5G Exchange (5GEx) – Multi-domain Orchestration for Software Defined Infrastructures

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***Abstract*—Market fragmentation has resulted in a multitude of network and cloud/data centre operators each focused on different countries, regions and technologies. This makes it difficult and costly to create infrastructure services spanning multiple countries, such as virtual connectivity or compute resources, as no single operator has a footprint everywhere. The goal of the 5G Exchange (5GEx) project is to enable cross-domain orchestration of services over multiple administrations or over multi-domain single administrations in the context of emerging 5G Networking. This will allow end-to-end network and service elements to mix in multi-vendor, heterogeneous technology and resource environments. 5GEx aims to enable collaboration between operators, regarding 5G infrastructure services, with the view to introducing a unification via NFV/SDN compatible software defined infrastructure multi-domain orchestration for networks, clouds and services.**

I. Introduction

This paper presents the concepts and initial architecture of the 5GEx project which is planed for the next 2.5 years. Network Function Virtualisation (NFV) and Software Driven Networks (SDN) are creating major disruptive tendencies for communications networks and clouds, enabling services to be deployed as software functions running directly in the network on commodity hardware.

Market fragmentation results from having a multitude of telecommunications network and cloud operators each with a footprint focused to a specific region. This makes it difficult to deploy cost effective infrastructure services, such as virtual connectivity or compute resources, spanning multiple countries as no single operator has a big enough footprint. Even if operators largely aim to provide the same infrastructure services (VPN connectivity, compute resources based on virtual machines and block storage), inter-operator collaboration tools for providing a service spanning several administrative boundaries are very limited and cumbersome. This makes service development and provisioning very time consuming. For example, having a VPN with end-points in several countries, in order to connect multiple sites of a business (such as a hotel chain), requires contacting several network operators. Such an approach is possible only with significant effort and integration work from the side of the business. This is not only slow, but also inefficient and expensive, since the business also needs to employ networking specialists to do the integration instead of focusing on its core business.

Ideally, a customer would expect a one-stop shop, where such infrastructure services could be purchased from a single operator, who would in turn sub-contract other operators if it lacks the necessary footprint, capacity or other capabilities to provide the entire service. A useful parallel can be drawn with the very successful concept of roaming for mobile services. In that case, the subscriber needs only to establish a contract with one mobile operator, yet can seamlessly receive services in all countries of Europe – without having to buy and constantly change SIM cards in the phone. Likewise, in case of postal services the sender needs to buy only a single stamp from its local postal company and the mail is delivered even to foreign countries through collaboration between postal companies.

The European 5G Exchange (5GEx) project aims to bootstrap such collaboration between telecommunications operators regarding 5G infrastructure services. Such services and associated resources will play a crucial role in making 5G happen as they provide the foundation of all cloud and networking services apart from the radio interface itself. 5GEx will enable operators to buy, sell, and integrate infrastructure services, enabling one-stop shopping for their customers. It will provide the ability to automatically trade resources, verify requested services, and it will lead to clear billing and charging. It should be noted that such an exchange requires the removal of not only technical barriers, but also business ones. Therefore the 5GEx project will study the business aspects of such an exchange so that it becomes an efficient market that can be bootstrapped.

Technology fragmentation represents a major bottleneck not only for such a multi-operator exchange, but also internally within an operator. Different networks and different parts of a network may be built as different domains using separate technologies, such as optical or packet switched (with different packet switching paradigms included); having equipment from different vendors; having different control paradigms, etc. Managing and integrating these separate technology domains requires substantial amount of effort, expertise, and time. The associated costs are paid by both network operators and vendors alike, who need to design equipment and develop complex integration features. In addition to technology domains, there are other reasons for having multiple domains within an operator, such as, different geographies, different performance characteristics, scalability, policy or simply historic (e.g., result of a merge or an acquisition). Multiple domains in a network are a necessary and permanent feature however, these should

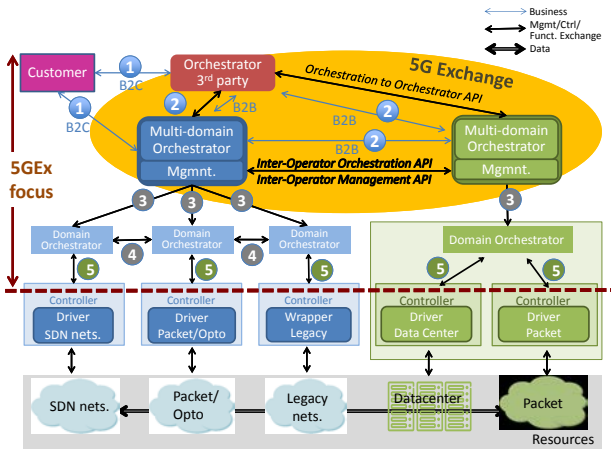

Fig. 1. Multi-domain logical interworking architecture

not be a roadblock towards service development and provisioning, which should be fast and efficient.

The 5GEx project aims to deal with both the multi-operator collaboration issue, and address the multi-domain problem within a single network operator. While these two problems are quite different, they also share a lot of common aspects and – we believe – have a number of common tools to solve them. Our goal is to enable – through operator collaboration – a unified European infrastructure services market, integrating multiple operators and technologies, such that service provisioning is fast and automated and which results in a stronger economy via economies of scale. The 5G Exchange target is efficiency which can bring innovation and allow a rich set of 5G services to market in a short period of time, benefiting Europe as a whole.

II. The 5GEx concept

A. Overall approach

5GEx provides an innovative solution to the challenge of orchestrating services across multi-domain, multi-technology 5G networks. 5GEx means 5G Exchange, and it is an expansion of the IPX concept into 5G networking by enabling the automated provisioning of Infrastructure as a Service. The term "multiple domain" denotes either multiple network operators or sub-domains or logical slices within a single operator, and "multi-technology" pertains to the multiple technologies of layer 1 to layer 3 backhaul, and core network, combined and complemented with data centres that contain compute and storage resources that can be allocated to services.

Fig. 1 highlights the scope of 5GEx by presenting a logical interworking architecture, showing not only entities but also the different APIs between them. The core of 5GEx system is composed of (i) the Multi-domain Orchestrator/Manager, (ii) various domain orchestrators and (iii) collaboration with domain orchestrators and controllers that are in charge of enforcing the requested services on the underlying network, compute, and storage components.

Co-operation between operators takes place at the higher level through the inter-operator orchestration API (2) that exchanges information, functions and control. This interface also serves for the Business-to-Business relation between operators in complement to the Business-to-Customer (1) that carries the customer requests. A 3rd party Orchestrator can also be part of the different scenarios envisaged by 5GEx. Domain orchestrators (3) & (4) and controllers (5) operate during the orchestration, control, and enforcement of domain components decided by the multi-domain orchestration. This approach allows for a clear separation between the multi-domain elements and the local elements, while still ensuring the flexibility to handle both multi-technology and keeping local infrastructure details confidential. The multi-domain orchestrator is in charge of abstracting the underlying infrastructure before it announces what utility and functions the operator is capable of to its neighbouring operators. Using such an inter-working architecture for multi-domain orchestration will make possible use-cases that are nowadays hard to tackle due to the interactions of multiple heterogeneous actors and technologies.

To address the project objectives, an integration framework (the 5GEx model is shown in Fig. 1) is required which can accommodate 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. The main ideas and assumptions of the 5GEx model are based around a three layer holistic techno-economic model. This model includes (A) Multi-operator wholesale relationships, (B) Multi-vendor inter-operability and within that, the possibility for Multi-technology, and (C) Physical Resources.

Regarding (A) we expect that a Customer will specify the "Service" they require via an electronic Service Manifest document to a provider. This provider will be the origin provider for that customer. This requires the origin provider to provide a Business-to-Business (B2B) or Business-to-Consumer (B2C) facility to the Customer. In order to do deliver the "Service" the origin provider may be able to fulfil all the requirements himself, however for fully cross-domain service deployments he will need to engage with third parties to procure network resources, or compute resources, or other third party capability, in order to fulfil the full Customer request.

From a business / economics viewpoint, the origin provider will become a buyer of wholesale goods from a third party, who is in a fulfiller role. There will be a sub-contract relationship whereby the fulfiller can deliver the wholesale goods to the buyer. Due to the nature of the possible services that may be requested, the origin provider can initiate these buyer/fulfiller requests to many other third parties in order to construct the elements needed for a full service deployment. As any provider can interact with customers, the model can be recursive (i.e., cascading building upon existing trust and business relationships) and stakeholders can have both roles depending on the nature of the request.

Regarding (B) we consider a model based on orchestrators and controllers. Each orchestrator will be deployed to manage different kinds of technology (core networks, data centers, etc) and will interact with a set of controllers that directly interact with the devices themselves. The controllers accept high-level commands from the orchestrators and each contains different device drivers depending on the technology of the

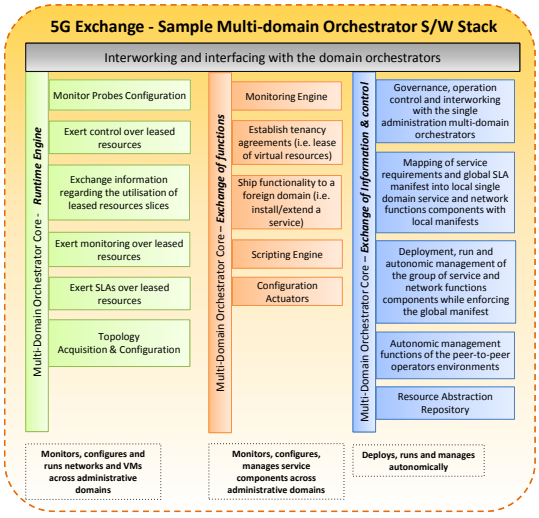

Fig. 2. Sample internal architecture of the Multi-domain orchestrator

underlying resources, and in this way 5GEx can address multi-technologies.

Physical resources (C) that are allocated to the customers can include the full set of network resource options whether Access networks, e.g., LTE (wireless), DSL (wireline), IP/MPLS, optical/GMPLS, OpenFlow based Software Defined Networks or other network technologies, as well as the full set of compute options including virtual machines, storage, bare-metal hosts, or applications. From the perspective of 5GEx these resources are considered to be a black box with a wrapper which will enable the device driver to configure and maintain the resources.

In order to overcome the traditional separation of network resources from compute and storage resources, 5GEx will be (i) fully software driven, (ii) allow the combination of networks and compute / storage within a service (e.g., [1]), (iii) define economic enabler components in the architecture and standard interfaces and SLAs that enable the automated trading and orchestration of networks and compute / storage in a service that comprises also an attractive market product.

Within a single domain, the modules and components will have specific well-defined functionality, interacting with the other modules and components using task specific APIs. For the inter-domain activity, there will be a set of these components that support various negotiation, trading and control operations between administrations. The inter-domain activities can be viewed with respect to two major configurations. The first is the operator to operator viewpoint, where the inter-domain activities are between entirely separate administrative domains that are operated by separate organisations, where only certain elements within each domain can interact with each other. The second is the in-operator viewpoint, where the inter-domain activities are within a single operator, and each of the domains may be a partition of or a logical domain within the organisational resources.

B. The 5GEx architecture

Fig. 2 presents the initial internal architecture of the Multi-domain orchestrator, showing the inter-working interface, together with its internal Core structure. Such internal architecture will be refined during 5GEx project. The Multi-domain orchestrator has three main core components: (i) the Runtime Engine, which manages networks and Virtual Machines across domains; (ii) the Exchange of Functions, which manages service components across domains, and (iii) the Exchange of Information and Control, which enforces interworking, SLAs, mapping and autonomic management of service and network functions. Finally, several APIs are identifed as key to the 5GEx system (see Fig. 1):

1) Service Specification API. This API allows End-Users and Business customers to specify their requirements for a service. The API has the operations and data structure definitions necessary to start, stop, and observe a service. The services can be specified as connectivity, network topologies, or full mix services of networks with compute and storage. This is a Customer-to-Business API.
2) Operator-to-Operator API. This includes interfaces between the Management System and the Multi-domain Orchestrator of operators. It allows management systems to establish business relations, authenticate and authorise and perform bill clearance. It also allows Orchestrators to perform cross-domain optimisations. It further allows the Multi-domain orchestrator to make requests of individual orchestrators, within a single domain, for orchestration. These requests can be for networks, for data centres, or for storage. This is a Business-to-Business API.
3) Multi-Domain Orchestration to Domain Orchestrator API. This allows a multi-domain orchestrator to interact with the orchestrator of various resource domains under the same administration. It sends control commands to the domain orchestrator, and it receives status information from it.
4) Domain Orchestrator-to-Domain Orchestrator API. This API allows coordination between Domain Orchestrators.
5) Domain Orchestrator-to-Controller API. This API allows the execution of orchestrator decisions and also supports monitoring.

5GEx focuses on and innovates regarding (2) to (4) above.

C. Showcasing 5GEx: the sandbox exchange

5GEx partners aim to experiment and validate the devised mechanisms and architecture of the multi-domain orchestrator. The Exchange concept is a set of multi-domain orchestrators dealing with information, control and function exchange for a set of multi-domain resources. Interface (2) in Fig. 1, is the dialogue of the exchange. The concept is realised in 5GEx as a sandbox Exchange. In the project we will integrate a set of testbeds using tunnels, from five operators with a set of multi-domain orchestrators to implement the sandbox Exchange. The sandbox Exchange will be used to complement existing peering functions with additional buyer-fulfiller functions. In order to get experiences on wide ranging and large deployments the focus of the experimentation is to: (i) determine the feasibility of end-to-end multi-domain orchestration, (ii) assess that the solution is of carrier-grade quality, and, (iii) verify the pertinence of the technological choices. This experimentation and

validation includes the testing of the designed orchestrator and the deployment on a multi-domain, multi-technology testbed to validate and assess the improvement of this system. The experiments will be measured against various use-cases 5GEx has devised.

III. Expected advances beyond existing work

5GEx will analyse and define the multi-operator problem by looking at three main dimensions as described below. The first dimension – intra-operator multi-domain scenarios – is the ambition to harmonise in an effective way interworking elements that have different technologies and/or vendors including 5G networks. The second dimension – multi-operator scenarios – is to extend to the multi-operator cooperation to provide an E2E interworking and servicing. In both these dimensions, 5GEx has the ambition to manage multi-domain heterogeneity according to SDN and NFV paradigms where network, compute and storage slicing and suitable virtualisation must enable new service models (E2E service level). 5GEx will provide advances beyond the state of the art both in each level separately and in their harmonisation in a solution that enables the new service models. The third dimension – business efficiency – is the proposition of new business models and economic mechanisms in the context of 5G for the provision of infrastructure (network, compute and storage) as a service, mitigating the inefficiencies of the current regime and enabling open markets and dynamic resource sharing.

The ambition of 5GEx is to develop and validate architecture and algorithms for providing automated and fast multi-operator on demand connectivity, Network as a Service (NaaS), and Multi-domain Infrastructure as a Service (MdIaaS) solutions. 5GEx will have to go beyond the current state of the art to be able to: (i) achieve a 90-minute services setup, (ii) integrate monitoring instances in the developed multi-operator architecture (i.e., extending and coordinating the existing monitoring capabilities that nowadays are proprietary and restricted to specific domains), (iii) optimally solve (i.e., in terms of resource utilisation and revenue) the embedding problem of service requests into the set of virtualised resources mapped into multiple operators domains while matching each service SLA requirements.

Nowadays, network, cloud and service infrastructures are organised in multiple domains that differ in geographical locations, management, control (e.g., legacy or different evolution to SDN), administrator boundaries, and vendor-specific technologies. The 5GEx ambition is to provide harmonic interworking and orchestration among different infrastructure domains including cooperation with both legacy domains and domains implementing new technology due to the extensions towards the backhauling network segment according to the 5G scenarios. In such a context, NFV and SDN are emerging as the predominant abstraction and provisioning framework for the automatic and dynamic inter-functioning between such heterogeneous domains. The UNIFY project proposed an SDN and NFV compliant orchestration framework [1] to address some of the technical challenges. The 5GEx project will go beyond and provide an innovative design for multi-domain automated infrastructure service provisioning.

The SDN premise for simplifying network/service management is based on breaking the current vertical integration separating the control plane from the data plane. Research efforts aimed at providing open, programmable interfaces to network boxes in order to build more flexible, dynamically adaptable networks. Initial approaches considered a centralised control plane [2] and on how packets are switched and routed through a SDN-switch, which has inherent scalability limitations with increasing network sizes and traffic dynamics. Also, efforts focused on a specific interface, which is used to configure the forwarding tables of switches [3]. To partly overcome these limitations research efforts proposed hierarchical solutions, which involve multiple levels of control, e.g., [4] [5] [6]. From the network management plane point of view, research has only considered centralised solutions, e.g., [7] [8], which cannot easily cope with network and service dynamics. 5GEx aims to extend the current SDN functionality beyond the scope of controlling simple connectivity resources to computation and storage, by creating and demonstrating new abstractions and associated interfaces. We envisage separate control and management planes of distributed nature, which will be able to better react to demand dynamics but also to changing service requirements.

NFV is about realising functionalities offered today by expensive middleboxes[1] in software that can run on standard server hardware and that can be moved to, or instantiated in, various locations in the network as required, without the need for installation of new equipment [9]. NFV is still at its early stages of development and proposes, to the extent possible, to replace network functionality that resides in specialised hardware running in the network, with equivalent functionality, running in virtualised environments on commodity hardware. Several use cases have been defined in [10]. 5GEx aims to build a platform that will be able to co-locate multiple instances of network functions on the same hardware, each running in one or more virtual machines, but also allow the physical distribution of functions in the network. Using this technology we intend to enable operators to dynamically instantiate, activate and (re)allocate resources and functions in a flexible and cost effective fashion in multi-domain operator environments. We plan to develop new SDN interfaces through which the placement and configuration network functions can be programmed so that the network and services performance can be optimised.

Orchestration has been defined as the functionality that governs the integrated behaviour and operations of systems with the objective to dynamically adapt and optimise network and service resources in response to changing context and in accordance with applicable business goals [11]. An orchestration plane was designed in the AutoI project to support operations for the interoperation of autonomic control loops, the functionality of which was subsequently used by the Univerself project for the management of virtual resources. The notion of orchestration has also been used in cloud computing for integrating basic services [12]. Orchestration has been proposed as core functionality for NFV [9]. An orchestrator prototype has been implemented in [13] to manage the creation and removal of virtual network nodes, and to configure, monitor, and run/stop software on them. 5GEx aims to extend existing solutions by developing a two-level

[1]Wired, Mystery google device appears in small-town Iowa, 2012. Online at: http://www.wired.com/wiredenterprise/2012/09/pluto-switch

orchestration functionality, which will be responsible for the deployment and operation of services across both multiple domains and administrative boundaries. Domain orchestrators will be responsible for coordinating the actions of multiple controllers corresponding to different resources types, whereas a multi-domain orchestrator will supervise the execution of end-to-end services, e.g., running on a distributed set of virtual machines across domains and operators. We expect that the proposed orchestration functionality will vastly improve service setup time and will make possible use cases that are nowadays hard to realise.

To fulfil the requirements of services, appropriate management mechanisms need to be in place to monitor and configure the available resources. Relevant monitoring systems include the ones developed in [14] [15] to collect information from virtual networks in a scalable manner, and in [16] [17] for the monitoring of service clouds. From the configuration point of view, efforts mainly focused on autonomic approaches that automatically react to stimuli from the network, e.g., traffic changes, [18] [19] [20] [21]. These approaches apply to isolated domains and operators. 5GEx aims to build upon previous work and extend monitoring and configuration solutions to fulfil the requirements of multi-domain and multi-operator scenarios. The project will develop an advanced monitoring system, which will be able to collect and analyse data from heterogeneous sources at the physical, virtual and service levels, but also from across administrative domains. By exposing this information to configuration and orchestration components of the architecture potential service performance degradation and security breaches can be detected and acted upon with the aim to support secure end-to-end service provisioning.

IV. Conclusions

The main goal of 5GEx is to enable cross-domain orchestration of services over multiple administrations or over multi-domain single administrations in the context of 5G Networking. Such orchestration will allow end-to-end network and service elements to mix in multi-vendor, heterogeneous technology and resource environments. In order to overcome the traditional separation of network resources from compute and storage resources, 5GEx will allow the seamless combination of networks with compute and storage across domains in a single service.

The major outcomes of 5GEx will be: (i) a proof-of-innovation multi-domain platform enabling multiple 5G use-cases and realistic scenarios that demonstrate the orchestration of complex end-to-end Infrastructure as a Service (IaaS) across multiple carriers, (ii) a set of open source software tools and extensions that can be utilised outside the scope of 5GEx, (iii) standardisation and contributions pushing for the concepts learned during the development and experimentation of the project, and (iv) greatly impact the telecom and IT market segments by stimulating the industry stakeholders engagement to actively adopt and extend 5GExs open solutions.

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