High mobility 5G services for vertical industries – network operator's view*

Lechosław Tomaszewski[1], Ioannis P. Chochliouros[2][0000−0002−4208−1676], Robert Kołakowski[1,3], Sławomir Kukliński[1,3], and Michail-Alexandros Kourtis[4]

[1] Orange Polska S.A., ul. Obrzeżna 7, 02-691 Warszawa, Poland
[2] Hellenic Telecommunications Organization (OTE) S.A., 99 Kifissias Avenue, 15124 Maroussi-Athens, Greece
[3] Warsaw University of Technology, ul. Nowowiejska 15/19, 00-665 Warszawa, Poland
[4] Orion Innovations P.C., Ameinokleous 43, 11744 Athens, Greece

Abstract. The 5G System (5GS) is regarded as a multi-faceted, universal communication platform that could address the increasingly stringent requirements of both modern industries and network end users. Several proposed mechanisms, such as Network Slicing, aimed to facilitate access to the network for the external stakeholders, enable the creation of one common ecosystem that could be exploited according to the specific service needs. With the recent advancements in the automotive and aviation sectors, the significant increase of interest regarding the current state of preparedness of the 5GS and its capabilities to support those services is observed. The paper presents the analysis of the 5G technology readiness in the context of high mobility vehicular scenarios, including automotive and aviation (UAV, Unmanned Aerial Vehicles) use cases. The significant features and key gaps and challenges have been outlined with the emphasis on the dynamics of business processes and interactions between automotive, aviation and 5G ecosystems.

Keywords: 5G System · MEC · Vertical services · V2X · UAV

1 Introduction

Since the early visions, the 5G System (5GS) has been presented as a versatile platform, able to build individualized communication solutions responding to the needs of very diverse and demanding use cases. The well known IMT-2020 triangle of fundamental use profiles at the vertices (eMBB, URLLC, and MMTC) [1] constitutes a map of use cases, showing conceptually their relation to these profiles. Furthermore, the KPIs characterising the "promised" 5GS in comparison to the previous generation show serious gaps to be filled (30-50× in E2E latency, 100× in individual connection data rate and served terminals per area unit, 1.5× in terminal velocity). Today, after 5 years and with more than 100 commercial implementations of 5GS all over the world, the first reality check can be performed to validate the 5G technology maturity vs. the excited

* Supported by the Horizon 2020 projects: EU-China 5G-DRIVE (Grant Agreement No. 814956) and EU 5G!Drones (Grant Agreement No. 857031).

expectations. A very important aspect, which goes beyond the internal features of 5GS, is the ability to be adopted operationally by the network operator and by the business processes of the wider ecosystem in which it will be embedded.

One of the flagship applications of 5G networks in vertical industries are automotive and unmanned aviation use cases, which are highly demanding in terms of data rate, latency, reliability and mobility as well as subject to strict regulations. In addition, the ongoing COVID-19 pandemic has exposed their socio-economic importance to be much greater than previously expected. For them, the 5G network must not only be a static, focused only on itself, element of the overall landscape, but must actively participate in various multilateral business processes. Thanks to the EU-sponsored trial projects of the H2020 program 5G-DRIVE and 5G!Drones, it was possible to recognize the broad context and needs of these industries, which challenge the 5G network and its operator.

2 Overview of the vertical industries in focus

2.1 Automotive sector

The automotive sector is rapidly gaining popularity on the market with the projected annual growth 44.2% and is expected to reach over 364% of its initial value in 2020 until the end of 2028 [2]. Currently, the automotive market is built atop two communication technologies: WLAN-based and cellular, C-V2X (LTE, 5G). Mobile communication systems are considered as the main drive of acceleration of development of V2X ecosystem, due to better performance in terms of cybersecurity and handling large numbers of messages in congested traffic environments – the features being inline with core motivations of V2X, i.e. improving road safety, traffic efficiency and energy saving. These motivations are planned to be achieved by building the extensive Intelligent Transport System (ITS) allowing road users to acquire, share and use the information to support individual actions.

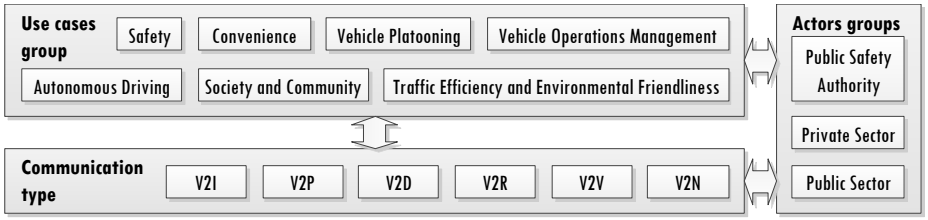

Fig. 1. V2X ecosystem

The V2X ecosystem (cf. Fig. 1) concerns interactions of vehicles with the infrastructure (V2I), network (V2N), pedestrians (V2P), devices (V2D), grids (V2D), Road-side (V2R) units and other vehicles (V2V). Typically, the V2X use cases are grouped into the following categories [3]: (i) *Safety:* mechanisms for safety improvement (emergency braking, collision warning, lane change assistance, etc.); (ii) *Society and Community:* use cases of interest to the society and

public (Vulnerable Road User protection, traffic light priority, crash reporting, etc.); (iii) *Convenience:* facilitation for drivers (infotainment, assisted and cooperative navigation, autonomous smart parking); (iv) *Autonomous Driving:* semi-, fully-automated and remote; (v) *Vehicle Platooning:* creating dynamic groups of vehicles to exchange information and coordinate operations (e.g. maintenance of inter-vehicle distance); (vi) *Traffic Efficiency and Environmental friendliness:* enhancements for traffic optimization (e.g. Green Light Optimal Speed Advisory, traffic jam information, Smart routing); (vii) *Vehicle Operations Management:* operational and management use cases benefiting vehicle manufacturers (sensors monitoring, remote support, etc.).

Demand for handling diverse service data with different QoS requirements causes the 5G to be projected as a leading communication technology for V2X systems. In addition to connectivity, 5G can facilitate automotive services by hosting the systems as part of the 5GS on the Mobile Network Operator's (MNO) infrastructure or close to the edge of the network, e.g. via integration with MEC.

2.2 Unmanned aviation sector

The vast expansion of Unmanned Aerial Vehicles (UAV) services' market is commonly expected in all regions of the world (137% global market value growth between 2019 and 2026 [4]) due to the huge variety of UAV use cases in multiple economic areas. Further market acceleration can be achieved by overcoming the "Visual Line of Sight" flights barrier with an omnipresent communication platform, optionally with aid of "First Person View" (FPV) – real time 360° video for pilot. Hence, the 5G services supporting UAV operations are potentially a huge business opportunity for MNOs.

The unmanned aviation is a highly regulated sector, primarily due to safety, in terms of flight and airspace management. It is commonly accepted that the UAV ecosystem will be built around the UAV Traffic Management (UTM) system [5], which in EU will be developed as U-space, i.e. a framework of services and procedures for management of massive UAV traffic in a common EU airspace, to be implemented in 4 phases (U1-U4), gradually introducing new obligatory services within a common EU regulation (U1 in force since January 1st, 2021).

The U-space ecosystem [6] (cf. Fig. 2) – composed of multiple actors and entities – is founded on the U-space Service Provider (USP), i.e. an operator of a UTM system. To induce competition, there may exist more than one USP in a specific area. The USP's role is to provide services essential for coordinated flight planning, execution and control, which may be categorized as: (i) *Identification and Tracking:* registration, e-identification, position reporting and surveillance; (ii) *Airspace Management and Geofencing:* automated airspace areas access control; (iii) *Mission Management:* operation plan preparation, optimisation and processing, risk analysis assistance and dynamic management of airspace capacity; (iv) *Conflict Management:* pre-/in-flight conflict resolution; (v) *Emergency Management:* incident, accident and violations reporting; (vi) *Monitoring:* infrastructure monitoring, traffic control and lawful recording of all U-space inputs; (vii) *Environment:* weather, geo-spatial positioning, electromagnetic inter-

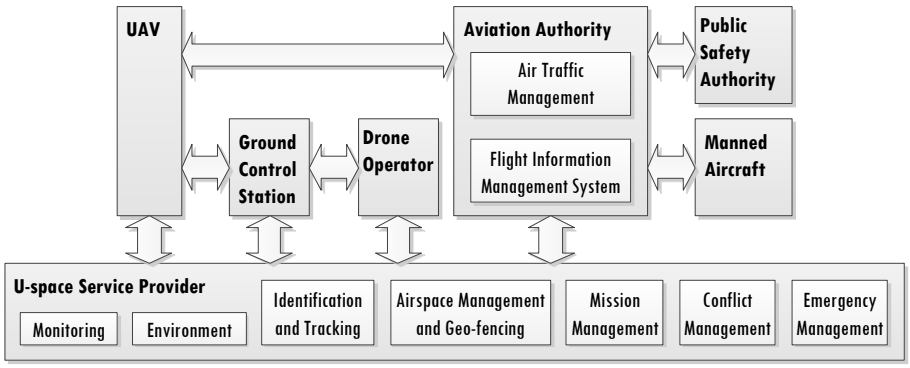

Fig. 2. The U-space ecosystem

ference, navigation and communication coverage, and population density. 5GS functionalities can actively contribute to various USP services. Therefore, it can be perceived as a part of USP and 5GS services and capabilities as "added-value" U-space resources. To enable support of massive UAV traffic, deep integration of both aviation and 5G ecosystems, including business processes, is advisable.

Last but not least, the role of 5GS is to provide the connectivity between U-space entities and actors, especially the communication links both for non-payload (flight-related, i.e. for UAV control and traffic management) and payload exchange (use case-specific, e.g. real-time video, still photos, sensoric data, etc.), meeting the QoS requirements. Additionally, the UAV actors' systems can be distributed and hosted by the MNO's infrastructure (especially at the edge).

3 3GPP 5GS support of vertical industries in focus

3.1 Approach to the requirements

V2X/UAV service requirements for 5GS are defined in [7]/[8], respectively. QoS KPI targets have been specified for various communication links necessary for both vehicle classes. In case of V2X there is a non-payload communication only, compared to payload/non-payload context differentiation used for UAV. The top targets are more challenging in case of V2X by one order of magnitude (e.g. latency of 3 ms for emergency trajectory alignment vs. 10 ms for approaching autonomous navigation infrastructure; data rate of 1 Gbps for low-distance V2V sensor information sharing vs. 120 Mbps for 4×4K AI surveillance; reliability of 99.999% for remote driving control vs. 99.99% for FPV aid). Such approach is motivated by much higher proximity of automotive vehicles and their higher maximum speed (250 km/h vs. 160 km/h). Merely, the required horizontal positioning accuracy is comparable (0.1 m), for UAV specified only for payload.

Apart from the above requirements related to the quality properties of communication links, both sectors impose added-value functional requirements:
Group communication: it is required to enable communication between V2X objects (vehicles, roadside infrastructure, pedestrians etc.) in proximity, which

expose V2X applications to others, including their discovery, either directly or via 5G network, with integrity and confidentiality kept, also inter-PLMN (inter-Public Land Mobile Network). In case of UAVs, this feature addresses broadcasting of drone's presence (ID, location, flight parameters) for collision avoidance in a small radius (600 m).

Connectivity sharing: enabled by detection of other V2X User Equipment (UE), the on-board UE may obtain network access via another V2X UE, when unable to connect directly. While the feature is not demanded for UAVs, it might be used for sustaining the connectivity in poor coverage areas.

Service assurance and provisioning: both sectors request the 3rd party (V2X application, UTM system, etc.) ability to receive service monitoring information on per-UE basis, including early notification about possible QoS fluctuations or potential connectivity stopping. It is also required that the 5GS shall expose the information about service status (availability, estimated QoS) in a certain geographical area at a certain time, which is of premium importance for remote driving planning as well as for UAV legally required flight plan approval procedures. Additionally, in case of V2X sector the support of negotiation of spatial/temporal connectivity QoS between the 3rd party and the 5GS is required. This feature might be also useful in case of necessary flight plan alterations for on-going flights.

User Plane data augmenting: requested for UAV services; here, the User Plane data packets sent to UTM are demanded to be additionally "certified" by the PLMN with e.g. UE id (IMSI) or its location.

Joint authorization: UTM (generally: 3rd party) can be involved in UAV UE authorization to operate, i.e. admission to the specific communication network.

UE capability validation and problems detection: the 5G network is required to identify and validate if the UE has the UAV-specific capabilities, especially supports its interaction with UTM. Additionally, the 5G network shall support detection, identification and reporting of problematic UAV system components with on-board UE to UTM.

Control take-over: there is a requirement of the 5GS ability to enable UTM (or other lawfully authorized entity) to take over the communication used for UAV control. This requirement is related to the public safety issue; a problematic UAV may be forced to land or steered to a safe crash area.

Identity handling: the approach to this issue is extremely different. While in the V2X sector the privacy protection is fundamental [9] to avoid vehicle tracking by its UE identity (pseudonymization required), continuous vehicle identification and tracking is fundamental in the aviation.

The area of possible synergy of both sectors' high-level requirements is large. Apart from that, there are disjoint requirements, which may contribute as added value to the complementary sector, however. Only the last issue is contradictory. Hence, shared components should be expected, for architectural and operational reasons (reusability and common know-how for operation/maintenance).

3.2 Implementation of requirements – architecture and mechanisms

The generic vision of the 5GS architectural framework [10] envisions functionalities and mechanisms to support basic V2X/UAV requirements, i.e. related to providing communication links with specific QoS targets. Moreover, its inherent functional upgradeability provides means for implementation of "added-value" requirements. The features of 5GS, fundamental for the V2X/UAV support, are:

Control and User Plane Separation (CUPS), i.e. Control Plane (CP) functions may be independently placed in a centralized location, while the User Plane (UP) can be implemented at the closest possible location to the user or UP-supported application (e.g. for latency minimization), which further enables independent scaling of both planes, more flexible design, deployment and dimensioning of the network, and dynamic optimization of UP traffic distribution.

CP programmability, additionally boosted by its **Service-Based Architecture** (SBA), where 5GS-native Network Functions (NFs) and specific Application Functions (AFs) expose services as their Producers or discover/consume them as Consumers, within the RESTful framework (API) based on JSON (serialization), HTTP/2 (application layer), and TCP (transport).

UP programmability, i.e. UP Function (UPF) flexibly composed as a chain of atomic functions to process the UP traffic (e.g. firewall, Deep Packet Inspection, selective marking or altering, encapsulation, classification, forwarding or redirection of user traffic, anti-virus protection, parental control, etc.).

Network slicing (NS), i.e. split of handling of various communication services with mutually conflicting requirements among separated specialized sub-networks (to be built on flexibly shared common resources), which are customized according to service specificity. Efficient customization of these sub-networks is further enhanced by CUPS and SBA. Slice-specific CP functions may be flexibly integrated with 5GS CP, using separation mechanisms of the CP communication bus. Slice-specific UP data processing chain – as a service-customized UPF. As the UE may use applications demanding various communication services, the UE multi-slice attachment ability has to be supported.

Embedded analytics is included as special Network Data and Management Data Analytics Functions (NWDAF in CP and MDAF [11] in management layer, respectively), which expose their services to other functions. Their functionality include NFs data collection, processing, analysis and metadata exposure, including notifications of data-driven events (e.g. threshold- or condition-based).

Network control/management capabilities exposure for external systems integration is based on Network Exposure Function (NEF) located in CP and Exposure Governance Management Function (EGMF) located in management layer [11]. For standardization of supported integration mechanisms at the 5GS North Bound Interface (NBI), additional Common Application Programming Intertface Framework (CAPIF) [12] and Service Enabler Architecture Layer for Verticals (SEAL) [13] have been defined.

4 Key gaps and challenges

The 5GS readiness to handle the services for high mobility applications is currently limited in many aspects, discussed below. Due to 3GPP standardization timeline, the majority of them is still under the development (either from scratch or being enhanced) as a part of the Release 17 scope (further indicated as ^{R17}). Therefore, vendors' solutions will be available well after the half of 2022, i.e. after the freeze of the 3GPP Release 17.

4.1 Network Slicing

NS is a fundamental enabler of majority of 5G services for the high mobility applications. It concerns especially the UAV sector, where multiple non-payload and payload communications links with drastically different characteristics may be required. However, there are currently two factors to detain implementation of NS: the migration policy adopted by MNOs and the current status of the 3GPP standardization^{R17}. In Europe, all MNOs have chosen to implement the 5G network according to the Non-Stand Alone architecture, with at least the overwhelming majority of the Option 3/3a/3x (cf. [14],[15]), so NS is not supported there, inherently. This approach accelerated the 5G technology implementation in Radio Access Network (RAN), especially as in some countries new 5G bands are still unavailable. However, it may have further negative effect by delaying the implementation of 5G Stand Alone architecture. Until then, 5G networks in Europe will remain "boosted LTE networks" (with just higher data rates) without full 5G functionality and services support.

4.2 RAN mechanisms

5GS is expected to bring several RAN solutions to address diverse and elevated transmission requirements implored by robustness of served communication types. Several mechanisms have already been introduced to the New Radio (NR) both at physical and procedural level. The intensive work on development of NR features is a major part of the 3GPP Release 17 and subject to its timeline.
RAN slicing^{R17}: a fundamental NR mechanism to ensure QoS levels of PDU sessions and their isolation, by means of L1/L2 scheduling and per-slice Radio Resource Management policies [16]. Its support is only in scope of Release 17.
Proximity Services (ProSe)^{R17}: a basis for direct UE-UE communication. So far, the preliminary studies have been published, outlining i.a. the key issues as discovery of UEs, relay support and charging aspects [17]. The essentials of the ProSe core element, i.e. Sidelink (PC5 interface), have already been defined [16].
Minimization of Drive Tests (MDT)^{R17}: a mechanism for collection of radio measurement data provided by UEs. These data might by further used for 3D network coverage optimization and exposure.
Beam management: essential mechanisms for interference mitigation. Some of them (beamforming, beam sweeping etc.) have been described for NR in [18]. Nonetheless, the technology is still not mature enough for URLLC use cases [19].

Radio Resource Allocation: mechanisms, grant-free access for the UL and preemptive punctured scheduling for the DL [16], which enable skipping resource allocation negotiation procedures and mitigation of related delay, critical for URLLC transmission. Other mechanisms may be added during the Industrial IoT URLLC enhancements studies***R17***.
Applications impact on RAN: the O-RAN concept that introduces RAN programmability is of premium importance for V2X and UAV services. The O-RAN real-time controller enables applications impact on RAN mechanisms. The navigation data can be used e.g. to modify RAN coverage or handover scheduling.

4.3 Specific architectural support of V2X/UAV use cases

In addition to generic 5GS mechanisms, 3GPP addresses some aspects of service support for high mobility use cases to specialized architectural and application-layer solutions, individually defined for each of the vertical sectors in focus.

The specific support of V2X services is partially standardized within the 3GPP Release 16 and covers SEAL-based application layer issues (dynamic grouping, group communication – via PC5 or mobile network, file and application message distribution and cross-PLMN PC5 communication) [20] and relevant 5GS architecture-level mechanisms (V2X communication, including its authorization, provisioning and QoS; V2X application server discovery and subscription) [21]. Further enhancements are in progress***R17*** and the studies both for layers of application (extended QoS specific for V2X use case category – cf. section 2.1 – and automation level; tele-operated driving; network slicing and multi-PLMN support; connection relaying; enhancements of group communication and management; vehicle tracking, multi-V2X service provider support) [22] and 5GS architecture (QoS-aware power efficiency of PC5 for pedestrian UEs) [23] have recently been finalized.

The UAV-specific support has not been provided within 5GS, yet. Its first standardization is currently underway***R17***. The studies on UAV connectivity, identification and tracking (UAV and its controller identification, authorization for operation and connectivity to UTM – commonly with UTM, pairing and tracking) [24] and SEAL-based application layer support for the UAV ecosystem (mechanisms of direct and on-network broadcast communication; network capability exposure and management related to QoS provisioning, UAV real-time monitoring/locating/trajectory deviation tracking, UAV command and control communication modes switching, real-time media session monitoring; UAV systems pairing and identification; alignment of UAV and edge enabler layers) [25].

Although the finalized studies in both vertical sectors are only proposals for further selection and validation during the normative documents development, there is a fundamental difference in the architectural approach. It is assumed that V2X Application Servers will be integrated with 5GS individually via NEF as V2X-specific AFs to interact separately with 5G CP. In case of UAV sector, it is proposed to implement specialized shared function(s) to expose 5GS CP services to the UAV environment actors: drone operator, UTM or third party authorized entity. Such approach follows the idea of a UAV ecosystem gateway

function proposed in [26], which is not only a mediator to expose generalized UAV-related mechanisms through an API commonly used by these actors. Its role is also to coordinate all their interactions with 5GS CP, to exploit functional similarities in various interactions and contexts for simplification of the overall architecture and to avoid excessive signaling exchange from the same, multiplied requests (e.g. continuous, real-time UAV tracking for reporting to UTM and drone operator, for position broadcasting, for mechanism of early warning about possible connection loss and for autonomic trajectory deviation detection).

4.4 Multi-Access Edge Computing

The UAV/V2X Application Plane is expected to operate at the edge of the network, therefore usage of ETSI Multi-Access Edge Computing (MEC) framework [27] capabilities is deemed as an enabler for latency reduction and transport network offloading. Whilst the latter is an indisputable advantage, the foremost is questionable due to properties of virtualization technologies. Studies [28, 29] show that each Virtual Machine (VM) or container impose significant latency overhead due to sharing of physical resources and extra processing layers for virtualization (∼150-300 μs for working alone and even a few ms in heavily loaded clusters by concurrent bandwidth-demanding VMs). Moreover, the paradigm of high modularization and distribution multiplies the effect above and in turn nullifies the gain on infrastructure placement close to RAN (each 6 μs of delay is the equivalent of ∼1 km of fiber). The 3GPP standardization of integration of MEC with 5GS has been recently started[R17], but there are still unsolved concerns about the overall architecture of integrated frameworks [30].

4.5 Agile management and provisioning architecture

Considering high mobility and latency-critical UAV/V2X services, the need for efficient mechanisms of management and orchestration becomes a fundamental issue, especially when responsiveness to service and traffic demand changes introduces safety risks. While NS enabled by softwarization and virtualization is a widely adopted vision, the dynamic slicing [31] – i.e. the dynamic and continuous metamorphoses of the network, following the needs in a timescale of seconds – still remains an open challenge, thus the need for extensive research.

3GPP adopts the ETSI Management and Orchestration (MANO) framework [32] and designs the vision of the 5GS management as complementary to MANO. Its centralized operation fundamentally increases the overhead related to slice modification such as resource reallocation, and also raises significant concerns in terms of scalability and efficiency. In the case of multi-domain hierarchical and recursive orchestration, reconfiguration of stitched sub-slices would incrementally intensify the issue. In [33], the results of time needed for slice instantiation and scaling-out (which is only the final, actuating step of the entire process of adaptive network transformation) have been presented. In case of small slices, the first process consumed from around 15 s to 50 s depending on the slice size (number of VNFs). The latter proved to be executable in approximately 15 s,

which for the time being might not be sufficiently fast to satisfy the soaring UAV/V2X requirements.

The initial stage of the adaptation process requires the appropriate mechanisms for obtaining relevant input data. While the generic SBA-based 5GS CP architecture allows for the potential implementation of any analytical functions as AFs, the "turnkey" mechanisms to support V2X/UAV use cases are of premium importance for carrier-grade implementation. The recently finalized study [34] proposes new 5GS automation enablers (as new services or capabilities of NWDAF) for e.g. optimized radio access technology/frequency selection, anomaly detection and aiding its cause analysis, UE dispersion analytics, UE movement patterns and traffic analytics, predictive mobility management, real-time data collection and analytics. Further mechanisms for so called "context awareness" will need to be developed in the future. The research on artificial intelligence-driven decision algorithms is also only at the beginning of the way (initiated several EU research projects on automated management).

Finally, it should be noted that the scope of the 3GPP vision of network management, and therefore also of the 5GS integration with the ecosystems of vertical industries, is very limited compared to the comprehensive vision of the telecommunications operator's processes and related information systems map by TMF [35]. The integration of telecommunications and vertical industry sectors must also include the integration at the operational process level. For example, flight feasibility check request cannot be comprehensively answered based on momentary status of 5GS, read out from CP or real-time management system. Other support systems have to be involved, e.g. configuration management, change management, planning management, etc. In case of emergency flight route replanning, the dynamics of the end-to-end interaction (from changed route feasibility check request through answer validation and provisioning request to report of successful completion of reconfiguration) will be extremely high and the timescale of tens of second may be demanded. Therefore, a comprehensive reference architecture for integrating the cooperating ecosystems must be thoroughly thought out.

5 Conclusions

The participation of telecommunications operators in European projects has resulted in the understanding of the broad context of the needs of industrial sectors that are addressed to the telecommunications network. This is all the more important as the wide adoption of network virtualization and slicing will bring serious market disruption in the long term. Therefore, operators must give a proactive response to these changes, looking for new business opportunities in ground and airborne vehicular vertical industries.

This paper presents the current progress of 5GS development in the context of offered support for the vertical industries in focus. The preparedness of the network to meet the expectations has been evaluated on the basis of mechanisms that could facilitate vehicular use cases and with respect to the requirements es-

tablished by the 3GPP in preceding standardization activities. From the operator's point of view, the 3GPP support for UAV/V2X services is still very limited mostly due to lack of implementation of NS as well as mechanisms that enable addressing the requirements for URLLC transmission (RRM, adaptive coverage improvement etc.). Considering characteristics and dynamics of vehicular services, a substantial gap exists with relation to mechanisms for direct UE-UE communication. Moreover, the approach to deployments of latency-critical services at the edge of the network needs redefinition to enable mitigation of the delay overhead induced by virtualization process.

The aforementioned standardization limitations will probably be overcome by 3GPP in the next 1.5 years. However, a significant challenge beyond the scope of 3GPP interests are the mechanisms necessary for highly dynamic automated 5G network management and orchestration, as well as, in particular, full integration of operational processes through the integration of a broader spectrum of information systems of both sectors than in the 3GPP vision.

References

1. ITU-R: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond (M.2083, Feb 2015)
2. Markets and Markets: Automotive V2X Market, https://www.marketsandmarkets.com/Market-Reports/automotive-vehicle-to-everything-v2x-market-90013236.html
3. 5GAA: C-V2X Use Cases Methodology, Examples and Service Level Requirements, https://5gaa.org/wp-content/uploads/2019/07/5GAA_191906_WP_CV2X_UCs_v1-3-1.pdf
4. Markets and Markets: Unmanned Aerial Vehicle (UAV) Market, https://www.marketsandmarkets.com/Market-Reports/unmanned-aerial-vehicles-uav-market-662.html. Last accessed 25 Feb 2021
5. Global UTM Association: UAS Traffic Management Architecture, https://www.gutma.org/docs/Global_UTM_Architecture_V1.pdf. Last accessed 25 Feb 2021
6. GOF USPACE Project: SESAR 2020 GOF USPACE Summary, FIMS, Design and Architecture, https://www.sesarju.eu/node/3203. Last accessed 25 Feb 2021
7. 3GPP: Service requirements for enhanced V2X scenarios (TS 22.186 V16.2.0, Jun 2019)
8. 3GPP: Unmanned Aerial System (UAS) support in 3GPP scenarios (TS 22.125 V17.3.0, Apr 2021)
9. 3GPP: Service requirements for V2X services (TS 22.185 V16.0.0, Jul 2020)
10. 3GPP: System architecture for the 5G System (TS 23.501 V17.0.0, Mar 2021)
11. 3GPP: Management and orchestration; Architecture framework (TS 28.533 V16.7.0, Apr 2021)
12. 3GPP: Common API Framework for 3GPP Northbound APIs (TS 23.222 V17.4.0, Apr 2021)
13. 3GPP: Service Enabler Architecture Layer for Verticals (SEAL); Functional architecture and information flows (TS 23.434 V17.1.0, Apr 2021)
14. 3GPP: Architecture configuration options for NR, (RP-161249, Jun 2016)
15. 3GPP: Study on new radio access technology: Radio access architecture and interfaces (TR 38.801 V14.0.0, Apr 2017)

16. 3GPP: NR and NG-RAN Overall description; Stage-2 (TS 38.300 V16.5.0, Mar 2021)
17. 3GPP: Study on system enhancement for Proximity based Services (ProSe) in the 5G System (5GS), (TR 23.752 V17.0.0, Mar 2021)
18. 3GPP: NR; Medium Access Control (MAC) protocol specification, (TS 38.321 V16.4.0, Mar 2021)
19. Li, Y. R., Gao, B., Zhang, X., Huang, K.: Beam Management in Millimeter-Wave Communications for 5G and Beyond. IEEE Access **8**, 13282–13293 (2020). https://doi.org/10.1109/ACCESS.2019.2963514
20. 3GPP: Application layer support for Vehicle-to-Everything (V2X) services; Functional architecture and information flows (TS 23.286 V17.1.0, Apr 2021)
21. 3GPP: Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services (TS 23.287 V16.5.0, Dec 2020)
22. 3GPP: Study on enhancements to application layer support for V2X services (TR 23.764 V17.1.0, Dec 2020)
23. 3GPP: Study on architecture enhancements for 3GPP support of advanced Vehicle-to-Everything (V2X) services; Phase 2 (TR 23.776 V17.0.0, Mar 2021)
24. 3GPP: Study on supporting Unmanned Aerial Systems (UAS) connectivity, Identification and tracking (TR 23.754 V17.1.0, Mar 2021)
25. 3GPP: Study on application layer support for Unmanned Aerial Systems (UAS) (TR 23.755 V17.0.0, Apr 2021)
26. Tomaszewski, L., Kołakowski, R., Kukliński, S.: Integration of U-space and 5GS for UAV services. 2020 IFIP Networking Conference, pp. 767–772
27. ETSI: Multi-access Edge Computing (MEC); Framework and Reference Architecture (GS MEC 003 V2.2.1, Dec 2020)
28. Oljira, D. B., Brunstrom, A., Taheri, J., Grinnemo, K.: Analysis of Network Latency in Virtualized Environments. 2016 IEEE Global Communications Conference (GLOBECOM), pp. 1–6. https://doi.org/10.1109/GLOCOM.2016.7841603
29. Sollfrank, M., Loch, F., Denteneer, S. Vogel-Heuser, B.: Evaluating Docker for Lightweight Virtualization of Distributed and Time-Sensitive Applications in Industrial Automation. IEEE Transactions on Industrial Informatics **17**(5), 3566–3576 (2021). https://doi.org/10.1109/TII.2020.3022843
30. Tomaszewski L., Kukliński S., Kołakowski R.: A New Approach to 5G and MEC Integration. In: Maglogiannis I., Iliadis L., Pimenidis E. (eds.) Artificial Intelligence Applications and Innovations. AIAI 2020 IFIP WG 12.5 International Workshops. AIAI 2020. IFIP Advances in Information and Communication Technology, vol 585. Springer, Cham (2020). https://doi.org/doi.org/10.1007/978-3-030-49190-1_2
31. Chochliouros I. P., Spiliopoulou A. S., Lazaridis P., Dardamanis A., Zaharis Z., Kostopoulos A.: Dynamic Network Slicing: Challenges and Opportunities. In: Maglogiannis I., Iliadis L., Pimenidis E. (eds.) Artificial Intelligence Applications and Innovations. AIAI 2020 IFIP WG 12.5 International Workshops. AIAI 2020. IFIP Advances in Information and Communication Technology, vol 585. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-49190-1_5
32. ETSI: Management and Orchestration (ETSI NFV MAN 001 V1.1.1, Dec 2014)
33. Trakadas, P. et al.: Comparison of Management and Orchestration Solutions for the 5G Era. Journal of Sensor and Actuator Networks. **9**(1), 4 (2020). https://doi.org/10.3390/jsan9010004
34. 3GPP: Study on enablers for network automation for the 5G System (5GS); Phase 2 (TR 23.700-91, V17.0.0, Dec 2020)
35. TMF Homepage, https://www.tmforum.org/opendigitalframework/. Last accessed 10 Apr 2021