The 5G EVE end-to-end 5G facility for extensive trials

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***Abstract*—The challenge before reaching the production stage for 5G is to assess its performance in large-scale facilities. EU-funded 5G PPP project 5G EVE is addressing this challenge by building a distributed and interworking 5G end-to-end facility in Europe across various sites. In this paper we explain the architecture of the 5G EVE end-to-end facility and present each site with their respective features, including the interworking among them, which provides a clear add-on to country-based trials. The 5G EVE site facilities are designed to offer automated network slice deployment tools and a new validation framework. This framework will offer tools for testing 5G radio and various core solutions. It will also allow experimenting and benchmarking different classes of end-to-end network slices and services. These services are defined by a set of selected vertical use cases in sectors like energy, transport, smart cities, tourism, and manufacturing (Industry 4.0). 5G EVE's large-scale trials are being deployed in four European countries: Italy, France, Spain, and Greece.**

Keywords—5G experimental validation, 5G KPIs, 5G trials, end-to-end facility, interworking, orchestration, vertical industries

I. Introduction

Many advanced solutions for 5G radio and core networks have been developed in recent years, covering network slicing, automation and softwarization of network functions. The latest advancements in 5G technologies, architectures and facilities are reducing the gap towards the deployment of operational infrastructures based on the new 5G architecture. Standards from, e.g., 3GPP, ITU and ETSI are advancing the detailed specifications of 5G architecture and its interfaces. Various operators are fast moving towards the definition of their 5G service offers, and there are plans to target nation-wide 5G deployments in various countries even before 2020.

The challenge before reaching the production stage for 5G is to assess its performance in large-scale facilities, closer to real life deployments, in order to validate the various KPIs in truly end-to-end conditions. The imminent availability of 5G services on the market calls for a solid and extensive base of measurements and full-chain evaluations in realistic large-scale trials capable of reproducing real-life network operation condition and a truly end-to-end 5G service chain, from radio up to the core and to data centers. As of today, the assessment of 5G KPIs and the mechanisms to access 5G services have been generally covered in demonstrations of limited focus: e.g. in specific network segments (i.e. radio, edge/flex-haul, and core network), in bi-lateral interoperability tests between devices, or through the validation of 5G orchestration with small facilities and/or selected vertical use cases. The performances of 5G solutions have been substantially validated by vendors, researchers and operators in laboratories and small-scale field trials as reported in various news and scientific papers.

5G EVE [1], the '5G European Validation platform for Extensive trials' funded by the European Commission within phase 3 of the 5G Infrastructure Public-Private Partnership (5G PPP) [2], is a research project with the ambition to be instrumental towards the pervasive roll-out of 5G end-to-end networks in Europe. The 5G EVE concept is based on further developing and interconnecting four existing European sites to form a unique 5G end-to-end facility. In 5G EVE, the 5G end-to-end facility is composed of various elements, including 5G new radio (NR), distributed Cloud or MEC (Multi-access Edge Computing) solutions, backhaul technologies, core and service technologies, as well as slicing and orchestration. Each facility is compliant with standards, like 3GPP R15/R16 and ETSI NFV, and offers advanced 5G testing mechanisms to implement KPI monitoring and performance diagnosis. To facilitate the engagement of verticals in 5G experimentation, the project is developing high-level interfaces, which will be offered to verticals. These interfaces are capable of abstracting the complexity of the underlying 5G network in the form of service intents. From these high-level vertical-driven service blueprints (or intents), mechanisms for end-to-end orchestration of network slices and related KPI monitoring functions and tasks will be generated. To implement this, the 5G EVE project is led by strong European industry players, including vendors and operators with vast experience on 5G standardization, product implementation, and benchmarking. Moreover, the consortium includes relevant vertical industries, SMEs and

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research centers with key solutions and important stakes in 5G development.

In this paper, we present the architecture of the 5G EVE end-to-end facility (sec. II) and describe the site facilities and their interworking capabilities (sec. III). The discussion of architecture and sites is followed by an overview on how the 5G EVE end-to-end (E2E) facility will contribute to the adoption of 5G services in Europe (sec. IV).

II. ARCHITECTURE OF THE 5G EVE END-TO-END FACILITY

We are currently at the turning point of 5G development, when the usability of 5G is being demonstrated, and when its market success is determined. 5G EVE is designed to build a realistic validation environment capable of attracting and supporting vertical industries in their path towards 5G adoption, influencing standardization, and also ensuring impact and sustainability of a large set of business cases generated by various vertical industries (e.g. Industry 4.0, public utilities, smart cities and smart transportation). 5G EVE is a vertical-oriented open validation framework for 5G networks, designed to address the needs of a wide range of industries. In 5G EVE we are developing a vertical-agnostic approach based on vertical blueprints to express in a simple way “what” an end-to-end service slice should provide, leaving the decision on the "how" to the 5G EVE orchestration engine. Despite being vertical-agnostic, we focus on six specific use cases, namely smart transport, smart tourism, Industry 4.0, smart utilities, media and entertainment, and smart cities. Our goal is to address their specific challenges and apply the lessons learned to consolidating a robust and versatile E2E validation platform, which supports other vertical industries as well.

The general approach of 5G EVE for achieving its technical objectives is twofold. First, the project will target the implementation of Release 16-compatible technologies in the four sites, starting from the evolution of current Release 15. Then, the project will focus on designing, implementing and offering key value-added features for E2E validations tests, including site interworking and multi-domain and multi-technology (multi-x) slicing/orchestration mechanisms, and intent-based APIs, which enable specifying experiments in high-level terms, in order to abstract the complexity of the underlying infrastructure. Other features include the advanced KPI framework as a means for the generation of appropriate environment conditions, result analysis, technology benchmarking and performance diagnostics as well as an open framework.

Figure 1 illustrates the overall functional concept of 5G EVE for implementing the aforementioned objectives: vertical industries will interface with a portal, which serves as the main point of contact with the 5G EVE end to end facility. This portal comprises several tools for testing, benchmarking, validation, and experimentation. Verticals may use the intent-based API directly, instead of the web interface, to automate the process. The portal also includes a VNF repository that indexes the VNFs that can be instantiated in the 5G EVE end-to-end facility, and it offers model transformations for supporting the interaction with the vertical industries. The platform for 5G experimentation and validation interacts with the underlying resources offered by each of the site facilities. This includes, for example, the capability of creating network slices or allocating and scheduling resources for experimentation. It is done through the multi-x slice and network orchestrator, which is being implemented in the project. The site facilities interwork among themselves, both on the control and the user plane, for providing aggregation capabilities and services for building a 5G end-to-end experience.

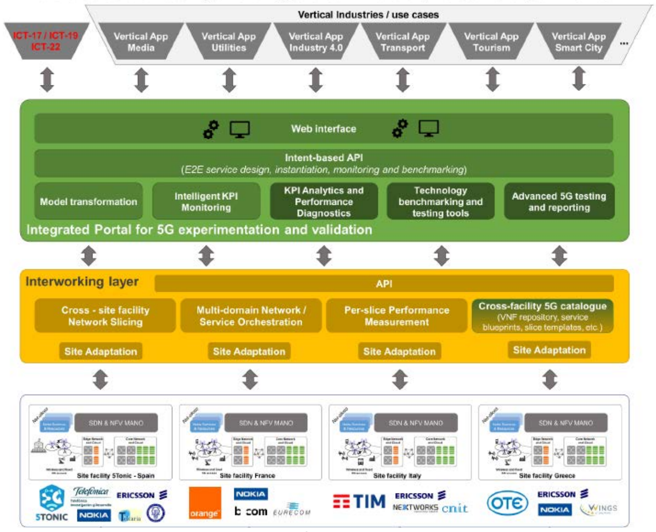

Figure 1: 5G EVE functional architecture

A. *Design and Implementation of 5G EVE Facilities*

The creation of a 5G end-to-end facility for the vertical industries requires a meticulous analysis of the needs established by these companies to achieve their objectives. Having captured the business requirements and related technical requirements on the 5G network from these vertical use cases, we have started to design the various sites facilities in terms of access networks, service functions to be supported and chained, orchestration mechanisms to be adopted and monitoring platforms to collect performance metrics. The resulting 5G EVE facility architecture includes:

- Radio access architecture, including: the software-controlled architecture, the control and user plane split, protocol stack integration options, 3GPP RAN
- Interworking (LTE, LTE advanced, NB-IoT, LTE-M and 5G-NR), and non 3GPP access technologies such as WiFi and LoRa
- Site interconnection capabilities, including detailed physical connectivity map, intermediate protocols and expected performance
- Service management aspects such as service design, management and orchestration, and self-organizing networks and services.

In each facility, the 5G data plane ranges from the radio fronthaul/backhaul to edge and core PoPs, where the various network and application functions can be executed in the form of virtualized network functions and virtual machines. The 5G NFV-capable infrastructure can implement network slicing: in each slice, various network services can be realized with different service profiles through the stitching of Virtual network Functions (VNF) and Physical Network Functions (PNF) along Forwarding Graphs. To implement

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such functionalities, an SDN & NFV Management and Orchestration layer is deployed, which implements the site-local 5G service orchestration, the NFV service and resource orchestration, the management of the VNFs via various VNF Managers (VNFM), the SDN-based traffic flow control within the PoP infrastructure and in the WAN. In a first release, VPN tunneling – e.g. based on IPSec or GRE via public Internet – is planned to interconnect a 5G EVE site facility to other sites, as depicted in Figure 2. Two VPN gateways are logically identified at the boundary of the control and data plane areas of a site facility, which are used to serve the different purposes of connecting to other external data planes and to other control entities.

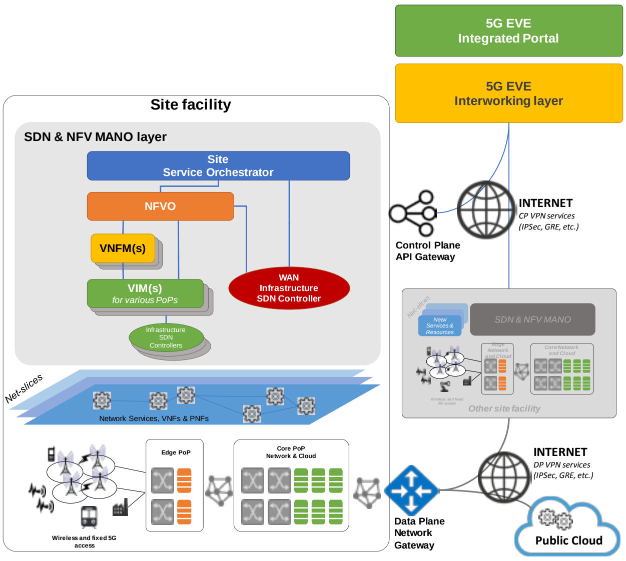

Figure 2: Generic interconnection model for a 5G EVE site facility

The Control Plane API Gateway (CP API GW) is a functional entity which allows connecting the SDN & NFV MANO layers to the 5G EVE interworking layer, in order to implement: a) cross-site facility network slicing; b) multi-domain network or service orchestration; c) per-slice performance measurement across multiple sites and towards the 5G EVE portal; d) providing access and publish services and functions into the cross-facility 5G catalogue for VNF, service blueprints, slice templates, and more. Each 5G EVE site will interact at control plane level through the 5G EVE interworking layer. Most of the APIs offered will be based on RESTful interfaces implementing Open API to the NFV and SDN layers, as specified by ETSI NFV 0 and by the software released for the selected SDN controllers and related applications.

The Data Plane Network Gateway implements the secure interconnection of the network services running in the site facility with corresponding data plane elements in other site facilities and with vertical applications possibly executed in Public Cloud.

B. Testing, Measurement and Validation Services

The 5G EVE platform includes a per-site facility testing toolbox to support vertical users in their functional testing of early features and to assist experimenters with performance validation of initial tests. 5G EVE offers mechanisms to design, instantiate and operate end-to-end network slices and 5G services across multiple administrative domains and various 5G network sections (radio, FH/BH, access, core). Those base services are enriched with 5G measurement toolsets and many monitoring artefacts that can be deployed at the various sections of the 5G network, and allow verticals to assess and validate their new applications on 5G, measuring KPIs in a repeatable and reproducible manner.

The 5G EVE end to end facility can provide a unified functional and operational infrastructure for vertical industry experimentation. 5G EVE will provide a set of tools for execution and logging of end-to-end vertical experiments by utilizing a unified methodology for the management of testing and tests. This methodology will be realized by the adoption of an abstraction layer in each of the site facilities that hides the complexity of network management and operation. In addition, the 5G EVE end-to-end facility provides an advanced performance diagnosis mechanism based on data analytics processes to guarantee the full exploitation of the test results and enable the acquisition of in-depth insights per vertical category and use case, while at the same time providing suggestions for performance improvement. Finally, the 5G EVE portal will provide to vertical experimenters the necessary tools for evaluation and easy reporting, based on their initial definition of requirements and KPIs.

C. KPI Validation Framework

In 5G EVE we have developed a KPI Validation Framework, which supports 5G PPP KPIs and also some of the application-level KPIs of the industries that participate in the project in its first phase.

The KPI framework includes the description of mechanisms for collecting the base information for the generation of KPIs, correlation strategies for different experiments and measurements, architectures of the supported performance simulators, information aggregation strategies for the generation of KPIs and proposals for visualizing the results of the KPIs.

Moreover, sources of information for the generation of 5G KPIs and KPIs of services of vertical industries are described, including descriptions of the activity files of the elements of the network and of the servers, information of the active probes, information of the passive probes and information on specialized monitoring elements.

Finally, the description of possible uses of the KPI information in the system by different vertical industries is also part of the KPI framework. It is important that not all vertical industries can have all the ideal resources of a brand-new network within reach, and therefore, different deployment architecture solutions must be supported to cover a wide range of deployment possibilities, even if the requirements of certain industries could be the same.

III. 5G EVE SITE FACILITIES AND THEIR USE CASES

Four operational site facilities are currently part of the 5G EVE end-to-end facility (see [3][4]): different locations in France, Athens in Greece, Turin in Italy, and Madrid in Spain. Each site facility, including radio spectrum, is operated by a network operator – Orange in France, OTE in Athens, TIM in Turin, and Telefonica in Madrid.

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Each site facility allows meeting the requirements of use cases by deploying their components accordingly. The 5G EVE project is working to support the following specific use cases:

- Smart Transport: Intelligent railway for smart mobility – at 5G EVE Turin facility (Italy)
- Smart Tourism: Augmented Fair experience – at 5G EVE Madrid facility (Spain)
- Industry 4.0: Autonomous vehicles in manufacturing environments – at 5G EVE Madrid facility (Spain) and Athens facility (Greece)
- Utilities (Smart Energy): Fault management for distributed electricity generation in smart grids – at 5G EVE France facility and Athens facility (Greece)
- Smart cities: Safety and Environment – at 5G EVE Turin facility (Italy) and Athens facility (Greece)
- Media & Entertainment: UHF Media, On-site Live Event Experience and Immersive and Integrated Media – at 5G EVE France and Spain facilities.

The initial access to verticals is planned to be released by April 2019. From Q1/2020, the 5G EVE facility will also support validation tests from additional vertical use cases proposed by external research projects, including those to be funded under the Horizon 2020 ICT-19 call for projects.

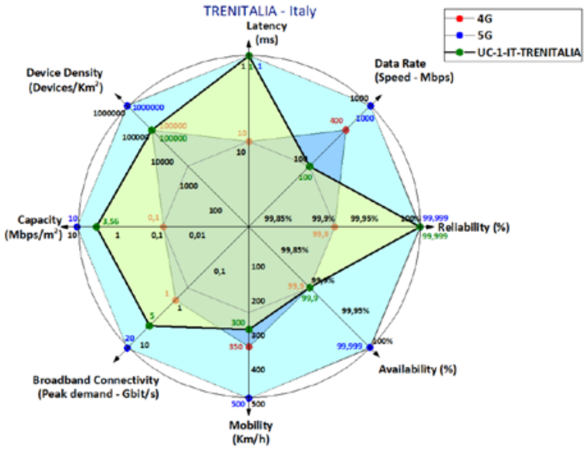

Figure 3: 4G/5G capabilities and Use Case 1 Smart Transport Requirements provided by TRENITALIA

For each use case, a first analysis of the target Key Performance Indicators (KPI) has been executed (see [3]), in which we identified the expected performance improvements with respect to the 5G state of the art. An example of such an analysis is illustrated in the radar graph for the smart transport use case (Figure 3).

A. Brief Overview of 5G EVE Site Facilities

Greece—The Greek 5G EVE site facility covers a region of Northern Athens, around the R&D site of the Greek National Telecommunication Organization (OTE). The OTE site serves as a testing ground for services, equipment, and new features prior to their commercial release, including (pre-)5G equipment, while it also maintains a real-time connection to the commercial 4G+ network of OTE. The existing equipment and network functionalities are a mix of Ericsson and Nokia technologies, which will be progressively extended by both vendors to support 5G during the project. OTE, Ericsson GR and Nokia GR with the help of WINGS ICT SOLUTIONS are responsible for preparing and upgrading the Greek site facility to be able to handle the three 5G oriented vertical use-cases.

Italy—The 5G EVE site facility in Italy is deployed in the city of Turin, where an initiative to experimentally evaluate the 5G systems has been already started by the Municipality of Turin that is planning a series of activities towards 5G in the area of the city. The 5G site facility in Turin will be a coherent synthesis of live and laboratory-based experimental environments for the evaluations of 5G features. It will mostly rely on 5G equipment provided by Ericsson as part of "Torino 5G" project. The infrastructure will consist in 5G radio fronthaul and backhaul, open source tools for the management and orchestration of the NFV infrastructure and on various networks offered by TIM to interconnect the various edge/peripheral locations to core data center sites, to other 5G EVE site facilities and to external public Clouds.

Spain—The 5G EVE Spanish site facility is located at IMDEA Networks premises in Leganés/Madrid. It has access to other locations for the support of different network functions and use-cases (Madrid, Almagro, etc.). It relies on the 5TONIC Open 5G Lab created in 2015 by Telefónica I+D and IMDEA Networks Institute with a clear vision of setting up an open research and innovation ecosystem laboratory in which industry and academia come together to boost technology and innovative business ventures. The current infrastructure used in 5G EVE is intended to evolve in the first half of 2019. For the initial access it is planned to have two non-integrated network infrastructures, one based on the network elements provided by Ericsson, UC3M, Telefónica, IMDEA Networks and Telcaria (plus 5TONIC own infrastructure), and the other based on Nokia provided network elements plus 5TONIC common infrastructure.

France—The French site facility is composed of a cluster of four nodes located in different cities. The entrance point of the French cluster is based at Orange in Châtillon, where the ONAP orchestrator manages the other facilities interconnected via VPN IPsec tunnels. Its main feature is that it rests on two main pillars. The first pillar comprises a pre-commercial Nokia 4G/5G E2E network facility composed of the pre-commercial 5G platform based on open-source and inner-source products developed by Nokia's Mobile Networks Business Unit located in Paris-Saclay. The second pillar consists of Open Source building blocks, mainly based on OpenAirInterface™ (see [7]) and distributed across several facilities. One of these is elements is the Plug-in platform, which is operated by Orange in Châtillon/Paris. This innovative 5G platform proposes a whole framework for developing 5G components. Another key element of the facility is the *Flexible Netlab* platform operated by b<>com in Rennes. It is a dedicated multi-tenancy environment, which benefits from some key corporate resources like a private cloud infrastructure. The French site facility is completed by the OpenAir5G playground located in Sophia Antipolis, operated by Eurecom and based on OpenAirInterface™, and the "NOKIA research platform", an open-source and inner-source platform developed at Nokia Bell Labs that manages

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cloud-native and microservice workloads across Edge and Core.

A more detailed description of the 5G EVE site facilities and planned roadmaps is available in a dedicated deliverable [3].

B. Interworking of 5G EVE Sites

The 5G EVE platform provides services and capabilities to allow verticals to define their experiments across multiple site facilities. The 5G EVE interworking framework (see Figure 1 and [6]) is the key element in this process because: i) it provides a common interface to the verticals for defining their experiments and ii) it allows to interconnect 5G EVE sites at different levels, including orchestration, control and data plane.

The aim of the common interface for verticals is to hide the complexity of the 5G EVE sites and to isolate the verticals from the different technologies, orchestrators and solutions present in the sites by providing a common model that represents the services, capabilities and capacities of the 5G EVE sites. This model is offered using a unique interface, based on ETSI NFV SOL 005 and extended with new capabilities. The interworking framework deals with technological complexity by providing *Drivers* for each technology, orchestrator and – in case of non-standard interfaces – vendor, which allows to integrate 5G EVE sites into the framework and to reuse the *Drivers* for all the sites.

Regarding the interconnection among 5G EVE sites, the interconnection of orchestrators allows to orchestrate resources from all 5G EVE sites, whilst the interconnection at the control plane allows defining experiments that can use different parts of the networks located in different 5G EVE sites. For example, in the Industry 4.0 use case, we plan to demonstrate the scenario of an industry with remote production at a premise covered by a 5G EVE site A, mainly served through 5G radio coverage, a central business logic of the process running in the operator cloud interconnected by another 5G EVE site B. Finally, the interconnection of the data plane allows defining experiments where the peers of a data interconnection are in different countries. This kind of interconnection is very critical due to restrictions in terms of latency and bandwidth, which are consequence of the physical distance between 5G EVE sites. Due to that reason, not all use cases are eligible for this kind of interconnection.

IV. Contribution of 5G EVE to the Adoption of 5G

Despite the numerous positive forecasts on 5G deployment, it is possible that the roll-out of 5G services may be slowed down by economic factors directly impacting the end users. This would represent a significant barrier to the realization of the expected business impacts. The 5G EVE project will provide operators, equipment manufacturers and verticals with real-life evidence of 5G performance metrics, thus supporting the identification of many real markets and improving their positioning of 5G service offers on these markets. The use-case experiments through the 5G EVE platform will allow assessing values and benefits of 5G spectrum allocation, test various approaches for sharing control tools and implement efficient network slicing via SDN/NFV, and demonstrate the interworking of 5G technologies, e.g. various options of 3GPP R15, R16, and beyond. Moreover, 5G EVE will help to reduce technology fragmentation or find solutions to manage it. 5G EVE builds on 4 key 5G site facilities linked to consolidated initiatives on Smart City and Smart District development (e.g. Turin, Madrid, Athens) which integrate into a composite set of 5G technologies from multiple vendors and from the Open Source community. Moreover, 5G EVE has plans for concrete contributions to standardization, leveraging the practical experience gained from the implementation of the validation framework and the deployment of production-style 5G infrastructures outside the lab.

V. Conclusion

The 5G EVE end-to-end facility is uniquely designed to meet the needs of experimenters from vertical industries, who would like to assess and validate their 5G services and applications on a large scale. The 5G EVE facility considers actual vertical sector requirements and is designed to be used by verticals as easily as possible. By providing a unified functional and operational infrastructure for vertical industry experimentation, the 5G EVE end-to-end facility is expected to significantly contribute to accelerating the time-to-market and adoption of 5G services and applications in Europe. Based on the insights gained in designing and operating the 5G EVE end-to-end facility, the project will make a contribution to common standards and global best practices in the field of 5G trials and experimentation.

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