T-NOVA: A Marketplace for Virtualized Network Functions

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***Abstract*— Network Functions Virtualization (NFV) is a concept, which has attracted significant attention as a promising approach towards the virtualization/ “softwarisation” of network infrastructures. With the aim of promoting NFV, this paper outlines an integrated architecture, designed and developed within the context of the EU FP7 T-NOVA project, which allows network operators not only to deploy virtualized Network Functions (NFs) for their own needs, but also to offer them to their customers, as value-added services (Network Functions as-a-Service, NFaaS). Virtual network appliances (gateways, proxies, firewalls, transcoders, analyzers etc.) can be provided on-demand as-a-Service, eliminating the need to acquire, install and maintain specialized hardware at customers’ premises. A “NFV Marketplace” is also introduced, where network services and functions created by a variety of developers can be published, acquired and instantiated on-demand.**

***Keywords*—** Network Functions Virtualisation, Infrastructure Softwarisation, Virtualisation, Resource Orchestration, NFV Marketplace.

I. INTRODUCTION

For decades, networking infrastructures have traditionally relied upon hardware platforms as their building blocks; functionalities such as routing/switching, traffic filtering, analysis, adaptation etc. have been mostly provided by dedicated equipment based on bespoke hardware, in order to assure stability and resiliency but also performance. However, the recent advances in the virtualization of computing and networking resources as well as their unified management, accompanied with the emergence of Software Defined Networks (SDN) and the ever-increasing performance of high volume computing platforms, significantly promote the opportunity of migrating most of in-network operations from hardware to software modules. This migration is commonly referred to as Network Functions Virtualization (NFV). NFV introduces several key benefits, such as:

- Efficient management of hardware resources via the co-existence of multiple NFVs into a single physical platform. This leads to reduction in operational and capital expenditure by using standard x86 high volume hardware;
- Exploitation of existing IT virtualization and cloud management technologies for virtual NFV instantiation, hosting and handling;
- Increased automation and real-time monitoring through the use of standard IT technologies. This has the benefit of consolidating and simplifying operations, allowing the automated scaling of resources, as well as the continuous optimization of their allocations.
- The introduction of sophisticated analytics that look at network functions at higher levels of granularity e.g. Solid-State Drive Input/Output Operations Per Second (SSD IOP) performance for a virtual Content Delivery Network (vCDN) or at broader system level for Quality of Service (QoS) delivery analysis;
- Rapid introduction of new network functions to market;
- Easy upgrade and maintenance;
- Promotion of innovation, by opening a part of the networking market and transforming it to a novel virtual appliance market, facilitating the involvement of

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software entrants, including Small and medium enterprises (SMEs) and even academia;

While software-based versions of network appliances have been on the market for a number of years, specific challenges exist with regard to the automated and large-scale deployment of virtualized network functions in carrier grade environments. Such challenges are:

- The simultaneous, joint management of network and IT (computing/storage) re-sources for instantiating the Virtual Network Functions (VNFs) – an implementation of a Network Function that can be deployed over a Network Function Virtualization Infrastructure (NFVI) - and steering the desired portion of the traffic through them;
- The availability and fault resilience of VNFs;
- The performance of VNFs, compared to the corresponding hardware-based versions;
- The compatibility of virtual NFs with existing network management platforms;

In an effort to address all these challenges via a standardization activity, ETSI has launched a dedicated Network Functions Virtualization Industry Specifications Group (NFV ISG) [1], as a joint initiative by telecom operators. The ISG has produced and publicly released a first round of technical documents on NFV terminology, use cases, requirements and high-level architectures.

The current paper is structured as follows: Section II presents the T-NOVA concept for Network Function as a Service, Section III gives an overview of the High-level architecture along with the foremost areas of innovation. Finally section IV presents the anticipated actors and business roles for T-NOVA.

II. T-NOVA CONCEPT FOR NETWORK FUNCTION AS A SERVICE

T-NOVA (Network Functions as a Service over Virtualized Infrastructure) [2] is an FP7/ICT Call 11 Integrated Project focusing on NFV. With five of its consortium participants already actively involved in the ETSI NFV standardization, T-NOVA is driven by a strong industrial core assisted by innovative SMEs and acclaimed academia in the field, with the aim of presenting an integrated solution for the offering, deployment and management of Virtualized Network Functions over composite (Network/IT) infrastructures.

In addition to allowing network operators/service providers to efficiently handle and manipulate NFVs for their own needs, T-NOVA introduces an additional innovative concept: it also considers the offering of Network Functions to operators' customers, as value-added services (Network Functions as-a-Service, NFaaS). Providers have the unique potential to enhance their traditional connectivity services with virtual network appliances (virtual gateways, proxies, firewalls, Intrusion Detection Systems/Intrusion Prevention Systems (IDS/IPS), media transcoders, traffic analyzers etc.) which are provided to their customers as-a-Service, eliminating the need to acquire, install and maintain specialized hardware at the customers' premises. It must be noted that NFaaS has been identified as a key use case for NFV in the latest ETSI ISG Specification [4].

The T-NOVA project aims to realize the NFaaS concept by designing and implementing an integrated management architecture, including an Orchestrator platform, for the automated provision, management, monitoring and optimization of Virtualized Network Functions over Network/IT infrastructures. T-NOVA leverages and enhances the state-of-the art cloud computing management frameworks for the elastic provision and (re-)allocation of IT resources assigned to the hosting of network functions. It also exploits and extends SDN aspects, focusing on the OpenFlow standard, for efficient management of network resources, including network slicing, traffic redirection and QoS provision.

The composite service offered by the T-NOVA NFaaS platform to the service providers' customers consists of two components:

- A connectivity service (i.e. network links with specific capacities and QoS). For the management of the connectivity component, including establishment of virtual networks (vNets) where required, T-NOVA adopts network management schemes based on SDN.
- A set of associated Network Functions, ranging from flow handling and control mechanisms to in-network packet payload processing, according to customer needs. In order to support these functions, computing (processing/memory/storage) resources are allocated by the orchestrator platform within the infrastructure and assigned to the virtual nodes participating to the offered service.

III. HIGH LEVEL ARCHITECTURE

A high-level view of the T-NOVA architecture is depicted in Fig. 1. The system to be designed and developed has the objective of implementing all the functionalities of a complete NFVI, as envisaged by ETSI.

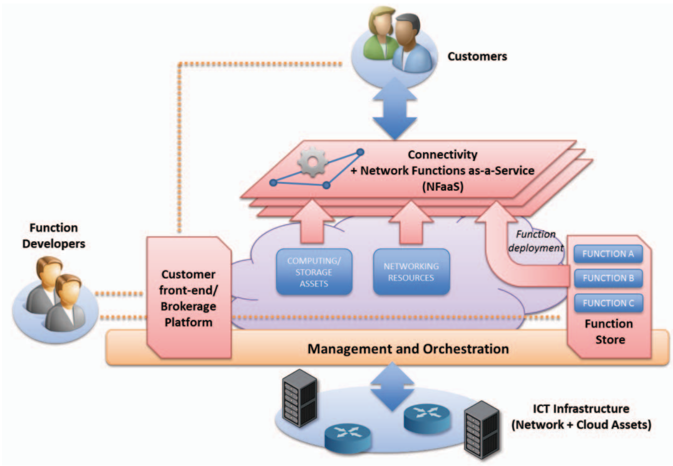

Fig. 1. High-level visualization of the T-NOVA architecture

As seen in Fig. 1, in addition to core NFVI operations (virtualization, orchestration, resource management) in order to facilitate the involvement of diverse actors in the NFV scene, T-NOVA introduces an innovative "Network Function Store", following the paradigm of already successful OS-specific "App Stores". The Network Function Store contains NFs by several third-party developers, published as independent entities and accompanied with the necessary metadata. The Store allows customers to select the virtual appliances that most appropriately match their needs, "plug" them into their existing connectivity services and configure/adapt them according to their needs. Service request and initiation is carried out via a tailored customer front-end/brokerage platform.

Through the Function Store and the customer front-end, T-NOVA will introduce and promote a novel Marketplace for VNF's, introducing new business cases and considerably expanding market opportunities by attracting new entrants to the networking market. This capability is particularly important for SMEs and academic institutions who can leverage the T-NOVA architecture by developing innovative cutting-edge Network Functions as software modules that can be included in the Function Store. This also enables the rapid introduction of VNFs into the market.

A. *Orchestrator Platform*

The Orchestrator Platform is the orchestrating entity of the T-NOVA system. It is responsible for the automated deployment and configuration of NFs and the federated management and optimization of networking and IT resources for accommodating network functions. To enable this capability the orchestrator will have the ability to deploy and monitor T-NOVA Services by jointly managing Wide Area Network (WAN) resources, in-network cloud (compute/storage) assets, and data center cloud assets. In other words, cloud assets will no longer be restricted to data centers, but can also be spread throughout the network.

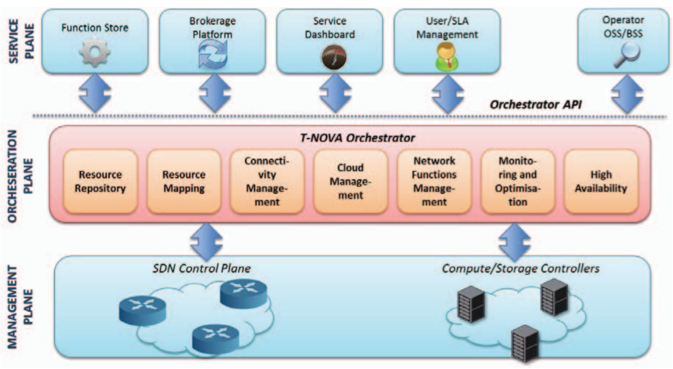

Fig. 2. T-NOVA Orchestrator platform, modules and interfaces

Fig. 2 shows the T-NOVA Orchestrator platform modules and interfaces. It features a set of northbound and southbound interfaces (for interfacing with the Service Plane modules, and communicating with the Cloud and Network Controllers, respectively).

Although the T-NOVA Orchestrator extends beyond traditional cloud management (i.e. single datacenter), it will leverage established cloud management architectures, namely those at the infrastructure level. The allocation and management of networking and cloud resources within T-NOVA will be based on the exploitation of open APIs such as OpenStack's RESTful API [5] and/or the Open Cloud Computing Interface (OCCI). Specifically, regarding the network resource management, the T-NOVA Orchestrator relies on a dedicated SDN control plane. Additionally ongoing initiatives such as OpenDaylight [3] will also be considered. Note that, despite the goal to maximize the compatibility with widely adopted cloud and network controllers, the integration of the T-NOVA orchestrator with other control frameworks is possible as long as appropriate plugins are developed.

The control of the Orchestrator will be realized via an open "T-NOVA Orchestrator API" to be defined and implemented. This interface will expose functionalities to be utilized by the Service Plane modules, such as: network and cloud resource advertisement; function deployment and service provisioning; service monitoring and reconfiguration; and service teardown.

Furthermore, the orchestrator's internal modules guarantee the entire lifecycle management (planning, provisioning and maintenance) of a T-NOVA service. The Orchestrator hosts all the appropriate modules for these tasks (see Fig. 2), namely:

- *Resource Repository module* - this includes a network topology service, featuring a flexible representation of the network infrastructure as well as the available IT resources for VNF hosting, in order to assist the resource mapping procedure.
- *Resource Mapping module* – implements a novel resource mapping algorithm, tailored for virtual Network Function deployment, deciding on NF resources, NF virtual machine (VM) placement and vNet embedding, while jointly optimizing IT and network resources.
- *Connectivity Management module* - depending on the customers' needs and the negotiated service level agreement (SLA), this step involves instantiation of virtual networks and QoS provision.
- *Cloud Management module* – communicates with the underlying Cloud Controller API (e.g. OpenStack) to allocate computing and storage resources for NF instantiation
- *NF Management module* – parameterizes the deployed NFs, (virtual interface configuration and addressing, traffic selection, configuration of NF parameters etc.)
- *Monitoring and Optimization module* – constantly monitors networking and computing/storage assets and optimizes them by triggering decisions e.g. for VM resize/migration or virtual network reconfiguration.
- *High Availability module* – performs detection and forecast of operational anomalies. The module also triggers fault mitigation procedures (e.g. VM migration, network re-planning etc.) when an anomaly is detected.

B. *Infrastructure virtualisation and management*

ETSI NFV ISG has focused their efforts on the deployment of NFV's using commercial server platforms. However to achieve the necessary performance especially for high traffic volume or delay intolerant network functions will require specific optimization through both hardware and software [6]. This requirement also applies to the data-path connections from the network interfaces of virtual machines hosting the NFV applications.

In T-NOVA the virtualized environment is achieved using standard methods offered by the IaaS Cloud Controller API, which in turn communicates with the underlying Hypervisors (e.g. Xen, KVM, LXC, ESXi). However cloud infrastructure needs to evolve to meet carrier grade needs in the deployment of NFV and SDN. Key to achieving this goal is adding more intelligence into the orchestration process by exposing the underlying physical and logical landscape of the computing and networking environment into which a VNF must be deployed and an SDN must manage [7]. Secondly the characteristics of the network function to be deployed must be understood with a high degree of granularity, e.g. what is the vCPU utilization profile in a multi-socket platform. A key focus for T-NOVA will be to develop insights into how workloads can be tuned for virtualized environments. Considerations such as the optimal mixture of compute, storage and network bandwidth for various workloads will be examined through a standardized profiling processing using approaches such as platform instrumentation and monitoring. Within this context approaches for optimizing the network platform and services for dependability, performance and efficiency must be defined in order to provide with the necessary foundational elements to develop an understanding of both QoS and Quality of Experience (QoE) affinity for specific platforms features.

T-NOVA expands beyond heuristic type approaches to consider how exposure of platform features such encryption acceleration features can be appropriately incorporated into the placement decision. This becomes especially important in a typical datacenter having multiple generations of servers, with increasingly advanced features on the newer ones. It is important that VNF workloads will only be scheduled to run on servers with these advanced features. Differentiating platform features through network management APIs is critical both from a cloud and SDN perspective. Secondly, the most significant parameters for a given category of VNFs that should be considered when making a placement decision must be identified.

One of the commonly cited benefits of NFV is the ability of operators to consolidate multiple network functions into "multi-tenant" environments to maximize return on infrastructure investment. However, consolidation of functions can only be successfully achieved if the interplay among the various functions is understood appropriately. Placement decisions in virtualized environments should be careful to avoid effects such as "noisy neighbors" that can adversely affect performance of co-located VNF's. T-NOVA enables an infrastructure repository, which contains key data about the available platform characteristics that can be used by the orchestrator together with data on workload characteristics to make intelligent placement decisions and avoid performance issues. The context location for VM instantiation and VNF placement is also very important; if e.g. the network function consists of a virtualized middle-box, the respective VM must be instantiated in a datacenter in proximity to the network nodes conveying the customer traffic. This is crucial, in order to avoid excessive latency and network overload due to inefficient traffic redirection to remote VMs.

C. Marketplace

T-NOVA proposes the realization of a NFV marketplace to attract new market entrants. The marketplace allows network services and functions by a variety of developers to be published and brokered/traded. Customers can browse the marketplace and select the services and virtual appliances that best match their needs, as well negotiating the associated SLAs and billing models. Three are the main functionalities identified:

- *Publication of resources and NF advertisement.* Through a customer front-end, Third-party VNF developers describe their functions in the T-NOVA Function Store, and customers place their requests for services and virtual appliances.
- *VNF discovery, resource trading and service matching.* Through a brokerage module customers can place their requests for T-NOVA services and declare their requirements for the corresponding VNFs, receive offerings and make the appropriate selections, taking into account the offered SLAs. Trading and billing policies such as long-term lease, scheduled lease, short-term lease or spot markets can be based either on a fixed-price or action-based strategies.
- *Customer-side monitoring and configuration of the offered services and functions.* Via a service dashboard users can interact with the T-NOVA Orchestrator platform for monitoring the status of the established services and associated NFs, as well as for performing – according to their associated permissions – management operations on them.

Another important aspect within T-NOVA is the billing of services. This includes the establishment of pricing mechanisms for different NF and the study of how these prices are affected by SLAs evaluation, so that customers may receive certain compensations depending on the overall service delivered. Of course, billing in such scenarios must contemplate not only final customers of T-NOVA services, but also the commercial relationship between NF providers and infrastructure providers.

IV. Business Roles and Use Cases

A. Business Roles and their interactions.

Several roles are involved in the T-NOVA value chain. Even though, depending on the concrete implementation, the granularity can be smaller than this approach, i.e. some of these roles are not always involved in all use cases and/or some of these roles can be grouped, we prefer to be exhaustive in this analysis in order to explore the different commercial relationships that the T-NOVA paradigm brings:

- **End User (EU)**: This is the end consumer of the purchased service, which is acquired by the Customer (C).
- **Customer (C)**: The T-NOVA Customer purchases T-NOVA services.
- **T-NOVA Service Provider (SP)**: The SP supplies a finished product to end customers. Services offered to end customers can be single functions or bundles containing a combination of functions from different Function Providers (FP). The SP may also facilitate within the service the infrastructure required to run it (which may be owned by the SP or not).
- **Function Provider (FP)**: The FP supplies virtual network appliances (gateways, proxies, firewalls, transcoders, etc.) eliminating the need for the customer to acquire install and maintain specialized hardware. The FP commercializes NFs through the T-NOVA SP.
- **Cloud Infrastructure Provider (CIP)**: The CIP provides the cloud infrastructure the NF run on.
- **Network Infrastructure Provider (NIP)**: The NIP provides the physical connection to the cloud infrastructure.

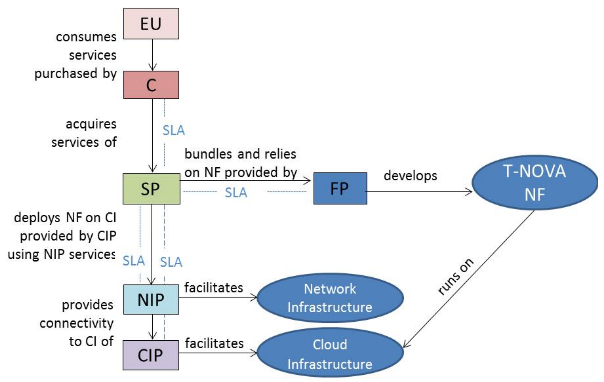

Fig. 3. T-NOVA Business Roles

Fig. 3 represents the relationship among the T-NOVA roles. These roles may be condensed, depending on the particular use case. For example, in residential scenarios, the C and the EU could be played by the same business entity. Another example is that the T-NOVA SP may also act in the role of the CIP and the NIP. This would be the case of a telecom operator that provides NF over his own infrastructure (cloud and network resources).

These roles interact among them in order to build the T-NOVA landscape. There are interesting relationships to explore as far as SLAs are concerned. For example, C agrees on an SLA with the T-NOVA SP who, in turn, agrees on an SLA with each FP and also with the CIP and the NIP.

The ability to negotiate and acquire SLA's is a key feature of the T-NOVA Marketplace. T-NOVA implies different kinds of stakeholders (e.g. FP, NIP/CIP etc.), which makes the business matrix within the telecoms landscape more complex and more flexible than it is today. The SLA management in T-NOVA fosters a trust framework for these providers to have incentives to cooperate. Indeed, the relationships and mutual responsibilities for a service to be delivered in T-NOVA have to be analyzed appropriately. When a software solution is deployed into a virtualized network, a key question emerges with respect to who is responsible for the SLA? The hardware supplier running someone else's software, or the software supplier who has no control over the hardware it is run on? Decoupling hardware from software requires advanced SLA management to enable each player to advertise and respond to the appropriate commitments. Mechanisms for establishing and controlling SLAs according to customers' requirements are required in order to track the provider's record, robustness, systems, technology and agility in the aim of increasing the trust level, which is essential for the T-NOVA paradigm to be adopted.

V. Conclusions

Network Functions Virtualization constitutes a topic of immense interest to the networking community –in both the research/academic and commercial domains- and is a candidate approach for short-term exploitation. Via the concept of infrastructure "softwarisation", NFV has the potential to entirely transform the networking market and open it to new entrants. In this context, T-NOVA introduces a complete open solution for NFV deployment, focusing on the NFaaS perspective with a strong business orientation. The project is currently at the early phase of use cases/requirements identification and system design. All initial deliverables containing the system specification have been categorized as public and will be released at the project website upon finalization, towards maximizing the impact of the project to the NFV community.

Acknowledgment

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