5G and Edge Computing as Driving Force behind Autonomous Vehicles

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***Abstract*— Multi-access Edge Computing (MEC) uses the edge of the network to bring computing closer to consumers and the data generated by applications, which reduces latency and increases connection speeds. 5G is the next generation of mobile networks that promises to have estimated network speeds as fast as 10 Gb/s and ultra-reliable low latency communication. Both MEC and 5G are considered disrupting technologies on their own, but combined, they will become a powerful force in the world of computing. Connected Vehicles and especially Connected Autonomous Driving (CAD) vehicles bring a whole new ecosystem with new requirements on the network architecture to support and to satisfy the real-time service requirements. This paper provides an overview of the automotive use cases, some of the key challenges and how MEC and 5G can play a vital role in overcoming these challenges.**

Keywords-Edge Computing; 5G; Autonomous Vehicles; DSRC; C-V2X.

I. INTRODUCTION

The automotive industry is evolving towards connected and autonomous vehicles that offer many benefits, such as improved safety, less traffic congestion, less environmental impacts and lower capital expenditure. A key enabler of this evolution is vehicle-to-everything (V2X) communication, which allows a vehicle to communicate with other vehicles, pedestrians, road-side equipment and the Internet. With V2X, critical information can be exchanged among vehicles to improve situation awareness and thus avoid accidents. Furthermore, V2X provides reliable access to the vast information available in the cloud. For example, real time traffic, sensor and high-definition mapping data can be made available, which is useful not only for today’s drivers, but will be essential for navigating self-driving vehicles in the future.

The paper is organized as follows: Section II provides an overview of the V2X communication and use cases, Section III describes the current status of V2X implementation using the standard IEEE 802.11p. Section IV describes the Cellular V2X and the associated use cases. In Section V, we propose the application of V2X using MEC-based architecture support in the 5G infrastructure. It provides insights into how emerging 5G technologies will accelerate the realization of advanced V2X communication to improve transportation experience and quality of life. For example, 5G-based V2X is expected to enable very high throughput, high reliability, low latency and accurate position determination use cases. Some of the use cases will involve 5G working in tandem with other technologies including cameras, radar and lidar. Cellular V2X Communications Towards 5G [3] describes these use cases, starting with the advanced driving categories identified in 3GPP, including ranging/positioning, extended sensors, platooning and remote driving. The paper conclusion is that a combination of these technologies can be helpful in achieving the strict requirements of the V2X communication. It also summarizes how mobile network operators, vehicle manufacturers, cloud service providers and regulatory bodies can work together to deliver a brand-new experience for drivers, travelers and other road users in the near future.

II. OVERVIEW OF V2X

V2X, which stands for 'vehicle to everything', is the umbrella term for the car's communication system, where information from sensors and other sources travels via high-bandwidth, low-latency, high-reliability links, paving the way to fully autonomous driving.

There are several components of V2X, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) communications. In this multifaceted ecosystem, cars will talk to other cars, to infrastructure such as traffic lights or parking spaces, to smartphone-toting pedestrians and cyclists, and to data centers via cellular networks. Different use cases will have different sets of requirements, which the communications system must handle efficiently and cost-effectively.

Figure 1 illustrates some examples of V2X communication [1]. It is implied that these communications are generally bidirectional.

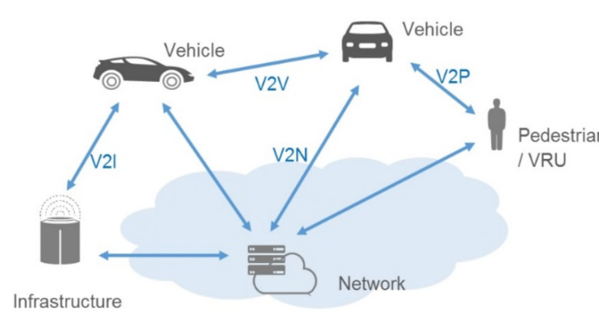

Figure 1. Types of V2X Communication

V2V technology consists of wireless data transmissions between motor vehicles. The primary purpose of this communication is to prevent possible accidents, allowing

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vehicles in transit to transfer data on their position and their speed within an ad-hoc mesh network. It uses a decentralized connection system, which may provide either a fully connected mesh topology or a partially connected mesh topology.

Depending on how the technology is developed, the driver of a vehicle can receive a warning in the event of an accident risk or the vehicle itself can independently take preventive actions, such as emergency braking, if it is designed to carry out safety interventions.

Unlike the V2V communication model, which allows the exchange of information only among vehicles, the V2I enables vehicles in transit to interface with the road system. These components include RFID readers, traffic lights, cameras, lane markers, street lamps, signage, and parking meters.

V2P involves direct communications between a vehicle and one or multiple pedestrians within close proximity. In addition, communication can be to other vulnerable road users, such as cyclists. V2P is conducted directly or through the use of network infrastructure. It will facilitate warnings to be provided to the pedestrian of an approaching vehicle, and warnings to the vehicle of vulnerable road users.

V2N enables both broadcast and unicast communications to take place between vehicles and the V2X management system and also the V2X AS (Application Server). This is achieved by making use of the Cellular network infrastructure. Vehicles are able receive broadcasted alerts regarding accidents further down the road or warnings of congestion or queues on the planned route.

V2V and V2P transmission are based on primarily broadcast capability between vehicles or between vehicles and vulnerable road users (e.g., pedestrian, cyclist), such as for providing information about location, velocity and direction to avoid accidents.

The 5G Automotive Association (5GAA) categorizes a comprehensive list of connected vehicle applications [1] [2], categorized in four main groups of use cases:

- Safety,
- Convenience,
- Advanced Driving Assistance and
- Vulnerable Road User (VRU).

To maximize the benefit that connected vehicles can bring, fast, secure and reliable wireless communications are required.

Various vehicular communication standards have been proposed over the years with the dominant standard known as IEEE 802.11p. IEEE 802.11p defines only the lower layers of the communication system. The upper layers are defined in separate standards: in the US this is IEEE 1609 while in Europe this is ITS-G5.

III. V2X BASED ON IEEE 802.11P

The original V2X standard is based on a Wi-Fi offshoot, IEEE 802.11p (part of the IEEE's WAVE, or Wireless Access for Vehicular Environments program), running in the unlicensed 5.9GHz frequency band. IEEE 802.11p, which was finalized in 2012, underpins Dedicated Short-Range Communications (DSRC) in the US, and ITS-G5 in the European Cooperative Intelligent Transport Systems (C-ITS) initiative.

V2X communication via 802.11p goes beyond line-of-sight-limited sensors such as cameras, radar and LIDAR, and covers V2V and V2I use cases such as collision warnings, speed limit alerts, and electronic parking and toll payments.

The DSRC system transmits a basic safety message (BSM) between vehicles [3] [4]. The BSM includes information such as exact vehicle location and direction of travel, speed, braking status, and some other useful and relevant data. The driver doesn't see it, but the BSM provides safety warnings and could trigger action such as automatic braking or other collision avoidance maneuvers or warnings. The BSM is updated and transmitted 10 times per second [5] [6].

Another proposed function of DSRC is V2I communications. The vehicle links up with roadside access points that can provide additional useful information, such as traffic or road conditions, weather, construction and traffic light status. A V2N connection is also possible for other services to be determined.

However, DSRC has several limitations. There is no apparent path for continued evolution of the radio standard to meet changing technological and consumer needs. Additionally, as it was designed for rapid transmission of short-range basic safety messages, it is unable to meet the higher bandwidth demands of V2N applications such as autonomous driving, multimedia services. DSRC also doesn't have the bandwidth necessary to transmit the raw vehicle sensor data that will become increasingly common in automated vehicles [3]. DSRC also has limited range: about 300 m.

DSRC would require the deployment of tens of thousands of RoadSide Units (RSUs) embedded or attached to roadway infrastructure to enable an effective network along the nation's roads [3].

In summary, there are several challenges present with DSRC. First, the system relies on RSUs, which are not currently deployed. Secondly, at the physical layer, several inefficiencies arise due to the asynchronous nature of the system, resulting in reduced performance, such as range. The worst packet delay in DSRC is unbounded and it also lacks deterministic Quality of Service (QoS) guarantees. Due to the ad hoc nature of DSRC, it is difficult to bind the worst case CSMA backoff time for MAC scheduling. Finally, there is currently no evolutionary path (or IEEE 802.11 standards activities) to allow for improvements in the DSRC physical/MAC layers with respect to range, robustness and reliability [1].

However, a complementary technology, LTE and 5G cellular systems, has the potential to support existing DSRC use cases [7] [8]. In addition to that, low latency, high reliability and high bandwidth offered by the cellular systems can play a pivotal role in supporting advanced, futuristic and more challenging features and use cases [9] [10].

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IV. Cellular V2X

A challenger to DSRC for V2X has emerged from the cellular industry: it is called C-V2X and it is designed to complement and extend existing cellular capabilities. Cellular V2X is an umbrella term for 3GPP-defined V2X technologies, encompassing both LTE- and forthcoming 5G-based V2X systems.

LTE cellular networks are already deployed and cover most parts of the world. With the planned deployment of 5G in 2020, it will further enhance the network capabilities.

C-V2X can be used in many possible different ways to improve road safety, while making more efficient use of transport networks and infrastructure. The Intelligent Transportation Systems (TIS) services can be broadly categorized into safety-related services and non-safety related services. This section gives examples of the many use cases in which C-V2X can help to enhance safety and improve user experience [11]:

1) Vehicle Status Warning. The Vehicle Status Warning use case includes vehicle detection of abnormal safety conditions and signaling the associated danger to others.

2) Traffic Hazard Warning. The Traffic Hazard Warning use case includes vehicle or road infrastructure alerting other approaching vehicles of immobilized vehicles (e.g., an accident, a breakdown, etc.) or current roadwork. This use case prevents collisions by helping vehicles to avoid a dangerously immobilized vehicle situation or roadwork.

3) Collision Risk Warning. The Collision Risk Warning use case includes informing a vehicle of approaching vehicles intending to turn across traffic. This feature mitigates the risk of collision at an intersection by warning vehicles in the affected area. A RSU detects and alerts two or more vehicles.

4) Traffic Condition Warning. The Traffic Condition Warning use case allows vehicles and roadside stations to signal to other vehicles of current traffic conditions. This function helps drivers to choose the best route and leads to less traffic congestion and brings environmental benefits by reducing energy consumption.

5) Queue warning. Roadside infrastructure can also use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking. More broadly, the roadside infrastructure can use C-V2X to help vehicles retain a consistent speed and reduce the number of so-called phantom traffic jams caused by the ripple effect caused by sudden braking and lane changes on motorways.

6) Avoiding collisions. Each vehicle on the road could use C-V2X to broadcast its identity, position, speed and direction. An on-board computer could combine that data with that from other vehicles to build its own real time map of the immediate surroundings and determine whether any other vehicle is on a potential collision trajectory. The vehicles involved could then take an evasive action, such as braking or accelerating, that will enable a collision to be avoided. In cases where a human driver is about to cause an accident, the information collected by C-V2X could be used to over-ride the manual controls. For example, if a driver is about to pull out at a junction into the path of another vehicle, the on-board computer could automatically apply the brakes and prevent the car from moving forward.

7) Automated overtake. Fully-automated vehicles will need to perform overtake maneuvers on two-way roads. Such maneuvers may be dangerous as a quickly approaching oncoming vehicle may be out-of-range of vehicle sensors. Vehicles thus need to cooperate to allow a safe overtake without a risk of collision.

See through sensors enable the exchange of video information between a vehicle and the one behind it. For instance, a vehicle behind a truck receives a video stream coming from the camera at the front of the truck. This will give the driver an extended vision of the environment, thus allowing safer decision making (e.g. when the vehicle decides to overtake the truck). Such use cases require a high reliability, availability and data rate, as well as a low latency.

8) High Definition Map (HDMap) download. In fully autonomous driving, the use of usual 2D digital roadmaps is not enough. Indeed, autonomous vehicles require precise information about their complex environment. HDMaps represent a new generation of maps that could be used for this purpose. Such maps have high precision at centimeter level accuracy, but require high data rate to be downloaded by vehicles.

9) Cooperative Adaptive Cruise Control (CACC). The CACC use case uses unicast V2X cooperative awareness messages to obtain lead vehicle dynamics and general traffic ahead of a vehicle.This allows the vehicle to enhance the performances of its existing ACC.

10) Platooning refers to the formation of a convoy in which the vehicles are much closer together than can be safely achieved with human drivers. Such automated convoys make better use of road space, save fuel and make the transport of goods more efficient. C-V2X can be used to enable communications between up to three vehicles in the platoon, so that they all slow down or speed up simultaneously. C-V2X could also be used to signal the presence of the platoon to other vehicles and roadside infrastructure. Platoons will be flexible in that they will typically be established on a motorway, then broken up when a vehicle leaves the motorway. For platoons of more than three vehicles, relaying information between vehicles takes too long to enable synchronous braking. Therefore, platoons of more than three vehicles will also need to make use of the low latency cellular network infrastructure that will be deployed with 5G [12].

11) Out-of-Coverage Operation. C-V2X can operate outside of network coverage using direct communication without requiring provisioning of a Universal Subscriber Identity Module (USIM). To enable USIM-less communication, automobile Original Equipment Manufacturers (OEMs) will pre-configure the vehicle device with parameters necessary for out-of-network operation [4], including:

- Authorization to use V2X.
- A list of authorized application classes and the frequencies to use for them.
- Radio parameters for use on direct links.

- Configuration for receiving V2X messages via cellular broadcast, for example, Multimedia Broadcast/Multicast Service (MBMS).

Direct USIM-less communication allows C-V2X to support critical safety services when network coverage is unavailable or if the vehicle does not have an active cellular subscription. These parameters can also be securely updated, if needed, by the OEM, just like any other updates. Vehicle OEMs and mobile operators can work together to ensure the parameters they each provision are compatible, resulting in harmonious operation of various vehicle devices using the direct link in an area.

There are two modes of LTE V2X operation: direct and via the network [13].

Direct communication uses the LTE PC5 interface, which is based on Release 12's proximity services communications ("ProSe") feature [14]. It also has enhancements to accommodate high speeds/high doppler, high vehicle density, improved synchronization and decreased message transfer latency. This mode is suitable for proximal direct communications (hundreds of meters) and for V2V safety applications that require low latency, for example Advanced Driver Assistance Systems (ADAS), situational awareness, etc. This mode can work both in and out of network coverage.

Network-based communication uses the LTE Uu interface from the UE located in the vehicle and the eNBs. UEs send unicast messages via the eNB to an application server, which, in turn, broadcasts them via evolved Multimedia Broadcast Multicast Service (eMBMS) for all UEs in the relevant geographical area to receive. This mode uses the existing LTE Wide Area Network (WAN) and is suitable for more latency-tolerant use cases (e.g., situational awareness, mobility services).

With widely deployed infrastructure in major countries, LTE has proven its reliability in bandwidth and coverage area. In spite of such convenience, LTE is still only trusted with non-time critical and non-safety critical communication such as hyperlocal weather, road conditions, traffic data, etc. The main concern comes from the centralized LTE architecture. On the data plane, we have eNodeB (eNB), the Serving Gateway (S-Gw), and the Packet Gateway (P-Gw). eNBs are normally distributed across the nation providing radio access to User Equipment (UE), while S-Gw and P-Gw are part of the Evolved Packet Core (EPC) located at highly centralized data centers. Since the P-Gw anchors all UEs IP addresses, all user plane packets must cross a large backbone network to reach P-Gw of EPC before being routed towards their destination. The actual end to end LTE packet delay could be as high as 60-100 ms, exceeding the designed 20 ms user plane latency. Therefore, current cellular networks become unsuitable for time critical safety messaging [15].

To decrease latency, LTE-D2D and LTE-V are developed, where user devices communicate directly to their target rather than going through a base station and the core networks. However, they share similar issues with most distributed communication. If the wireless access channels are managed by the LTE scheduler, we can only communication between two stationary devices under the same cell coverage, otherwise the mobility issue could also be challenging.

Since V2X must be deployed in the near term and should be extended to the future, it must offer the necessary high performance to meet use cases, e.g., intersection movement assistance, emergency electronic brake light, forward collision warning, blind spot warning, lane change warning, etc., while being future proof and scalable to meet the requirements of use cases of tomorrow, e.g., ADAS, where vehicles can cooperate, coordinate and share sensed information, and ultimately CAD.

V. 5G, MEC AND C-V2X

In this section, we propose/analyze an edge-computing architecture based on 5G for C-V2X in light of some of the standard use-cases discussed above.

The stringent latency requirements posed by the V2X system can be satisfied by introducing Multi-access Edge Computing (MEC) technology to the cellular network architecture. Let us consider a MEC-assisted network architecture, in which MEC hosts are collocated with eNBs/gNBs. They can receive and process VRU messages at the edge of the access network. Leveraging its ability to provide processing capabilities at the cellular network's edge, an overlaid MEC deployment is expected to assist vehicles in achieving low packet delays, due to its close proximity to end users. By means of numerical evaluation, it has already been observed that, for some of the investigated system parameterizations, the proposed overlaid deployment of MEC hosts can offer up to 80% average gains in latency reduction as compared to the conventional network architecture [16].

Focusing on the C-V2X technology, the architecture of the cellular network is expected to have a vital impact on the support of delay-intolerant V2X services. This occurs because the End-to-End (E2E) latency of C-V2X signaling is limited by the quality and dimensioning of the cellular infrastructure, i.e., the capacity of backhaul connections, the delays introduced by both the Core Network (CN), as well as the Transport Network (TN). As one would expect, these latency bottlenecks will be more prominent for high loads corresponding to coverage areas of high vehicular/ pedestrian densities. MEC can play an important role in overcoming these challenges and reducing the latency in high density scenarios [16].

Figure 2 illustrates the typical network scenario where MEC and 5G infrastructure will be deployed to support the challenging requirements of C-V2X communication and support the various use cases listed above. Another variant of this network scenario can be where MEC, 5G and 4G infrastructure co-exist. The edge supports some of the core network functionalities that are hosted from the core network. The existing eNB/gNB and/or the RSUs with processing and storage capabilities can also be used to host some of the core network functionalities.

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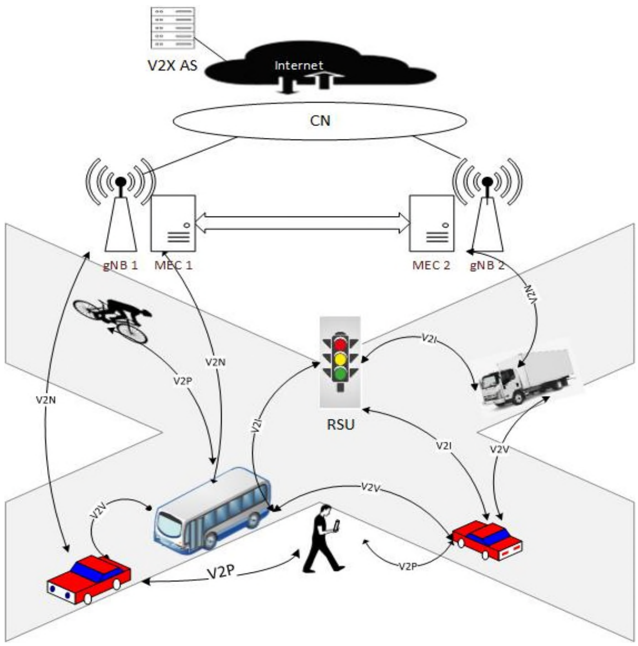

Figure 2. C-V2X Network Architecture with MEC and 5G

5G will support a broad range of V2X and non-V2X use cases [18], including enhanced Mobile Broadband (eMBB), massive Internet of Things (mIoT) and mission-critical services. These use cases have diverse requirements, including high data rates for eMBB, low power consumption and high scalability for mIoT, as well as Ultra-Reliable and Low Latency Communications (URLLC) for mission-critical services [17]-[19].

Network slicing allows network operators to define different types of services and dynamically allocate proper resources to support this end-to-end service by configuring different network segments. By using slicing technology, one physical network can be divided into multiple virtual networks, each supporting different service requirements or even different customers [20].

V2N and communication via the network are typical use cases for network slicing. For instance, autonomous driving or safety/emergency services would require an URLLC network slice. Meanwhile, some auxiliary/comfort or personal mobility services would require either a best effort slice or an eMBB slice in the case of streaming infotainment videos. A given vehicle could access different slices at the same time, with passengers watching an HD movie while a see-through application detects a road hazard and triggers an emergency message for the cars behind or nearby to slow down or stop to prevent an accident.

C-V2X is designed to be fully compatible with 5G, meaning investments in infrastructure and modules today will not become obsolete for a long time to come.

The deployment of commercial 5G networks from 2020 onwards based on the 3GPP standards will enhance C-V2X in several different ways [11]. In the 5G era, C-V2X will be able to support:

- Very precise positioning and ranging to support cooperative and automated driving.
- High throughput and low-latency connectivity to enable the exchange of raw or processed data gathered through local sensors or live video images.
- High throughput to build local, dynamic maps based on camera and sensor data, which can then be distributed at street intersections. For example, C-V2X could be used to supply a driver or an on-board computer with a bird's eye view of an intersection or see-through capability when driving behind a truck.
- Very low latency and high reliability to support high-density platooning [21] [22].

VI. CONCLUSION

In this paper, we have described various V2X use cases, existing DSRC implementation for V2X communication, its advantages and some of the challenges associated with it. Also, we have covered the Cellular V2X, which is entering the vehicular communication space, in competition with the tried and tested DSRC.

Cellular V2X communication has the potential to enhance the traffic safety, comfort and is going to play a crucial role in supporting the future use cases towards autonomous driving. However, under high load conditions, it might not be able to meet the latency requirements for the safety related use cases. The automotive industry, OEMs, standard bodies need to work towards the co-existence of these technologies to leverage the full potential, which will make 802.11p and LTE-A/5G more compatible, and can even consider the option to merge the two, to create a heterogeneous vehicular networking system that leverages the best of both – the ability of 802.11p to support safety-related use-cases, and the ability of LTE-A/5G to support non-safety-related use-cases.

Widespread deployment of Multi-access Edge Computing in 5G networks can help in achieving the latency requirements to support safety-related use-cases and will act as accelerators for autonomous driving cars. Network slicing is also going to play an important role to meet the diverse requirements of a variety of safety related and non-safety related use-cases. However, security and safety aspects will play an important role for V2X communication, be it DSRC, LTE, MEC or 5G.

REFERENCES

[1] V2X Cellular Solutions http://www.5gamericas.org/files/2914/7769/1296/5GA_V2X_Report_FINAL_for_upload.pdf [Retrieved: 06/2019]

[2] "5G Automative Association," http://5gaa.org/ [Retrieved: 06/2019]

[3] "Cellular V2X Communications Towards 5G" http://www.5gamericas.org/files/9615/2096/4441/2018_5G_Americas_White_Paper_Cellular_V2X_Communications_Towards_5G__Final_for_Distribution.pdf [Retrieved: 06/2019]

[4] J. Kenney, "Dedicated Short-Range Communications (DSRC) Standards in the United States". Proceedings of the IEEE. 99. 1162 – 1182, 2011. 10.1109/JPROC.2011.2132790.

 ISBN: 978-1-61208-727-6

[5] K. Abboud, H. A. Omar, and W. Zhuang, “Interworking of DSRC and cellular network technologies for V2X communications: A survey,” IEEE Transactions on Vehicular Technology, vol. 65, no. 12, pp. 9457– 9470, Dec. 2016.

[6] Heterogeneous Vehicular Networks By Kan Zheng, Lin Zhang, Wei Xiang, and Wenbo Wang.

[7] “V2X Communication for ITS - from IEEE 802.11p Towards 5G”

https://futurenetworks.ieee.org/tech-focus/march-2017/v2x-communication-for-its [Retrieved: 06/2019]

[8] Z. Mir, and F. Filali, “LTE and IEEE 802.11p for vehicular networking: a performance evaluation”

https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/1687-1499-2014-89 [Retrieved: 06/2019]

[9] “C-V2X Enabling Intelligent Transport”

https://www.gsma.com/iot/wp-content/uploads/2017/12/C-2VX-Enabling-Intelligent-Transport_2.pdf [Retrieved: 06/2019]

[10] “Cellular V2X as the Essential Enabler of Superior Global Connected Transportation Services”

https://futurenetworks.ieee.org/tech-focus/june-2017/cellular-v2x [Retrieved: 06/2019]

[11] ETSI TR 102 638 V1.1.1 (2009-06) Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions

[12] G. Nardini, A. Virdis, C. Campolo, A. Molinaro, and G. Stea, “Cellular-V2X Communications for Platooning: Design and Evaluation” https://www.mdpi.com/1424-8220/18/5/1527 [Retrieved: 06/2019]

[13] “C-V2X Conclusions based on Evaluation of Available Architectural Options” http://5gaa.org/wp-content/uploads/2019/02/5GAA_White_Paper_on_C-V2X_Conclusions_based_on_Evaluation_of_Available_Architectural_Options.pdf [Retrieved: 06/2019]

[14] ETSI TS 123 303 V12.6.0 (2015-10) LTE; Proximity-based Services (ProSe); Stage 2, 3GPP TS 23.303 version 12.6.0 Release 12 https://www.etsi.org/deliver/etsi_ts/123300_123399/123303/12.06.00_60/ts_123303v120600p.pdf [Retrieved: 06/2019]

[15] S. Zhou, P. P. Netalkar, Y. Chang, Y. Xu, and J. Chao, "The MEC-Based Architecture Design for Low-Latency and Fast Hand-Off Vehicular Networking," *2018 IEEE 88th Vehicular Technology Conference (VTC-Fall)*, Chicago, IL, USA, 2018, pp. 1-7. doi: 10.1109/VTCFall.2018.8690790 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8690790&isnumber=8690547 [Retrieved: 06/2019]

[16] M. Emara, M. C. Filippou, and D. Sabella, "MEC-Assisted End-to-End Latency Evaluations for C-V2X Communications," *2018 European Conference on Networks and Communications (EuCNC)*, Ljubljana, Slovenia, 2018, pp. 1-9. doi: 10.1109/EuCNC.2018.8442825

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8442825&isnumber=8442432 [Retrieved: 06/2019]

[17] “5G Communications for Automation in Vertical Domains” http://www.5gamericas.org/files/1815/4222/3220/5G_Americas_White_Paper_Communications_for_Automation_in_Vertical_Domains_November_2018.pdf [Retrieved: 06/2019]

[18] “5G to Accelerate the Realization of Autonomous Cars” http://www.5gamericas.org/en/newsroom/press-releases/5g-accelerate-realization-autonomous-cars/ [Retrieved: 06/2019]

[19] “A 5G V2X Ecosystem Providing Internet of Vehicles”

https://www.mdpi.com/1424-8220/19/3/550/htm [Retrieved: 06/2019]

[20] C. Campolo, A. Molinaro, A. Iera, R. R. Fontes, and C. E. Rothenberg, "Towards 5G Network Slicing for the V2X Ecosystem," *2018 4th IEEE Conference on Network Softwarization and Workshops (NetSoft)*, Montreal, QC, 2018, pp. 400-405. doi: 10.1109/NETSOFT.2018.8459911 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8459911&isnumber=8458492 [Retrieved: 06/2019]

[21] V. Vukadinovic et al., (2018). 3GPP C-V2X and IEEE 802.11p for Vehicle-to-Vehicle communications in highway platooning scenarios. Ad Hoc Networks. 74. 10.1016/j.adhoc.2018.03.004. URL: https://www.researchgate.net/publication/323843658_3GPP_C-V2X_and_IEEE_80211p_for_Vehicle-to-Vehicle_communications_in_highway_platooning_scenarios [Retrieved: 06/2019]

[22] D. Sabella et al., “Toward fully connected vehicles: Edge computing for advanced automotive communications,” [Online]. Available: http://5gaa.org/news/toward-fully-connected-vehicles-edge-computing-for-advanced-automotive-communications/ [Retrieved: 06/2019]