Control Plane Architectures Enabling Transport Network Adaptive and Autonomic Operation

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ABSTRACT
The maturity and flexibility of Software Defined Networking principles, favouring centralized control deployments, featured application programming interfaces and the development of a related application ecosystem, has paved the way for the design and implementation of advanced and adapted control plane architectures that specially target and enable efficient and massive monitoring and data collection. In this line, the steady increase in the use of open and standard interfaces and data modelling languages, as well as the wide adoption (in a vendor independent way) of model-driven solutions and a unified approach for data collection and processing facilitates shifting the focus to the actual processing of information, towards autonomic networks and self-* capabilities. Scoped to the control of a flexi-grid optical transport network, and in line with major industry trends, in this paper we cover our requirements for efficient data collection and processing, and we propose and detail a control and management architecture, building on the concepts of front-end and back-end entities, dynamic instantiation of control plane functions within the ETSI NFV framework and the applicability to use cases such as in-operation network planning, on-demand network optimization and parameter tuning.
Keywords: SDN/NFV Control of Optical Networks, Active Stateful PCE, Front-end/Back-end architectures, In operation network planning, On-demand control functions, Service Function placement.

1. INTRODUCTION

There is a clear trend of integrating network telemetry, machine learning and big data analytics into the SDN control, in view of implementing operator-defined and adaptive policies for multi-fold purposes: traffic off-loading, efficient resource usage, dynamic link resizing, automatic traffic engineering, and network optimization (see, for example [1]) .

Key aspects in the proposed refinements of control and management architectures, for both networks and integrated cloud/network systems, are decoupling of functions, relying on open and standard interfaces and clearly detailing applicable workflows and events triggering control plane actions.

2. EFFICIENT MONITORING AND DATA COLLECTION INTERFACES AND FRAMEWORKS

A first key requirement is the efficient collection of data from multiple sources This requires the development and adoption of advanced interfaces overcoming the limitations of existing ones (e.g., SNMP Traps) to maximize efficiency and minimize latency, bandwidth usage and data processing requirements. These interfaces have stringent functional requirements, e.g. *i)* to monitor the status of hundreds or thousands of entities in a large scale network; *ii)* to configure programmable pipe-lines in terms of asynchronous events and flexible filters, including expressive and domain embedded languages in a publisher-subscriber pattern; *iii)* to enable the automatic discovery and monitoring of key parameters (e.g. , to validate SLA requirements), commonly known as performance monitoring, and *iv)* do this in a context defined by the use of Open Source projects and open and standard interfaces. In this regard, ongoing IETF drafts are being produced adapting and extending existing Yang [2] notification mechanisms (e.g. adopting the mechanisms defined in [3][4]) allowing a network operator to subscribe notifications on a per client basis; configure what parameters to apply filtering and selective collection at the point of origin of the notification, and to request whether notifications are periodic, event-driven, etc.

3. ADAPTIVE AND AUTONOMIC NETWORK OPERATION

The second main requirement is to extend and adapt existing control plane architectures, such as the ones based on SDN [5] or the Application Based Network Operation (ABNO) [6] framework, to leverage the flexibility of these interfaces while attaining efficient use of the collected information. In the following, we present a selected set of developed architectures focusing on the functional split between control components. Basically they rely on replicating functions for robustness and scalability, making use, where appropriate of the know-how deployed within the cloud management frameworks to scale on an as-needed basis. A common trait of the presented architecture is related to decomposing functions that can be executed remotely, rendered open via an open and standard interface and whose resource allocation can be decoupled from the allocation of other functions within a control plane. Such functions are referred to as back-ends.

3.1 Active Stateful PCE Front-end / Back-end Architecture and In-Operation Network Planning

An Active Stateful Path Computation Element (AS-PCE) is an entity that is able to, on the one hand, perform constrained path computation on a network topology (Traffic Engineering Database, TED) and, on the other hand, provision and reroute connections either directly [7] or driving a GMPLS control plane [8], effectively becoming a kind of SDN controller.

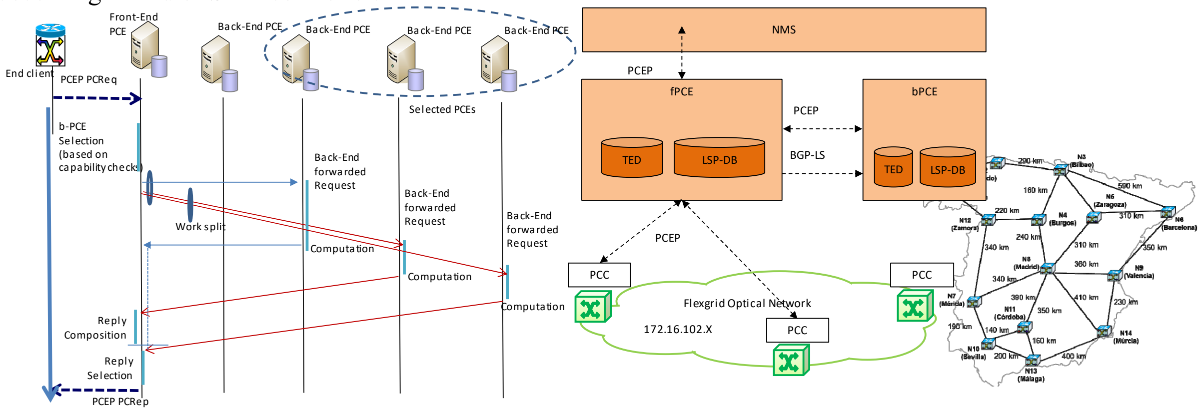

Figure 1. the Front-end / Back-end PCE architecture, showing main workflow and message exchange (left) and the applicability to in-operation network planning, re-routing and network optimization (right).

Our first use case relies on decoupling, from a control plane perspective, the functions of path computation and path provisioning, introducing flexibility in terms of algorithms and capability selection. Although it is commonly assumed that a PCE is centralized, we considered the design of a flexible, policy-enabled architecture where a number of PCEs may exchange information regarding their capabilities. This provides to network operators further control in the path computation function, supporting advanced deployments ranging from load-balancing mechanisms to partitioning the path computation into specialized PCEs. The so-called front-end/back-end architecture (FBA) [9] relies on a front end and one or more dedicated back ends. A common use case is based on deploying one or more PCEs with in the same Traffic Engineering (TE) domain, aiming at providing a higher level of robustness and redundancy. The f-PCE and b-PCEs will have persistent connections and are able to perform capability exchange at any moment since those capabilities may change dynamically (see Fig.1) during the lifetime of the session. As a particular instance targets the In-Operation Network Planning, with the deployment of one or more PCEs specialized in computations for network planning exploiting the Global Concurrent Optimization (GCO), applied for real-time restoration [10][11] (shown in Fig. 1, right).

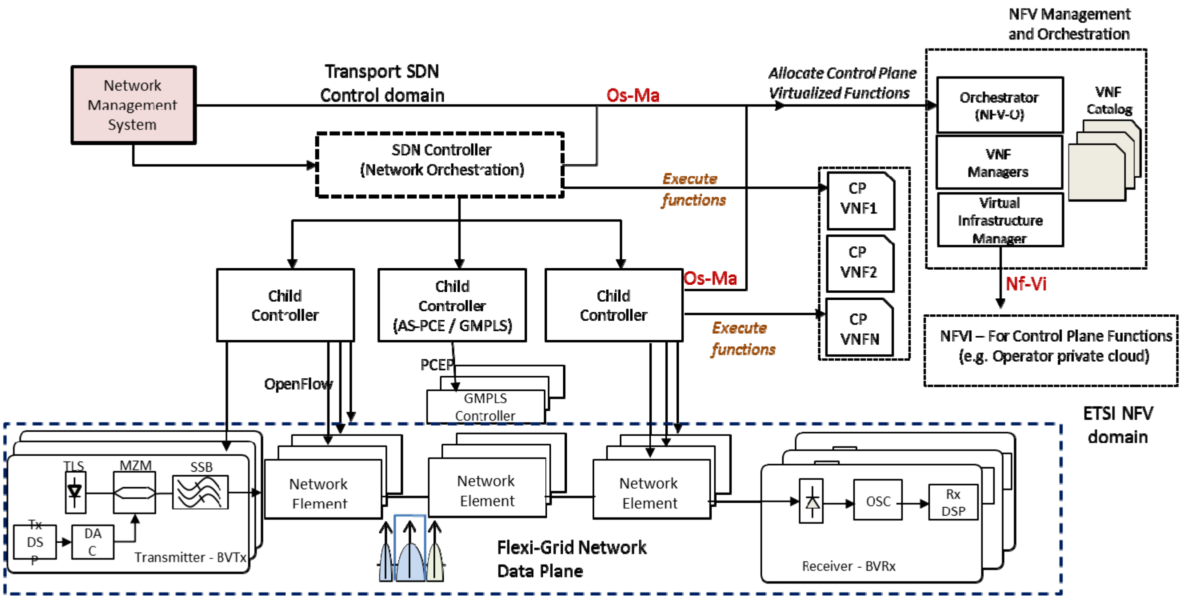

Figure 2. Block diagram of the architecture allowing on-demand NFV instantiation of control plane functions.

3.2 On-Demand Modular Control Plane Function Allocation

Network planning and traffic engineering are becoming harder due, to, in part, the ever changing traffic patterns and the need to dynamically adapt and resize resources. This also applies to the control plane (CP) since *i)* the efficient and flexible use of computing resources is one of the drivers for adopting NFV, including increase in CP robustness; *ii)* there is need for the ability to slice the infrastructure and support slicing and multi-tenancy, instantiating CP instances on demand and on a per tenant basis. In short, CP instances (e.g. controllers) can be instantiated as needed and scaled dynamically, e.g., in cases with no known-pattern of resource usage. We addressed this problem as follows: first, to instantiate CP instances adapted to the specifics of a given deployment, enabling a cognitive approach (e.g. on a per-slice basis as in [12] supporting multitenancy). Second, we consider the modularity of the CP itself to support efficient allocation and composition of CP functions. It is thus possible to use the same framework and procedures to allocate CP-specific functions at different (shorter) time-scales as, for example, time consuming and scoped functions such as de-fragmentation of re-optimization. As shown in Fig. 2, a common ETSI/NFV Management and Architecture (MANO) framework [13] can be used to instantiate SDN Controllers as VNFs, and such controllers may instantiate CP functions, both in an operator private cloud infrastructure. In [14] we considered the Bandwidth Variable Transponder (BVT) parameter optimization (see Fig. 3).

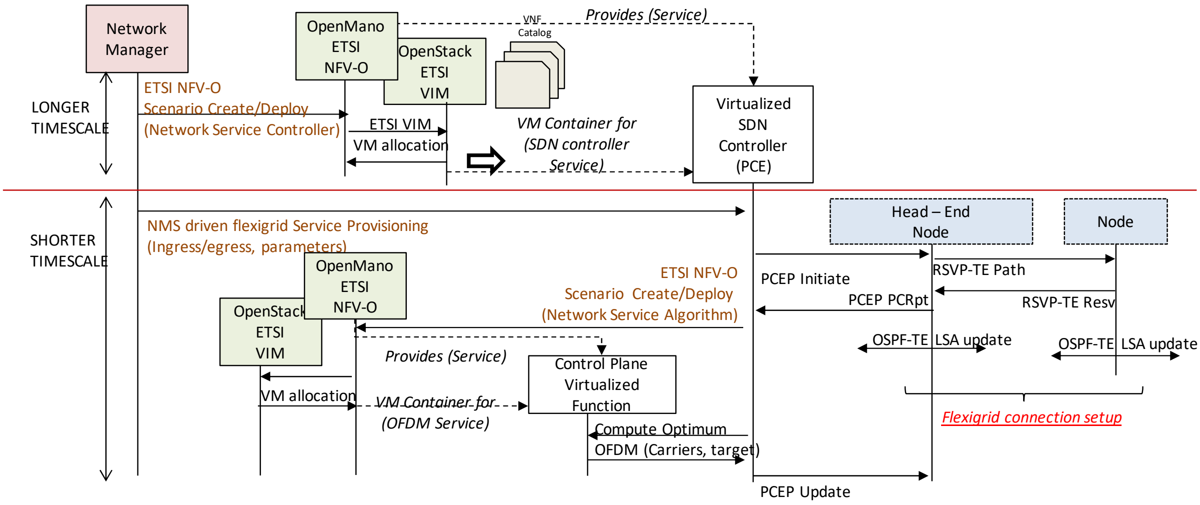

Figure 3. Flow corresponding to the dynamic instantiation of SDN Controllers and CP-specific functions.

3.3 Overlay Network Placement in a SDN/NFV context

Our last use case considers the orchestration of computing (cloud) resources as well, motivated by additional requirements: *i)* new 5G-services are conceived around the joint allocation and use of heterogeneous resources, combining networking and computing ones (processing, storage) and, *ii)* there is a need for network slicing, understood as a partitioning and composition of infrastructure resources for e.g. the support of vertical sectors and services. Extending our previous work [15] and in the scope of the 5G-Crosshaul project [16] -- where a unified transport network for fronthaul and backhaul traffic is proposed -- we consider the service of the placement of overlay Virtual Machine (VM) networks, that support VNF graphs. The VIMaP component extends the concept of NFV Virtual Infrastructure Manager (VIM), designed to orchestrate of network and cloud resources distributed among different providers and locations (Fig. 4).

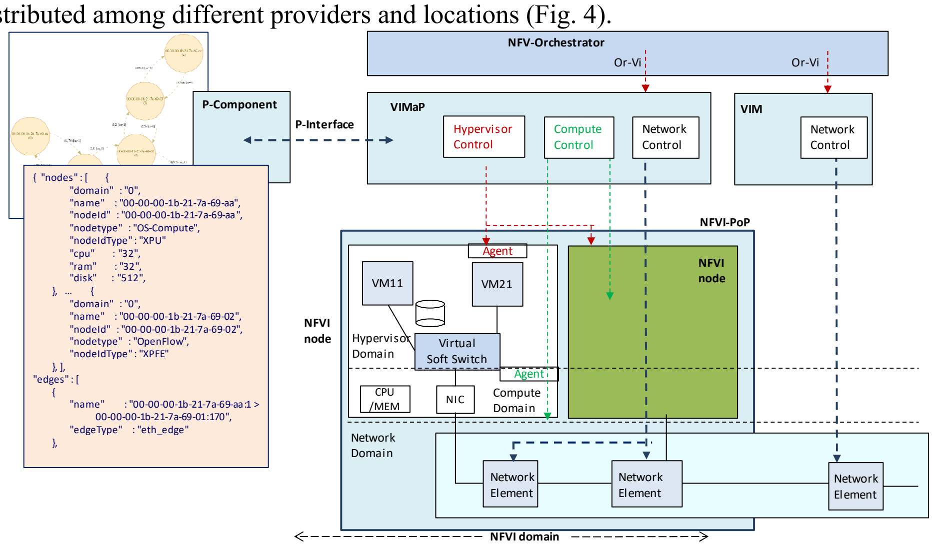

Figure 4. The VIMaP allows delegation of the computation of the VM placement to the P-Component

A first proof-of-concept was presented in [17], using a baseline implementation of a resource allocation algorithm, relying on a first reduction which consist in: a) finding a VM allocation among the substrate hosting nodes and, b) find a feasible allocation solution for the links connecting VM in different hosting nodes. The last refinement deals with decoupling the placement function to an external entity, named the Planning Component (P-Component) enabling that dedicated resources (back-end) lead to attain a more optimal computation. If needed, the virtualization of the P-Component can be also rolled out. The P-interface is based on existing REST interfaces providing the attributes and features of the compute nodes attached to the network.

4. CONCLUSIONS

There is a huge trend to apply big data, machine learning and artificial intelligence to the control, management and orchestration of transport networks. This requires both efficient data collection that scales and tailored control plane architectures enabling the use of such knowledge in adaptive and cognition frameworks. The centralized model of common SDN architectures is, at the same time, an opportunity and a threat; it is more straightforward to make efficient use of collected data and enable application ecosystems in a centralized model, but such systems scale less than distributed ones. Consequently, several architectural refinements driven by actual use cases are needed. In this paper, we have focused on a reduced set of such cases from both perspectives: a pure network orchestration and an integrated network/IT orchestration. A common pattern relies on having multiple adapted and optimized back-end systems which can be dynamically instantiated, scaled and released as needed and upon demand basis for an efficient and cost effective infrastructure operation.

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