Advanced 5G Architectures for Future NetApps and Verticals

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***Abstract*—With a growing commercial and innovation potential for software developers to provide new and innovative 5G-empowered network applications (NetApps) across multiple industry verticals, 5G architecture and infrastructure are challenged to continuously evolve in order to cope with all these NetApps requirements. The paper is focused on 5G architectures adaptation for future NetApps and verticals and begins with a short introduction on 5G current and future environment, then continues with the 5G-PPP projects that contributed to early deployment of 5G testbed in Romania. Further we will focus on the NetApps and vertical context, as they are highlighted through the two 5G-PPP projects, VITAL-5G and 5GASP, the step by step 5G network evolution to support all these challenging NetApps and vertical's use cases.**

Keywords—5G, architecture, NetApp, vertical, testbed, use case

I. INTRODUCTION

The mobile networks evolved in the last years from the well-known 4G networks to 5G networks, providing increased speed and improved latency, comparable with the optical fiber networks, serving different use cases requirements. The 5G usage is not only to serve the three fundamental scenarios: Enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC) and Ultra Reliable Low Latency Communications (URLLC), but also to provide the automatic deployment, orchestration and service instantiation for the vertical's use cases, providing communication services through dedicated network slices, as it is relevant to mention that the 5G verticals have very different needs in terms of communication.

The novel 5G features and capabilities offered to the consumers are technically sustained by the virtualized, software based network functions, cloud-native applications and orchestration tools, automatic deployment and instantiation of different VNFs (Virtual Network Functions), lifecycle management (LCM) tools for the software functions, horizontal and vertical scaling. These initial concepts as Network Slicing, 5G RAN and Core reference architecture or virtualized environment deployment and orchestration have been presented in different 5G-PPP projects and papers, as described in [1][2][3] .

Innovative 5G environments need to respond to the novel cutting edge Network Applications and have to be implemented and validated through advanced 5G testbeds, testbeds that ensure interoperability with the 5G vertical's specialized services requirements.

In near future telco operators need to apply DevOps principle in their facilities and have to introduce the end to end network automation capabilities, support from the cognitive Artificial Intelligence algorithms, to build on top of the existing testbeds and infrastructure and to provide network support for future 5G experiments and tests.

The telco operators' activities will be oriented to foster the development and testing of new and innovative NetApps, Apps built on the top of 5G NFV (Network Function Virtualization) based reference architecture, as 5G requires dynamic allocation of computing and storage resources, flexible deployment of functions in distributed cloud infrastructures. The 5G service should be delivered wherever needed, considering also the transport level, for the required end-to-end control and data plane connectivity between entities, across physical and virtualized network elements in order to meet NetApps end-to-end demands.

The paper is organized as follows. Section II presents some related work on future NetApps and Verticals, highlighting research done in 5G-PPP projects, while Section III provides insight on the context of NetApps and Verticals. Section IV presents the evolution of 5G architectures with respect to future NetApps and Verticals while Section V draws the conclusions.

II. RELATED WORK

In this section we discuss relevant research related to the development of 5G software and applications as well as 5G-PPP projects and activities, focusing on those that have been used to early deploy 5G testbeds in Romania.

A. Research papers

Substantial commercial and innovation potential exists for software developers to provide new and innovative 5G-empowered applications across multiple industry verticals. There are numerous examples of verticals where there is potential for many enhancements.

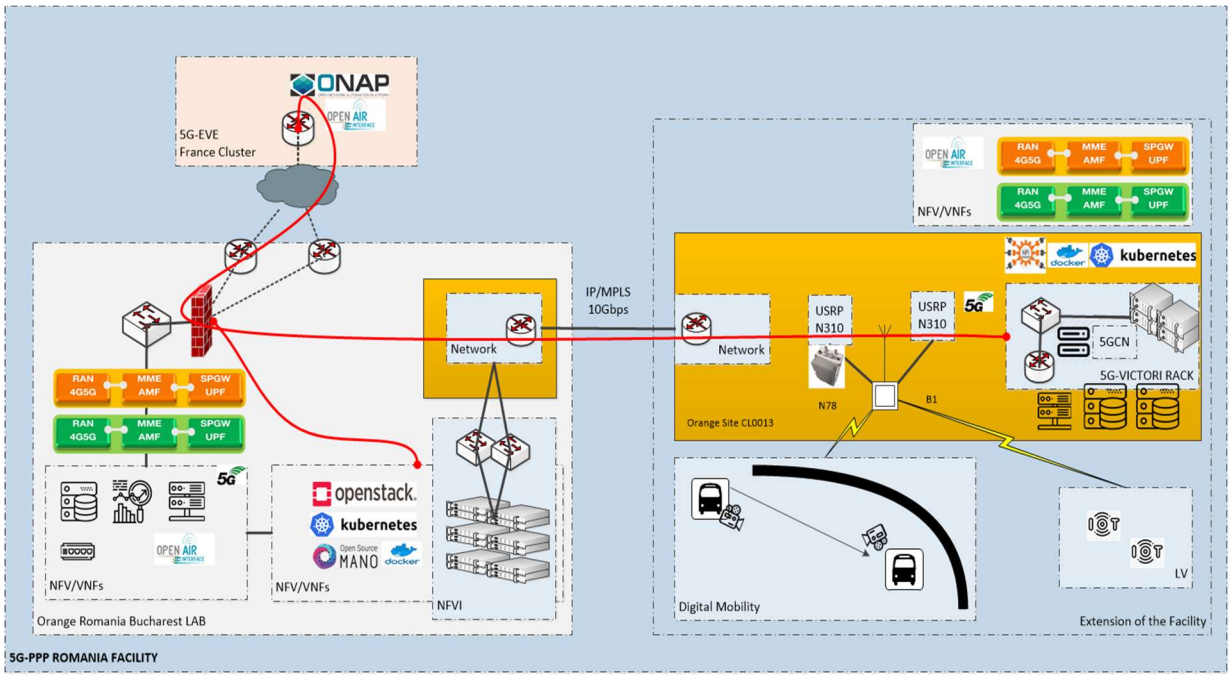

Fig. 1. End-to-end 5G reference architecture for Romanian testbed experimentation facility

For example, authors in [4] propose a 5G-enabled EC-IoV system framework for specific computation offloading, while authors in [5] identify technologies of information security and privacy protection to support the diverse services and applications in future 5G-V2X networks.

Agriculture is a major vertical supported by 5G systems and several applications such as UAV navigation, AI driven robots and AR&VR [6] as well as pirivacy-preserving data publishing schemes [7] have been proposed.

Applications using 5G network-based Internet of Things have been proposed in smart grid scenarios for demand response [8] as well as real-time electricity consumption monitoring [9] and also ensuring security and privacy for such critical infrastructure [10].

eHealth data collection and management is proposed inside isolated 5G network slices [11] for achieving a holistic view of patients while decentralized blockchain-based 5G IoT eHealth frameworks and applications [12]. are also increasingly being present

Finally, in the Transport & Logistic (T&L) vertical, there are several proposals such as intelligent logistics cost control [13], logistics taxation data monitoring [14] and blockchain-based approaches [15]

B. Research projects

5G-EVE [18] is the 5G European Validation platform for Extensive trials, the project that creates the foundations for a pervasive roll-out of end-to-end 5G networks in Europe by offering to vertical industries and to all 5G-PPP Phase3 projects facilities to validate their network KPIs and their services.

MATILDA [19] is a holistic, innovative framework for the design, development and orchestration of 5G-ready applications and network services over sliced programmable infrastructure. The vision of MATILDA is to design and implement a holistic 5G end-to-end services operational framework tackling the lifecycle of design, development and orchestration of 5G-ready applications and 5G network services over programmable infrastructure, following a unified programmability model and a set of control abstractions.

SLICENET [20] is an End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualized Multi-Domain, Multi-Tenant 5G Networks. The project aims to design, prototype and demonstrate an innovative, verticals-oriented, QoE-driven 5G network slicing framework focusing on cognitive network management and control for end-to-end slicing operation and slice-based/enabled services across multiple operator domains in SDN/NFV-enabled 5G networks.

5G-VICTORI [21] is a 5GVertIcal demos over Common large scale field Trials fOr Rail, energy and media Industries, conducting large scale trials for advanced vertical use case verification focusing on Transportation, Energy, Media and Factories of the Future and cross vertical use cases. It also leverages 5G network technologies developed in other 5G-PPP phase 1 and 2 projects, such as 5G-XHaul and 5GPICTURE, and exploits extensively existing facilities interconnecting main sites of all ICT-17 infrastructures, and exploits extensively existing facilities interconnecting main sites of all ICT-17 infrastructures i.e. 5G-VINNI, 5GENESIS and 5G-EVE and the 5G UK testbed in a Pan-European Infrastructure.

The relevant output of this 5G-PPP work is described in Fig. 1, presenting an end-to-end 5G reference architecture for the testbed experimentation facility focusing on the Romania implementation.

The relevant features for Romania cluster are highlighted as follows:

- ICT-17/19 5G Testbed based on OAI over virtualized infrastructure (K8s) for RAN & Core and use case applications, deployed in Bucharest laboratory. As the testbed is virtualized and the automated network

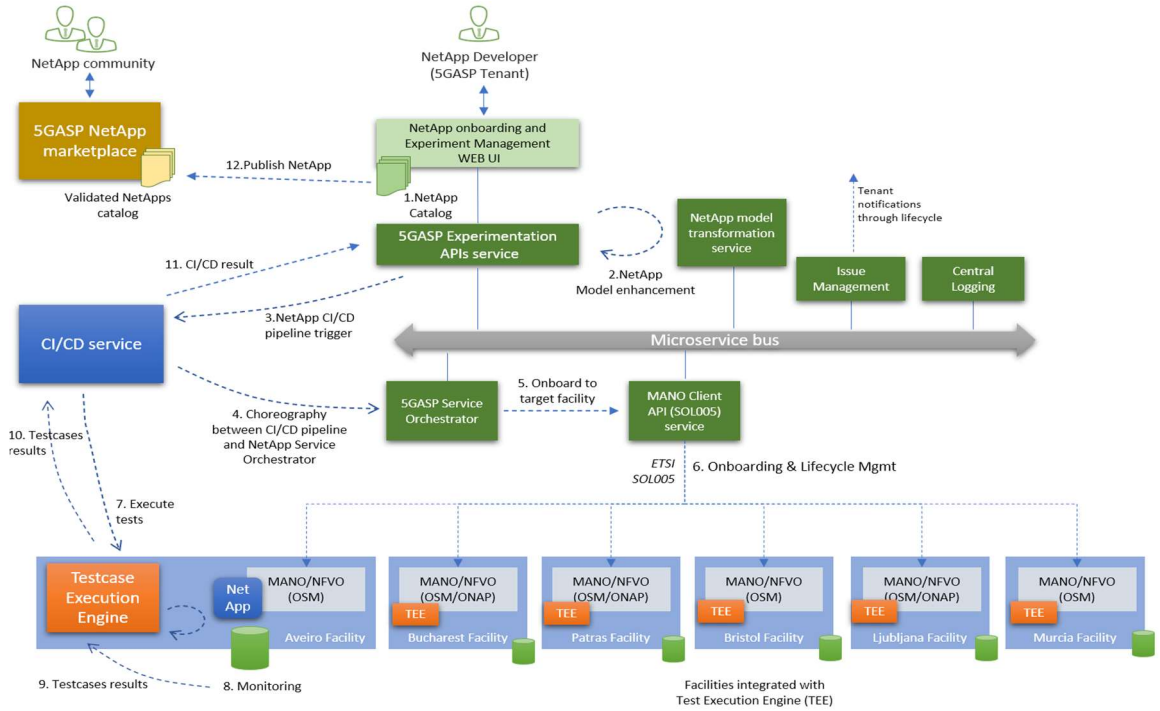

Fig. 2. 5GASP approach on DevOps experimentation and certification readiness lifecyle

deployment is in place, the platform offers 5G NSA/SA capabilities (Rel 15), 5G RAN vEPC/5GC network, RAN SDNs, Orchestration tools (ONAP) [16] and Portal onboarding, system monitoring and metrics collection, IaaS/CaaS capabilities (Openstack/K8s).

- 5G SA Release 16 testbed, 5G SA Core and RAN, 5G SA capabilities (Rel. 16), 5G RAN antennas and 5GC SA network capabilities, orchestration tools (ONAP), system monitoring and network and infrastructure metrics collection, IaaS/CaaS capabilities (OpenStack/K8s), easily to be extended, completed by the CI/CD (Continuous Integration and Continuous Deployment) framework.

III. NetApps and Verticals Context

The VITAL-5G [22] facility will provide application developers with the necessary testing and validation tools platform. The objective is the creation of a virtualized experimentation facility composed of a virtual platform and three distributed 5G-testbeds for testing and validation of transport and logistic NetApps in real-life conditions, utilizing 5G connectivity.

5GASP [23] aims at accelerating SMEs towards the 'new world' of 5G-based Network Applications (NetApps) which would empower various verticals with unique capabilities that will unleash the potential in respect to the 'real-world' use of 5G technologies. The technical objective of 5GASP is to build and operate an Open, and Inter-Domain 5G NFV-based Reference (Open5G-NFV) ecosystem of Experimental Facilities. This ecosystem [23] will not only integrate existing facilities already proven in previous ICT projects, but will also lay down the foundations for instantiating fully software architectures of vertical industries. Furthermore, it will provide facilities to test and validate NetApps taking into consideration vertical-specific requirements. 5GASP will demonstrate its Open5G-NFV ecosystem for two very distinct verticals deployed across the state-of-the-art 5G infrastructures: Automotive and Public Protection and Disaster Relief (PPDR). The proposed 5GASP approach on DevOps experimentation and certification readiness lifecyle is depicted in Fig. 2.

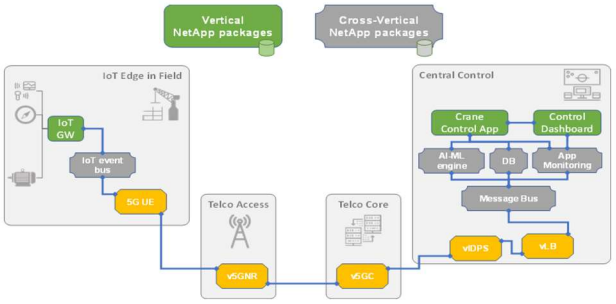

Fig. 3. VITAL-5G NetApp concept

NetApps in VITAL-5G are defined as packages containing NFV descriptors, software images, and configuration scripts for the service chains formed by virtualized and physical functions. NetApps components are both vertical and connectivity related (VNF/PNF) and chained into a Network Service for both vertical specific and agnostic applications described below:

- Vertical specific NetApps (green boxes in Fig. 3), serving functionalities that address specific industry challenges e.g. Indoor robot navigation, human-robot collaboration, AI/ML (Artificial Intelligence and Machine Learning) based vessel warehouse automated fault detection

- Vertical agnostic NetApps (grey boxes in Fig. 3) serving general-purpose functionalities: distributed sensor data collection, fusion & post-processing, remote inspection & risk assessment, IoT management platform, real time digital twin, data stream organization.

The VITAL-5G platform will be composed of a Service Portal for NetApps lifecycle management and an Open Online Repository, allowing capabilities to design, onboard, instantiate, monitor/manage and benchmark transport and logistic vertical NetApps. The verticals will run their experiments by accessing the Service Portal via a dashboard or a programmatic API. The portal and the API will expose an intent-based interface which will allow for the abstraction of the service description for the Vertical and autonomously transform service intents into 5G/NFV service descriptions and lifecycle management actions. The Service Portal acts as abstraction and aggregation layer across different domains of a 5G facility (RAN, edge/core based on NFV MANO) and will interface with MANO and NG-RAN control systems available at the trial facilities, where network slice creation, resource instantiation and data collection actions will be executed as a result of the lifecycle management in the Service Portal.The Open Online Repository will contain and manage onboarding procedures for the NetApp packages. The catalogue service will implement a programmable APIs, a web-based graphical front-end to on-board, query, retrieve and update VNF packages, network slice and network service descriptors/service blueprints and a role based access control (RBAC) to regulate access and actions permitted on NetApp packages

Testbed facilities will be validated through a number of use cases focused on the implementation of a data-enabled assisted navigation application using IoT sensing system and video cameras installed in Romania's Galati port and on a ship and barges. The following NetApps will be developed as part of this use case:

- distributed sensor data collection, fusion & post-processing - will support the targeted improvement in accuracy of electronic navigation maps creation;
- data stream organization - will support the targeted improvement in navigation dangerous events occurrences related issues;
- on board data collection & interfacing for vessels supporting the targeted cost reduction;
- AI/ML mechanisms, IoT, data fusion, collection, post-processing and other additional areas, such as fraud detection and sanity checks, bringing several key innovations and improving port operation and security;
- data-enabled assisted navigation 5G connectivity using IoT sensing system and video camera;
- real-time control operations implemented by collecting data via cameras and sensors, taking navigation and operating decisions based on on-line analytical processing;

All developments will be applied on the sensor data for ship insurance purposes based on AI/ML mechanisms, while preparations for customs operations and predictive ships / cargo checks may take place based on additional sensors placed onboard the ships and cargo hold.

Access to live video streaming from the surroundings will be deployed through high-definition video cameras. A transceiver will be installed on the ship which will communicate with other ships by exchanging information about different obstacles accident detection etc.

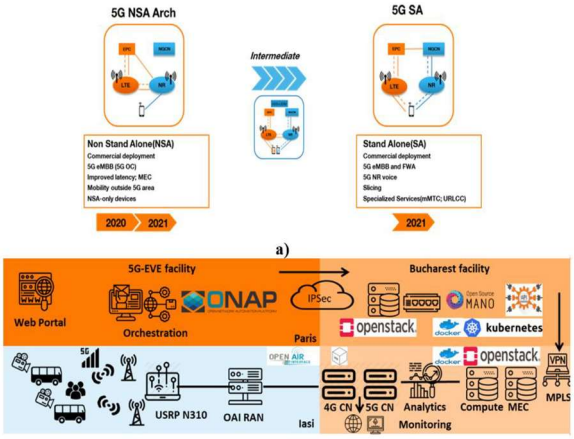

Fig. 4. Romanian open tools based 5G-testbed upgrade roadmap

All associated information will be sent through 5G radio links to a central server located in port and will be used as input data to update, in real time, an electronic map containing river parameters and weather conditions. The service performance will be evaluated based on a set of predefined KPIs as shown in Table I.

TABLE I. VITAL-5G VERTICAL AND NETWORK KPI'S

KPI	Thresholds
Service creation time	< 90 min
Reliability	99,999% (~ 5.26 min. downtime per year)
Bit rate	20 Mbit/s in 99% of locations)
Throughput	> 1 Gbps for remote monitoring (360o view through UHD cameras)
Latency	< 5 ms

IV. 5G ARCHITECTURES EVOLUTION FOR FUTURE NETAPPS AND VERTICALS

Three VITAL-5G vertical experimentation areas like Port of Antwerp, Danube River, Athens logistics hub will be used for validation of the released platform and online repository. These facilities have been built in previous European projects such as 5G-EVE for Athens/Bucharest and 5G-Blueprint for Antwerp or derived from production 5G rollout initiatives like 5G roll-out in Romania by Orange. The 5G testbeds that will be developed in the project are not intended to be integrated in cross-border service deployments, they will support and extend instead radio coverage to the port and warehouse areas as part of technology roadmaps set by facility owners.

The Romanian 5G-testbed will support the river port experimentation near Galati will be based on parts of the commercial 5G network of Orange Romania already deployed in the area and on implementations and infrastructure created by the 5G-PPP 5G-EVE [1] project composed by several open tools. The testbed facility is providing Release 15 capabilities, NSA Option 3X implementation in 800 MHz and 3.6 GHz spectrum, and fully supports OpenAir5G platform, developed by Eurecom and supported by OpenAirInterface (OAI) [17], including the OAI 5G RAN platform, the OAI Core Network implementations and various orchestration platforms and tools such as ONAP for lifecycle management and operation of VNFs, SDNs, ETSI-MANO NFVI and OSM.

The access to the 5G-testbed will be provided through a specifically provisioned 5G site in the Danube Port of Galati,

by mid-2022, to address the need for connectivity of the VITAL-5G project. Within the VITAL-5G lifecycle it is expected that the testbed will be upgraded to support 3GPP Rel. 16 capabilities, in an SA deployment, with upgrades in the RAN and Core components to improve support for eMBB and FWA, 5G NR Voice, Slicing and services such as mMTC, URLLC.

The 5G testbeds should be an open ecosystem capable to cope with various NetApps, as the 5G testbed in Romania will be designed as a collaborative work activity between the two 5G-PPP projects, VITAL-5G and 5GASP. The same testbed facility from Romania will answer also to following 5GASP NetApps:

- **Virtual On-Board Unit (vOBU)** provisioning NetApp, enabling the possibility to implement Multi-access Edge Computing (MEC) capabilities
- **Multi-domain Migration** NetApp, providing virtual counterparts in a MEC are suitable for vehicular scenarios. The main problem that arises is the high mobility of vehicles and how to maintain the connectivity of their OBUs with their correspondent virtual surrogates when switching between different network domains
- **Vehicle-to-Cloud** (V2C) Real-Time Communication NetApp, Autonomous vehicles are usually equipped with multiple 4K cameras and sensors that generate tens of Megabit of data per second
- **Remote Human Driving** NetApp - Teleoperation for assisting vehicles in complex situations, a remote operator takes full/partial control over an autonomous vehicle in unusual/dangerous situations

Beyond the existing 5G capabilities, the testbed will be extended with the NetApps and VNF Package catalogues, defining the information models, the high-level workflows and the access-based collaboration procedures, as from the 5G-testbed design perspective it will be develop the integration approach in terms of platform and use cases.

The 5G infrastructure will require upgrades and extensions, different system components integration to an open 5G platform and repositories, as described:

- DevOps for 5G Networks, new concept introduced in telecom operator networks, to shorten release cycles, improving reliability
- Vertical Testing and Inter-Domain, access to vertical testbed environments, fully integrated into a common testing platform orchestrated centrally and with the help of various MANO platforms (from OSM to ONAP)

To accomplish these objectives, the 5G architectures will develop several functionalities and services:

- NetApps onboarding, as a centralized NetApps experimentation portal, that allows to manage tenant's NetApps, to trigger and monitor the experimentation lifecycle
- NetApps Experimentation APIs service, backend service that exposes standardized OpenAPIs for providing programmatic access to the lifecycle and to the internal NetApp catalogue

Fig. 5. 5GASP - a DevOps for 5G Networks

- NetApps Service Orchestrator, service orchestrator for supporting deployment to facilities;
- MANO Client API (SOL005) service, service that interfaces the operation and experimentation, with the NFV orchestrators of the facilities, ETSI NFV SOL005 interface
- CI/CD service, CI/CD pipelines that coordinate the execution of test by interacting with different orchestrator

V. Conclusion and Further Work

In this paper we presented an existing 5G facility, developed through several 5G-PPP projects and research activities, with an advanced level of 5G infrastructure implementation and 5G capabilities. Network service slicing, orchestration, automation and infrastructure lifecycle management tools are already available, but all these capabilities do not answer the novel NetApps needs. The paper introduces this challenging 5G architecture evolution to a new environment, highlighting through the two projects VITAL-5G and 5GASP the step-by-step network evolution to support all these challenging NetApps and vertical use cases. The paper is building on previous efforts from 5G-PPP projects, establishing today the framework for the 5G network adaptation to respond to the new NetApps requests and it will be continued, following the project's developments and future achievements.

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References

[1] H. Ștefănescu, M.Iordache, B.Rusti, C.Brezeanu, J. Ghența, M.Chabiera, L.Rajewski, G.Panek, "5G Programmable Infrastructure Orchestration using ONAP", IARIA AICT The Sixteenth Advanced International Conference on Telecommunications, Lisbon, Portugal, 2020.

[2] L.Yala, M.Iordache, A. Bousselmi and S. Imadali, "Testbed Federation for 5G Experimentation: Review and Guidelines, "IEEE

Conference on Standards for Communications and Networking (CSCN), GRANADA, Spain, pp.106,2019.

[3] L.Yala, M.Iordache, A.Bousselmi and S.Imadali, “5G Mobile Network Orchestration and Management Using Open-Source, “IEEE 2nd 5G Forum (5GWF), Dresden, Germany, pp. 421-426,2019

[4] S. Wan, R. Gu, T. Umer, K. Salah and X. Xu, "Toward Offloading Internet of Vehicles Applications in 5G Networks," in *IEEE Transactions on Intelligent Transportation Systems*, doi: 10.1109/TITS.2020.3017596.

[5] W. Duan, J. Gu, M. Wen, G. Zhang, Y. Ji and S. Mumtaz, "Emerging Technologies for 5G-IoV Networks: Applications, Trends and Opportunities," in *IEEE Network*, vol. 34, no. 5, pp. 283-289, September/October 2020, doi: 10.1109/MNET.001.1900659.

[6] Y. Tang, S. Dananjayan, C. Hou, Q. Guo, S. Luo, and Y. He, “A survey on the 5g network and its impact on agriculture: Challenges and opportunities,” *Computers and Electronics in Agriculture*, vol. 180, p. 105895, 2021

[7] J. Song, Q. Zhong, W. Wang, C. Su, Z. Tan and Y. Liu, "FPDP:Flexible Privacy-preserving Data Publishing Scheme for Smart Agriculture," in *IEEE Sensors Journal*, doi: 10.1109/JSEN.2020.3017695.

[8] H. Hui, Y. Ding, Q. Shi, F. Li, Y. Song, and J. Yan, “5g network-based internet of things fordemand response in smart grid: A survey on application potential,”Applied Energy, vol. 257,p. 113972, 2020

[9] M. Forcan, M. Maksimović, J. Forcan and S. Jokić, "5G and Cloudification to Enhance Real-Time Electricity Consumption Measuring in Smart Grid," 2020 28th Telecommunications Forum (TELFOR), Belgrade, Serbia, 2020, pp. 1-4, doi: 10.1109/TELFOR51502.2020.9306518.

[10] G. Suciu, C.-I. Istrate, A. Vulpe, M.-A. Sachian, M. Vochin, A. Farao, and C. Xenakis, Attribute-based access control for secure and resilient smart grids, *6th International Symposium for ICS & SCADA Cyber Security Research* 2019 6, 2019, pp. 67–73, DOI: 10.14236/ewic/icscsr19.9

[11] E. Kapassa et al., "An Innovative eHealth System Powered By 5G Network Slicing," 2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS), Granada, Spain, 2019, pp. 7-12, doi: 10.1109/IOTSMS48152.2019.8939266.

[12] M. A. Uddin, A. Stranieri, I. Gondal, and V. Balasubramanian, “Blockchain leveraged decentralized IoT eHealth framework,” *Internet of Things*, vol. 9, p. 100159, 2020

[13] J. Wang, Z. Yang, and Z. Wang, “Intelligent logistics cost control based on 5G network and IoT hardware system,” *Microprocessors and Microsystems*, p. 103476, 2020

[14] Y. Liu, “International logistics taxation data monitoring based on 5G network and cloud computing platform,” *Microprocessors and Microsystems*, vol. 82, p. 103826, 2021

[15] Lenny Koh, Alexandre Dolgui & Joseph Sarkis (2020) Blockchain in transport and logistics – paradigms and transitions, International Journal of Production Research, 58:7, 2054-2062, DOI: 10.1080/00207543.2020.1736428

[16] ONAP Architecture Overview, https://www.onap.org/architecture, (visited on 06/12/2020).

[17] OpenAirInterface 5G RAN, https://openairinterface.org/5g-modem (visited on 15/02/2021)

[18] 5G EVE: 5G European Validation platform for Extensive trials, H2020-ICT_2017, https://5G-ppp.eu/5g-eve/

[19] MATILDA: A holistic, innovative framework for the design, development and orchestration of 5G-ready applications and network services over sliced programmable, H2020-ICT-2016-2, https://5g-ppp.eu/matilda/

[20] SLICENET: End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualised Multi-Domain, Multi-Tenant 5G Networks, H2020-ICT-2016-2, https://5g-ppp.eu/slicenet/

[21] 5G-VICTORI: Verical demos iver Common large scale fields Trials for Rail, Energy and Media Industries, H2020-ICT-2019, https://5G-ppp.eu/5g-victori/

[22] VITAL-5G: Vertical Innovations in Transport And Logistics over 5G experimentations facilities, H2020-ICT-2020, https://5g-ppp.eu/vital-5g/

[23] 5GASP: 5G Application & Services experimentation and certification Platform, https://5g-ppp.eu/5gasp/