5G-Crosshaul Network Slicing: Enabling Multi-Tenancy in Mobile Transport Networks

Xi Li, Ramon Casellas, Giada Landi, Antonio de la Oliva, Xavier Costa-Pérez, Andres Garcia-Saavedra, Thomas Deiß,Luca Cominardi, and Ricard Vilalta

The authors present the 5G transport network architecture designed in the 5G-Crosshaul project. An SDN/NFV-based control plane has been designed that enables multi-tenancy through network slicing. The proposed solution allows for flexible and efficient allocation of transport network resources to multiple tenants by leveraging widespread architectural frameworks for NFV and SDN.

ABSTRACT

5G requires a redesign of transport networks in order to feed the increasingly bandwidth hungry radio access networks and to benefit from the performance/cost efficiency provided by the integration of both backhaul and fronthaul segments over the same transport substrate as well as the incorporation of cloud RAN architectures. In addition, to increase its usage and cost efficiency, this new transport network should allow simultaneous use by different tenants (e.g. MVNOs, OTTs, and vertical industries). This article presents the 5G transport network architecture designed in the 5G-Crosshaul project to address this challenge. An SDN/NFV-based control plane has been designed that enables multi-tenancy through network slicing. The proposed solution allows for flexible and efficient allocation of transport network resources (networking and computing) to multiple tenants by leveraging on widespread architectural frameworks for NFV (ETSI NFV) and SDN (e.g., Open Daylight and ONOS).

INTRODUCTION

Fifth generation (5G) mobile transport networks will support multiple cloud radio access network (RAN) functional splits in a flexible and unified manner. This will allow for various degrees of RAN centralization, varying from distributed RAN (D-RAN) to fully centralized RAN (C-RAN). Thus, 5G transport networks will flexibly distribute and move base station functions across data centers, introducing another degree of freedom for resource management. In this context, the division between *fronthaul*, which is the interface between the remote radio heads (RRHs) and their associated centralized processing units (baseband units, BBUs), and *backhaul* will blur, since varying portions of functionality of the base stations will be moved flexibly across the transport network, as required for cost efficiency/performance reasons. In order to fulfill these requirements, we propose a new generation of transport networks for 5G integrating both fronthaul and backhaul segments into a common transport infrastructure, defined as **5G-Crosshaul** [1]. This 5G transport network aims to enable a flexible and software-defined reconfiguration of all networking elements in a multi-tenant and service-oriented unified management environment, through unified data and control planes interconnecting distributed 5G radio access and core network functions, hosted on in-network cloud infrastructure.

One of the most important and desired features of 5G-Crosshaul is *multi-tenancy*, that is, the ability to support multiple tenants while enabling flexible sharing of the 5G-Crosshaul physical infrastructure, so that each tenant can operate, independently, a subset of such resources. The aim of multi-tenancy is to maximize the degree of utilization of infrastructure deployments and to minimize the costs of rollout, operation, and management — reducing both the capital (CAPEX) and operational (OPEX) expenditures — and to reduce energy consumption, which are essential goals of 5G [2]. In our context, a tenant can be associated with an administrative entity or a user of a given service and implies a notion of ownership of one or more service instances and isolation between these instances.

Multi-tenancy is enabled by technologies such as network virtualization and network slicing, both covering the processes by which an infrastructure is physically or logically partitioned, segmented and assigned to different users. More formally, in line with related work (e.g., [3]), we define a *network slice* as *a self-contained, coherent set of functions along with the infrastructure required to support such functions, offering one or more services for end users.*

Although multi-tenancy is a concept that has been developed in many contexts, its applicability and benefits within transport networks has been addressed more recently. In the scope of the Fifth Generation Public Private Partnership (5GPPP), projects like 5G-NORMA and SESAME are addressing RAN multi-tenancy [4] while CHARISMA covers 5G access networks. The work in this article complements related work by focusing on the transport network aspects directly related to the combined fronthaul and backhaul, targeting per-tenant services that combine computing, storage, switching and transmission resource management. This article presents a novel architecture unifying the aspects of resource virtualization, virtual infrastructure, and network service management, combining the European Telecommunications Standards Institute (ETSI) network functions virtualization (NFV) management and

Xi Li, Xavier Costa-Pérez, and Andres Garcia-Saavedra are with NEC Laboratories Europe; Ramon Casellas and Ricard Vilalta are with CTTC/CERCA; Giada Landi is with Nextworks; Antonio de la Oliva is with Universidad Carlos III de Madrid; Thomas Deiß is with Nokia; Luca Cominardi is with Interdigital Europe.

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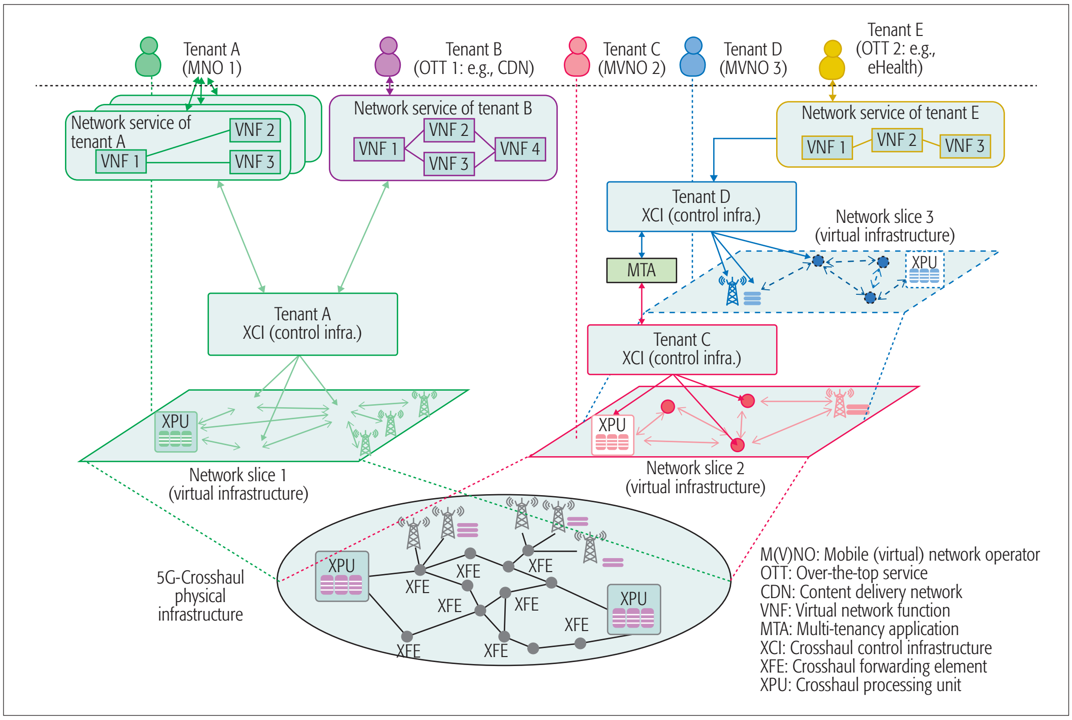

Figure 1. Network Slicing in 5G-Crosshaul for multi-tenancy support.

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network orchestration (MANO) framework with integrated software defined networking (SDN)-based control. Note that the general concepts proposed in this article also can be applied to other segments of a mobile system (i.e., the core network and the RAN) to constitute an end-to-end (E2E) system. E2E network slicing relies on E2E orchestration (in some cases federation) between different network domains.

Our final target is to enable *slicing as a service* addressing the dynamic allocation of slices over a shared 5G-Crosshaul. The allocation of a slice involves the selection of the functions, their constrained placement, and the composition and configuration of the underlying infrastructures (either physical or virtual) fulfilling the services' requirements, in terms of latency, bandwidth, processing capacity, and so on. We consider two main network slicing services that enable different degrees of explicit control and are characterized by different levels of automation of network slice management:

- The provisioning of virtual infrastructures (VIs) under the control and operation of different tenants — in line with an infrastructure-as-a-service (IaaS) model
- The provisioning of a tenant's owned network services (NSs) as defined by the ETSI NFV architecture [5]

In the former, detailed later, a VI is defined as a logical construct composed of virtual links and nodes, which, as a whole, behaves as and can be operated as a physical infrastructure, enabling different degrees of internal control (i.e., can be operated by the tenant via different SDN control models). The service involves dynamic allocation of a VI, and its operation and deallocation. The actual realization of a VI combines many aspects like partitioning and bookkeeping of resources, and the instantiation of connections supporting virtual links. The provisioning of a VI commonly requires direct hardware element support or its emulation via software for multiplexing over the shared infrastructure.

In the latter, described later, an NS is instantiated directly over a shared infrastructure, and as a set of interrelated virtual network functions (VNFs). An NS corresponds to a set of endpoints connected through one or more VNF forwarding graphs (VNF-FGs). Note that whether the allocation of a NS is implemented in terms of the allocation of an underlying VI and the subsequent instantiation of the VNFs over the containing virtual machines (VMs) is an implementation choice.

Multi-tenancy is an orthogonal characteristic of both services, guaranteeing separation, isolation, and independence between different slices coupled with efficient sharing of the underlying resources. Consequently, 5G-Crosshaul defines the term *tenant* as a logical entity owning and operating either one or more VIs or one or more NSs, ultimately controlling their life cycle. The concept is illustrated in Fig. 1, where the owner of the physical infrastructure allocates VIs over its substrate network, providing multiple network slices to offer different tenants. Each tenant, such as a mobile (virtual) network operator (MNO or MVNO), owns and operates a network slice. In this example, tenants A, C, and D own network slices 1, 2, and 3, respectively. Moreover, tenant A itself can also allow sharing of its infrastructure by other tenants. The M(V)NO tenants can further deploy their own NSs or allow multiple third party tenants (e.g. over-the-top, OTT, service providers) to instantiate their NSs on top of the VI (e.g., tenant B deploying its NS over the VI of tenant A). It is possible to instantiate a VI on top of another one following a recursive approach (e.g., the VI of tenant D is instantiated over the one of tenant C.)

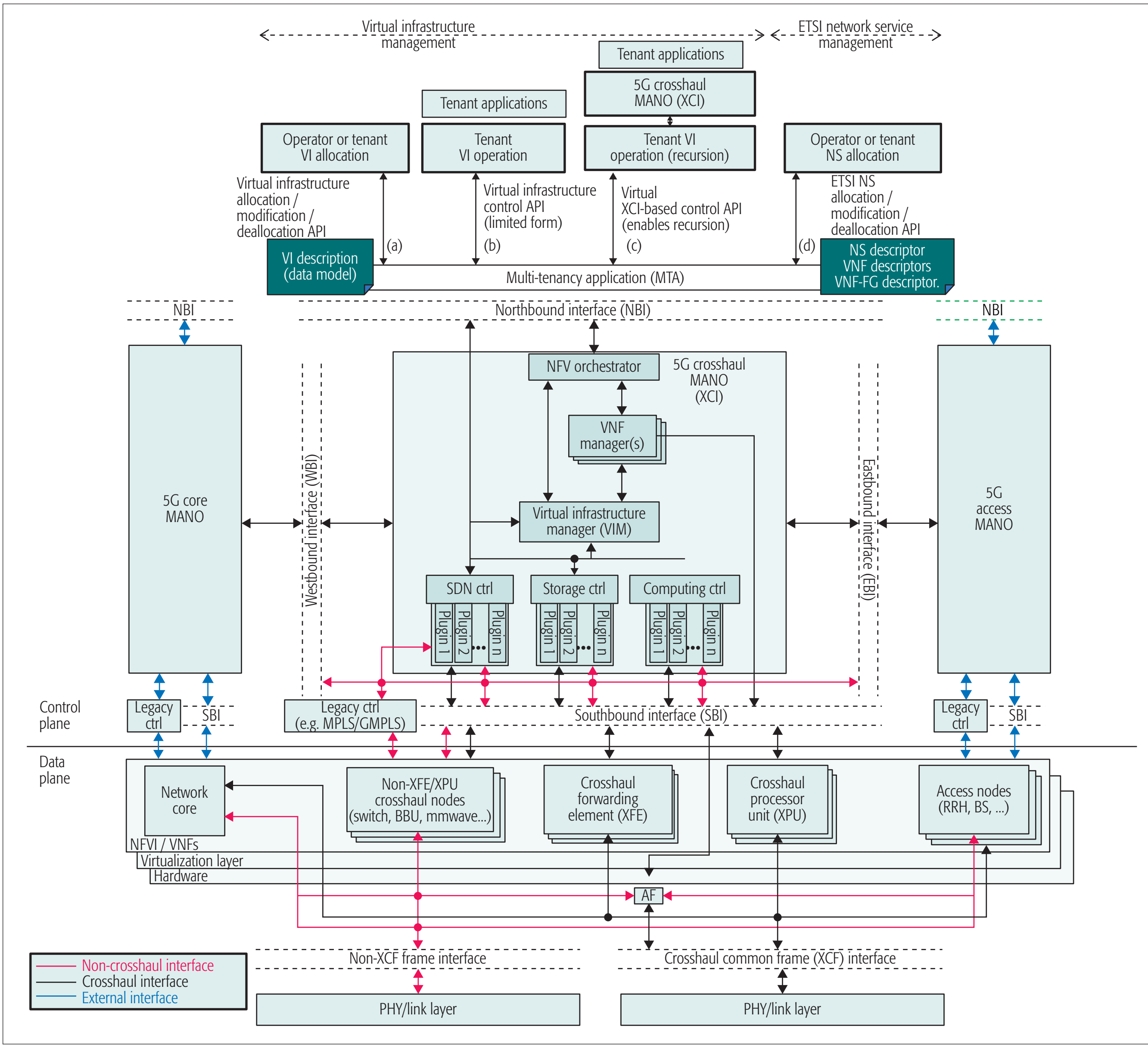

Figure 2. 5G-Crosshaul architecture for multi-tenancy.

From the point of view of business models, network slicing allows MNOs to open their physical transport network infrastructure to the concurrent deployment of multiple logical self-contained networks. The availability of this vertical market multiplies the monetization opportunities of the network infrastructure as:

- New players may come into play (e.g., automotive industry, e-health).
- Higher infrastructure capacity utilization can be achieved by exploiting multiplexing gains.

For the particular 5G-Crosshaul services, VI deployments are oriented to the business-to-business (B2B) market, targeting customers like MVNOs and cloud providers specializing in customizable IaaS services, since they need deep control of the network segment between distributed data centers. VIs also can be deployed by network operators to create virtualized and highly controlled environments to test and validate services before their rollout. Conversely, NSs target customers operating in the B2C segment, like application or service providers that offer services to end users (e.g., content providers specializing in streaming services).

5G-Crosshaul Architecture

The extended 5G-Crosshaul architecture based on the baseline design in [6], supporting several use cases of multi-tenancy, is depicted in Fig. 2. It follows the SDN principles:

- The data and control planes are fully decoupled.
- Control is logically centralized.
- Applications have an abstracted view of resources and states.

Our design approach leverages state-of-the-art SDN and NFV architectures to maximize the compatibility and integration of the system design with the existing standard frameworks and reference specifications, and to allow the reuse of open source projects to facilitate its deployability while minimizing the implementation costs. The extensions we proposed on top of the baseline architecture are the multi-tenancy application (MTA) and a set of application programming interfaces (APIs) to support the various multi-tenancy services, as shown in Fig. 2, for the control of a VI or NS lifetime, instantiation, modification, and deletion (API classes a and d in the figure), and for the control of the VI in its limited or full-featured form (API classes b and c, respectively).}

The **data plane** comprises Crosshaul forwarding elements (XFEs) and Crosshaul processing units (XPUs). XFEs are switching units, based on packet or circuit technologies, that interconnect a broad set of link and PHY technologies using a common framing (Crosshaul common frame, XCF) to transport both backhaul and fronthaul traffic. XPUs take care of most of the computational burden including BBUs or medium access control (MAC) processors, virtual network functions (VNFs), and other virtualized services. To this aim, the data plane makes use of an NFV infrastructure (NFVI) relying on generalized hardware components.

The **control plane** is divided into two layers: an application layer at the top and the 5G-Crosshaul control infrastructure (XCI) below. The XCI is our 5G transport MANO platform, compliant with the NFV MANO reference architecture, and provides an abstracted view of available resources, states, and control and management functions to an ecosystem of applications via a northbound interface (NBI). The XCI is connected to the data plane elements via southbound interfaces (SBIs) to execute control and management functions on the actual hardware components. The NFV orchestrator (NFVO) manages an NS life cycle. It coordinates the VNF's life cycle and the resources available at the NFVI in the data plane (supported by the virtual infrastructure manager, VIM) to ensure an optimized allocation of the necessary resources and connectivity to provide the requested virtual network functionality. The VNF managers (VNFMs) are responsible for the life cycle management of VNF instances. Finally, the VIM is responsible for controlling and managing the NFVI computing (via computing controllers), storage (via storage controllers), and network resources (via SDN controllers).

Although the scope of the XCI is limited to the transport network, it is essential to also consider the end-to-end coordination with other network segments (notably the 5G access and core segments). As shown in Fig. 2, our design includes westbound and eastbound Interfaces (WBI/EBI) to communicate with the 5G core MANO and the 5G access MANO. They can be used for functions like reachability dissemination or (abstracted) topology and provisioning information to help achieve system-wide optimization, enabling either a purely hierarchical architecture or a distributed/peer model for the orchestration of all involved segments. That said, the 5G access and core are out of the scope of 5G-Crosshaul. Work in complementary projects like 5G-Exchange can be leveraged for multi-domain orchestration and federation [7].

The MTA is the application that implements the support for multi-tenancy, by coordinating and managing tenants' access to the shared infrastructure, driving resource allocation for instances assigned to different tenants, and delivering multi-tenancy related services by means of dedicated APIs.[1] A high-level requirement is resource isolation, understood as the function of partitioning, separating and book-keeping of resources such that a tenant has no visibility of or access to the resources associated to another tenant. To perform this function, the MTA uniformly wraps and complements the infrastructure elements' (SDN controllers, cloud management systems, network elements, etc.) capabilities to provide multi-user and resource isolation support, offering uniform and abstracted views to tenants. Regarding mechanisms for isolation, our approach is to rely on existing ones, with the MTA acting as middleware and hypervisor. Full resource isolation requires system/infrastructure support, and it is not straightforward or may not even be achieved, for example, without hardware redundancy. 5G-Crosshaul provides soft resource isolation including, notably, driving the SDN controllers capabilities to create per-tenant networks, allocating software switches within XPUs dedicated to per-tenant traffic, defining security groups and per-tenant addressing, switching and routing within XPUs, and logically separating traffic within XPEs. Similarly, from the ETSI NFV/MANO perspective, the MTA manages state regarding allocation of NSs mapping tenants to actual instances and relying on implementations support.

5G-Crosshaul Virtual Infrastructure Services

The allocation of a VI can be triggered by a tenant (e.g., a VNO), either directly consuming the MTA API — Fig. 2, API a — or via the intervention of the infrastructure operator in a less dynamic environment, after an offline service level agreement (SLA). The VI concept is quite generic and can be extended to incorporate infrastructure elements beyond the ones considered herein. As part of the deployment of a VI, network, computing, and storage resources need to be partitioned and aggregated, eventually recursively if a hierarchy is enabled. This partitioning can be committed in full at the time of instantiation (hard allocation) or reflected in terms of predefined quotas that are enforced at the time of use (soft allocation).

It is noteworthy that VI allocation follows an IaaS model, so the actual use of the VI (including the functions and related business logic) is defined by the tenant. The infrastructure owner is agnostic to the VI end use. Once a given VI has been allocated, the 5G-Crosshaul MTA empowers the tenants with different degrees of control to be exerted over it, with different operational models of control and management. In simple terms, this ranges between either of the following:

- The control and management are restricted to the operational management and integration with the tenant operation support system (OSS)/base station support (BSS), and the operation of VI is mostly autonomous, with limited involvement of the tenant, such as monitoring and SLA validation.
- Each tenant is free to deploy their choice of the infrastructure operating system and control plane, allowing the optimization of the resource usage within each VI.

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[1] In the considered model, a single tenant entity owns one or more instances of each service in a 1:N relationship.

The tenant has access to application-level interfaces only and the NS provisioning API follows an "intent-based" modeling approach where the tenant asks just for the composition of some network functions, without caring about how they should be deployed and delivered.

The former model involves the MTA offering an API that enables the tenant to have a limited form of control over the (abstracted) elements that constitute the VI — Fig. 2, API b — including a set of operations and policies that can be applied (e.g., retrieve an aggregated view of the virtual infrastructure topology and resource state, and apply rules that affect element configuration and behavior). Low-level operations such as the actual configuration and monitoring of individual flows at the nodes may not be allowed. The latter implies per-tenant controller — Fig. 2, API c — or per-tenant MANO (XCI), including, most importantly, the ability to offer network services over its allocated virtual infrastructure. This approach ultimately enables recursion.

5G-Crosshaul ETSI/NFV Network Services

The allocation of an NS extends and complements the concept of VI deployment — Fig 2, API d — to deliver isolated chains of virtual services composed of specific VNFs in an automated manner. The tenant request usually specifies the type of VNFs (i.e., the desired virtual application components) in the NS Descriptor, their capabilities and dimensions through one or more VNF Descriptors, and how they must be interconnected through a VNF-FG Descriptor. Templates for the unified description of these information elements are currently under the standardization process in the ETSI NFV Interest Study Group (ISG) and OASIS TOSCA standards [8].

In the VI case, the tenant is responsible for the low-level deployment and configuration of its own applications over the allocated VI, while maintaining a certain level of control on the operation of the virtual resources. In the NS case, the tenant is interested in operating the applications that run in these virtual resources and expects that the needed level of resource capacity is seamlessly available in real time without any further configuration effort. The deployment and continuous management of the whole service is completely automated and totally delegated to the MTA and the NFVO within the XCI. The tenant has access to application-level interfaces only, and the NS provisioning API follows an intent-based modeling approach where the tenant asks just for the composition of some network functions, without caring about how they should be deployed and delivered.

In this scenario, the MTA is responsible for maintaining and coordinating the logical mapping between tenants, assigned services (in terms of NS and VNFs instances), and underlying virtual resources, in compliance with the SLAs established. Multi-tenancy is handled at different levels: at the lower level, a tenant has assigned physical and/or virtual resources in the domain of a VIM; at the upper levels, tenants have assigned VNFs and NSs. These different kinds of tenants can overlap and be merged in a single entity or be mapped over separate entities. For example, a VNO can further virtualize the rented VI to serve different kinds of business customers, like CDN providers, delivering dedicated VNFs and NSs. The management of these tenants' relationships, together with the correlated authorization and SLA validation and assurance procedures are under the responsibility of the MTA. Moreover, in these scenarios, NSs are not built directly on top of physical resources, but over VIs through the allocation of VNFs and VNF-FGs in VMs and virtual network nodes, following a recursive approach. This involves the operation of multiple MTA instances deployed at different levels and requires the mediation of XCI components deployed over the VI itself (further details are provided later).

At a lower level of service coordination, the NFVO in the XCI is responsible for the instantiation of the different NS components, based on the descriptors and metadata provided at the instantiation stage by the tenant. The NFVO, with the optional cooperation of the MTA, makes decisions about the most convenient usage of infrastructure resources, and allocates the required VMs and network connections accordingly. Moreover, during the NS life cycle, the NFVO is also responsible for the continuous monitoring of resource failures or infrastructure and application performance, coordinating the automated reactions for up/downscaling and self-healing procedures at the single VNF and global NS levels.

Requirements and Enabling Technologies for Multi-Tenancy

Multi-tenancy support requires a coordinated, holistic approach from the hardware to the XCI controllers up to the application layer, where the MTA acts as a global orchestrating entity. In this section we present the main requirements to support multi-tenancy at all these layers, analyzing the approaches that can be adopted to meet them.

Data Plane

When carrying the data of several tenants through the network, several requirements have to be considered:

- Traffic *separation*. One tenant should not be able to listen to the traffic of other tenants or of the network provider.
- Traffic *isolation*. The network has to provide guaranteed quality of service (QoS) to traffic of different tenants. Traffic of one tenant should not impact the QoS of the traffic of other tenants.
- Traffic *differentiation*. The traffic of different tenants may be forwarded differently, even when entering or exiting the network at the same points of attachment.
- *Statistical multiplexing*. Multiplexing gains should be possible among the traffic of different tenants.

The technical solution for traffic *separation and isolation* depends on the specific data plane technology adopted for the XFE, circuit or packet switched forwarding. For circuit switched forwarding, traffic separation, isolation, and differentiation can be achieved by creating different circuits per tenant. Although this is beneficial to achieve low and deterministic latency, for example, it does not provide *statistical multiplexing* gains among the traffic of different tenants, which are instead enabled with packet switching technologies.

For packet switched forwarding, the multi-ten-

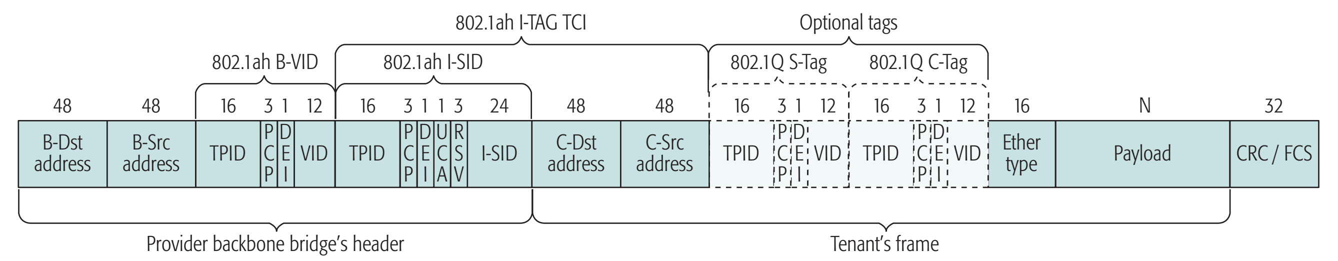

Figure 3. Provider backbone bridge — traffic engineering header.

ancy requirements are supported by using a common frame format across the network and different transmission technologies: the 5G-Crosshaul XCF. We propose provider backbone bridge — traffic engineering (PBB-TE) [9] as a common format to encapsulate the tenants' traffic, but other frame formats such as multiprotocol label switching — transport profile (MPLS-TP) can be used alternatively (for a comparison of PBB-TE and MPLS-TP see [10]).

In our solution, the fields in the PBB-TE header (Fig. 3) are used to achieve the multi-tenancy requirements as follows. Traffic *separation* is based on the backbone VLAN ID (B-VID) and the service ID (I-SID), used to identify the traffic for different tenants by using unique identifiers per tenant or even per service of the tenants. This allows the creation of different virtual networks and keeping the traffic separate at the XFEs. Independent forwarding decisions are also made at the level of these separate traffic flows, thus achieving traffic differentiation on a per-tenant basis. Traffic *isolation* regarding QoS is based on the three priority-code-point bits within the header, used to distinguish different types of service within the network and to schedule the packets for forwarding based on this priority information. At the ingress of the network, this priority has to be set appropriately and consistently across the different tenants to simplify the rules within the network.

Per-tenant XCF forwarding decisions are elaborated at the control plane and configured on the data plane following a forwarding abstraction model common to all the XFEs, either circuit- or packet-based. Such models are defined by the southbound protocols that define the interaction between the data and control planes. We propose the use of the OpenFlow protocol suite as the SBI for controlling the forwarding of XCF frames.

Control Plane

Support of multi-tenancy has a strong impact on the XCI components, from the network controller to the VIM and MANO components for the orchestration and delivery of VNFs and NSs.

At the SDN controller level, multi-tenancy requirements are related to the following aspects:

- *Delivery of per-tenant virtual network infrastructures*, providing the user with a uniform, abstract, and data-plane-independent view of its own logical elements, while hiding the visibility of other coexisting virtual networks
- Logical *partitioning of physical resources* to allocate logical and isolated network elements handling per-tenant traffic
- *Configuration of traffic forwarding* at the data plane level compliant with per-tenant traffic separation, isolation, and differentiation in the data plane

Tenant-based *virtual networks delivery* is handled through a dedicated SDN controller service. Its northbound APIs allow authorized tenants to request and operate their own network instances following abstract specifications (e.g., based on intent-based network models). Access to virtual resources is wrapped by the SDN controller and regulated at the northbound APIs based on tenants' profiles. *Physical resource partitioning* is managed within the SDN controller service through resource allocation algorithms combined with procedures to map logical network concepts with their corresponding entities or traffic configurations at the physical level. *Traffic separation* is achieved through the creation of tagged connections, exploiting the XCF multi-tenant features as explained earlier. Forwarding rules for the resulting traffic flows are then installed across the physical network following the paths computed by the resource allocation algorithms on a per-tenant basis (*traffic differentiation*), while QoS is handled through the creation of meters or queues (*traffic isolation*).

An example of SDN application for provisioning of multi-tenant virtual network infrastructures is the OpenDaylight Virtual Tenant Network (VTN) project [11]. The VTN application allows a tenant to request a virtual network. The mapping between network packets exchanged between OpenFlow switches at the data plane and instances of virtual networks defined at the logical level is based on ports and/or VLANs (Fig. 4). Each virtual network entity implements the typical functions of a corresponding physical element; for example, virtual routers provide routing, Address Resolution Protocol (ARP) learning, and Dynamic Host Configuration Protocol (DHCP) relay agent functions. Moreover, the tenant has the possibility to control the network behavior, defining a set of actions for flows matching layer 2–3 (L2–L3) filters.

At the VIM and VNF MANO level, beyond similar considerations of virtual resource allocation and isolation extended to computing elements, suitable modeling of the tenant and its capabilities needs to be supported. *Resource allocation* is handled through the creation of VMs and software switches assigned to specific tenants within the XPU, with isolation managed allocating specific addressing spaces and configuring proper routing rules and security groups. *Tenant profiles* are defined at the VIM and at the NFV orchestrator. At the VIM, each tenant has its own view of the VIM capacity, policies to regulate the access to the resources (e.g., a quota of dedicated resourc-

Our MTA approach is based on virtualization, and this usually involves refinements in the components architecture, enabling one-to-many and many-to-many relationships of software components and implementing the required mechanisms to guarantee security and isolation.

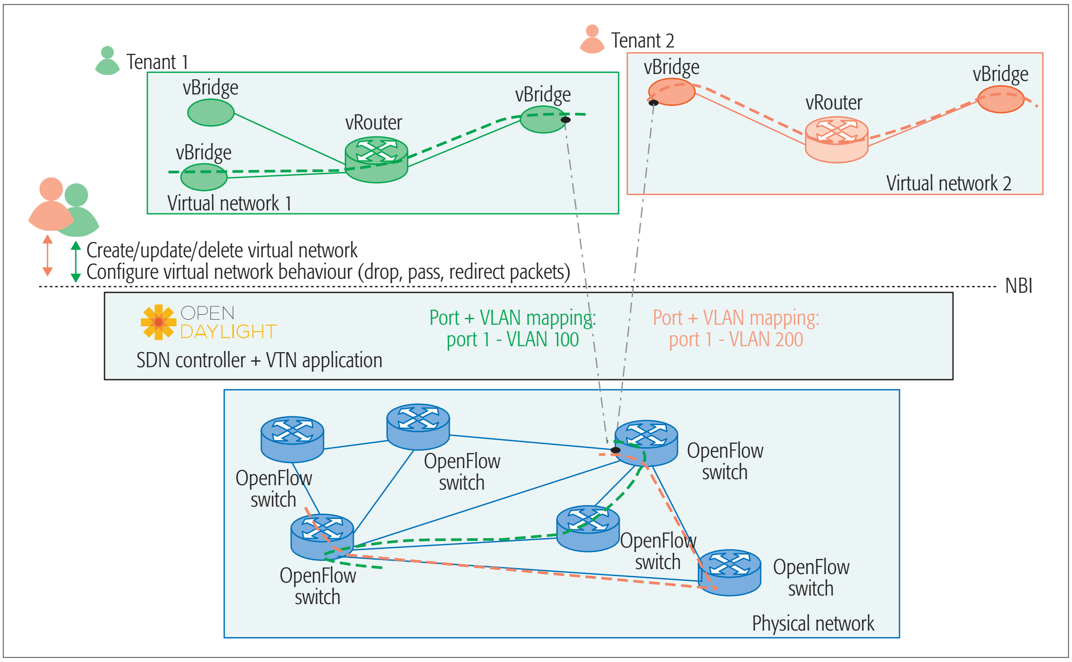

Figure 4. Virtual networks mapping in the OpenDaylight Virtual Tenant Network application.

es), and, optionally, custom resource flavors and VM images [12]. Requests for new VI must be authenticated and authorized, and they are evaluated based on the resources still available in the tenant's quota. Finally, access to the instantiated VI is strictly limited to the tenant owning the specific instance. Most cloud computing platforms (e.g., VMware, OpenStack) support multi-tenancy.

A similar approach, based on per-tenant profiles and policies, needs to be adopted at the NFV orchestration level, extending the virtual resources concept to VNF and NS entities. Each tenant must have a view and control of its own VNFs and NSs only; they must be maintained fully isolated from other entities belonging to different tenants, to guarantee their security and their desired key performance indicator (KPI) level independent of the load of other VNFs. New service requests must be granted depending on the tenant's profile, in combination with the tenant-related policies at the VIM level. Currently, this implies extending the functions of the NFVOs such as Open Source Mano and OpenBaton to manage tenant separation and mapping between tenants and NSs.

In general, our MTA approach is based on virtualization, and this usually involves refinements in the components architecture, enabling one-to-many and many-to-many relationships of software components and implementing the required mechanisms to guarantee security and isolation. From the point of view of performance, the overhead strongly depends on the underlying infrastructure and technology support (VLAN tagging, separate switching instances, compute resource quotas, etc.) and the need or not to emulate such features purely in software. In our considered use cases it is largely within acceptable operational ranges.

Application Plane

Coherent management of multi-tenancy is required horizontally for unifying the concepts of infrastructure virtualization and multi-tenancy in all involved segments and resources. The MTA at the application level provides such management, becoming the logical decision entity and serving as an optimizer to decide the allocation/modification/deallocation of network, compute, and storage resources. Essentially, the application decides an optimum subset of nodes (node mapping) and links (link mapping) in the substrate network to build a VI for a tenant that satisfies its resource demand and SLAs, by solving classical virtual network embedding (VNE) problems.

A VNE process consists of two coupled subproblems: node mapping and link mapping. The node mapping problem consists of reserving, for each virtual node, enough computational resources of a substrate node without exceeding capacity. Analogously, the link mapping phase consists of finding, for each pair of virtual nodes, a path (a collection of substrate links) to connect them. The selected paths must satisfy the networking requirements of each virtual link without exceeding network capacity on the physical links. The problem is recognized as NP-hard, and several approaches (e.g., [13]) have been proposed, which compromise optimality to find feasible solutions.

To deploy and enforce the computed mapping, the MTA needs to interact/coordinate with several functional entities inside the XCI — the SDN controller, the NFVO, and the VIM — either to collect information (GET command) or to provide commands (PUT command) (Fig. 5). The MTA covers both network- and computing- related functions. The actual workflows are strongly dependent on each use case. For the network-related services, the MTA first collects information on physical topology, traffic paths, and link load through the XCI, then computes the optimum allocation of networking resources and commands the XCI to perform the required configuration. This may involve direct requests to the SDN controller (to provision network paths and/or allocate virtual nodes providing the desired mapping between physical and virtual ports). For the computing-related services, the MTA may ask

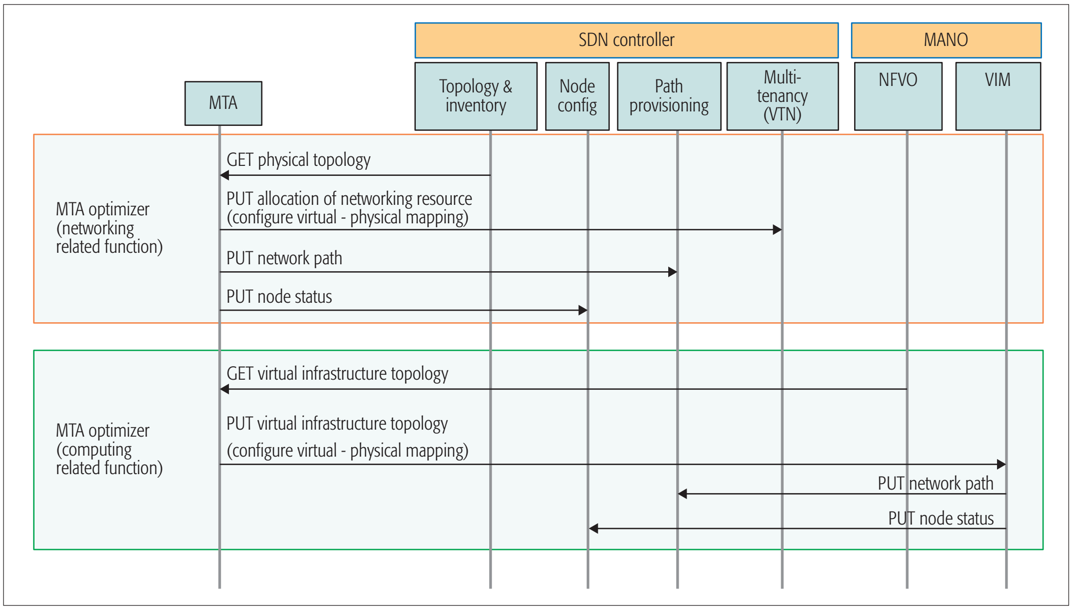

Figure 5. Workflow of the multi-tenancy application: interaction with the control plane.

The 5G-Crosshaul architecture has been designed to not only support sharing of the common transport infrastructure by multiple tenants, but also to allow each tenant to own and deploy its own MANO system. We refer to this case as multi-MANO, building a hierarchy of tenants operating on top of slices of VI.

the NFVO to provide a VI topology specifying where the VNFs must be placed or to directly instruct the VIM to enforce the mapping between virtual infrastructures and corresponding physical resource. The VIM itself will in turn request the SDN controller for the provisioning of required network paths and related node configurations.

Multi-Tenancy Recursion

The 5G-Crosshaul architecture has been designed to not only support sharing of the common transport infrastructure by multiple tenants, but also to allow each tenant to own and deploy its own MANO system. We refer to this case as *multi-MANO*, building a hierarchy of tenants operating on top of slices of VI. This concept requires support for XCI recursion to allow multiple instances of the 5G-Crosshaul MANO operating on top of the set of services provided by the XCI instance below. The 5G-Crosshaul architecture enables this functionality, on one hand, by providing support and bookkeeping of resources, maintaining a consolidated state of the virtual resources provided to each tenant, and, on the other hand, by providing a homogeneous API for controlling the underlying virtual resources which is transparent to the level of the hierarchy where the tenant is operating.

Figure 6 shows the recursive architecture. In the lower layer, the owner of the physical resources (MNO), instantiates its XCI. Different tenants request the provisioning of VIs to the MTA. By means of a template, blueprint, or SLA, each tenant specifies not only the slice characteristics (topology, QoS, etc.) but also some extended attributes such as the level of resiliency desired. The provider must take care of meeting the requirements and managing the available resources. Through the use of the MTA application, the resources at the MNO are hidden to the MVNOs, providing a layer of abstraction easing the management of each slice.

In a recursive and hierarchical manner, each tenant can operate its VI as the MNO operates on the physical one, allocating and reselling part of the resources to other MVNOs. Figure 6 shows this practice between Tenant#1 and Tenant#2. The infrastructure of MVNO#2 operates over the virtual network offered by MVNO#1, which operates on top of the MNO infrastructure (the physical one).

The multi-tenant architecture presented in this section is very challenging and one of the central points of innovation of the project. To devise a feasible and flexible framework, we have followed the recursion principles of the ONF architecture [14]. Although here we have presented mainly the control plane related issues, enabling multi-tenancy in such an architecture also requires modifications in the data plane. For example, isolation of resources/traffic is required, as described earlier. In addition, we have designed a specific OpenFlow-based pipeline to deal with the forwarding of traffic with different requirements and resources per tenant.

Summary and Conclusions

5G requires a new generation multi-tenant transport network integrating fronthaul and backhaul segments into a single transport infrastructure. In this article we have presented the 5G transport network architecture designed in the 5G-Crosshaul project that enables multi-tenancy through network slicing.

We have considered two main network slicing services that enable different control and automation levels of network slices management:
- Provisioning of virtual infrastructures under the control and operation of different tenants
- Provisioning of tenant-owned network services as defined by ETSI NFV

The former deals with the allocation and deallocation of VIs, logical entities encompassing a set of compute and storage resources interconnected by a virtual, logical network. In the latter, NSs are instantiated directly over a shared infrastructure, and as a set of interrelated virtual network Functions.

A multi-tenancy application (MTA) building on the network slicing services has been described that coordinates and manages the tenants' access to the shared infrastructure, performs resource isolation

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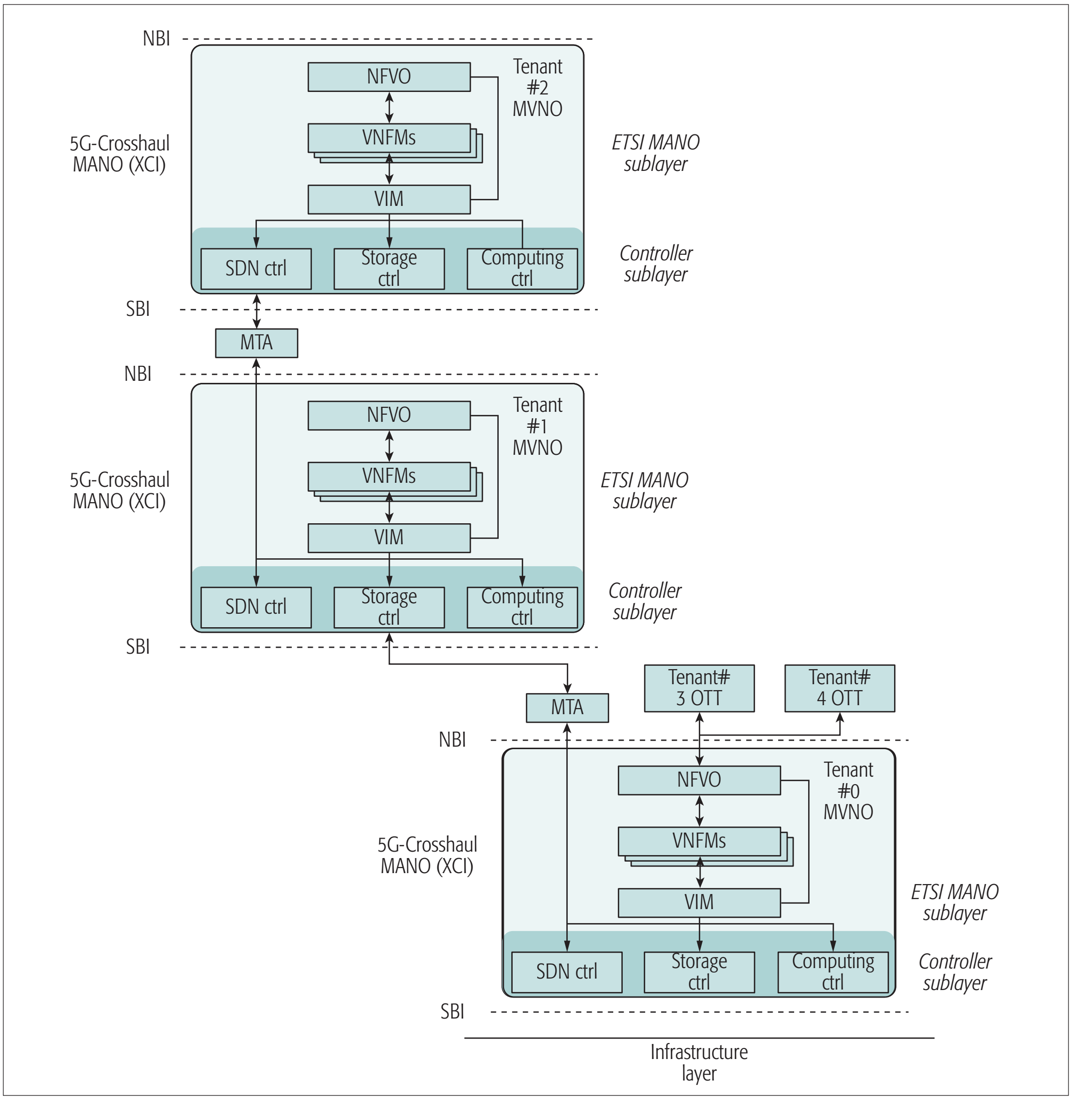

Figure 6. Crosshaul Control Infrastructure (XCI) Recursion: Multi-MANO.

between instances assigned, and delivers related services, such as the allocation and operation of VIs or NSs, by means of a set of proposed APIs.

Finally, the multi-tenancy recursion case (multi-MANO) has been considered, which requires support for multiple instances of the 5G-Crosshaul MANO simultaneously.

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Biographies

Xi Li received her M.Sc. in 2002 from TU Dresden and her Ph.D. in 2009 from the University of Bremen, Germany. From 2003 to 2014 she worked as a research fellow and lecturer in the Communication Networks Group at the University of Bremen,

leading several industrial and European research projects on mobile networks. In 2014 she worked as a solution designer at Telefonica, Germany. Since 2015 she has been with NEC Laboratories Europe, working as a senior researcher on 5G networks.

RAMON CASELLAS graduated in telecommunications in 1999 from UPC and ENST. He worked as an undergraduate researcher at France Telecom and BT Labs, completed a Ph.D. in 2002, and worked as an associate professor (ENST) until joining CTTC in 2006. He is a senior researcher, involved in research and technology transfer projects. His research interests include network control, GMPLS/PCE, and SDN/NFV. He has co-authored over 150 papers, 4 book chapters, and 4 IETF RFCs.

GIADA LANDI holds an Italian Laurea degree cum laude in telecommunication engineering from the University of Pisa. She holds 10+ years experience in telecommunication networks, with focus on control plane architectures and protocols. Currently, she is an R&D project manager at Nextworks. Her main research areas include SDN/NFV, cloud computing and orchestration, ASON/GMPLS, and PCE architectures. She has participated in industrial projects and consultancies on PCE, SDN, and NFV topics, and is active in European research projects.

ANTONIO DE LA OLIVA obtained his degree in telecommunication engineering from UC3M in December 2004 and his Ph.D. on telematics engineering in July 2008. He has served as Vice-Chair of the IEEE 802.21b task group and Technical Editor of IEEE 802.21d, and is now serving as Rapporteur of the ETSI WP on Crosshauling. He is currently working as Deputy Project Manager of the H2020 5GPPP 5G-Crosshaul project.

XAVIER COSTA-PÉREZ is head of 5G Networks R&D at NEC Laboratories Europe, where he manages several projects focused on 5G mobile core, backhaul/fronthaul, and access networks. He is a 5GPPP Technology Board member and Technical Manager of the 5G-Crosshaul project. His team contributes to projects for NEC products roadmap evolution, European Commission research collaborative projects, and related standardization bodies. He received his M.Sc. and Ph.D. in telecommunications from the Polytechnic University of Catalonia (UPC-BarcelonaTech).

ANDRES GARCIA-SAAVEDRA received his M.Sc. and Ph.D. from University Carlos III of Madrid in 2010 and 2013, respectively. He then joined the Hamilton Institute at Trinity College Dublin, Ireland, as a research fellow in 2014. Since July 2015 he has worked as a research scientist at NEC Laboratories Europe. His research interests lie in the application of fundamental mathematics to real-life computer communications systems and the design and prototyping of wireless communication systems and protocols.

THOMAS DEIß received his degree in computer science in 1990 and his Ph.D. in 1999 from the University of Kaiserslautern. He joined Nokia in 1999. He has contributed to standardization in the area of automated testing and worked in requirements engineering for backhaul functionality of WCDMA and LTE base stations with a focus on backhaul sharing among radio technologies.

LUCA COMINARDI received his B.Sc. and M.Sc. degrees in computer science from the University of Brescia, Italy. He also received an M.Sc. degree in telematics engineering from University Carlos III Madrid, where he is currently pursuing a Ph.D. in the same field. He has six years of experience in European research projects, such as FP7 FLAVIA, FP7 ICT iJOIN, and H2020 5G-Crosshaul, and he is now with InterDigital Europe as 5G Radio Access Network researcher.

RICARD VILALTA has a telecommunications engineering degree (2007) and a Ph.D. degree (2013), from UPC, Spain. Since 2010, he has been a researcher at CTTC in the Communication Networks Division. He is currently a research associate at the Open Networking Foundation. His research is focused on SDN/NFV, network virtualization, and network orchestration. He has been involved in international, EU, national, and industrial research projects, and published more than 100 journal and conference papers and invited talks.