5G Exchange for inter-domain resource sharing*

Csaba Simon, Markosz Maliosz, József Bíró
HSNLab, Dept. of Telecomm. and Media Inf.
Budapest University of Technology and Economics (BME)
Budapest, Hungary
{simon|maliosz|biro}@tmit.bme.hu

Balázs Gerő, András Kern
Ericsson Research
Budapest, Hungary
{balazs.peter.gero|andras.kern}@ericsson.com

***Abstract*— Market segmentation and technological heterogeneity are major obstacles along the way towards the realization of fast service creation expected to be part the fifth generation network feature set. In this paper we present our vision of creating a 5G Exchange that remove these obstacles by enabling the orchestration of networking and service resources in an automated way across technological and administrative domains, We describe the challenges and our motivation, the proposed networking architecture framework, showing and its relation to current standardization efforts. We present the next steps in terms of implementation and experimentation, and propose a sandbox environment where partners may experiment with life-size multi-domain network orchestration.**

Keywords—NFV; SDN; 5GPP

I. Introduction

The expansion of high performance mobile devices and the variety of sensors used in several application fields spawns new service types and new user demands. Along with the individual and social networking based human-centric services we also witness the proliferation of Internet of Things (IoT), generating several order of magnitudes larger demand in application areas as Smart City, vehicular communications or real-time control of industrial processes. Such a heterogeneous service profiles cannot be supported by any single currently available networking technology, although from service provider side there is a need to support all the above services in a unified architecture. In order to live up to the expectations the network architecture should enable the coexistence of heterogeneous services, whose requirements will not be restricted on higher access speeds, but will specify more complex QoS statements. Fulfilling these requirements can be possible only if the architecture is highly flexible and allows smart, common resource exploitation, involving not only inter-domain, but also inter-operator cooperation.

5G networks [1], currently being in various phases of research, development and standardizations, offer a potential answer to the above listed requirements. Technological evolution on medium term will lead to a higher capacity radio standard [2]. The 5G radio interfaces will bring a tenfold improvement to both the 1Gbps peak capacity of current 4G networks, and to the packet latency, the latter reaching 5ms [3]. Nevertheless, the advantages of 5G networks are much more than those conferred by such high performance radio interfaces.

Current market is characterized by fragmentation at service provider level, which isolates into virtual silos the valuable resources which otherwise would suffice to satisfy user demand. Increase in the capacity of the infrastructure cannot fully replace (or solve) the implementation and introduction of new services unless the resources access is not limited to intra-domain use. These virtual silos can be broken up if automated mechanisms exists that enable multi-domain and/or multi-operator cooperation, thus 5G network architecture should be designed with these goals in mind, too. In order to answer the service provider requests for flexible, scalable and business-wise viable services [4], the vendors are prepared to design service-oriented and multi-domain products [1][5], which offer end-to-end solutions for user-demand oriented services, classified into QoS classes, including continuous mobility and connectivity.

In this paper we propose a 5G network architecture capable of supporting the above requirements, including those related to inter-domain and inter-operator cooperation. We present our vision on 5G networking and the design derived from this vision. We also present the first steps in terms of implementation and experimentation.

In our vision significant improvement in seamless, flexible, scalable and globally efficient resource usage during service creation can be achieved only if there is an enabling technology that automatically supports resource exchange among domains and operators. Although there are several interconnection models in place, traditional interconnection services involve time-costly offline procedures [6]. A relevant model to our vision is federation. ETICS community concept [7] is proposed to be a novel three-stage collaborative service provisioning paradigm. A different approach is pursued in VITAL [8] and BATS [9] that applies federation and coupling between satellite and terrestrial systems for hybrid access. In line with our vision, Arjuna [10] argues that service providers can share resources according to self-defined flexible policies. Cloud federations such as OnApp [11] focus on interoperability of different (cloud) platforms, while Cloud28+ [12] emphasizes the need for fair comparison of available services versus customer requirements. CDNi [13] contributes interesting use cases and collaboration models among Content Delivery Networks (CDN) providers, including the bilateral agreement and the exchange model.

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Our 5GEx innovation project [14], funded by the European Commission under the Horizon 2020 program, proposes to provide a solution that makes possible that competing service providers can share their resources in a flexible and automatic manner to provide new services. It is working on a reference architecture specification and prototypal implementation of a multi-domain service and resource orchestrator, leveraging a number of key enabling technologies like Network Function Virtualization (NFV) [15] and Software Defined Networking (SDN) [16]. In its work, the consortium members rely on their previous activities in the field of network function virtualization, notably UNIFY [17], ETICS [7] and T-NOVA [18]. In order to bootstrap collaboration among stakeholders of future 5G service providers, we propose a 5GEx Sandbox that offers an European-wide 5G ecosystem deploying the implemented functionalities built over a federation of partner lab platforms and near-production networks.

The paper is organizes as follows. In the next section we present the motivation and requirements for our work, and then we introduce the 5GEx network architecture. In section 4 we explain how this architecture relates to the ongoing standardization efforts. In section 5 we present our methodology to practically implement and deploy the proposed 5GEx network architecture among operators, and finally we conclude our paper.

II. 5G CHALLENGES

A. Challenges

Our vision is that service creation across multiple domains will become an automated, cost-effective and fast process. Actually, this is part of the 5G PPP targets, the consortium setting the benchmark of 90 minutes for completing this process. Our solution presented in this paper paves the way towards this vision, offering a framework to service platform designers to specify requests and consume resources through a programmable interface. It will also facilitate resource owners to meet demands arriving outside of their administrative and technological domains.

When considering global (or at least European) resource sharing, a major issue is the level of interaction among operators with different focus and interest. In this respect we can distinguish the Network Service Providers (NSP), who own a network and provide resources and the Online Service Providers (OSP), who are in direct interaction with the customers. In many cases the same company acts as both NSP and OSP in the same market. In order to make our vision happen, NSPs and OSPs must collaborate, which is not typical in current internetworking environment. In our recent whitepaper [19] we took a deeper look at the problem, and as summarized below, we identified five specific issues that make such collaboration cumbersome, drawing back the fulfillment of the 5G goals.

- applications are implemented using several app- and vendor-specific modules locking them in in vertically integrated cross-layer silos, making agile service customization and service enhancement impossible or very costly
- over-the-top applications (OTTs) hide from the underlying network the real application requirements, thus the application and service needs cannot be supported by the network architecture
- due to the absence of standards for inter-domain functions there is a lack of trust and cost-efficient solution for inter-domain service creation
- inter-provider service agreements are mostly negotiated off-line, lacking inter-provider automation
- market fragmentation and unstructured resource trading leads to outdated business models with limited cooperation

B. Requirements

In order to design a networking architecture that addresses the issues presented earlier in this paper we must meet several requirements. The goal is to have a mechanism that enables the automated provisioning of network services across multi-domain, multi-technology 5G networks. This also calls for an integration framework capable of accommodating software-defined specifications of networks and of computational and storage resources, as well as all of the modules and components which provide the facilities and functions for the multi-domain operations and business interactions.

We came to the conclusion that a successful 5G networking architecture should reach the above goals, which boils down to the following three requirement points

- find the correct abstraction level at which the domain owners are willing to expose their domain details
- make efficient service hosting decisions based on the information exposed in the abstracted data representation
- provide efficient techniques for life-cycle management of those hosted service components.

III. 5GEX MULTI-DOMAIN NETWORK ARCHITECTURE

A. Resource slices

At the core of our proposal is the 5G Exchange, an expansion of the Internet eXchange Point (IXP) [20] concept into 5G networking. In order to make our vision happen 5GEx proposes a new framework architecture that supports the dynamic exchange of networking and VNF resources required to implement the customer facing services. The domains within the framework have an orchestrator that manages the services and resources of the respective domain. Then the architecture introduces a new orchestrator type, called Multi-domain Orchestrator (MdO) that is capable of handling these domain orchestrators.

The MdO can provide the services fast in a dynamic and efficient manner to its users if the resources offered by domain-level orchestrators are already bundled in less complex commodity resource packages, called *slices*. The slices are created on demand based on the requests of the MdOs, being a managed set of resources tailored to the service types. An additional advantage of the slices for the resource owners is that simplify the resource usage related accounting and billing process.

Virtual resources and Network Functions (VNFs) can be packaged into slices and offered northward within the framework as infrastructure services, and we call this concept Slice-as-a-Service (SlaaS). This way, any high-level services can be decomposed and supported in a dynamic and scalable manner.

B. 5GEx network architecture and interfaces

The 5GEx network architecture brings multiple domains into a single framework in order to support agile service-creation. The proposal details the interfaces between the various orchestration types, which once implemented provide a technical control plane for both physical and virtual resource control. These interfaces are used for the orchestration of the VNFs as well.

The building blocks of the network architecture framework are presented in Figure 2. We also show the proposed five interfaces (I1 to I5) that play a key role in implementing the 5G network interactions. The basis of the 5G architecture are the different physical resource types, to the likes of access (Wi-Fi, 3G, 4G, Ethernet, etc), aggregation and core network links, as well as the compute and storage resources of the clouds and data centers, illustrated in the lowest layer of the figure.

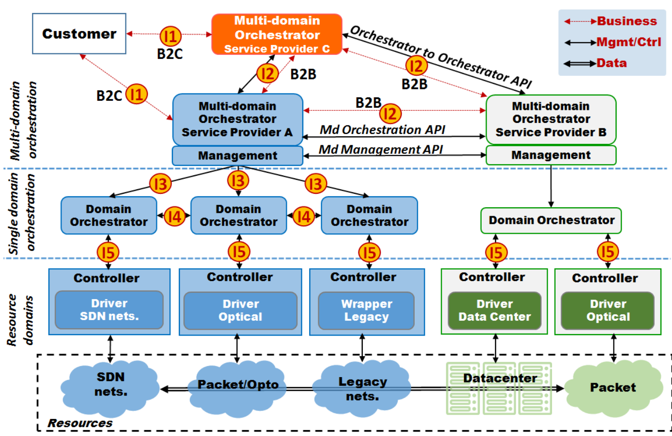

Fig. 1. 5GEx network architecture proposal.

The customer, pictured on the top left corner, has two options to initiate its service request over interface I1. It may ask a 3rd party orchestrator (provider C), which acts a service broker and which will contract the resources from fellow operators. Alternatively it may buy from its traditional provider (provider A), who federates resources from the domains under its own administration. As can be seen from the figure, in both cases the MdO in direct (i.e. business-to-customer: B2C) relation to the customer might involve other operators, as well (illustrated by provider B in the figure) in the service offering process. Indeed, in our framework the operators may request (and buy) from other operators in an automated manner various resources (e.g., geographic coverage, capacity, etc.) indispensable for their services over this interface. From MdO-to-customer relation perspective the border between the "broker" and the "own provider" is blurred, and in both cases the origin of the resources are masked from the customer. The various communication roles between the MdOs owned by different operators are implemented over the interface I2. Current standards do not offer such interface readily available.

At the next level each provider maps these requests onto its own domains (e.g., a wireless and a wired network domain) – this is implemented by the interface I3, where the slices introduced earlier in this section are advertised and requested. During this mapping step we have decomposed the request to domain level requests that can be handled by a domain-level orchestrator (DO). In certain scenarios the DOs should directly interact with each other, which can be done over the interface I4. Starting from this point the way the request orchestration is mapped onto the concrete control process depends on the technology deployed in the domain and it is implemented over the interface I5.

C. Benefits

The slice-based resource offering assures a flexible, yet scalable technological solution. It also allows that operators can "package" both their requests and advertisements such as they comply with their business and security policies. Operators will be able to manage multi-domain heterogeneity according to SDN and NFV paradigms.

The 5GEx network architecture, with the multi-layer hierarchical multi-domain orchestration proposed enables the creation and deployment of various user demands implying very different QoS even at per-user granularity. This can be achieved without human operator involvement, using the API towards the MdO by the service provider of the user. This framework opens up the resource silos, allowing the use of VNF resources by foreign operators and/or remote domains, leading to a more efficient global level resource usage, too.

The larger networking community will also take advantage from the innovations of 5GEx presented above. Most notably, the extensions to SDN functionalities will make possible much flexible and powerful control of networking assets for third party applications and services. Similarly, the innovations in the field of VNF management will enrich the tool set of service/application developers focusing on private cloud systems, too.

Finally, during the implementation of the networking architecture several cloud management related functions (with a special focus on OpenStack services) will be made available as open source libraries. This will provide more powerful APIs to those who have to manage and control VMs in clouds.

IV. Alignment with the Standardization Efforts

A. NFV related standardization efforts

In order to ease the adoption of our design and increase the impact of our work the 5GEx architecture is also harmonized with the current standardization efforts. Nevertheless, there are several parallel ongoing efforts on the creation of new specifications on architectural frameworks (or alignment of the old ones with) integrating SDN and NFV technologies and we selected the ETSI NFV model as the closest one to our approach, therefore we mapped 5GEx orchestration functions into the ETSI NFV MANO model. Before we discuss this mapping, we briefly review the chief standardization efforts across the community, putting the reader into the broader context of the topic addressed in this paper.

ETSI NFV ISG (Industry Specification Group) [21] is endorsed by top telecommunication operators, and has rapidly grown up incorporating other operators, network vendors, ICT vendors and service providers and the details relevant to our work are presented in the next sub-section. The Telecom Management Forum (TMF) [22] proposes the Zero-touch Orchestration, Operations and Management (ZOOM) program to develop Virtualisation and NFV & SDN best practices and standards, which works on the Information Model, API requirements and the definition of the concept of orchestration, elements that all relate to the 5GEx architecture. IEEE Next Generation Service Overlay Network (NGSON) [23] [24] is a framework for control and delivery of composite services over diverse IP-based networks, context-awareness being a distinguishing features of their proposal. The NGSON functional architecture includes service-related functions, transport-related functions, and operation and management functions. Only recently has been established a connection between the IEEE SDN Initiative and the NGSON WG to identify potential new standards in SDN/NFV areas interesting for 5GEx. The SDN Research Group of Internet Engineering Task Force (IETF) has recently adopted a draft document exploring the separation between Service and Transport concerns in SDN, which is important for 5GEx [25].

Apart from the above four bodies, several other stakeholder forums deal with issues that relate to parts of the 5GEx architecture, as presented below. The Metro Ethernet Forum Lifecycle Service Orchestration (MEF LSO) Reference Architecture [26] proposes a multi-domain orchestration model. The Broadband Forum (BBF) [27] started to include SDN and NFV under study, its first reports are under finalization, while the 5G specific issues are considered in its report under work “5G Requirements and Enablers“. The Open Networking Foundation (ONF) [28] promotes the adoption of SDN through the development of the well-known OpenFlow protocol as open standard. It also deals with building blocks that are part of 5GEx architecture. This includes, among others, specification of controller capabilities and the interfaces with the other elements in the architecture and slicing for 5G.

If we focus on the more generic frameworks, after we evaluated the industrial stakeholders behind the ETSI NFV and their commitment during their work in the standardization process, we expect that the most impact on the area addressed in this paper will be reached by the ETSI NFV. Corroborating with the reasons presented in this section above, we came to the conclusion to closely follow the IETF, TMF and IEEE activities in this area, but the model that is used as a reference for the 5GEx architecture will be the ETSI NFV.

B. Functional mapping to the ETSI MANO model

In order to align the 5GEx architecture introduced in the previous section with ETSI MANO NFV management and orchestration framework we started from the service- and resource orchestration split of the latter model, as illustrated in Figure 2. If we take another look at Figure 1, we can see that the during the processes involving the elements from the lower part of the figure the focus is on managing the resources, while in the upper part of the figure the elements have a service-oriented view.

Figure 2 shows the different functional blocks responsible for service orchestration (SO) and resource orchestration (RO) ETSI Open Source MANO model. For a detailed description of the ETSI NFV MANO elements please refer to [29]. The right hand side block (the NFV MANO) together with Network Service orchestration is responsible with the resource orchestration. In ETSI NFV terminology Networks Service (NS) refers to the NFVs and the links among their implementation in the NFV Infrastructure, and it is in line with our slice definition. Service orchestration configures parameters within VNFs via element managers and is implemented by the OSS/BSS.

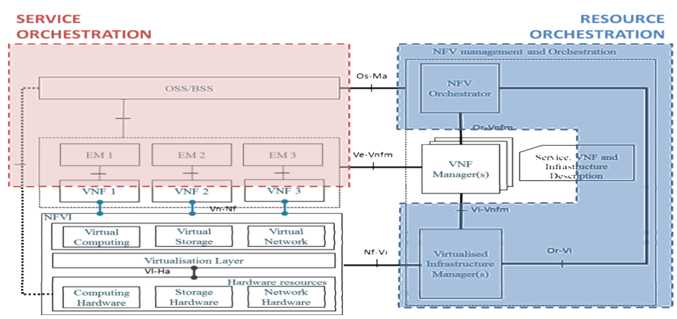

Fig. 2. Orchestration functions to the ETSI MANO model (source: [29])

Now we turn to the interfaces of the 5GEx architecture that support the multi-domain/multi-operator operation of the architecture, and try to identify the corresponding interfaces in the ETSI model. The support of multi-domain network services can be mapped to the OSS/BSS – NFVO interface, when it is opened between MdOs of different providers. The support of multi-domain resource orchestration corresponds to the VNFO – VIM interface opened to other domain orchestrators.

V. 5GEx Sandbox exchange for experimentation

In order to bootstrap collaboration among stakeholders of future 5G service providers, we propose a 5GEx sandbox that offers a European-wide 5G ecosystem deploying the implemented functionalities built over a federation of partner lab platforms and near-production networks. This also serves as validation testbed for the proposed 5G network architecture. This includes the evaluation of the ability of including a third party operator to join (to connect its domain) the existing 5G networking framework, potentially implemented on vendor hardware differing from those owned by the partners. It also serves as a trial platform for the devops methodology: developed modules will be deployed and used in VMs that theoretically should not affect other VNFs running in the sandbox in a large near-operational networking infrastructure, without the danger of discontinuing live commercial services.

The testbeds, provided by 12 different 5GEx partners, among whom 5 are large telecom operators, are utilized to reproduce a realistic implementation of multi-domain heterogeneous resources encompassing cloud infrastructures (e.g., OpenStack) interconnected by transit networking domains.

Figure 3 illustrates the sites provided by the partners to be interconnected within the 5GEx sandbox. We propose a multi-domain heterogeneous transport network that resembles ISP exchange hierarchy: several (3-5) partners will provide almost complete mesh connectivity among them (corresponding to Tier 1), while the rest of the partners connect their testbeds towards only one or two of them (corresponding to Tier 2). Technology-wise the sandbox federates heterogeneous networking domains: IP-MPLS, PCE based segment routing, (GMPLS-based) optical and SDN based packet networks. Most of the testbeds support KVM virtualization technology and OpenStack cloud services, and we evaluate the possibility of supporting Dockerized VNFs [19]. The SDN transport networks in the partner testbeds are controlled by different controller software: ONOS, Floodlight, OpenDayLight and Ryu [30].

Fig. 3. The partners hosting testbeds for the 5GEx Sandbox

The testbed interconnections are implemented through IPsec/GRE tunnel specifically established to enable the setup of a homogeneous control infrastructure over the set of heterogeneous technologies and resources. The testbed interconnections are exploited to provide isolated data and control plane interconnections, too. They are typically able to guarantee latencies of up to few tens of milliseconds and bandwidth in the order of few tens of Mbps. Specifically, based on the measurements the mean VM in testbed –to- VM in testbed delay is 47.2ms, with a standard deviation of 39ms. Even if we use 1Gbps network interface cards, the best effort testbed-to-testbed internet connection is less than 100Gbps, the measured average value being 61Mbps (the standard deviation is 43.5Mbps). As it can be seen, the sandbox is suitable to evaluate the inter-MdO communication to validate and test the interfaces introduced in Section III, but it is not suitable for generic inter-domain service delivery involving large amount of inter-domain data.

VI. Conclusions

Market segmentation and technological heterogeneity are major obstacles along the way towards the realization of fast service creation expected to be part the fifth generation network feature set. In this paper we presented our vision of creating a 5G Exchange that remove these obstacles by enabling the orchestration of networking and service resources in an automated way across technological and administrative domains. We aligned our proposal with the ETSI Open Source MANO model and proposed the 5G Sandbox Exchange to validate our concepts and stimulate the engagement of telecom and IT market actors to actively adopt and extend 5GEx open solutions. During our future work we will spend our efforts on bringing our vision to life by implementing the proposed architecture and sustaining proper standardization activities.

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