Manufactured by software: SDN-enabled multi-operator composite services with the 5G Exchange

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Abstract

Foreseen 5G verticals hold the promise of being true value-added services, hence bringing significant income to their respective providers. However, the nature of these verticals are very demanding in terms of both economic and technical requirements, such as multi-operator cooperation, end-to-end quality assurance and the unified orchestration of network and cloud resources. Existing systems fall short of satisfying these requirements, but emerging network softwarization and resource virtualization technologies, such as Software-Defined Networking (SDN) and Network Function Virtualization (NFV) show promise for being key enablers in such context. In this paper, we introduce the 5G Exchange (5GEx) concept that builds on SDN and NFV, and facilitates the provisioning of multi-operator 5G services by means of inter-operator management and orchestration of virtualized network, compute and storage resources. We present potential 5GEx use cases, conceptual architecture and value proposition. We also outline open research questions on how to exchange information in such a co-opetitive environment, and provide an outlook on the impact of 5GEx on a network service provider's business and operation.

1. Introduction

Internet services have evolved rapidly, covering all aspects of communication and infotainment. Services such as video-on-demand and online gaming are already popular, while additional verticals, also integrating cloud and the Internet of Things (IoT), are envisioned in the context of 5G [1]. Efficient provisioning of these services as high-value products in the market requires service-aware routing, *end-to-end* Quality of Service (QoS) assurance including dependability aspects, elastic resource and dynamic service orchestration (over network and cloud infrastructures) and flexible service management. These requirements are currently not met by Best Effort Internet and the inherent shortcomings of a single-traffic-class approach: Large buffers for statistical multiplexing gain inevitably increase delay; there is no way to protect critical over non-critical traffic; the flow control protocols cannot efficiently adapt to congestion and match application requirements with network capabilities, while BGP does not allow for multiple choices for service-aware routing of delay-tolerant versus delay-critical traffic so as to both optimize QoS and load balance the network.

Internet service layer stakeholders buy and sell Internet services and are categorized as Connectivity Providers, Information Providers, also referred to as Over-The-Top (OTTs), and end-users. Connectivity Providers, also referred to as Network Service Providers (NSPs), normally own their network and are responsible for the provisioning of its functionalities. The fact that multiple network (including 5G radio access), cloud and OTT stakeholders comprise the multi-actor value chain of 5G services, inevitably calls for *multi-operator business and service coordination jointly over the network, compute and storage domain.* Unfortunately, currently there is no open and global solution to multi-service internetworking, resulting in costly, legacy, provider-specific service provisioning. This limits the potential of standardized integration of network, compute and storage infrastructure under a **unified** service orchestration, control and management framework. Thus, it is insufficient to carry the 5G value creation at the edge of the networks across the backbones hindering the 5G services value creation. The softwarization of the network control plane and the virtualization of resources can be powerful enablers in the context of a novel exchange mechanism supporting on-demand service creation, standard resource abstractions, resource trading and flexible inter-provider Service Level Agreements (SLAs). Such an exchange framework has the potential to remove the inherent shortcomings of today's solutions, enables 5G value creation at the network edge and matching of requirements of 5G applications and services to properties of connectivity services end-to-end over the virtualized network infrastructure.

Multi-operator services currently rely on best-effort connectivity enabled by service-agnostic interconnection agreements pertaining to inter-domain traffic aggregates. As a result, services experience unpredictable network performance that mostly depends on insufficient and inefficient overprovisioning [2]. Paired with the increasing overall traffic demand and the limited incentives for investing in new infrastructure, 5G services provisioning is a formidable challenge. Overprovisioning is a bad strategy for parts of the network, since a capacity upgrade also brings substantial benefit to a less well-provisioned but interconnected network, making the latter also more attractive to end-users [3]. Thus, though both networks could benefit from an upgrade, selfishly maintaining a low quality interconnection is often a dominant strategy for large ISPs [4].

In this paper, we introduce the novel 5G Exchange (5GEx) concept: drawing on the disruptive innovative technologies of softwarized service orchestration and control (SDN) and resource and network function virtualization (NFV), 5GEx is positioned to be a key market enabler for the provisioning of multi-operator infrastructure services and a catalyst for materializing the value of 5G verticals. From the technical resource orchestration aspect, 5GEx enables the transition from dedicated physical networks and resources for different applications to a "network factory", where resources and network functions are traded on-demand and new services are "manufactured by software" (see Figure 1). Orchestration of the heterogeneous resource domains are achieved via virtualization of resources and network functions and a smart slicing method operating over those virtualized entities.

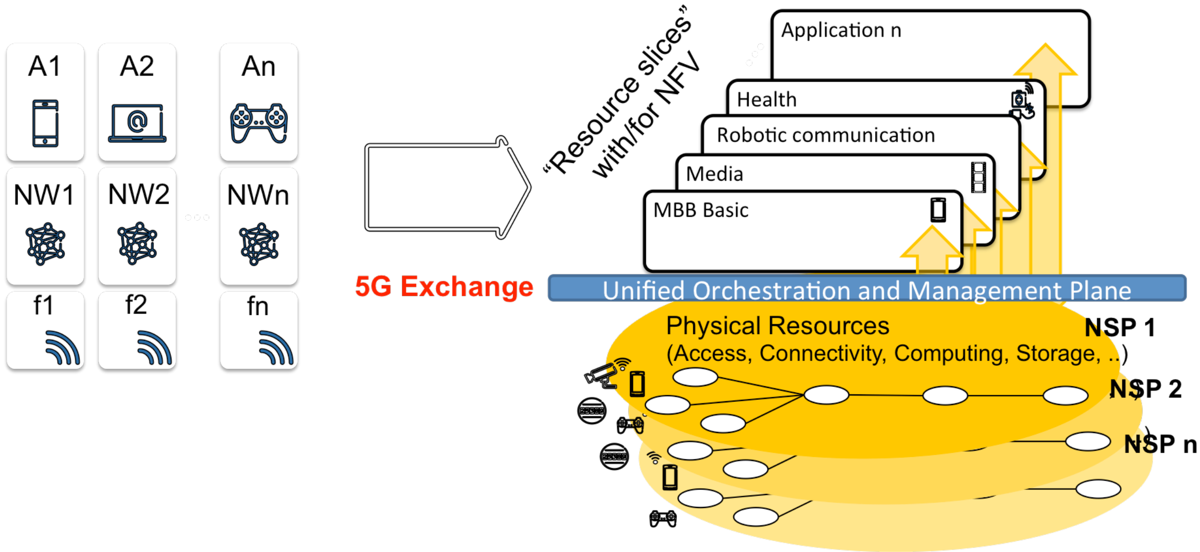

Figure 1 From dedicated physical resources to network factory: services manufactured by software

The rest of the paper is organized as follows. Section 2 presents the state-of-the-art in multi-operator interconnection alternatives. Section 3 presents the benefits of SDN and NFV, and how these characteristics enable the proposed exchange framework. Section 4 introduces the conceptual design of the 5G Exchange. Section 5 discusses operational challenges and opportunities in the context of the exchange from the operator's aspect. Finally, Section 6 concludes the paper.

2. Multi-operator interconnection: state-of-the-art

Multi-operator services have been implicitly supported over the Internet by means of pure connectivity services and interconnection agreements between the operators. Networks rely on **BGP** to build the Internet connectivity graph. They solely exchange BGP announcements and data; interconnection agreements specify whether and how each network should accept and terminate or forward the traffic coming from a neighboring network. Existing *peering* and *transit* interconnection agreements do not provide any type of service-aware routing and management or QoS assurance, and pertain to inter-domain traffic aggregates of multiple services (elastic and inelastic).

From an economic standpoint, the work in [3] points out inefficiencies, such as unfair revenue distribution among providers which discourages network upgrades. The current **"walled garden"** digital service provisioning regime, i.e., operators focusing on intra-domain services for their customer base while being reluctant to cooperate with other operators beyond peering and transit, results in well-known business and economic inefficiencies. This motivates an increasing research and business interest in providing solutions for enabling sustainable ecosystems where services relying on open, agile, elastic management, as well as *quality assurance* can be efficiently provisioned [2].

The ETICS research project has attempted to mitigate these inefficiencies by complementing traditional interconnection peering and transit products with additional products for the provisioning of quality assurance to the inter-domain interconnection services termed **Assured Quality (ASQ) products** [5]. ASQ products support technology-agnostic paths of assured performance and attributes such as IP addresses/prefixes, delay, jitter, bandwidth; SLA attributes are propagated via an overlay of Path Communication Elements, horizontal and vertical interfaces that map them to and enforce them in the underlying networks. ASQ products allow a finer degree of traffic control over inter-domain network paths and regions, while peering pertains to two networks and transit offers global connectivity to the buyer.

Evolving from a separate industry strand, the **IP Exchange (IPX)** is a non-Internet telecommunications interconnection model developed by GSMA for the exchange of IP-based traffic between customers of separate mobile and fixed operators as well as ISPs; essentially, a privately managed IP backbone [6]. IPX, in contrast to the Internet approach, inherently supports QoS interconnection with respective SLAs and cascading payments between operators. There are two characteristics of IPX, which go against IPX becoming a truly global solution. First, IPX uses Network Address Translators and per session gating at IPX border routers making it hard to scale at a global level. Second, IPX is required to be compatible with legacy voice services, adding additional complexity. These characteristics render IPX too complex and expensive for serving as a general purpose backbone for 5G services.

From a cloud provider's standpoint, **cloud federations and exchanges** are gaining momentum, including data center interconnection over federated infrastructure. A typical example is OnApp [7], a federation of cloud providers with cloud and CDN product offerings of fine geospatial granularity worldwide. In addition, UK-based CloudStore [8] supports public, private and hybrid clouds and IaaS, SaaS, PaaS and Specialist Cloud Services. While certainly a hotbed of technical and business innovation recently, solutions from the cloud domain have to be complemented and harmonized with end-to-end assured quality connectivity to successfully provision 5G services.

3. Enabling technologies: SDN, NFV and SFC

While there has been tremendous activity in the networking research community with regard to service quality assurance spanning multiple decades, we believe that the time has just become ripe for capitalizing on a well-designed solution. Two of the key requirements have just materialized: 1) we have the "killer apps" in form of value-added 5G verticals whose value chain is inherently multi-operator in general and 2) enabling technology has just reached the needed maturity level, in the form of Software-Defined Networking (SDN), Network Function Virtualization (NFV) and Service Function Chaining (SFC), and how these technologies can be integrated around the concept of network (and later compute and storage resource) slices.

SDN, in its original interpretation, decouples control from the data plane (and therefore vendor-specific hardware), assigning it to a software controller. SDN simplifies routers and switches and can improve data throughput and reduce congestion via traffic management and optimized resource allocation applied by the controller. In the context of 5G, SDN enables service-aware routing, flow-level quality assurance and efficient dynamic resource management by a logically centralized control logic. The defining benefit of SDN for us, however, lies in its ability to provide an abstraction of the physical network infrastructure. SDN provides network programmability: several customized *network slices* can be configured in parallel using the same physical and logical infrastructure. Thus, one physical network can support a variety of services in an optimal way.

NFV allows for a network function to be implemented in software instead of by a piece of dedicated hardware. This concept comes with inherent scalability supporting the delivery of on-demand, dynamically re-scalable and global services. For us, the key feature of NFV lies in its ability to execute NFs independently of location; this essentially means that the same network function can be executed at different locations for different network slices. Hence, a service-aware virtual network environment is created by the actual placement of NFs.

SFC is not a novel concept in itself: the delivery of end-to-end services often requires various network service (e.g., firewall) and application-specific functions (e.g., HTTP header processing) to be "chained". However, if functions are virtualized and can be placed at arbitrary physical location, and SDN policies are used to steer data traffic through them in a service-specific manner, we have the ultimate elastic service environment: instantly, rapid creation, destruction, scaling and migration of service functions and (with an agile service insertion model) services become possible.

SDN and NFV allow architects to build systems with greater degree of freedom and abstractions, thus network flexibility: with their help the vertical networking of yesterday can be broken down to building blocks that can be chained together to suit the services to be supported. We refer to this concept as *service-aware slicing*; we believe it has the potential to enable the highly-coveted flexibility in service provisioning and delivery (the "Holy Grail of 5G"), while reducing overall costs at the same time.

SDN is also a key enabler from a multi-operator collaboration perspective, as it allows for the direct expression of flexible policies potentially tailored to different applications and service quality requirements (a potential stepping stone for an improved SLA framework). Drawing from (a simplified version of) this idea, the project **SDX** (SDN eXchange point) [9] proposes to deploy SDN-capable switches at Internet Exchange Points (IXPs) in order to make a step from conventional hop-by-hop, destination-based forwarding and enable participating ISPs to apply diverse actions on packets from the IXP such as inbound traffic engineering, redirection of traffic to middleboxes or load balancing. We believe that SDX is a step in the right direction, and serves as an important precursor to 5GEx.

4. The 5G Exchange concept

The **5G Exchange project** aims at enabling 5G verticals by designing an exchange framework capable of handling the orchestration of both network and cloud resources over multiple technological and administrative domains [10]. Apart from catering to the needs of future 5G services, 5GEx also has an objective of overcoming the historical technological and market fragmentation of the European telecommunications sector by bootstrapping operator collaboration with regard to infrastructure services. Such infrastructure services (and associated resources) provide the foundation of all 5G verticals making use of cloud and networking services, apart from the radio interface itself. The envisioned 5G Exchange will enable operators to buy, sell and integrate virtual resources and services, thus enabling one-stop shopping for their customers: it suffices for the customer to contact and contract with a single operator, who will then outsource part of its commitments to other operators given the lack of geographical footprint or available resources. Furthermore, the generic, open and standardized offering of various connectivity modes supported with other 5G capabilities, will enable the numerous SMEs and content providers to differentiate and monetize their online content and application offerings. This will open up new venues of innovation for many businesses and verticals yet unseen, in various consumer, business and public sector markets.

5G services extend personal communication and video services with the integration of Cloud, IoT and machine-to-machine communication into the 5G architecture and service model. NGMN [1] specifies 24 **use cases** for 5G, to be delivered across various devices (smartphone, wearable, machine module) grouped to 8 families, along with related customer-facing services (verticals): 3 families of high-speed broadband access everywhere with HD video sharing as vertical, massive IoT with sensor/smart home networks as verticals, 3 families of lifeline/ultra-reliable communications with e-health/telemedicine as vertical and broadcast services for infotainment. These use case families and verticals motivate the wholesale infrastructure services needed to support them, enabled by resource virtualization, network softwarization and service orchestration and management of the proposed 5GEx multi-operator exchange. 5GEx can be seen as the 5G evolution of exchange environments such as IPX, SDX and IXPs; a core subset of 5G infrastructure services envisioned that are capable of supporting the aforementioned use cases and verticals are Connectivity (e.g., VPN+), Virtual Network Function as a Service (VNFaaS, e.g., vCDN) and Anything-as-a-Service (XaaS, e.g., Gi-LAN).

Connectivity is a use case family of wholesale connectivity services over multiple domains, capable of supporting next-generation connectivity verticals such as VPN+. VPN+ denotes an improved Virtual Private Network service (aimed at an enterprise customer) with a *Network-as-a-Service* (NaaS) element such as partial topology description and dependability requirements. The vCDN use case implements a virtual Content Distribution Network, where a video portal (customer) purchases the right to use the CDN facilities of a CDN provider: this also involve *storage* resources. XaaS represents the most challenging use case in that it potentially involves the full range of *network, compute and storage* resources with strict performance and dependability guarantees, e.g., ultra-low latency and adequate computational capacity, to enable demanding verticals such as industrial robotics and Mobile Edge Computing (MEC) scenarios. A very concrete instantiation of XaaS inspired by a true operator need is international mobile data roaming (referred to as the *Gi-LAN* use case). Since the EU will ban mobile roaming fees within Europe, a drastic increase of roaming data usage is expected. The normal process of roaming would involve building tunnels back to the home Packet GateWay (h-PGW) through international exchange points: an expensive and unfavorably scaling mechanism. Moving the h-PGW and the entire Gi-LAN functionality to the roaming operator’s data center results in a cheaper and dynamically scalable solution. (While this list of use cases is clearly not exhaustive, they demonstrate the different expected capabilities of 5G Exchange well.)

The aforementioned wholesale 5GEx infrastructure services can efficiently serve verticals by relying on lower-level 5GEx fundamental services and SDN/NFV techniques, with the core element being the **slice**. A slice is defined as a managed set of 5G resources and network functions set up within the 5G system that is tailored to support a particular type of user or service. Note how the slice concept is an evolution of network slices as used in SDN also incorporating cloud resources and NFs. These slices are then instantiated on-demand using APIs exposed by the management plane, which provides dynamic orchestration for multilayer and multi-domain networks. SDN and NFV greatly simplify slice and service orchestration and management, as opposed to the traditional inter-working of legacy networks and clouds. 5GEx uses a) standard interface (1) for multi-domain orchestrator to translate the 5GEx customer service request to a chain of VNFs and underlying network, storage and cloud resource requirements b) standard interface (2) and respective SLAs for trading slices and 5GEx higher-level services among 5GEx-enabled orchestrators and c) standard interface (3) for the management of own or leased – via interface (2) – resources. For a simplified conceptual architecture of 5GEx please refer to Figure 2. Precursor projects containing ideas and code for interfaces include ETICS (interface 2, [5]), UNIFY (interface 3, [11]) and T-NOVA (interface 1, [12]).

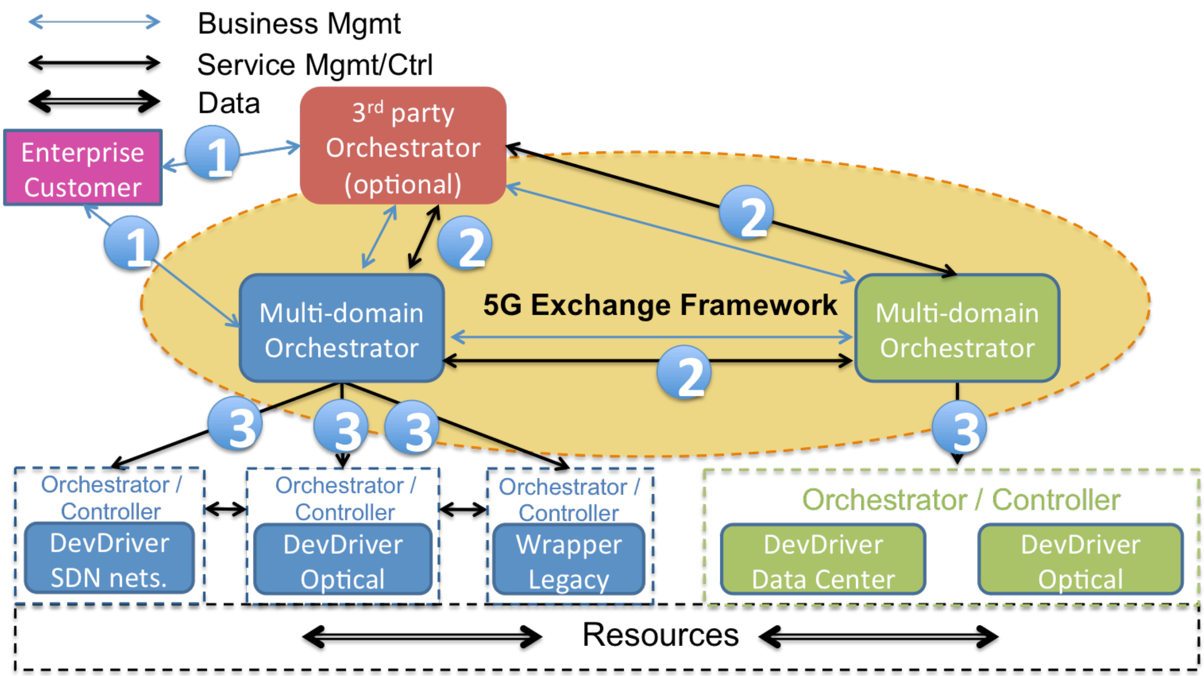

Figure 2 Simplified conceptual architecture of the 5G Exchange

The proposed 5G Exchange Framework supports a **variety of specific deployments and coordination/collaboration models** such as: i) “direct peering” at an already established local or remote IXP, ii) distributed multi-party collaboration, where the operators host the exchange mechanism in a distributed manner inside their own infrastructure, and iii) a dedicated (for-profit) Exchange Point Provider as a standalone entity, offering exchange point services. In addition, the 5G Exchange Framework also supports higher level abstractions and advanced models covering views, resources and services across several exchange points or PoPs. Also note that the customer-facing “3rd party Orchestrator” in Figure 2 is an optional role in the ecosystem, essentially referring to a virtual network operator who implements the multi-domain orchestrator functionality, but does not own an infrastructure.

The clear separation of functionality allows 5GEx to make the most out of SDN and NFV, creating an open agile management and orchestration environment where multi-operator services become only marginally more complex than single-operator services due to the common interfaces and functionality for the management of both own and leased services. There is an analogy here with the cloud ecosystem in terms of architecture and value proposition, with the various 5GEx layers [13] mapped to cloud resources and services ranging, e.g., from Amazon's S3 through EC2 to CloudFront high-level service, as depicted in Figure 3. Lower-level resources are the *low-margin commodity building blocks* of differentiated higher-level services for serving 5G verticals. At all levels of the value chain, we use the service concept appropriate for the given level. Virtual resources and NFs are composed into slices utilizing the Network Function Infrastructure as a Service (NFVIaaS) paradigm; slices make up infrastructure services, by the concept of Slice-as-a-Service (SlaaS); finally, infrastructure services comprise a custom 5G vertical, which in turn can be purchased by a customer residing outside the 5G Exchange (high profit margin). Therefore, intra-5GEx services by-design consider the needs of 5G customer-facing services. The (potentially recursive) trading of slices and 5GEx services over interface (2) can support multiple coordination models, including push and pull, if goods are built on-demand or pre-built and part of a catalog, as well as distributed or centralized, whether the multi-domain orchestration is a centralized third-party service or implemented in a distributed fashion over multiple instances, one per 5GEx infrastructure service provider.

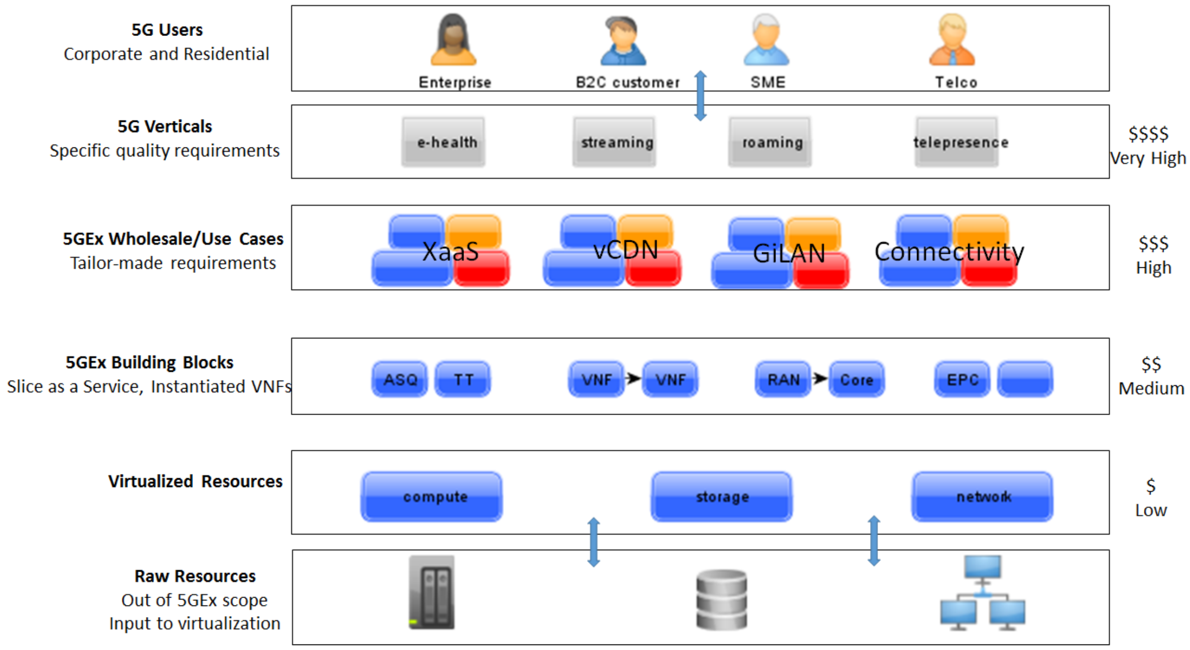

Figure 3 Levels of 5GEx goods and value proposition mapped to the current cloud ecosystem

Although the conceptual architecture and value proposition are clear, there are still some design challenges ahead, the most glaring focused on the exchange of information among 5GEx operators (see Figure 4 for an example with User 1 as customer and Op1 as customer-facing operator). On the one hand, SDN supports a rich set of possibilities for exchanging information as described in Section 3. On the other hand, what kind of information should be shared, with what granularity and how to calculate relevant KPIs and design corresponding SLAs are all mostly open questions. Naturally, there is a tradeoff between the business interests (sharing the least amount of information possible) and optimal end-to-end resource management guaranteeing assured quality (sharing the most precise information possible). Furthermore, virtualization involves aggregation of information about the physical resources, network topology and policies; multiple levels of virtualization in 5GEx makes matters even more complex. Thus, the chosen method of information exchange has far reaching consequences with regard to both performance and dependability of the provisioned services.

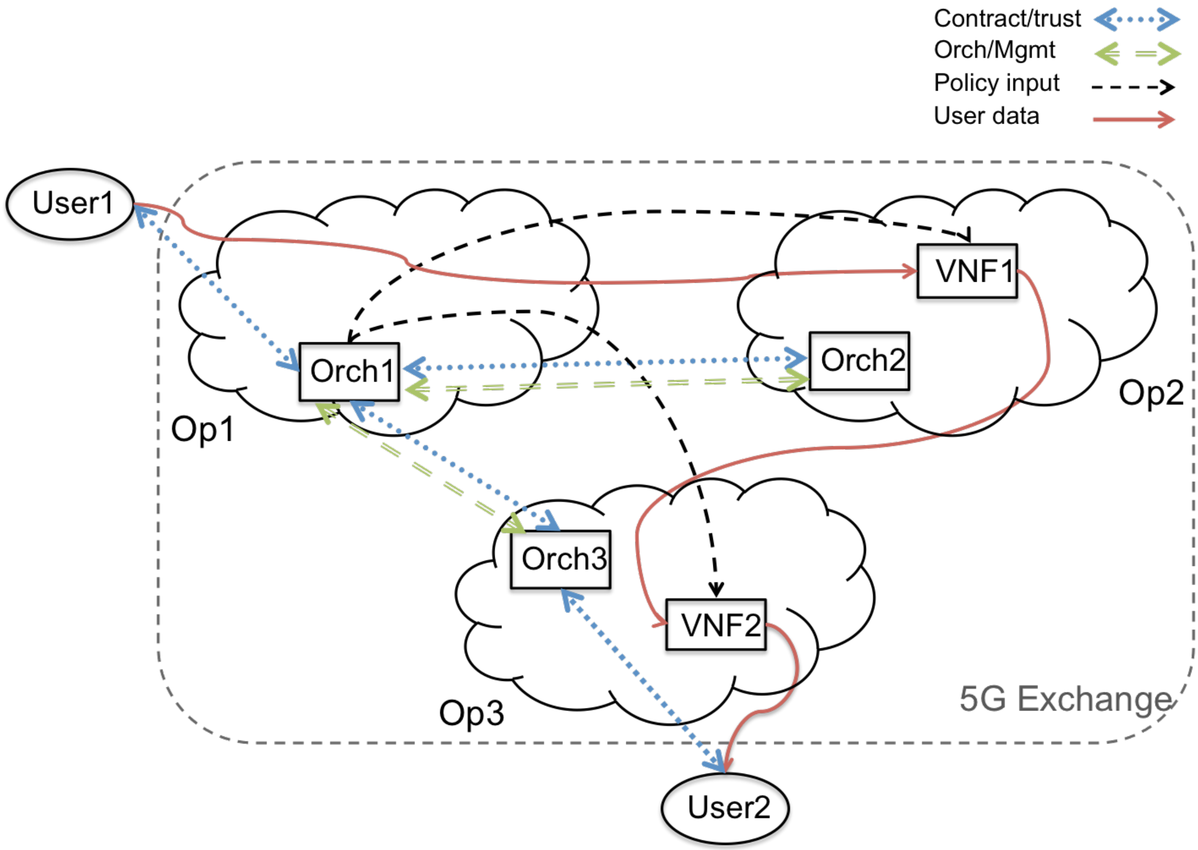

Figure 4 Example: information flows in a 5GEx scenario

In order to rise up to this challenge, the following research roadmap could be followed. First, we have to understand what is the maximum amount and finest granularity of information we could possibly collect using advanced SDN and cloud monitoring techniques. Second, we should carefully investigate and quantify the interdependence of virtual compute, storage and network resources with regard to both performance and dependability, both within a domain and over multiple domains, or if they share some physical resources. Third, we should repeat step 2 upwards in the value chain to have a model of the whole ecosystem. Finally, we should go beyond basic aggregated mean values when it comes to KPIs, and consider quantiles and even full probability distributions of important performance and dependability metrics, potentially leading to more descriptive SLAs, supporting assured quality service delivery.

5. Business and operational impact

In summary, driven by the 5G technology innovations and enablement of new verticals and their diversity of future applications, there are numerous economical drivers to push and reshape the overall response by the industry in terms of multi-provider services. We foresee a future where business and technology enablers will be carefully aligned and provide an agile, efficient and open multi-service multi-provider solution. Enabled by SDN we anticipate an evolution into a powerful multi-service platform that goes beyond pure connectivity offerings.

This multi-provider platform will also accommodate the needs of, as well as integrate the capabilities of, the emerging NFV and softwarization solutions.

While learning from the IT and cloud industry, the Telco and NSP industry will find themselves in an even more uncertain position and challenged with many strategic questions. On the one hand, the new technology enablers will allow on-demand trading, flexibility in re-negotiating SLAs, elasticity and dynamic traffic, resource and service management. However, which resources should you own and which resources and services should you buy? What is the best contract duration, and the better roadmap for my service and capability offerings? What kind of partnerships should I develop? How will I best adjust my organization and my operational processes to become an excellent player in such a future [14]? Perhaps the biggest challenge to the network infrastructure and services is “bootstrapping” the basic solution enablers when faced with so many multi-stakeholder coordination issues. On the positive side, solution proposals are now getting more mature and business attention is rising as the need for solving the challenges are becoming more clear. The use cases and 5G verticals mentioned above are good examples for that.

SDN-enabled solutions can help NSPs evolve their networking solutions in manageable steps according to their business developments and roadmap. By evolving the current IP traffic exchange solutions, it can complement and augment the current BGP-based operations with managed quality and multi-service inter-NSP 5G-ready traffic exchange services and SLA management solutions. When such a managed and assured quality traffic exchange solution is enabled among a set of initial partners, the solution can scale and grow into a full fledge traffic, resource and service trading and exchange platform. This holistic multi-domain resource slicing solution will unleash the full potential of 5G.

The value-added connectivity and services that are specific to the end-customer are handled by appropriate policies at the SDN-enabled service edge nodes. The traffic flows are then steered onto the appropriate infrastructure ASQ paths and back-office data centers, according to the application requirements. This way, consistent end-to-end traffic and service handling across domains can be achieved and supported by the intelligence of SDN controllers and the SDN-enabled monitoring and service assurance capabilities. The above anticipated multi-domain service and resource orchestration, hierarchical SLA management, and the need for automated mapping between high-level and lower level SLAs and their specific configurations and monitoring capabilities will become more crucial as the industry evolves [15].

6. Conclusions

The advent of the 5G era brings with itself the promise of value creation by means of a wide range of verticals. On the one hand, we have demonstrated how today’s best effort Internet is not suitable for the assured quality interconnection these inherently multi-operator services require; other existing solutions are either too domain-specific or have incomplete functionality. On the other hand, we have shown which features of SDN and NFV technologies supplemented with service function chaining serve as key enablers for a novel alternative concept called 5G Exchange (5GEx). We have introduced the 5GEx conceptual architecture and presented how it is able to handle the inter-operator orchestration of composite (network and cloud) resources with the main technical concept of resource slicing. We have also outlined the 5GEx value proposition enabling the creation and trading of complex, high margin services built on top of low margin, commodity building blocks. Furthermore, we have addressed the open question of how to exchange information within the 5GEx framework and provided a roadmap for future research. Finally, we have investigated the business and operational impact of the envisioned solution. We believe that the 5G Exchange is capable of satisfying both the technical and business requirements of future 5G verticals and ushering us into the 5G era.

Acknowledgments

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