Requirements and design of 5G experimental environments for vertical industry innovations

Anastasius Gavras, Spyros Denazis, Halid Hrasnica, Christos Tranoris

***Abstract*—In a global concerted effort, the networking community is defining 5G as the next generation networking infrastructure. New in the approach is the focus on the requirements of the vertical sectors. The salient characteristic of these sectors is that they are rapidly becoming open ecosystems built on top of common infrastructures. This requires a high degree of technological convergence among vertical industries empowering them with technical capacity and triggering the development of new, innovative products, applications and services. On the technology side, 5G is adopting new concepts and developments such as virtualization at all levels of the infrastructure enabling the 5G network infrastructure to become a key asset of the emerging common environment for technical and business innovation in the vertical sectors. In order to answer the questions "How holistic and unified such an environment can be?", and "How an infrastructure can satisfy and reconcile competing requirements of the vertical sectors?", we present the concept and approach of 5GINFIRE, a project that is tasked to build and operate an open, and extensible 5G NFV-based reference ecosystem of experimental facilities, laying down the foundations for a fully software controlled instantiation of virtual networks meeting the requirements of the vertical sectors.**

***Index Terms*—5G, experimentation, NFV, SDN, SFC, vertical industries**

I. Introduction

5G network infrastructures and embodied technologies are considered as a key asset of an emerging common environment and instrumental for the digitalization of the traditional industries as they are positioned to "*become a stakeholder driven, holistic environment for technical and business innovation integrating networking, computing and storage resources into one programmable and unified infrastructure*" [1]. It is this 5G vision that when it is further projected to accommodate verticals raises a number of technical issues that require careful architectural consideration.

5G architecture work consolidates specifications and results from related technical areas such as Cloud and Mobile Edge Computing (MEC), Network Function Virtualization (NFV), Mobile and Wireless Networks, etc. However we are still at the beginnings of a 5G platform architecture that is driven by and evolves through operational experience. Most of the work concentrates on addressing the question of *how such a holistic and unified environment should look like*, by advocating a common network substrate comprised of complementary technologies, such as SDN, NFV, and SFC. Despite the progress achieved so far, we are still far from providing a conclusive answer.

Addressing the question of how can a platform host and integrate verticals and concurrently deal with reconciling their competing and opposing requirements, requires operational 5G infrastructures that can host the various verticals. A key issue is the lifecycle management of the various verticals' services by means of Virtualized Network Functions (VNF) deployment and programmability techniques. This bares strong similarities with research experimentation deployment and management, targeted by ambitious research program initiatives such as FIRE [3] in Europe and GENI [4] in the US. It also presents an opportunity to evolve existing facilities into a 5G-oriented experimental playground for vertical industries. Architectural and technological convergence needs to be reached between FIRE and 5G and corresponding standardization activities.

The technical objective of 5GINFIRE is to build and operate an Open, and Extensible 5G NFV-based reference ecosystem of experimental facilities that lays down the foundations of a standards-based network substrate for instantiating fully softwarised architectures for vertical industries purposes.

II. Use cases and requirements

5GINFIRE derives its requirements from a set of simple use cases that are positioned in the areas of the automotive vertical sector and smart cities. The use cases are used as source of requirements for building the infrastructure and to showcase its capabilities.

In the automotive case the requirements are extracted from scenarios such as sensing-based and video-camera-based assisted driving, which use a multitude of information sources (intra-vehicle, as well as inter-vehicle and vehicle-to-infrastructure) to enable assisted driving. A second scenario is providing event recording services in virtualised multi-stakeholder network environments to showcase function

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virtualisation of a service that collects important vehicle data and stores them in the network in a tamper-proof way, mimicking the functionality of a "black-box".

In the smart cities case the requirements are derived from the scenarios to facilitate the use and exploitation of available open data provided by existing sensor deployments in cities, as well as interfacing with the capabilities of the existing deployments of sensor functionality in the testbeds of the project partners in Bristol (U.K.), Aveiro (Portugal) in Europe and São Paulo and Uberlândia in Brazil.

A common requirement is the ease of deployment of software components to build end-to-end services in a consistent way. Although, the ETSI NFV architecture primarily focuses on network functionality and its deployment as software components to build end-to-end network paths, the concept is powerful enough to provide the basis for more general deployment scenarios if combined with complementary technologies such as Cloud Computing and Mobile Edge Computing.

It is this observation that leads us to exploit the NFV approach to instantiate whole architectures of verticals applications as softwarised experimental environment instances. These instances encompass any type of virtual vertical functions (VVF), not just network functions, which, in turn, may host a variety of experiments on top of the same physical infrastructures. Experimental Vertical Instances (EVIs) emerge as compositions of several virtual functions spanning all layers from application and services to networking. We refer to these virtual functions as VxFs when we do not want to distinguish between network-centric functions and vertical-centric functions.

III. Conceptual architecture

Fig. 1 illustrates the 5GINFIRE conceptual architecture derived from the ETSI NFV reference architecture [5] and upstream open source projects. It depicts the major architectural areas and shows in a workflow manner the various interactions. Although not exhaustive, the conceptual architecture highlights the functionality that is required to integrate existing open source components and physical infrastructures or being developed by the project. It provides an indication on how the required architectural and technological convergence with mainstream industrial and open source activities could be achieved.

In Fig. 1 an application is composed of services that are configured to offer this application. These services are further decomposed into virtual networking and vertical functions (VxFs) that are deployed at the corresponding points of presence in the infrastructure. A use case from the automotive vertical is used to validate the platform. Following similar practices more types of experimentation virtual environments may be instantiated. The proposed approach takes into account the following high-level requirements:

- Adopt and be interoperable with current standards (Cloud/SDN/NFV/MEC)
- Use open standards and integrate technologically mature, and widespread open source toolsets
- Enable experimentation and make it effortless for experimenters to deploy experimentation scenarios
- Enable experimentation with verticals at the levels of applications, services or VNFs on top of 5G-enabled experimentation infrastructure that also supports specialized infrastructure for verticals e.g. Automotive
- Be interoperable with FIRE standards and facilities

5GINFIRE adopts the ETSI architectural recommendation for services that are being considered for NFV and being implemented under the NFV model, augmented for application and service composition and experimentation capabilities. In order to instantiate experimentation scenarios users will use the portal and tools to design and deploy the experiment. The Application Composer Toolkit is used to create the composition of services needed to instantiate an application that will contain the artefact under test. The request is transformed to a Cloud Request Archive (CSAR), a standard proposed by OASIS [5].

Open source projects such as the Murano Project [7] or Juju by Canonical [8] enable developers and cloud administrators to publish cloud-ready applications in a catalogue. We plan to enhance these technologies for verticals experimentation, offer CSAR capabilities and integrate them with the 5GINFIRE middleware and portal. The 5GINFIRE middleware and portal is a core entity responsible for multiple services. It offers:

- An endpoint for accepting experimentation requests
- A portal that users can subscribe to, manage experiments,

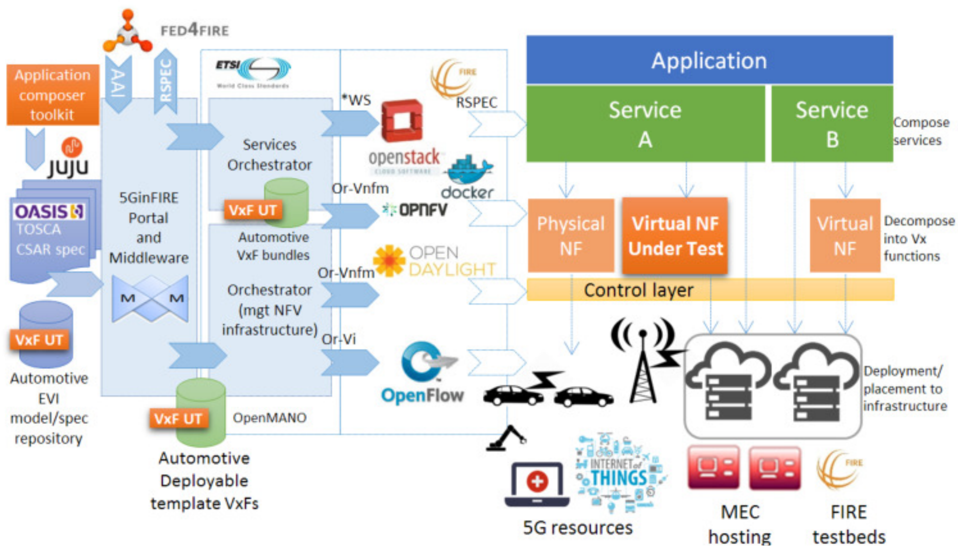

Fig. 1. 5GINFIRE Conceptual Architecture for Experimentation (Workflow, Technologies and Infrastructures)

browse the repository, monitor experiments, etc.
- Services allowing admins and DevOps to manage the 5GINFIRE platform and to manage the repository
- Support for VxF developers: Users that maintain and offer their VxFs through our 5GInFIRE repository
- Authentication-Authorization-Identification (AAI) with other FIRE testbeds via the Fed4FIRE [9] AAI technology, enabling the creation of federated experiments and facilitate integration of existing FIRE facilities
- Visibility of the 5GINFIRE repository via RSPEC, thus browsable by other FIRE catalogues
- Model-to-model transformations to automate the transformation of the experimentation and service requests into actions for the *Services and Management orchestrators* of the MANO layer.

5GINFIRE middleware communicates with the endpoints of the orchestration services that are responsible for orchestrating the managers for instantiating the experimentation scenarios. At this stage we envisage two orchestrators: one responsible for the deployment and configuration of services that comprise an application and an NFV orchestrator for configuring VNFs. At this layer we use the Open Source MANO [10] implementation that is based on the corresponding ETSI specification. At the next stage we adhere to other ETSI NFV specifications and adopt state-of-the-art mature and open source tools such as Openstack, Docker, OpenDaylight OPNFV, etc.)

Finally, through the implementation of the 5GINFIRE architecture, the project will provide a platform that allows experimenters to easily deploy their *VxFs under test*. To achieve this, the user needs to submit to the repository the VxF specification, its metadata and deployment template so that the platform can deploy it on top of the infrastructure and configure it to be used by existing services. The following is a list of innovative actions that 5GINFIRE brings to the experimentation world combined with 5G infrastructures, SDN, NFV and Cloud technologies:
- 5G experimentation management platform on top of 5G experimentation infrastructure, validated through an automotive vertical case study
- Standards-based 5G experiment provisioning, scheduling, experimenter management etc.
- Open repository for sharing VxF artefacts while facilitating developers of VxFs to easily maintain them
- Standards-based experimentation description (CSAR)
- Tools that transform the CSAR specification to Service Composition and Orchestration services
- AAI integration with Keystone authentication
- Define the experimentation VxF under test in terms of the vertical model and the VxF Deployment Bundle
- Experimental Vertical Instances (EVI) repositories which need to be bridged with technologies like Juju charms, Openstack GLANCE/SWIFT, Docker Hub, in order to be easily deployed on such platforms
- Align 5G resources, MECs and testbed gateways with Openstack or Docker APIs for deployment of VxFs; Opendaylight and Openflow APIs for network service topology, control and configuration

IV. Model Entities Specification, Design and Experimental Infrastructure Architecture

This section introduces the 5GINFIRE processes and envisaged roles and usage scenarios of the 5GINFIRE platform and presents its concrete architecture.

A. Actors

The offered services and tools target to accommodate the following envisaged user roles. The users are assumed to be of an authenticated role:
- The *experimenter* represents the user that will utilize the platform services and tools to deploy an experiment. That is the experiment description in terms of NSD (Network Service Descriptor) or TOSCA specification
- The *VxF developer* is responsible to upload VNF and NSD Descriptors in the 5GINFIRE services repository
- The *testbed provider* represents users that are responsible for testbed administration, configuration, integration, adaptation, support, etc.
- The *services administrator* represents the user that are responsible for maintenance of the 5GinFIRE services

An anonymous non-authenticated user role is used for signup through the portal.

B. Terminology

Experiment: defined as a set of experimentation activities that will be conducted during an allocated time-slot. The experiment may involve multiple 5GINFIRE test-beds and might require the utilization of several network services, which will be indicated during the experiment definition and will be validated by the 5GINFIRE operations. This network services may be used by the experimenter during the allocated timeslot.

Virtualised Function (VxF): complex constellations of virtual functions, all running on a mix of real and virtual network or computing elements. We refer to virtual functions as VxFs when we do not want to distinguish between network-centric functions and vertical application centric functions.

C. Experimentation Workflow

Fig. 2 provides an overview of the workflow process. There are three main horizontal lines: the experimenter, the 5GINFIRE operations and the 5GINFIRE testbed providers that interact during an experimentation life-cycle. At the simplest case, users signed-up to the platform via the portal are approved by 5GINFIRE operations. To perform an experiment over the 5GINFIRE infrastructure at its simplest form the user needs to create an experiment by providing experiment metadata, scheduling, purpose etc. and selecting available VNFs or deploying new ones. Then he needs to compose the experimentation solution. This can be done either as an OSM Network Service Descriptor or in terms of a TOSCA specification. In the first version of the architecture, the user will provide an OSM-supported YAML description of

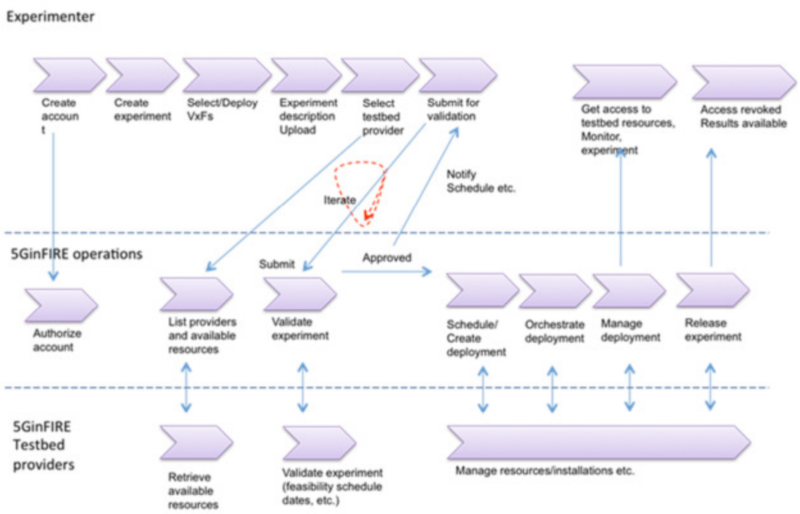

Fig. 2. 5GINFIRE experimentation workflow overview

the network service, potentially aided by a graphical composer. Subsequent refinements of the architecture may consider the utilization of TOSCA-based NFV descriptions, which would be mapped to into OSM-supported YAML by specific 5GINFIRE middleware. This development depends on the availability of specification for VNF descriptors based on the TOSCA model, which is currently being addressed by both OASIS and ETSI NFV. As soon as everything is in place for an experiment description, the experimenter selects the testbed facility based on resource availability after the experiment is submitted for validation.

The platform triggers a process for validating an experiment in terms of rules such as schedule, resource availability, etc. The validation process is closely performed together with the target testbed providers. We expect this to be iterative in various cycles involving the experimenter by either asking questions or modifying any experiment details and parameters.

As soon as an experiment is approved, it is scheduled by 5GINFIRE operations for deployment. Through the portal or the Management and Orchestration, which is based on Open Source MANO (OSM) [10], the 5GINFIRE operations create a deployment by uploading descriptors etc. Afterwards, OSM will orchestrate the deployment by triggering the services instantiation. Initially this is performed in close collaboration with the testbed providers during the management of the orchestration/deployment. After deployment the resources are available and accessible to the experimenter.

In the end of the experiment schedule, the resources of the experiment are released and access is revoked. Any available results of the experiment are made available to the experimenter.

D. *Usage Scenarios*

This section lists the identified usage scenarios that are initially supported by the 5GINFIRE platform and the provided tools and services. Fig. 3 displays a UML use case diagram with the identified actors. The supported features, capabilities and provided services of the 5GINFIRE architecture are currently being defined in detail. Additional requirements for the architectural components and the processes are defined from the usage scenarios that we describe below.

- Signup, Login to Portal: The anonymous user can create an account and login as one of the roles. During sign up the user can express the interest of such a role or roles. The portal services administrator needs to approve a user and his role(s). More specifically, the user can create an account by specifying a username and a password, along with any personal data and indented role(s), or present federation credentials issued by FED4FIRE.
- Issue resolution and technical support: An experimenter or a VxF developer should be able to identify operational issues and obtain technical support, using the communication channels established for these purposes. Issue resolution and technical support may involve testbed providers and/or the services administrator.
- Browse available VxFs, NSDs and Experiments in portal: An experimenter can browse all available VxF descriptors and NSDs registered at the portal marketplace. It can browse its uploaded experiments or any publicly shared experiment descriptions.
- Define experiment: An experimenter should be able to define an experiment. An experiment definition may include: a) time requirements; b) indication of the network services that will be instantiated during the experiment; c) description of the testbeds, facilities and resources required for the experiment. The service chaining can be defined by submitting an OSM-supported YAML description or possibly enhanced by using a graphical interface.

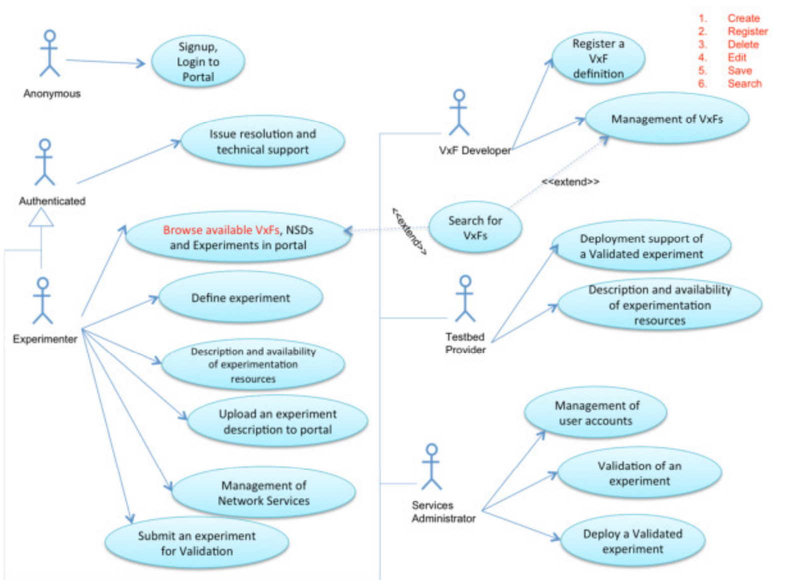

Fig. 3. Use cases diagram

- Description and availability of experimentation resources: Using the portal, an experimenter should be able to get a description and a tentative availability of experimentation resources, i.e. the availability of 5GINFIRE testbeds and facilities. This information may serve as a reference to the experimenter, for the purposes of experimentation planning, but might not be the final scheduling as this will be decided by the experiment validation phase. Information about the availability of resources may be updated by testbed providers according to their scheduled experimentation activities.
- Upload an experiment description to portal: It should be possible to upload just a YAML descriptor created on some other tool, through the portal. The experimenter will upload an experiment description based on YAML. More Experiment metadata: name, creation date, etc. must also be available during upload.
- Management of network services: An authorized experimenter should be enabled to upload to the 5GINFIRE repository a deployment template for a Network Service (NS), i.e. an NS descriptor, including the description of the VxFs that comprise the service and their interconnection. In the first version of the platform, the user will provide an OSM-supported YAML description of the NS. The user should be able to refer to the NS in the 5GINFIRE repository for subsequent use. By default, a network service is only visible to its creator. Complimentary, the experimenter should be able to edit and delete a NS.
- Submit an experiment for validation: The experimenter should be able to request the validation of the experiment, which is evaluated offline by the responsible entity of 5GINFIRE operations, with the support of the testbed providers. Independent of the validation process, the experimenter should be able to check the status of the validation request from the portal. In case of successful validation, the information provided to the user may also include indication of time slots allocated to the experiment.
- Search for VxFs: An authorized experimenter should be able to search for a VxF definition in the repository.
- Register a VxF definition: An authorized VxF developer should be able to create a VxF definition in the repository. The VxF developer registers any metadata of the VxF together with a packaging archive to the repository.
- Management of VxFs: The developer should be able to update a VxF descriptor, along with the archive of the VxF, to the repository. The VxF developer may or may not set the VxF descriptor as public/visible to other users of the platform. Analogously, the VxF developer should be able to edit or delete a VxF descriptor and its corresponding archive images.
- Search for VxFs: An authorized VxF developer should be able to search for a VxF definition in the repository.
- Deployment support of a validated experiment: In case of successful validation of an experiment by system administrators and testbed providers, the experiment is marked as validated. The deployment process may require support from the testbed providers, prior, during and/or after the experiments.
- Description and availability of experimentation resources: The description and availability of resources may be updated by testbed providers according to their scheduled experimentation activities.
- Management of user accounts: The service Authorizes administrator should be able to manage users and their roles.
- Validation of an experiment: The experiment will be evaluated offline by the responsible entity of 5GINFIRE, with the support of the testbed providers. Portal and issue management services are used to communicate with the experimenter and validate it.
- Deploy a validated experiment: In case of successful validation of an experiment by 5GINFIRE responsible system administrators and testbed providers, the experiment is marked as validated. 5GINFIRE responsible system administrators should be able to instantiate the network services indicated by the experiment definition, during the time slots assigned to the experimentation activities.

V. CONCLUSION

In this paper we present the architectural concept of 5GINFIRE that is deploying the tools and facilities for early 5G trials and experiments, enabling experimenters to easily start performing tests of their 5G services and applications in verticals industries. Through open calls 5GINFIRE will invite experiments and service providers to engage in the 5G testing and experimentation ecosystem being created.

VI. ACKNOWLEDGMENT

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