

Multi-domain Orchestration and Management of Software Defined Infrastructures: a Bottom-Up Approach

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Abstract— Clear requirements towards the end-to-end orchestration and management plane for 5G networks have been issued by various Industry operators’ associations and standard organizations. Over the past couple of years a number of orchestration frameworks have emerged in attempts to realize those requirements. These orchestration frameworks provide coordination and automated management of cloud and networking resources as well as service functions, typically, over a single domain. However, the extension of the orchestration function to coordinate multiple administrative domains has not been directly addressed so far. This paper presents a multi domain functional architecture of the 5G end-to-end management and orchestration plane as an ongoing effort towards its realization within the H2020 ICT14 project 5G Exchange (5GEx). Our architectural proposal follows a bottom up approach based on the analysis of multiple existing resource domains and domain orchestration components.

Keywords—5G Network Architecture; orchestration; network management.

I. INTRODUCTION

Current telecommunication networks are built upon dedicated hardware appliances requiring complex yet static planning and provisioning; specific skills are necessary to design, integrate and operate each individual network element. A fundamental requirement issued by the industry operators associations such as NGMN [1] for 5G systems is to support flexible and configurable network architectures, adaptable to use cases that involve a wide range of service requirements. Logical architectures, consisting of virtual functions connected by virtual links, shall be hosted by software defined infrastructures.

Given these premises, the role of 5G networks will not be limited to providing connectivity: they will rely on coordinated allocation of cloud (compute, storage and related connectivity) and networking resources. The management and orchestration plane has an essential role of mediation between the service plane and the infrastructure plane, in order to ensure an

efficient utilization of the infrastructure while fulfilling performance and functional requirements of heterogeneous services. In this context the differentiation between telecommunication services and online service vanishes, introducing new business opportunities as well as new challenges to network and service providers: new infrastructures and services will be “manufactured by software”, hosted in a “infrastructure factory” where resources and network functions are dynamically and flexibly traded and provisioned.

This paper describes the functional architecture of an end-to-end management and orchestration plane fulfilling requirements issued by industry and standard associations such as NGMN [1], ITU-T FG IMT-2020 [2] and IMT-2020 (5G) [3]. The proposed multi-domain architecture is derived from a bottom-up approach that unifies existing technology and domain specific management and orchestration frameworks in a coherent end-to-end framework. This framework is the result of an analysis carried out within the scope of the H2020 ICT14 project 5GEx (5G Exchange) [4]. The main objective of 5GEx is to design, implement and test in a large scale platform a multi-domain management and orchestration (Mdo) framework. Indeed, end-to-end management and orchestration can be realized only resolving two fundamental multi-domain issues:

- Multi-domain as multi-technology: currently, several resource management and orchestration frameworks expose resource virtualization and support automated provisioning of resources to services; it is necessary to unify management and orchestration of heterogeneous resource technology domains in order to realize an end-to-end software defined infrastructure suitable to host 5G services.
- Multi-domain as multi-operator: the implementation of end-to-end management and orchestration must deal with the interaction of multiple administrative domains (i.e. different service and/or infrastructure providers) at different levels: resource management and orchestration, service management and orchestration, inter-operator Service Level Agreement (SLA) fulfillment.

The target is to optimally host, in terms of resource utilization and revenues, service requests into the set of virtualized resource domains mapped into multi-operator and multi-technology domains while matching each service SLA requirements.

The paper is organized as follows. Section II introduces the

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requirements issued to the end-to-end management and orchestration plane by various 5G related white papers. Section III defines multi-domain management and orchestration concepts and our reference framework. Section IV analyzes existing virtualization domain frameworks and their related management and orchestration capabilities as well as current initiatives aiming at developing Mdo components. Section V concludes the paper and elaborates on future work within the project 5GEx.

II. REQUIREMENTS FOR 5G NETWORKS

A. General architectural requirements

According to the NGMN's vision, "5G is an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models". The following are the key requirements related to 5G networks deployment, operation and management as elicited by industry and standard associations (NGMN, IMT-2020, ITU-T) in 5G related white papers:

- **Ease of Deployment-** The 5G system should allow an easy deployment on the existing network infrastructures, furthermore aid the deployment of new services or technologies minimizing the impact in the system or the user experience.
- **Flexibility and Scalability-** 5G networks should be able to change quickly the interconnections between devices and create new nodes to adapt the network to the changing demand services.
- **Fixed-Mobile Convergence -**5G should support the fixed and mobile domains unification to claim a better service user experience.
- **Operations Awareness -**5G systems should be able to access a segment of the information to have enough knowledge of the high variety of service requirements and acting accordingly to the situation to optimize the network traffic.
- **Innovation -** The 5G eco-system is an open eco-system that enables innovations at a fast pace, involving many partners. 5G should provide the capabilities to allow this, with value creation for the operators and the market as a whole. Programmability of the network, availability of 5G value enabling capabilities (e.g. location, QoS, identity, security) and the related APIs are needed to make this happen.

B. Requirements for e2e management and orchestration

In the 5G white paper issued by NGMN [1], the E2E management and orchestration (M&O) entity is introduced to operate as the contact point which translates the use cases and business models issued by a business application layer into actual network functions and slices. A slice is intended as a managed set of 5G network functions set up within the 5G system that is tailored to support the communication service to a particular type of user or service.

The E2E M&O entity defines the network slices for a given application scenario, chains the relevant modular network functions, assigns the relevant performance configurations, and finally maps all of these entities on the

infrastructure resources. The NGMN white paper assigns to the E2E M&O entity the capability to allow for third parties (e.g., MVNOs and verticals) to create and manage their own network slices, leveraging on APIs and XaaS principles supported by the underlying infrastructure resource layer. It is also stated that, due to the various tasks of the M&O entity, it will not be a monolithic piece of functionality. Rather it will be realized as a collection of modular functions that integrates advances made in different domains like NFV, SDN or SON. Furthermore, it will use data-aided intelligence to optimize all aspects of service composition and delivery. All these aspects will be covered by the architecture described in Section V of the current paper.

At the state of the art of the discussion in the ITU-T Focus Group IMT-2020 [2] a slice is again the managed collection of virtual or physical network, compute and storage functions connected by links to create an end-to-end networked system. The network management and orchestration plane manages the life cycle of slices: creation, update, deletion and operations/use. It also manages the physical infrastructure and virtual resources, which are abstraction of physical resources. A customer may send a request to the network management and orchestration issuing requirements for the instantiation of an end-to-end service.

5GMF [3] claims that network management in 5G will leverage on SDN/NFV and virtualization technologies to provide scalable and flexible network management to deal with short service life cycles. Also for 5GMF the network M&O plane instantiates and maintains end-to-end virtualized networks including cloud resources. These virtual network slices are instantiated on demand on to the software controlled network domain using APIs exposed by the management plane, which provide dynamic management (i.e. orchestration) for multi-layer and multi-domain mobile networks.

For the IMT-2020 (5G) Promotion Group [5], the network orchestration function creates, manages and deletes the network slices. The operator designs the network slice template, including required network functions, interfaces between network functions and the required network resources for each network function. The network orchestration function applies the network resources according to the network slice template, and instantiates the virtualized network functions and their interfaces on the allocated network resources.

III. MDO CONCEPTS

A. Terms and definitions

This section is meant to define some terms that will be used to describe our proposed architecture.

Resource: physical or virtual network (packet, optical, etc.) or cloud (compute, storage) element with given capacity attributes, QoS characteristics and connectivity ports.

Resource Domain: a topology of resources exposed as an abstraction.

Abstraction: a representation of an entity in terms of selected characteristics, while hiding or summarizing characteristics irrelevant to the selection criteria (ONF [6]).

Virtualization: an abstraction whose selection criterion is dedicated to a particular client or application (ONF [6]).

Network Function (NF): in this paper the term Network Function (NF) is used to refer to any of the following:

- Service Function (SF), IETF [7]: function that is responsible for specific treatment of received packets. A Service Function can be a virtual instance or be embedded in a physical network element.
- Network Function (NF), ETSI NFV [8]: a functional block within a network infrastructure that has well defined external interfaces and well defined functional behavior.
- Virtualized Network Function (VNF): an implementation of an NF (according to ETSI NFV) deployed on a Resource Domain.

Orchestration: automated management of complex systems, middleware and services (Wikipedia).

Resource Orchestration: automated management of resources in one or multiple resource domains to host an NF or a topology of NFs. A resource orchestrator only deals with resource level abstraction and does not understand the service that the NF or topology of NFs delivers.

Resource slice: a set of resources exposing a logically unified control and management interface; the resource slice is deployed and maintained by a resource orchestrator. Resource slices may recursively include other resource slices.

Service Orchestration: automated management of a topology of NFs that form a service requested by a customer (network service, cloud service, online service, etc.); a service orchestrator understands the service that the NFs topology delivers.

Service slice: a topology of NFs, providing logically unified control and management interfaces and a related service.

B. Reference framework

The 5GEx reference framework for organizing the components and interworking interfaces involved in multi-domain orchestration is described by Figure 1. At the lower layer there are Resource Domains, exposing resource abstraction on interface *I5*. In the middle layer, Domain Orchestrators perform Resource Orchestration and/or Service Orchestration exploiting the abstractions exposed on *I5* by Resource Domains. Interface *I4* allows coordination between Domain Orchestrators.

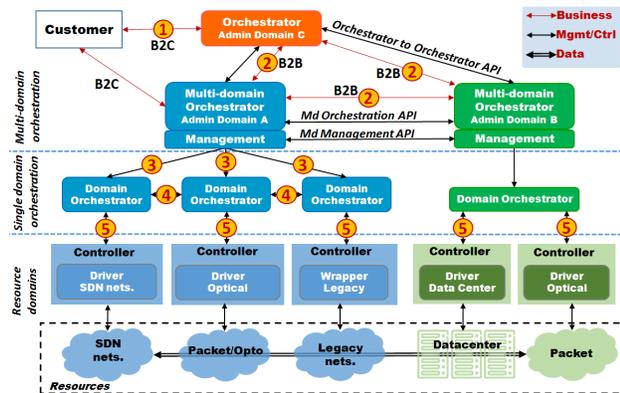


Figure 1 - Reference framework

A Multi-domain Orchestrator (Mdo) coordinates resource and/or service Orchestration at the multi-domain level, where multi-domain may refer to multi-technology (orchestrating resources and/or services using multiple Domain Orchestrators) or multi-operator (orchestrating resources and/or services using Domain Orchestrators belonging to multiple administrations). The Mdo interacts with Domain Orchestrators via *I3* APIs to orchestrate resources and services within the same administrative domains. The Mdo interacts with other Mdos via interface *I2* APIs (business-to-business, B2B) to request and orchestrate resources and services across administrative domains. Finally the Mdo exposes on interface *I1* service specification APIs (Customer-to-Business, C2B) that allow business customers to specify their requirements for a service.

C. Multi-operator SLA aspects

In a multi-operator environment the services offered by each operator may require NFs and resources from different locations in several neighbor domains (with different capabilities, requirements, constraints and different administrators) for its deployment. This can be managed by resource and service slicing and a contract becomes necessary between the different providers, including quality assurance by means of a Service Level Agreement (SLA). Operators delivering the service from a service topology, which can either be a star (customer-facing operator handles all contracts) or a multi-level tree (operators handle contracts in a cascading fashion). These topologies can be realized by means of Mdo interface *I2* for inter-operator relations and Mdo interface *I1* for customer to operator relations as depicted in Figure 1. For each resource or service slice there should be a parent SLA contract that is subdivided in several child SLA contracts, one for each operator that provides resource or service slices. As resource and KPI monitoring is operator-internal, an SLA aggregator function is required to be aware of all the SLA contracts that are attached to the parent, and aggregate the results of the partial SLA evaluations of each subcontract.

There are a lot of challenges with regard to SLA handling in a multi-operator environment. First, SLAs in general contain very simple conditions that may not capture all details. Second, the granularity and amount of internal information shared among operators is key to defining efficient SLAs and estimate the risk of not fulfilling them. Third, how the parent SLA is subdivided into several partial SLAs, how income is divided based on (un)fulfilled contracts and how to share the costs of remunerating the customer in case of not meeting KPIs are all important issues to deal with. Finally, the potential for on-demand service negotiation brings with itself the need for calculating SLA parameters on the fly.

IV. EXISTING DOMAIN FRAMEWORKS

A. Resource domains and domain orchestrator/managers

This section provides a brief description of the resource domains and of their respective domain orchestrators. Table 1 presents a categorization of the resource domains considered so far in the 5GEx framework. The information in the table is organized as follows: resource domain, resource type;

Table 1 – Resource domains and domain orchestrators

Resource domain		Managed resource type	Reference domain orchestrator	Domain properties and functionalities	Interface 5
Cloud domain	OpenStack Compute (Nova)	Computing	OpenStack Heat, ESCAPE	It manages the lifecycle of computing resources (i.e., Virtual Machines-VSs) implementing functions for spawning, scheduling, and terminating VMs on demand	OH: REST API through HTTP(S) protocol ESCAPE: Unify using OpenStack adapter
	OpenStack Block Storage (Cinder)	Block storage	OpenStack Heat, ESCAPE	It provides persistent block storage (i.e., Virtual Volumes) to VMs running in the cloud, managing the lifecycle of block storage objects (i.e., creating, attaching, detaching, and deleting virtual volumes)	OH: REST API through HTTP(S) protocol ESCAPE: Unify using OpenStack adapter
	OpenStack Networking (Neutron)	Cloud networking	OpenStack Heat, ESCAPE	It provides network connectivity to the VMs running in the cloud, managing the entire lifecycle (creation, deletion, use, and control) of all the involved networking objects (e.g. network trunks, subnets, virtual routers, etc.)	OH: REST API through HTTP(S) protocol ESCAPE: Unify using OpenStack adapter
Legacy Packet Domain		Networking	Harmonizer, VELOX EM	IP/MPLS domain composed of commercially available routers and Linux boxes. Support of Segment Routing, GMPLS control plane or Command Line Interface (CLI)	Harmonizer: PCEP and BGP-LS VELOX:TLV based proprietary Interface
SDN packet domain		Networking	ESCAPE, Harmonizer, VELOX EM	OpenFlow based network controllable by different OF controllers (i.e., Floodlight, POX, ODL, ONOS) and different OF versions (i.e., 1.0 and 1.3)	ESCAPE: Unify using POX/NETCONF adapters Harmonizer: OpenFlow1.3 VELOX: TLV based proprietary Interface
Optical Domain		Networking	Harmonizer	Optical domain composed of commercially available ROADMs and optical nodes controlled by Linux-based adapters. Supports flexi-grid	Harmonizer: PCEP and BGP-LS
EPC Network Domain		Networking	VELOX EM	EPC networks with Policy and Charging Rule Function (PCRF) exposed via Rx interface	VELOX:TLV based proprietary Interface

reference domain orchestrator(s) options; a brief description of the domain functionalities; and the option currently available for the implementation of interface *I5*. The most relevant domain orchestrators considered so far as candidates to be integrated in the 5GEx prototype are listed hereby.

OpenStack Heat (OH) [9] orchestrates cloud resources in the OpenStack framework, considering infrastructure object aggregations (i.e., stacks). To create, manage and delete infrastructure objects (described in template files written using the Heat Orchestration Template (HOT) language) OpenStack Heat collaborates with other components, i.e., *Nova* (for compute resources), *Swift* and *Cinder* (for storage resources), and *Neutron* (for connectivity resources). Interface *I3* of OH is based on REST API (HTTP or HTTPS based), and it is used for the management of the stacks.

ESCAPE [10] (Extensible Service ChAin Prototyping Environment), developed in the framework of the EU FP7 UNIFY project [11], enables the joint virtualization and programming of both cloud and networking resources. ESCAPE can orchestrate different technology resources using domain managers and adapters such as: Local Mininet domain manager with Mininet adapter; POX adapter; NETCONF adapter; OpenStack domain manager with Unify adapter. The interface *I3* of ESCAPE is implemented via the UNIFY SI-Or interface, which provides the capability of aggregating and managing resources in the NF-FG (Network Function Forwarding Graphs).

Ericsson Harmonizer [15] orchestrates heterogeneous networking domains, different for both switching technology (e.g., IP/MPLS, packet-optical) and control systems (e.g. Openflow, legacy GMPLS). Ericsson Harmonizer is able to provide an abstract view of the controlled domains in terms of QoS service parameters (e.g. peak/guaranteed bandwidth, loss,

delay, jitter) and to manage QoS paths crossing such domains. Interface 5 allows the use of several protocols for the communication, both standard (like PCEP and BGP-LS) and proprietary; Interface 3, instead, is based on a proprietary RPC based interface, but the migration to a netconf/YANG interface is planned (like Control Orchestration Protocol or COP interface defined in then Strauss project [12]).

Redzinc VELOX [13] EM (Equipment Manager) is a component of the VELOX framework that enables the reservation of (abstract) resources for the deployment of Virtual Path slices. It supports heterogeneous networking resources (i.e., IP/MPLS, SDN, EPC networks) by means of VELOX drivers. The interface 3 of VELOX is based on a proprietary northbound API towards the VELOX multi-domain orchestrator.

B. MdO candidate frameworks

T-NOVA FP7 project [14], implements a NFV orchestration framework compliant with ETSI NFV MANO [8], on top of which T-NOVA system includes a business layer or marketplace to facilitate commercial interactions among NFV business stakeholders e.g. Network Function NF software developers, Service Provider (SP) and customers. T-NOVA Marketplace allows SPs to purchase VNFs from software developers in order to compose network services and offer them to their customers, including SLA management, accounting and billing features and the corresponding interfaces with the NFV service orchestrator. The T-NOVA capabilities relevant to 5GEx multi-domain orchestration are:

- Service specification via an interface B2C (which can be mapped to MdO interface *I1*) based on the ETSI Network Service Descriptor (NSD) information model.
- Service and VNF catalogue that can be directly browsed by the customer.

- Structures to manage service instantiation and monitoring.
- SLA management by means of a component that facilitates SLA specification including definition of penalties or rewards and SLA evaluation.

UNIFY FP7 [11] project has proposed a novel SFC control plane architecture providing unified resource orchestration with joint network and software (compute, storage) virtualization and programming. ESCAPE [10] is a proof of concept prototype implementing the relevant parts of this architecture.

ESCAPE is a multi-domain orchestrator, thus strictly speaking, it implements the Orchestration Layer of the UNIFY architecture. However, a simple Service Layer interacting with clients, and an Infrastructure Layer based on Mininet were also added. The high-level components and their relations are shown in Figure 2. ESCAPE implements the main interface of UNIFY, namely the SI-Or, both at north and south. This enables multiple higher-level orchestrators on top of ESCAPE with corresponding virtual infrastructure views provided by virtualizers. ESCAPE itself constructs and works on a global domain view. The higher-level virtualizer configurations and VNF deployments are multiplexed in this element. The connection towards different infrastructure domains based on legacy or novel technologies are realized via dedicated adapter modules of ESCAPE. The most important one called UNIFY adapter implements the SI-Or interface that is a candidate for 5GEx interface I3.

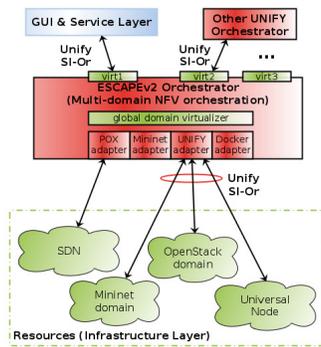


Figure 2 – ESCAPE

The most relevant capabilities provided by ESCAPE relevant to 5GEx multi-domain orchestration are:

- A Service layer, which receives service requests in form of service graphs according to ESCAPE interface U-SI.
- Service mapping into domains based on NFFG splitting.
- Network Functions configuration and monitoring.
- Resource control and monitoring for the resource domains supported in the UNIFY framework.

V. MDO ARCHITECTURE

The analysis of the candidate software components presented in the previous section results in the identification and definition of a set of functional requirements that are expected to be fulfilled by the Mdo. The functional blocks and interfaces of the Mdo are shown in Figure 3. Mdo modules are grouped in four major functional areas: *Exchange of Information and Control (EoIC)*, *Exchange of Functions (EoF)*, *Catalogs* and *Exchange of Resources (EoR)*.

The following sections describe the role of the Mdo modules and interfaces per functional area.

A. Exchange of Information and Control (EoIC)

The EoIC comprises of functional modules that operate buyer-supplier operations at service level, both for customers on interface I1, and Mdos belonging to other administrative domains on interface I2. Moreover the EoIC includes the modules that perform service mapping to topologies of NFs and SLA management. The service request management module exposes the API to request instantiation of services via interface I1-S. Moreover, it manages the instantiation of service slices, including: requesting the instantiation, configuration and interconnection of NFs as specified by the service mapping module. It is also responsible for providing SLA templates and SLA management instructions to the SLA management module to assess if the requested service SLA is fulfilled. Finally, it is also acknowledging the result of the service instantiation request through interface I1-S. Interface I2-S is meant to perform operations similar to those described for I1-S among EoIC belonging to different Mdos (i.e. to other Mdo Service Providers). EoIC modules coordinate using interface I2-S when the instantiation of the service involves multiple administrative domains. As introduced in Section III.C, both for I1-S and I2-S the service management operations imply the establishment of a business contract among the entities: Mdo customer to Mdo service operator - interface I1-S and Mdo operator to Mdo operator - interface I2-S.

With reference to the frameworks presented in Section IV.B, EoIC modules can be realized by the components implemented within the T-NOVA project.

B. Catalog

The modules exposing repositories of available services and NFs are part of the Catalog functional area. The service catalog's task is to expose available services to Mdo customers on I1-C and other Mdo service operators on I2-C. Each service is described by a service template, which includes a service graph (SG) of NFs. NFs could either be a basic service component, as described in the NF Information Base (NFIB), or recursively refer to services in the service catalog. Service templates are advertised across administrative domains using interface I2-C. The Mdo Service Provider A in Figure 3 can use services and NFs implemented by the Mdo Service Provider B and shared on I2-C to provision service to its customers. NFIB is a repository of NFs, including references to the abstract resources required to implement them. It also includes a description of the interfaces that the NF exposes, dependencies with other NFs, deployment artifacts and offered NF SLA.

With reference to Section IV.B, the T-NOVA framework implements a service catalog while Unify provide an NFIB.

C. Exchange of Functions (EoF)

The EoF functional area includes modules that deal with management, configuration and monitoring of NFs. The NF management module performs lifecycle management operations on individual NFs, which are defined in the NFIB, as well as fault management tasks, such as collecting alarms and notifications from the NF monitoring module and diagnosing failures. It also provides support for service re-

orchestration, performing operations like scaling in/out and migration on individual NFs over interface *I3-F* and *I2-F* for NFs deployed by other Mdo Service Providers.

The NF configuration module derives the necessary NF configuration instructions from the service specification and NFIB and from the orchestration decisions conducted by the service mapping module in EoIC. Any updates of the specification of the service instance or of its implementation may also trigger the reconfiguration of several NFs. Service configuration instructions may apply to Mdos in other administrations over interface *I2-F*.

The NFs need to be monitored during their lifecycle to assure that domains controlled by different Mdo instances provide enough resources to satisfy the required service specification, e.g. keeping the link latency under a given threshold. The NF monitoring module gets the monitoring configuration instructions from the NF management module and implements the required probes on Key Quality Indicators (KQI) at the NF level and Key Performance Indicators (KPI).

Some of EoF modules can be realised by components provided by the ESCAPE orchestrator in the project Unify.

D. Exchange of Resources (EoR)

The EoR functional area performs resource orchestration, exposing resource slices to EoIC and EoF. Four modules fall in this functional area, dealing with abstract resources and interfacing with underlying domain orchestrators for their realization. The resource topology acquisition module keeps an updated global view of the infrastructure topology exposed by domain orchestrators in multiple administrative domains using interfaces *I2-R* and *I3-R*. The topology information provided by the domain orchestrator or EoR in other Mdos might be a limited view of the domain infrastructure resources.

The resource bundling module aggregates resources belonging to different resource domains, implementing resource slices that may include abstract resources exposed by multiple domain orchestrators, even belonging to other administrative domains, e.g. to the Mdo Service Provider B in Figure 3, leveraging on APIs exposed on interface *I3-R* by domain orchestrators and *I2-R* by EoR of other Mdos.

The abstract resource monitoring and abstract resource control modules interface with the different domain orchestrators in multiple administrative domains to perform resource level operations as required by NFs, e.g. releasing infrastructure resources during the service shutdown process, scaling up/down computing resources, etc.

Some EoR modules can be realised by components provided by the ESCAPE orchestrator in the project Unify.

VI. CONCLUSIONS AND FUTURE WORK

Implementing end-to-end management and orchestration for 5G networks is feasible by appropriate development and integration of existing frameworks. In this paper we select a list of technology components for the management and orchestration of a complete spectrum of resource domains, covering cloud and networking. We identified in a set of components implemented by the FP7 projects T-NOVA and Unify as a baseline to realize resource orchestration and service orchestration in multi-domain environment.

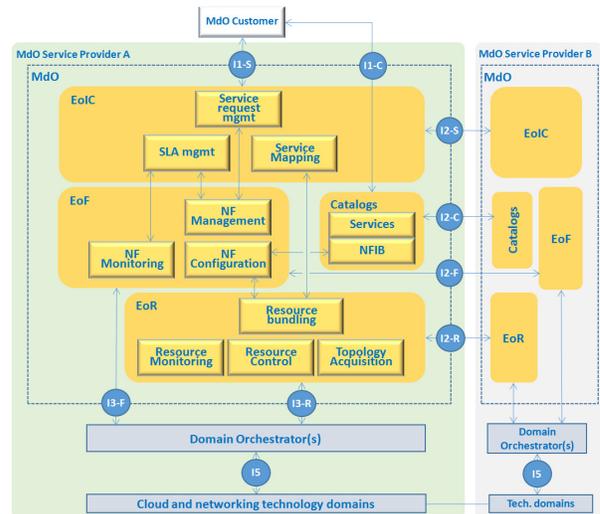


Figure 3 - Mdo Architecture

From this bottom-up approach we derived an Mdo functional architecture that covers all the requirements issued by industry operators association and standard bodies.

The Mdo functional architecture proposed in this paper is the first step of the H2020 ICT14 project 5G Exchange (5GEx) [4] towards the development and testing of a prototype for multi-domain orchestration and management of software defined infrastructures.

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