(Invited) 5G-IANA: A 5G Experimentation Platform for Intelligent Automotive Network Applications

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Abstract—**In this paper, we present an open 5G experimentation platform, on top of which third party experimenters (*i.e.*, SMEs) in the Automotive sector will have the opportunity to develop, deploy and test their services. An Automotive Open Experimental Platform (AOEP) is specified, as a set of hardware and software resources that provides the compute and communication/transport infrastructure as well as the management and orchestration components, coupled with an enhanced Network Application (NetApp) Toolkit tailored to the Automotive sector. The platform exposes secure and standardized APIs to experimenters, to facilitate the different steps towards the production stage of a new automotive service. The platform, being part of the H2020 5G-IANA project[1], targets different MANO solutions integrating a range of virtualization technologies for enabling the deployment of the end-to-end network services across domains (vehicles, road infrastructure, MEC nodes and cloud resources). The NetApp toolkit is linked with a new Automotive VNFs Repository equipped with an extended list of ready to use open accessible Automotive-related VNFs and NetApp templates, that forms a repository for SMEs to use and develop new applications. A distributed AI/ML (DML) framework as part of the platform provides functionalities for simplified management and orchestration of collections of AI/ML service components allowing ML-based applications to penetrate the Automotive world.**

I. 5G-IANA CONCEPT

5G-IANA will extend Network Management and Service Orchestration (MANO) technologies and enhance 5G infrastructure with a tailored Network Application (NetApp) Orchestration and Development framework (NOD), with which application developers can create their NetApps following a simple and conventional microservices-based approach. A main aspect of 5G-IANA platform is the interaction between the NOD and the Slice Manager (SM), allowing the NOD to interact with the SM following a dynamic on-the-fly deployment scheme. This allows the adaptation of a NetApp's service requirements and the preservation of the promised QoS throughout the lifecycle of the NetApp, something that is missing from the industry-dominant orchestrators. 5G-IANA integrates different MANO frameworks covering the following domains: vehicle On-Board Units (OBUs), Road-Side Units (RSUs), 5G SA networks and Data Centres/Cloud Resources. This enables the deployment of the end-to-end network services across the different domains. This will allow developers to take full advantage of the capabilities offered by the different nodes in the infrastructure (*i.e.*, OBUs attached on vehicles and RSUs deployed on the roads) and to address an efficient and effective NetApp deployment and orchestration. 5G-IANA enables an "on-vehicle" MANO by developing a programmable OBU/RSU ready to host containerized services. The developed OBU/RSU will support different HW architectures and will implement the most important ETSI C-ITS messages[2] that are the basis for the majority of the Automotive-related applications (*e.g.*, autonomous or remote driving, *etc.*).

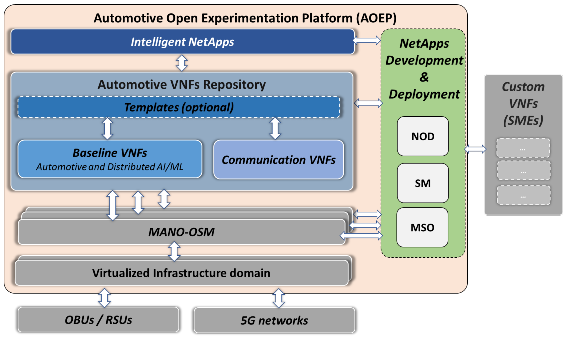

Fig. 1. The 5G-IANA experimentation platform

5G-IANA encapsulates the above mentioned management and orchestration components, together with the available computing and communication/transport infrastructure (i.e., OBU, RSU, MEC and Cloud resources) in an Automotive Open Experimental Platform (AOEP) (see Fig.1). The AOEP, is equipped with an Automotive VNFs (Virtual Netowork Functions) Repository holding an extended list of ready to use open accessible Automotive-related VNFs and NetApp templates. Besides the Automotive-related VNFs ready to be chained into NetApps, 5G-IANA will develop a distributed AI/ML (DML) framework as part of the AOEP. Special consideration will be given to distributed learning schemes (*e.g.*, Federated Learning [1]) due to the privacy and resource optimization issues that emerge in the Automotive world. This DML framework will allow ML-based applications to penetrate the Automotive sector, as its inherent privacy preserving nature will allow more end users (*i.e.*, vehicles and vehicle users) to participate in the learning process increasing the efficiency and the deployment areas of AI/ML services

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[1] https://5g-ppp.eu/5g-iana/

[2] https://www.etsi.org/technologies/automotive-intelligent-transport

(*e.g.*, object recognition or vulnerable road users' movement intentions). In the next sections the above mentioned building blocks are presented in more details.

II. AUTOMOTIVE OPEN EXPERIMENTAL PLATFORM

The proposed AOEP is depicted in Fig. 1 and consists of the following main components:

- The **Automotive VNFs Repository** is used to build Intelligent NetApps, *i.e.*, Automotive/vehicular-related applications. NetApps can be built by chaining Baseline and Communication VNFs or ready to use templates with Custom VNFs. The Repository is also equipped with the necessary VNFs to support distributed AI/ML applications (Sec. IV).
- When a NetApp deployment is requested, a suitable 5G slice is selected/composed using the available **virtualized infrastructure domain**, *i.e.*, OBU (vehicle), RSU (road), MEC nodes and Cloud virtualized resources. For the deployed application, the instantiated end-to-end slice is coordinated by the **Multi-domain Service Orchestrator** (**MSO**) (part of the NetApps Development and Deployment in Fig. 1), which handles the lifecycle management of the NetApp's components by interacting with underlying per-domain Management and Orchestration (MANO) software stacks, which may include open-source (like OSM - Open Source MANO[3] or ONAP - Open Network Automation Platform[4]) or proprietary assets or their combination.
- The **NetApps Development and Deployment** tools are used to develop, deploy and orchestrate Intelligent NetApps from both the application and the networking point of view, and include the **NetApp Orchestration and Development framework (NOD)**, the **Slice Manager (SM)**, and the **Multi-domain Service Orchestrator (MSO)** (Sec. III).

Each virtualized infrastructure domain – OBU, RSU, MEC-environment (server plus network slice), and cloud resources – has its specific capabilities, requirements, and limitations. For example, the availability of network interfaces may differ in the MANO platform of each deployment domain. In OBU deployment, short-reach ETSI ITS-G5 or C-V2X interfaces may be available together with 5G mobile connection, while in the MEC-environment deployment domain no short-reach interfaces are available. Availability of local modules is also different in each deployment domain. In OBU environment, the available physical resources may include an autonomous driving module or some cameras and sensors on the vehicle, while the RSU domain may comprise of roadside fixed sensors. Each deployment domain also comes with its specific Network Management and Service Orchestration (MANO) technology. The proposed AOEP will integrate different MANO frameworks for enabling the deployment of the end-to-end network services across different domains as a virtualized infrastructure. The integration of different virtualization and orchestration technologies/tools is needed to take full advantage of the capabilities offered by the different nodes in the infrastructure and to realize an efficient and effective Intelligent NetApp deployment and orchestration. For example, given the "on-vehicle" MANO, the target will be the implementation/integration of a "lightweight" orchestration on top of OBUs, *e.g.*, based on Kubernetes, for offering a more flexible and scalable deployment and administration of an NetApp in an OBU, while benefiting from a lower invocation latency with respect to VM-based deployments, resulting in time and cost saving. The same virtualization/orchestration model can be applied to RSUs, where Intelligent NetApps are deployed for guaranteeing short-reach distance communication (*i.e.*, ITS-G5 and/or C-V2X) capability for mission critical applications at the roadside. A 5G cellular network MANO allows the orchestration of cellular network resources to meet the requirements of one or several Intelligent NetApps. Performance requirements such as latency, transmission reliability, and transmission capacity can be determined. The latency requirements may *e.g.*, determine the proximity of the MEC server infrastructure to the application user, and the transmission time interval on the 5G radio interface. Different 5G network capabilities are organized in so-called network slices, which either can be configured by the application designer, or selected from a set of pre-configured network slices.

III. ORCHESTRATION AND DEVELOPMENT FRAMEWORK

The NOD and SM (including MSO) will integrate different MANO frameworks for enabling the deployment of the end-to-end network services across different domains as a virtualized infrastructure. The NOD and the NetApps Toolkit linked with the VNFs Repository will expose to verticals and experimenters secure and standardized APIs for facilitating all the different steps towards the production stage of a new implemented Intelligent NetApp. The AOEP will provide capabilities and functionalities for designing, validating and benchmarking Intelligent NetApps and their components (*e.g.*, VNFs) as well as for monitoring and dynamically adapting them at run-time.

NOD is an application orchestrator (operating at OSI Layer 7) and consists of a set of complementary components with fine-grained interfaces. NOD's architecture is comprised of layers, the first one is the NetApp Development Environment layer (*i.e.*, NetApp Developer Dashboard in Fig. 2) that includes a web-based NetApp IDE, a NetApp graph composer and a set of metamodels. The second layer is the Orchestration layer which supports the dynamic on-the-fly deployment and adaptation of NetApp service requirements. It consists of a deployment and execution manager, a monitoring engine, a real-time profiling and analytics engine, and a deployment and runtime policy engine. There is also the Network and resources management layer which is responsible for setting up all the deployment requests (in forms of slice intents) that have to be coordinated by the Slice Manager (in Fig. 2 this layer is not highlighted since it is part of the Deployment Manager). This layer also includes a set of mechanisms dealing with the lifecycle management of VNFs and the multi-site virtualized resources. Within the NOD, application developers can create their NetApps (in form of graphs) following a simple and

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[3] https://osm.etsi.org/

[4] https://www.onap.org/

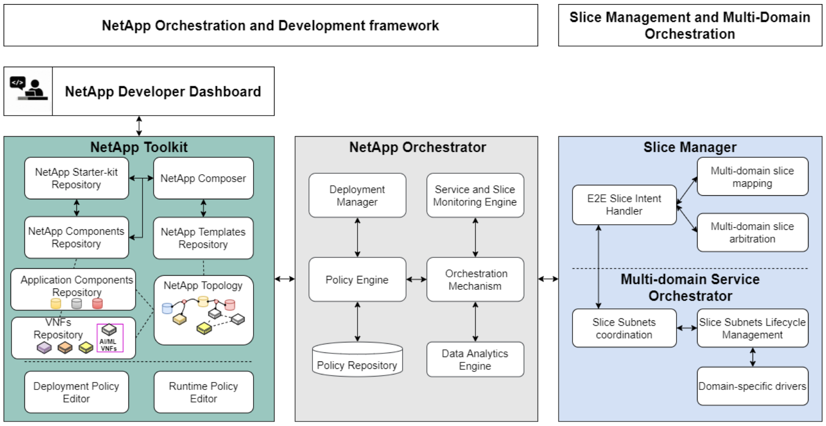

Fig. 2. The 5G-IANA orchestration components

conventional microservices-based approach[5] where each component can be independently orchestrated (*i.e.*, as VM images, containers or unikernels).

In the NOD Framework, the NetApp Toolkit (see Fig. 2) is the entrypoint for the end-users that enables the composition of their NetApps. The key objective of this toolkit is to lower the entry barrier for the potential NetApp developers by facilitating the process of composing, on-boarding and managing their NetApp. The NetApp Toolkit encapsulates the concept of cataloging where the users can index, access and reuse their components, VNFs, applications graphs, entire NetApps through respective catalogues. It is also worth to mention that NOD provides semantic backward compatibility *i.e.*, all the applications that are registered to the NOD platform can be orchestrated on other industry used solutions such as Kubernetes, Docker Swarm and Mesos.

One crucial aspect of the proposed platform is that the interaction between the NOD and the Slice Management layer is exposed. Specifically, when an application developer publishes an application in the form of an application graph that consist of chainable application components, the slice management layer (Slice Manager) selects this application graph and concretizes it by mapping it to the appropriate slice that can host the appropriate VNFs. This results in an enhanced graph that meets the specified networking requirements and will be deployed on top of the reserved resources using one of the multiple policies that may have been defined. The capability of the NOD to interact with the Slice Manager and Multi-domain Service Orchestrator layer (by using Slice Manager Network Exposure Functions) followed by the dynamic on-the-fly deployment can adapt the NetApp to its service requirements and preserve the promised QoS throughout the lifecycle of the NetApp. While there are several orchestrators like Kubernetes, Mesos, Docker Swarm on the market, this attribute of interaction between the orchestrator and the southbound layer is missing even from the industry-dominant orchestrators and will be provided by 5G-IANA.

The Slice Manager (SM) is the component in charge of defining and provisioning the end-to-end Network Slice (NS) across the underlying domain and technology-specific platforms (*e.g.*, NFV Orchestrators, MEC platforms, serverless orchestrators, *etc.*). In particular, the SM handles the NetApp deployment requests from the NOD by mapping them into an end-to-end Network Slice Template (NST) that will contain the Network Slice Profile (NSP, according to 3GPP standardization [2] and a list of included Network Slice Subnets (NSS)). Each NSS will correspond to a nested NS running an entire NetApp or a set of components that will be deployed in a specific domain. This distributed approach will allow to decouple the single service-specific management and orchestration from the end-to-end NS deployment, where the Multi-domain Service Orchestrator's (MSO) role is the correlation and coordination of the different NSS composing the end-to-end NS from an upper layer perspective.

IV. NETAPPS TOOLKIT AND AUTOMOTIVE VNFS REPOSITORY

The NetApps Toolkit and the Automotive VNFs Repository will provide functionalities for easing the design and chaining of new Automotive services. In particular, the Toolkit will implement a novel data-model for offering to verticals a simplified high-level representation of the different service components, with the main purpose of hiding the network complexity from the point of view of the service deployment and inter/intra-domain components connectivity. In particular, to further facilitate the composition of new services, the VNFs Repository will provide a set of baseline management, communication and optimization services, in the form of NetApp components labelled per domain availability and service type (*e.g.*, Infotainment, Movement Assist, Smart Traffic Management, *etc.*), to be integrated into innovative developed applications. NetApp example templates and "starter-kit" will be provided as well as a graphical NetApp composer with guidelines for intuitive end-to-end service design and chaining over a multi-domain infrastructure from an administrative and technology point of view.

The VNFs can be identified in two main categories: Communication VNFs and Baseline VNFs. Communication VNFs are virtual network functions that can be exploited by other VNFs and Intelligent NetApps to communicate with modules

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[5] https://5g-ppp.eu/wp-content/uploads/2018/07/5GPPP-Software-Network-WG-White-Paper-23052018-V5.pdf

and/or services that are outside the AOEP. The availability of a Communication VNF will depend on its deployment domain, *i.e.*, whether it is deployed in an OBU, an RSU, a MEC, or cloud-server infrastructure. For instance, a short-distance communication VNF is used for interactions that take place between an OBU and another OBU or an RSU. The Communication VNFs can be divided in two sub-categories: Local Communication VNFs and External Communication VNFs. Local Commuication VNFs perform information exchange between a NetApp running on an OBU/RSU and a local module. In a vehicle, a local module can be a camera, a LiDAR, or the autonomous driving module. External Communication VNFs include all the VNFs that communicate between the selected domain (*i.e.*, OBU, RSU, MEC, *etc.*) and an external domain. Vehicle-to-Vehicle communication can be supported for instance from a VNF belonging in this sub-category.

Baseline VNFs implement basic service functionalities that can be exploited by Intelligent NetApps. For example, Baseline VNFs can provide basic services such as Position and Time Information provision. Besides that, they can implement some of the facility entities presented in the ETSI ITS architecture [3], such as the Cooperative Awareness Basic Service or the Decentralized Environmental Notification Basic Service.

In AOEP, VNFs will be presented in a common unified and simplified data-model, providing relevant information about their availability with respect to the different domains, with the aim to reduce the development effort and ease the implementation of Intelligent NetApps. The Communication VNFs and Baseline VNFs role is to hide the complexity of the Automotive world and let the developers of NetApps focus on the high-level behaviour of their applications. In this way, developers don't have to be experts on specific aspects such as the format and encoding of C-ITS messages or about the management of position and time. Moreover, the Intelligent NetApps can exploit a reliable and secure channel since message integrity and authentication is managed by VNFs that are implementing the secure communication compliant to the relevant ETSI standards. Overall, the Automotive VNFs Repository will work as an aggregation and integration point, with the main purpose of offering to verticals a heterogeneous set of already existing virtualized management, communication and optimization functions for the Automotive industry and correlated business areas (*e.g.*, multimedia and entertainment).

V. DISTRIBUTED AI/ML FRAMEWORK FOR THE AUTOMOTIVE VERTICAL AND BEYOND

The distributed AI/ML (DML) framework of the proposed experimentation platform will provide functionalities for simplified management and orchestration of collections of AI/ML service components that support existing or newly chained services. The framework will implement a novel DML representation that provides functionalities such as ML pipeline topology selection and various performance and privacy configurations along the spectrums of ML model/parameter consistency and data distribution, respectively. For example, configurations will include synchronization options for decentralized training as well as placement restrictions for the ML nodes. These functionalities are mapped into chained VNFs that provide different ML capabilities to other VNFs (ML pipelines). ML VNFs can be categorized into different types such as Model Nodes, Aggregation Nodes, Parameter Server Nodes and Orchestrator Nodes. An ML VNF can be deployed to different environments such as OBUs, RSUs or MEC nodes. Depending on the type of the DML node a deployment to some environment such as MEC node is restricted. In particular, to facilitate the composition of distributed ML topologies, new ML service requests will provide a specification of the required ML functionality as well as the grade of distribution, *e.g.*, choosing model and or data parallelism or hybrid parallelism and pipelining. Further, when a service request is annotated with a distribution grade, it also may choose a corresponding topology for the distributed ML service, *i.e.*, tree-like, or geographically distributed P2P like topologies connecting the ML nodes. The framework calculates a default number of required ML nodes and their placements in the slice, *e.g.*, on the OBUs, RSUs or the MEC nodes. The placement of the ML nodes is carried out by the ML Orchestrator which provides for simplicity first a basic ML topology that chains the ML VNFs in a predefined topology if a standard service is requested. The orchestrator also calculates and deploys a placement of ML VNFs for customized service requests that adhere to certain privacy constraints such as ML VNFs on OBUs that only communicate certain parts of the results to the aggregation node. This allows for example for shared model parameters between different chained services. The framework allows the ML service to request adaptive distributed ML configurations such that the ML Orchestrator may change the configuration of the DML service, *e.g.*, the number of ML nodes, to increase the accuracy of the model.

VI. CONCLUSIONS

In this paper we presented the main components of an open and enhanced experimentation platform that will provide access to 5G network resources, on top of which third party experimenters (*i.e.*, SMEs) in the Automotive-related 5G-PPP vertical will have the opportunity to develop, deploy and test their services. The proposed platform will be developed in the course of the H2020 5G-IANA project. Besides the development of the platform and its components, its actual capabilities will be tested in two 5G SA testbeds in Ulm, Germany and Ljubljana, Slovenia through the development and extensive evaluation of seven highly demanding Intelligent NetApps from the Automotive vertical industry.

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[2] 3GPP, "TS 28.541 v16.1.0 Management and orchestration; 5G Network Resource Model (NRM);(Rel. 16)," 2019.

[3] ETSI, "TS 102 894-1 V1.1.1, Intelligent Transport Systems (ITS); Users and applications requirements; Part 1: Facility layer structure, functional requirements and specifications", 2013.