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Sharing of Crosshaul Networks via a Multi-Domain Exchange Environment for 5G Services

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***Abstract*— Next 5G networks will force service and network providers to support a huge variety of final services with very different requirements in terms of bandwidth, latency, etc. In parallel, vertical industries, as customers, will use 5G networks as technical enablers to support their businesses, demanding appropriate mechanisms for a flexible access and control of network and computing resource slices in the locations where such vertical have business. Since the footprint and the availability of resources to support the variety of services could be limited on the primary provider side, open environments enabling the trading of resources in the form of slices are required to facilitate the sharing of infrastructure with the necessary isolation and scalability. Here, this is exemplified by the proposal of adaptations between two prevalent architectures being defined in the EU H2020 projects 5G-Crosshaul and 5G-Exchange for allowing the trading of crosshaul resources enabling 5G services for Verticals.**

Keywords—SDN; NFV; Crosshaul; Multi-domain

I. INTRODUCTION

Future 5G services will require the support of different kind of services with very distinct needs onto the same physical infrastructure. Types of services [1] like enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC) and ultra-Reliable and Low Latency Communications (uRLLC) impose the need of supporting greatly different capabilities at the same time on the same infrastructure to meet all the requirements in terms of bandwidth, latency, number of handled sessions, etc. There is an obvious risk on the providers' side of wasting resources via overprovisioning.

In parallel, a revolution is expected with regards of the service provisioning and end-user experience thanks to the positioning of 5G networks as technological enablers for several industries as it is the case of vertical customers. A number of sectors (i.e., areas like Media and Entertainment, eHealth, Energy, Automotive, and Manufacturing-Factories of the Future) are advancing towards the definition of the requirements needed by 5G networks for playing such supportive role [2]. Clearly, vertical customers do not want any restriction in terms of coverage, service capability, resource constraints, geographical footprint, etc, coming from any potential limitation of the communications provider with which they maintain a commercial relationship as primary provider.

With this landscape, the sharing of resources and services is considered even more and more by service providers and telco operators as the path to reduce costs, trying to optimize the usage of the available infrastructures, including computing and networking. The deployment and orchestration of network services over multiple domains is then key to achieving this resource optimized sharing.

One of the crucial network segments in future 5G networks will be the Crosshaul, which considers both current and future fronthaul and backhaul network segments in an integrated approach, not only from the networking perspective but also from the viewpoint of making available distributed computing capabilities closer to the end users. The Crosshaul is key since it provides the necessary capillarity and modularity to reach the end user for the different kind of services as observed before.

It is yet to be defined the way in which the sharing of Crosshaul infrastructures can be traded with the necessary automation and flexibility as required by vertical customers in 5G networks. The customer, a vertical industry, will specify a service to a primary provider. In order to do deliver the service, the provider may require to trade network or compute resources with other providers to fulfil the full customer request. Such trading, if not done in a normalized manner, will require tremendous effort in customization and particularization case by case that could make it impractical. Then a normalized manner of enabling that multi-domain ecosystem is necessary to guarantee openness, competition and viability of the concept.

This article exemplifies such multi-domain scenario for the sharing of Crosshaul capabilities in 5G via a multi-domain exchange by analyzing the integration of the architectures proposed in the EU H2020 projects 5G-Crosshaul and 5G-Exchange (or 5GEx) for respectively the control and management of Crosshaul and multi-domain exchange environments in future 5G networks. A very first preliminary approach was described in [3]. This article details architectural implications in terms of architectural functional blocks and interfaces for allowing such integration. New initiatives like EU H2020 5G-Transformer will leverage on such integration for the support of vertical slicing.

The paper is structured as follows. Section II describes the requirements faced in future networks for the support of vertical customers. In order to exemplify this situation, Sections III and IV describe respectively the architecture and the control mechanisms defined in 5G-Crosshaul and 5G-Exchange. Section V presents a proposal for integrating both architectures to reach the goal of trading and sharing crosshaul capabilities via an open exchange. Finally, section VI provide some concluding remarks, identifying next steps towards the complete and full integration of both architectures.

II. SUPPORT OF FORTHCOMING VERTICAL 5G SERVICES

Vertical industries have traditionally run their own networks tailored to their specific applications. For example, emergency services in cities have usually deployed TETRA systems. Similarly, industrial manufacturers deploy dedicated reliable and low latency industrial networks to control sensors, robots and actuators. All of these networks, although well suited for their individual purposes, are costly to operate, maintain and evolve. Therefore, vertical industries are looking for new solutions allowing them to leverage on the existing mobile network infrastructures whilst being able to meet their specific needs. In this respect, as referred before, the 5G-PPP association has investigated the requirements and needs coming from several vertical industries, like Media and Entertainment, Automotive, etc. With this context, next generation networks will need to exploit and further develop the emerging concept of network slicing by enabling vertical industries to exploit an envisioned mobile transport and compute platform consumable in different manner and for different purposes.

On the other hand, the costs of adapting existing infrastructures or deploying new ones capable of supporting the variety of services foreseen are actually challenging, considering the uncertainty in the grade of market share and capture for each of the providers approaching this market. In this scenario mobile network operators can be keen to open their infrastructures in an as-a-service fashion to improve their profitability by extending their customer base and, consequently, increasing revenues. This trend started a while ago with mobile operators sharing their last mile fiber infrastructures and base stations towers, and continued with Mobile Virtual Network Operators (MVNOs) entering the market. The trend can be extended further now that a sophisticated computing infrastructure is increasingly deployed for supporting network virtualization (e.g., by deploying a virtualized version of an EPC). Services will be programmed, as opposed to physically deployed and configured, on top of virtual resources that can now be flexibly allocated and sliced.

Then next generation networks are envisioned as a conglomerate of federated providers of both networking and compute resources, contributing to the overall resources required to fulfil a specific service level or marketplace agreement. Therefore, it is needed to develop the framework of slice trading across different providers.

Additionally, it will be common that the footprint of the vertical industries not necessary equals the footprint of the service providers, then creating some mismatch that complicates the implementation of the services. Automation and flexibility for provisioning services across multiple administrative domains is the solution for offering a single one-stop shop experience for verticals.

Network sharing (understood in a broad sense by including compute capabilities as well) can be a mechanism to face the challenges described above. Currently, the existing network sharing agreements (limited to radio access and data transport facilities) provides advantages on CapEx and OpEx for both the owners (infrastructure providers) and the users (service providers) of the infrastructure thanks to a better utilization of the assets and the reduction of investments, respectively. Virtualization techniques has been proposed [4] to overcome the shortcomings of conventional network sharing methods for MVNOs. For instance, next steps towards the provision of 5G slices to MVNOs are proposed in [5].

In this manner, service providers could approach verticals for extending the services over infrastructures owned by other providers (as if they were owned by the service provider), and at the same time maintaining the commercial front-end with the vertical. This concept has to be extended in the context of SDN and NFV for multi-domain environments, with the purpose of trading resource slices from different providers that could allow the verticals to provide their services in a totally autonomous manner.

III. 5G-CROSSHAUL CONTROL MECHANISMS

5G-Crosshaul aims to integrate the fronthaul and backhaul segments providing capillarity for distributed 5G radio access systems. A detailed description is provided in [6].

5G-Crosshaul is based on three main building blocks: *(i)* a control infrastructure using a unified, abstract network model for control plane integration (Crosshaul Control Infrastructure, XCI); *(ii)* a unified data plane encompassing innovative high-capacity transmission technologies and novel latency-deterministic switch architectures (Crosshaul Forwarding Element, XFE); and *(iii)* a set of computing capabilities distributed across the network (Crosshaul Processing Units, XPUs). Figure 1 shows the architectural framework of 5G-Crosshaul.

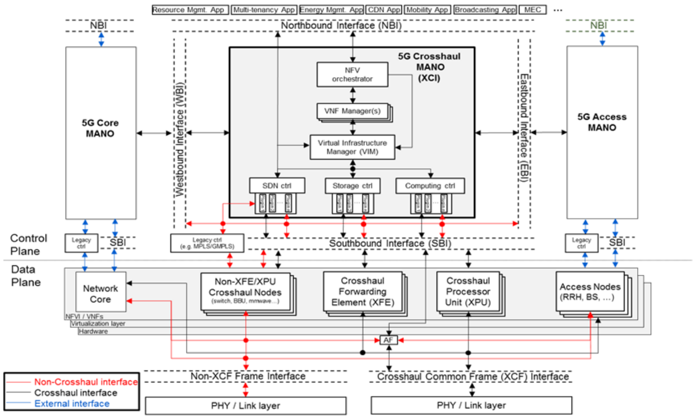

Figure 1. 5G-Crosshaul reference architectural framework

The XCI is compliant with the ETSI NFV architecture [7] with regards to management and orchestration. Additionally, it includes a set of controllers for managing networking, storage and computing resources. Furthermore, a number of applications can be located on top of the XCI. Of special interest for multi-domain environments is the Multi-Tenancy Application (MTA), conceived to support per-tenant infrastructure management in multi-tenancy scenarios. The following sub-sections provide more details in two key aspects of the 5G-Crosshaul architecture: the XCI as the control framework, and the support of multi-tenancy on the same crosshaul infrastructure.

A. 5G-Crosshaul control framework: the XCI

The XCI is the brain controlling the overall operation of the 5G-Crosshaul. The XCI part dealing with NFV comprises three main functional blocks, namely the NFV orchestrator (NFVO), the VNF Manager (VNFM) and the Virtual Infrastructure Manager (VIM).

The NFVO is a functional block that manages a Network Service (NS) lifecycle. It coordinates the VNF lifecycle (supported by the VNFM) and the resources available at the NFV Infrastructure (NFVI) level to ensure an optimized allocation of the necessary resources and connectivity to provide the requested virtual network functionality. The VNFMs are functional blocks responsible for the lifecycle management of VNF instances (e.g. instance instantiation, modification and termination). Finally, the VIM is a functional block that is responsible for controlling and managing the NFVI computing, storage and network resources via Computing, Storage and SDN controllers, respectively.

In addition to these modules, which are in charge of managing the different VNFs running on top of the 5G-Crosshaul, the XCI includes a set of specialized controllers. The SDN Controller is in charge of controlling the underlying network elements following the conventional SDN paradigm. 5G-Crosshaul aims at extending current SDN support of multiple technologies used in transport networks (e.g., micro-wave links or Ethernet-based forwarding elements) in order to have a common SDN controlled network substrate which can be reconfigured based on the needs of the network tenants. In addition to that, a Cloud Controller is proposed for handling Storage and Computing resources. A prominent example of this kind of software framework is OpenStack. Note that these controllers are functional blocks with one or multiple actual controllers (hierarchical or peer-to-peer structure) that centralize some or all of the control functionality of one or multiple network domains.

XCI components are based on REST APIs by design. Through those APIs, XCI exposes capabilities for different services, namely:

- *Network Topology and Inventory*, providing information regarding the network, including physical topology, as well as inventory related to network node and port capabilities;
- *IT Infrastructure and Inventory*, with similar scope as before but focused on the IT part;
- *Provisioning and Flow actions*, facilitating the request, the installation, and removal of forwarding rules in the network nodes;
- *Statistics*, for the collection of monitoring information of both network-related and IT-related statistics. This can be complemented by another service, *Analytics for Monitoring*, in charge of offering to the consumer elaborated information obtained from the processing of the network and computing statistics gathered before;
- *NFV Orchestration*, *VNF Management*, and Virtual Infrastructure Management, with similar scope as the defined in ETSI NFV architecture framework, with some augmentation in the latter case by adding planning capabilities (resulting in a *Virtual Infrastructure Manager and Planner*, VIMaP);
- *Local Management Service*, for managing the status and properties of the 5G-Crosshaul elements namely XFEs and XPUs.

It will be then required to consider this architectural structure for the integration with other administrative domains.

B. Multi-tenancy Support

Support of multi-tenancy has a strong impact on the XCI components. The SDN controller must support the provisioning of isolated virtual network infrastructures with a given set of capabilities. Traffic isolation can be achieved through the creation of tagged network connections, configuring the flows at the forwarding elements making use of the multi-tenant features in the 5G-Crosshaul data plane, based e.g. in traffic encapsulation headers with tenant-specific tags to guarantee the proper isolation. The SDN controller needs as well to support the creation and operation of virtual networks assigned to specific tenants, which could be specified e.g. following intent-based network models.

At the VIM level, multi-tenancy is handled through the modelling of the tenant concept, where each tenant has its own view of the VIM capacity, policies to regulate the access to the resources (e.g. a quota of dedicated resources) and, optionally, custom resource flavours and VM images. Requests for new virtual infrastructures must be authenticated and authorized, and they are evaluated based on the resources still available in the tenant's quota. Finally, the access to the instantiated virtual infrastructures is strictly limited to the tenant owning the specific instance.

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 Network Services entities. Each tenant must have the view and the control on its own VNFs and NSs only; they must be maintained fully isolated from other entities belonging to different tenants, in order to guarantee their security and their desired KPI level independently on the load of other VNFs pertaining to other tenants. New service requests must be granted depending on the tenant’s profile, in combination with the tenant-related policies.

IV. 5G-EXCHANGE AS ENABLER OF MULTI-DOMAIN SLICING AND NETWORK SHARING

5G-Exchange proposes an ecosystem for the trading of resources (with the slice as extreme case) in a multi-domain environment, as described in [8]. The initial architecture framework of 5GEx, shown in Figure 2, identifies the main functional components and the interworking interfaces involved in multi-domain orchestration, where different providers participate, each of them representing a distinct administrative domain.

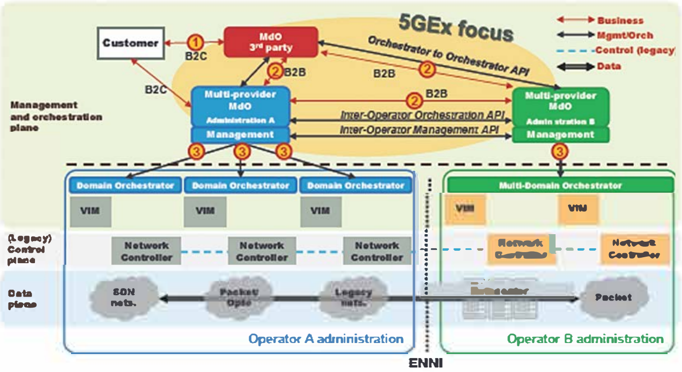

Figure 2. 5GEx reference architectural framework

The lower part of the figure shows different Resource Domains for a variety of technologies, hosting the actual resources. The middle shows Domain Orchestrators, responsible of performing Virtualization Service Orchestration and/or Resource Orchestration exploiting the abstractions exposed by the lower Resource Domains.

The key 5GEx component is the Multi-domain Orchestrator (MdO), shown at the top of the figure. The MdO handles the orchestration of resources and services from different providers, coordinating resource and/or service orchestration at multi-domain or multi-operator level, orchestrating resources and/or services using Domain Orchestrators belonging to multiple administrative domains.

A. *5GEx interfaces and APIs*

There are three main interworking interfaces and APIs identified in the 5GEx architecture framework. The MdO exposes service specification APIs (Customer-to-Business, C2B) that allow business customers to specify their requirements for a service on interface I1. The MdO interacts with other MdOs via interface I2 (Business-to-Business, B2B) to request and orchestrate resources and services across administrative domains. Finally, the MdO interacts with Domain Orchestrators via interface I3 APIs to orchestrate resources and services within the same administrative domains.

From the perspective of functional capabilities of such interfaces, the functional split considered on each of them is related to service management (-S functionality), VNF lifecycle management (-F), catalogues (-C), resource topology (-RT), resource control (-RC) and monitoring (-Mon). The full identification and specification of these interfaces in terms of protocols and/or APIs is currently being defined.

B. *5GEx functional architecture*

The 5GEx framework reference architecture has been further developed, defining the different components and interfaces into the functional model shown in Fig. 3. This architecture extends the ETSI MANO NFV management and orchestration framework [7], in order to implement Network Service and Resource orchestration across multiple administrative domains, which may belong to different infrastructure operators or service providers.

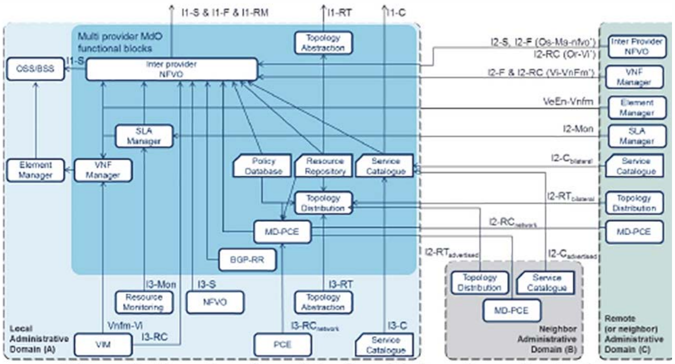

Figure 3. Functional model of multi domain orchestration

Fig. 3 highlights three different administrative domains (A, B and C) involved in the Multi-Domain service/resource orchestration process. All the providers in 5GEx are considered to contain the same components and modules (the Operator-Operator relationships are symmetrical in 5GEx), although in Fig. 3 the complete view is only shown for the provider on the left for illustration purposes, just showing exemplary consumer-provider roles with arrows from consumer to provider functional blocks. In the figure, Operator Domain A (left-hand) consumes virtualization services of Operator B (transit domain, in the middle) and Operator C (right-hand).

The main functional blocks in 5GEx are:

- The *Inter-Provider NFVO* is the NFVO that implements multi-provider service decomposition, responsible of performing the end-to-end network service orchestration. The NSO and RO capabilities are contained here;
- The *Topology Abstraction* module performs topology abstraction elaborating the information stored in the *Resource Repository* and *Topology Distribution* modules;
- The *Topology Distribution* module exchanges topology information with its peer MdOs;
- The *Resource Repository* that keeps an abstracted view of the resources at the disposal of each one of the domains reachable by the MdO;
- The *SLA Manager* is responsible for reporting on the performance of its own partial service graph (its piece of the multi-domain service);
- The *Policy Database* which contains policy information;
- The *Resource Monitoring* module dynamically instantiates monitoring probes on the resources of each technological domain involved in the implementation of a given service instance;
- The *Service Catalogue* in charge of exposing available services to customers and to other MdO from other providers.

C. *5GEx interaction between components and supportive interfaces*

For multi provider Network Service orchestration, the Multi-domain Orchestrator (MdO) offers Network Services by exposing an OSS/BSS-NFVO interface to other Multi-domain Orchestrators from other providers. For multi-provider resource orchestration, the MdO presents a VIM-like view and exposes an extended NFVO-VIM interface to other Multi-domain Orchestrators. The Multi Provider MdO exposes I1-S as the northbound interface through which an MdO customer (e.g., a vertical industry) sends the initial request for services. It handles command and control functions to instantiate network services. Such functions can include the request for the instantiation and interconnection of Network Functions (NFs). Interface I2-S is meant to perform similar operations between MdOs of different administrative domains.

Interfaces I2-RT and I3-RT are used to keep an updated global view of the underlying infrastructure topology exposed by domain orchestrators. In addition to that, resource orchestration is complemented with interfaces I2-RC and I3-RC to reflect resource control. The service catalogue exposes available services to customers on interface I1-C and to other MdO service operators on interface I2-C. Finally, I2-Mon and I3-Mon are used for resource monitoring.

V. INTEGRATION OF 5G-CROSSHAUL AND 5G-EXCHANGE ARCHITECTURES

After the review of both 5G-Crosshaul and 5GEx architectures, it becomes clear that functional adaptation is feasible for allowing the trading of 5G-Crosshaul slices through 5G Exchange, since the common starting point is the ETSI MANO NFV management and orchestration framework. However, there are yet some gaps that would require from certain extension in 5G-Crosshaul for full compliance with a 5GEx ecosystem. This section summarizes both aspects as follows.

A. *Integration in 5GEx of existing functional blocks from 5G-Crosshaul architecture*

Some functional components can be identified as common and existing in both architectures, then foreseeing a straightforward functional integration in this respect. The following components are considered common in both architectures under functionality viewpoint.

1) Statistics and monitoring of Crosshaul resources. The current 5G-Crosshaul architecture supports the collection of both compute and network statistics, as well as analytic reports derived from the monitoring information. All of this could be reported as part of the 5GEx I2-Mon interface, providing operational information to other adminstratoive domains requesting Crosshaul services.

2) Topology and Inventory. The topology information is critical in a multi-domain environment for an efficient and effective placement of functions and connectivity reservation. 5G-Crosshaul supports both network and compute topology and inventory reporting, thus enabling the dissemination of such information outside the Crosshaul domain borders. The population of this topology and inventory information can run on top of 5GEx I2-RT interface, for feeding the *Resource* and *Topology* functional blocks of the MdOs of the other provider domains in the Exchange.

3) Provisioning and Control of resources. The XCI in 5G-Crosshaul facilitates the control of the networking resources for adapt the underlying forwarding elements to the needs of the flows to be transported in the Crosshaul area. This capability can be easily integrated in 5GEx by mapping it to the I2-RC interface.

4) VNF management and orchestration. 5G-Crosshaul permits to accomplish the full management of the VNF lifecycle via the XCI. The APIs offered by 5G-Crosshaul for this can be homologated to the I2-F interface in 5GEx.

With the integration in a multi-domain environment, the 5G-Crosshaul XCI and the applications on top of it (as defined nowadays) become the 5GEx multi-domain orchestrator. Thanks to the recursiveness properties of XCI, another option could be to dedicate a specific XCI instance to multi-domain aspects interacting as a client with a XCI instance below focused on the Crosshaul domain.

Interestingly, the *VIMaP* functional block in 5G-Crosshaul provides additional capabilities for planning as an extension to the usual VIM functionality. These planning capabilities can be quite useful on assisting the decisions for placement and connectivity in certain services, as the VNFaaS proposition in 5GEx. In this sense, the I2-F interface from 5GEx could be augmented to support the interaction with the *VIMaP* module in 5G-Crosshaul in this direction.

B. *Proposition of additional functional blocks in 5G-Crosshaul for full compliance with 5GEx architecture*

There are instead some other functions not yet fully available in 5G-Crosshaul. The more notorious capabilities are the ones related to business support. Here there is a brief summarization of the findings:

1) Business support. Specially, the population of the services supported in 5G-Crosshaul in terms of catalogue of services is not yet defined. This capability is necessary for advertising the capabilities of each Crosshaul environment in an area in terms of networking and computing resources, as well as some added-value services that could complement the offer.

In order to complement the 5G-Crosshaul architecture, the proposal here is to define a new functional module on top of XCI in charge of disseminating to other domains the Crosshaul capabilities supported in such domain. This new block, the *5G-Crosshaul Service Catalogue* would be placed at the same level as the other applications defined in 5G-Crosshaul (e.g., Resource Management, Energy Management, etc). In addition, this block is required to support 5GEx I2-C interface for integration on 5GEx ecosystem.

2) Service specification and request. In a multi-domain environment such as 5GEx it is necessary to have a common understanding on the services offered by each of the participants in the Exchange. To do that, the same semantincs and abstractions have to be handled by the different administrative domains in order to ensure consistency. Such abstractions at technical level imply the utilization of common information and data models for the resources to be configured and used. In the case of integrating 5G-Crosshaul in a 5GEx environment, the former has to support the request of services through 5GEx I2-S interface.

C. *Interface adaptation*

The previous sub-sections have explored the integration feasibility of 5G-Crosshaul and 5G-Exchange. In general terms, the integration can be achieved through minor adaptations. Some new modules are required for enabling the trading of Crosshaul capabilities in a normalized way.

It has been also analyzed the mapping to 5GEx interfaces. While feasible, some adaptations could be also required to this respect. As mentioned before 5G-Crosshaul is based on APIs to retrieve the information in an asynchronous manner. However, 5GEx interfaces are not defined in such format. For example, the I2-RT interface leverages on BGP-LS for the dissemination of the topology information across domains. This means that in some cases, even with an easy conceptual integration between 5G-Crosshaul and 5GEx, some minor functional block could be required for interface adaptation. In the case of I2-RT, for instance, a block in 5G-Crosshaul implementing a BGP-LS speaker facing the multi-domain environment for synchronous exchange of information would be required, at the same time retrieving the internal Crosshaul information asynchronously.

All the details in this direction will become more clear once the final architectures of 5G-Crosshaul and 5GEx will be totally defined.

VI. CONCLUSIONS AND NEXT STEPS

Vertical industries will relay in future 5G networks for the provision of advanced communication services. Existing limitations in the way of providing services (e.g., lack of automation) or in the limited scope of the infrastructures (e.g., resource constraints) do not incentive the migration towards such advanced scenario. In order to do so, the sharing of resources and the deployment of network services over multiple domains appears as key to overcome those barriers. The advanced concept of slicing is a target on such scenario of multi-domain infrastructure sharing.

Of special interest is the idea of sharing Crosshaul capabilities in 5G networks. Crosshaul areas are those integrating fronthaul and backhaul and capable of providing the capillarity to reach the final end users (i.e., those consuming the offerings of the vertical industries). Finding a way of trading Crosshaul capabilities becomes relevant to facilitate the deployment of the vertical services in a smooth and normalized manner, without particularization per vertical client. Therefore, open environments are desired for such a one-shop ecosystem.

In this article, both 5G-Crosshaul and 5G-Exchange architectures are considered to exemplify the way in which this trading of slices could happen among providers. The article analyzes the way of integrating both architectures presenting the basis for interworking of both architectures, providing hints for integration and identifying architectural gaps.

Next steps will be directed towards a close definition of the modules identified as necessary in both architectures, and towards an alignment on the signaling methods to smoothly incorporate 5G-Crosshaul providers in 5G-Exchange environments. This is yet an ongoing work.

Final refinement of these architectures is yet ongoing, thus final adjustments or augments could be expected in the near future. If that is the case, also some adaptations to the integration here proposed could be expected.

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