# ORCHESTRATING NEXT-GENERATION SERVICES THROUGH END-TO-END NETWORK SLICING

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## I. TOWARDS END-TO-END NETWORK SLICING

To cater for the wide range of existing and future network services, with a large diversity in requirements such as reliability, throughput, latency, reconfigurability, etc., future network efforts such as 5G are targeting end-to-end (E2E) network virtualization (also known as network slicing) [1]. Network virtualization allows network resources to be used in a flexible, dynamic, and customized manner, and most crucially, provides isolation between different virtual networks [2]. As a result, each virtual network (or Network Slice (NS)) operates as a separate network, and can be individually configured to serve a particular purpose [3]. Services such as critical low-latency machine communication in cyber-physical systems, high-speed autonomous vehicle communication, and low-power sensor communication could therefore each be offered a specific network slice, which would be tailored to service requirements, and would guarantee a particular set of performance characteristics.

End-to-end networks can comprise multiple network segments, e.g., radio access networks, transport and core networks, and data centre networks, and these network segments are typically built for different purposes. Network segments also use different media, such as optical fibre, copper cables, and wireless spectrum, and thus employ different technologies and protocols, e.g., xPON, xDSL, and LTE., with unique configurations, policy enforcement and QoS management [4], [5]. Hence, the creation of E2E network slices to provide guaranteed performance requires the slicing of each individual network segment, and the subsequent combination of these network segment slices [4] [6]. This white paper presents the vision of the H2020 ORCA project on combining these individual network slices to create E2E network slices.

# II. ORCHESTRATING DIFFERENT NETWORK SEGMENTS

Network slices within a network segment are managed by an entity called an orchestrator, that orchestrates the use of network resources and the placement of functionality in a network segment, and also defines the configuration, policies, and management of a network segment. However, as described above, there are fundamental differences between distinct network segments, both in terms of physical resources, and in the way that the network segments are used. As an extreme example, we describe the differences between wired and wireless network segments below.

Firstly, it is not possible to guarantee the information throughput capacity of wireless links, due to the inherent stochastic nature of the wireless medium, whereas the capacity of wired links is predictable and known. Secondly, wireless links are broadcast, and thus have the potential to interfere with other wireless links, whereas in wired links this does not occur [7]. Thirdly, wireless nodes tend to be highly mobile, which means that i) strategies for location and handover are needed, and ii) the traffic can fluctuate significantly as nodes move around in a network.

The communities behind each network segment have their own abstractions and models to manage the particularities of each segment. Therefore, the orchestration of all networks segments by a single community would lead to an oversimplification of the other segments' technicalities, and the loss of fine-grained control over resources. However, the current cross-segment orchestration initiatives are driven by a single community, e.g., the Open Source Management and orchestration (OSM), and the Mobile-Central Office Re-architected as a Datacenter (M-CORD), both are used for deploying network services in the core network and baseband units in the radio access network, and are led by the NFV (Network Function Virtualisation) and the SDN (Software Defined Network) communities, respectively.

We believe that each network segment should have their own orchestrator, tailored to the segment's particularities, as illustrated in Figure 1. The use of a separate orchestrator for each network segment reduces complexity and breaks down the larger E2E network

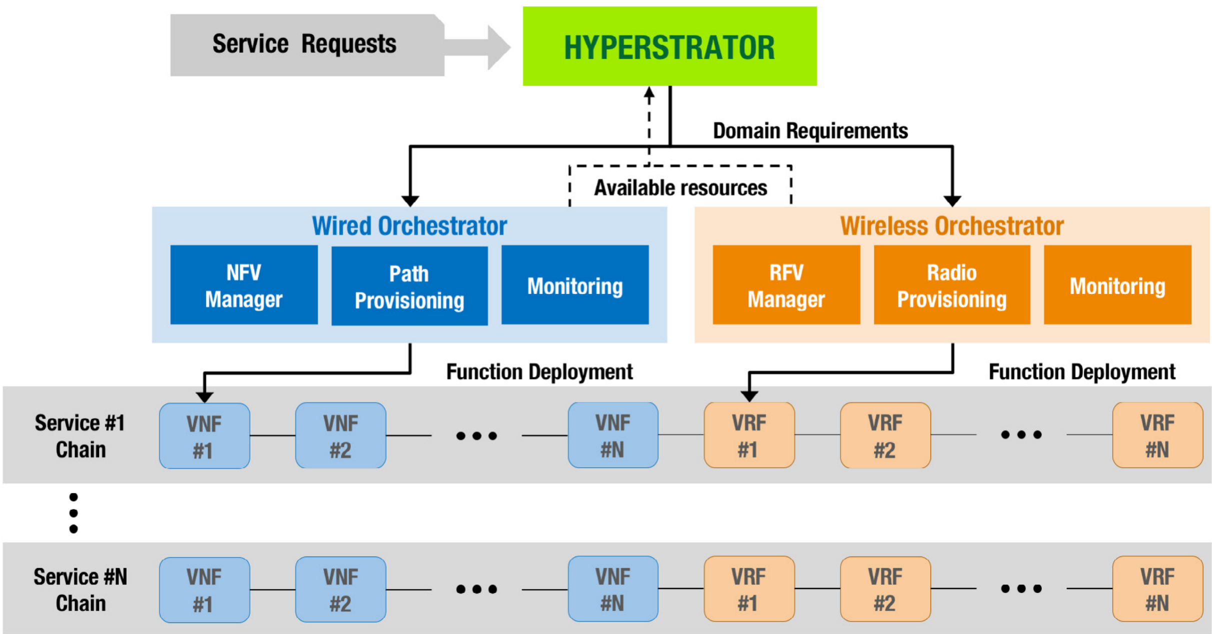


*Fig. 1: The hyperstrator receives service requests and decides the service resource requirements for each network segment, and delegates these to each segment orchestrator. Each orchestrator then provisions resources and deploys services as a chain of virtual functions.*

orchestration problem into smaller parts [8]. In this way, each segment orchestrator can focus on a limited number of well-defined tasks, reducing the software complexity, both in terms of design and implementation. We now highlight the potential tasks of wired and wireless orchestrators.

### A. Wired Orchestration

A wired network orchestrator is in charge of provisioning paths and deploying services in a wired network slice, building on SDN and NFV respectively. It should

1) know the geographical positions, points of presence (the interfaces between networks), storage capacity, computational power, etc. of physical nodes; and the throughput, delay, etc. of physical links;
2) instantiate virtual nodes and virtual links to deploy a network slice to establish a given path;
3) use a network slice to deploy services as a chain of Virtual Network Functions (VNFs) and Physical Network Functions (PNFs); and
4) possess monitoring capabilities to assess the state of the links, nodes, and services.

### B. Wireless Orchestration

A wireless network orchestrator is in charge of instantiating Radio Access Technologies (RATs) and providing radio coverage, leveraging Software-defined Radio (SDR) and Remote Radio Heads (RRHs). It should

1) know geographical positions, points of presence, computational power, storage capacity, radio front-end capabilities, etc. of physical base stations and access points; the spectrum resources, channel conditions, and the resulting average throughput, latency, etc. of the wireless links; and the maximum movement speed and propagation distance, etc. of radio terminals;
2) provision virtual radio stations and virtual links to deploy a radio slice to cover a given area;
3) use radio slices to deploy radio services, such as RATs, as a chain of Virtual Radio Functions (VRFs) and Physical Radio Functions (PRFs); and
4) possess monitoring capabilities to assess the state of the wireless links, radio stations, and radio services.

The ability to orchestrate E2E network slices across multiple networks segments is still missing, however, which requires a global view of network resources [8].

## III. HIERARCHICAL ORCHESTRATION OF END-TO-END NETWORKS

Different types of orchestrators are deployed according to the type of resources being managed: wired network orchestrators for managing NFV and SDN and for establishing paths and deploying services; wireless network orchestrators for managing RRHs and SDRs for creating RATs and provisioning radio access. However, E2E network slicing will require a combination of multiple types of orchestrators. In
this scenario, there must be an entity with a global view of the available resources and the capabilities of each orchestrator for establishing and managing flexible E2E networks, leveraging the virtualization of each network segment. This entity would be an orchestrator of orchestrators, which coordinates the interaction between the underlying virtualized infrastructure, namely a hyperstrator.

The hyperstrator would sit on top of different orchestrators for controlling the E2E allocation of resources and management of the entire network. It would be the responsible for mapping high-level E2E network requirements into the requisites for the different networks segments, while each of the underlying orchestrators would then map their own requisites into a realization using the available virtualized resources. The hyperstrator knows the available resources and the status of the current services by gathering information from its underlying orchestrators. Moreover, the hyperstrator must coordinate

the combination of slices between network segments for creating E2E NSs. Therefore, it is crucial for the hyperstrator to be aware of the points of presence between network segments, as these are the places where network segments interface and interconnect.
Our proposed hierarchical orchestration scheme is shown in Figure 1, using a hyperstrator on top of the network segment orchestrators to deploy E2E network services. The underlying orchestrators are responsible for deploying their parts of the service as a chain of virtual or physical network functions and radio functions. Apart from the coordination of resources within an administrative network domain, the hyperstrator could potentially be used for leasing or sharing E2E network resources with other networks operators, through their respective hyperstrators.

# IV. KEY BENEFITS

The architecture of the presented hierarchical orchestration scheme based on a hyperstrator and specialized orchestrators is both modular and extensible. Breaking down E2E network orchestration into specialized segment orchestrators designed by domain experts, reduces vulnerability to a single point of failure in the network. In addition, as long as there is a well-defined and open interface between the hyperstrator and the underlying orchestrators, each orchestrator can be easily and independently changed or upgraded.

Furthermore, the separation between system-wide requirements from the requirements of individual network segments facilitates the integration of orchestrators that manage additional (current or future) types of network segments.
Therefore, the architecture we propose enables the end-to-end provisioning of network slices, tailored to the particular requirements of future network services, and guarantees desired end-to-end network performances for different services.

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