicle among others.

Perception is a very challenging problem for several reasons. First, the environment is complex and highly dynamic, with some cases involving a large number of participants (dense traffic, populated cities). Second, it needs to work reliably under a wide range of external conditions, including lighting and weather (rain, fog, snow, dust). Perception errors are propagated and can be the cause of severe accidents. Some real examples include the 2016 Tesla AutoPilot accident, where a man was killed after its car crashed a truck: the camera failed to detect the gray truck against a bright sky while radar detection was discarded as background noise by perception algorithms. Later in 2018, a Tesla model X crashed a highway divider after the lane following system failed to detect faded lines and the concrete divider was not recognized, killing the driver. Also in 2018, an experimental Uber vehicle killed a woman that was crossing the road in the night, dressed in dark clothes. Only the LiDAR provided a positive detection, but it was discarded as a false positive by perception algorithms. One of the main features of this work is its focus on the relation between raw sensors data and meaningful information.

Section II reviews the sensor technologies commonly used for perception, its drawbacks and advantages, and related emerging technologies that can be used in the future. Section III describes the most important competences in perception, to proceed with a state of the art of perception algorithms and techniques grouped by competences. Sensors used on each work are enumerated, and their advantages and disadvantages are discussed. Section IV gives a perspective of the evolution of perception in Automated Driving, presenting the most relevant works and demos in the history of the discipline with a focus in sensor technologies used for each one. Finally, section V contains a discussion of the current state of the discipline and the future challenges for sensors and perception in Automated Driving systems. It includes a review of the most relevant alliances between OEMs (Original Equipment Manufacturers) and technological companies involved in Automated Driving projects at the time of writing. (643 words)

# QUIZ

1. What are the limits (in metres) to wireless localization accuracy of moving vehicles and how can these be improved?
2. What are some of the new techniques for channel coding in 5G compared to 4G/LTE?
3. A century ago what was the big problem with horses on the roads?
4. What is the name of Google’s self-driving car unit?
5. What are some of the techniques that can be utilized to minimize latencies of information flow in connected vehicles?
6. How many electronic system sensors does it take to match human performance?
7. How does platooning of connected vehicles make for reduction in system capacity demand?
8. How will network slicing help improve reliability and performance in 5G networks?
9. What is the forecast percentage in fall of urban car ownership by 2050?
10. How does the ISO 26262 standard help in the design of reliable connected vehicle systems?
11. What are the three most effective sensor technologies for automated driving?

