Fixed-Mobile Convergence Towards the 5G Era: Convergence 2.0

The past, present and future of FMC standardization

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***Abstract*—Fixed-Mobile Convergence (FMC) has been a trending topic in telecommunications during the last decade. Standard Development Organizations (SDOs) have addressed FMC in the context of different access and core networks, with special focus in the 3rd generation Partnership Project (3GPP) and in the Broadband Forum (BBF). This paper describes the standardization work done in this area based on the work done in 3GPP, BBF and IETF. It also reflects on how the standardized FMC toolbox together with the new network deployment paradigms such as Network Function Virtualization (NFV), network programmability and automation, and network slicing impact the design and standardization of multi-access, 5G networks.**

1. Introduction

The last decade has witnessed the evolution of Information and Communication Technologies (ICT) towards realizing a network society [1]. It is foreseen that these emerging ICT solutions will play an even more important role in creating industrial infrastructure supporting economic efficiency and urban infrastructure, enabling an Internet of Things (IoT) that increases peoples safety and security [2].

In this evolution, new business models and new social roles have been enabled, depending on the local geographical realities, by the technologies that operators have deployed in their networks. These realities, in turn, have increased even more the expectations and demands from all type of users on the availability, reliability and ubiquity of the connectivity and Internet services that they are consuming [3].

Operators worldwide have today the highest pressure in their history to maintain, and as much as possible, improve their connectivity and Internet services, while striving to keep profitable business models. The new 5G networks paradigm being discussed in the ICT industry at the present time is being designed with the promises to fulfill such demands and expectations [4].

Most networks are set to evolve towards supporting seamless service delivery, regardless of the access network technology (what has been known in the industry thus far as Fixed-Mobile Convergence, FMC), increased network programmability and automation capabilities of the existing and new network infrastructure as some of the key enablers to satisfy the requirements envisioned by the use cases driving the operators network evolution [5].

The FMC work done so far, and described in this paper, conform a foundation and a toolbox for the ongoing 5G network design and standardization activities, where multiple access technologies and networks must be exploited to provide as much bandwidth and reliability as possible to an end user. In 5G, this needs to be enabled by access-independent core networks, supporting common operational and service life cycle management, regardless of which access is used to deliver the service. This 5G key requirement might be satisfied through the existing FMC toolbox together with the new implementation paradigms facilitated by technologies such as Network Function Virtualization (NFV) and network programmability and automation. These are enablers to realize the so-called network slicing in 5G, which are expected to cater for the extremely diverse requirements to be supported by the same network infrastructure [6].

The work presented in this paper focuses on the standardization developments of network technologies and solutions for operators to be able to support the aforementioned requirements and satisfy the expectations on their networks evolution. The paper describes how this can be realized by means of the existing standardized FMC toolbox both through a 3rd Generation Partnership Project (3GPP) based mobile network as well as through a Broadband Forum (BBF) based fixed access network, and / or using all available network access technologies simultaneously, providing to a given end user all available bandwidth at a particular place and time. The paper also describes the role that NFV, network programmability and network automation play in enabling network evolution towards 5G; in a way redefining the existing FMC toolbox in the 5G era as the Convergence 2.0 network.

The paper is organized as follows: Section 2 presents the state-of-the-art standardization in control plane convergence; Section 3 describes the state-of-the-art in convergence of the

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user plane; Section 4 describes how the emerging technology paradigms NFV, network programmability and automation lead to a Convergence 2.0 network model towards 5G; finally Section 5 provides the main conclusion and takeaways of this paper.

2. Convergence in the Control Plane

During the consolidation phase of the telco market that has been ongoing during the past decade, many of the prevailing operators emerged as both fixed and mobile access network providers, also known as converged operators. This offered an opportunity for Operational Expenditure (OPEX) optimization, considering that operators would have to maintain equivalent network service functions for both access networks, like authentication, policy, charging or subscriber data management, which partially motivated the work described in the following sections.

2.1. Interworking between 3GPP and BBF

Starting from the service layer, the definition of the common IP Multimedia Subsystem (IMS) architecture was the baseline of a convergent service using both fixed and mobile access networks [7]. As for the technical network convergence, this problematic was brought in 2008 simultaneously to the 3rd Generation Partnership Project (3GPP) and the Broadband Forum (BBF), as the two most relevant standard bodies for mobile and fixed access networks. The joint collaboration work that started between the 3GPP and the BBF quickly concluded that interworking of policy and charging management aspects should be the first steps towards a convergent control. These aspects were detailed in the BBF Technical Report TR-203, which collects business requirements and architectures principles for the case where 3GPP UE devices handover between the BBF network, e.g. that include Wi-Fi access or small cells, and the 3GPP mobile access [8].

Working on the business requirements documented in the BBF TR-203, the necessary additions were made in the policy and charging architecture in order to support the interworking between the fixed and mobile domains. This work finalized in 2014 with the release of the 3GPP TS 23.139 and the BBF TR-291 [9], [10]. These specifications describe the basis of policy control interworking between BBF and 3GPP, including nodal requirements, procedures and reference points that enable the exchange of subscription information between both domains. This interworking function allows, for example: the BBF domain to authenticate 3GPP UEs; exchange and setup of charging and policy control information (e.g. gating information and Charging Data Records, CDRs); and control of traffic offload (i.e. which of the 3GPP UEs generated traffic is to be redirected to the 3GPP core network or offloaded through the BBF core network). Hyunsook Kim et al. summarize these enhancements done in 3GPP and BBF nodes and core network architectures, highlighting the major aspects of the standardization work [11].

2.2. Convergence for charging and policy control

Although enough for operators that still have separated domains at the administrative and technical levels, interworking is not convergence. Hence, a number of operators recognized that having a real converged control over both access would considerably reduce Capital / Operational Expenditures (CAPEX/OPEX) as well as facilitate the release of differentiated services.

Using interworking as starting point, BBF TR-300, documents how the 3GPP Policy and Charging Control (PCC) architecture can also manage BBF policy enforcement nodes, like the Multi-Service BNG (MS-BNG), in order to reduce the redundancy of policy decision information for one subscriber [12]. At the same time, a number of enhancements for policy control nodes QoS, gating and service differentiation and charging were developed and documented in 3GPP, for architectural work in order to support 3GPP UEs and fixed devices in the BBF network [13].

2.3. Towards a unified control plane

Figure 1 summarizes the architectural changes in 3GPP and BBF architectures to achieve Policy and Charging interworking and convergence of control plane signaling.

In red color in Figure 1, the reference points created to support control plane interworking between mobile and fixed domains are highlighted. S9a reference point is specified in 3GPP TS 23.139 and it is used to exchange policy and charging information (rules) from the centralized Policy and Charging Rules Function (PCRF) and BBF Broadband Policy Control Function (BPCF). BPCF is then able to use BBF standard procedures to send this information to the MS-BNG as specified in BBF TR-134 [14]. STa/SWa reference points were created based on existing ones, to authenticate 3GPP devices accessing a BBF network. This allows the BBF AAA to query the 3GPP AAA in the session establishment procedure as specified in the BBF TR-291 [10]. In orange color the 3GPP-defined reference points enhanced to support Policy and Charging mechanisms in the fixed domain are defined.

For policy enforcement, 3GPP Gx reference point was extended to include fixed and WLAN related information needed to correlate QoS and charging information in the MS-BNG, which in this scenario acts as Policy and Charging Enforcement Function (PCEF). With this setup an operator avoids subscription information redundancy and it can deploy mobile-based services within its fixed network.

For charging purposes this enhanced architecture proposes two models: a first alternative supported by extended versions of 3GPP Gy and 3GPP Gz reference points, allowing 3GPP-based credit control in a MS-BNG, controlled by the Online Charging System (OCS) and Offline Charging System (OFCS); and a second alternative, supported by Gya and Gza, which are different flavors of the previously mentioned reference points, enabling a OCS and OFCS to deploy credit control where AAA-based credit control

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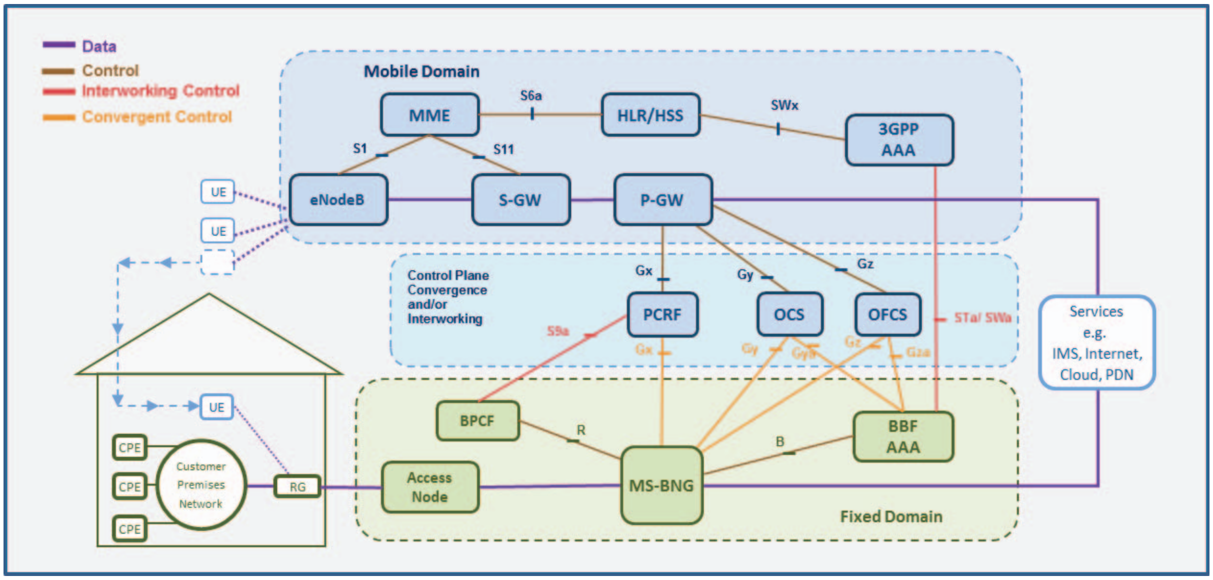

Figure 1. Convergence and Interworking of the Control Plane.

is used. This 3GPP-based architecture and procedures for policy and charging, enhanced to support the fixed domain are described in detail in [12], [13].

All the mentioned standardization work aiming a technical convergence of the control plane for policy and charging control is the building block towards a unification of the control plane for policy, charging and authentication functions. This potential unification paves the way for access-independent network management done by next generation core network serving the 5G multi-access networks, as documented by Leitão et al. [15].

3. Convergence in the User Plane

Similarly to what was described by the previous chapters, on the user plane one can distinguish two major technology approaches that enable seamless service delivery across multiple access as well as optimal use of all bandwidth available to the end user: 3rd Generation Partnership Project (3GPP) Broadband Forum (BBF) networks interworking; and the hybrid access.

3.1. User Plane Interworking

Based on the use cases previously specified in the BBF TR-203 and in the standardization work done in the 3GPP TS 23.203 and TS 23.139, the BBF TR-291 defines the requirements at the infrastructure level for the user plane of BBF networks to be able to deliver 3GPP services, according to 3GPP subscriber profile policies [8]-[10].

The use cases cover both converged operators that might consider all accesses under their domain as trusted domains (S2a-based interworking) as well as use cases for operators that do not have trusted relationships between the fixed and mobile domains (S2b-based interworking). This range of user plane solutions provide a toolbox of solutions for seamless service delivery across different accesses, under the control of a common core infrastructure, as described in the previous section.

In Figure 2 are represented these two interworking paradigms. For trusted domains interworking, the fixed domain may instantiate a Trusted WLAN Access Network (TWAN), a logical function usually co-located with the MS-BNG as suggested in Figure 2. The TWAN is responsible for the authentication of 3GPP devices visiting the fixed domain and traffic offload towards the 3GPP Packet Gateway (PGW). For this purpose it establishes a GTP based tunnel upon the S2a reference point. For untrusted domains interworking the MS-BNG cannot reach the PGW directly. This restriction comes for authentication/security and interoperability concerns. To overcome this situation the 3GPP UE device establishes an IPSEC tunnel directly with a 3GPP intermediate logical node: the Enhanced Packed Data Gateway (ePDG). The ePDG is reached by the MS-BNG through the SWn reference point. Then the ePDG may establish a GTP or PMIP tunnel towards the PGW, depending on the implementation requirements.

The TWAN, ePDG, corresponding reference points (S2a and S2b) and procedures for session establishment and maintenance are described in detail in the 3GPP TS 23.402 and BBF TR-291 [10], [16].

3.2. The Hybrid Access

The specifications previously described, assume that the subscriber was either using the mobile access or the fixed access, but not both simultaneously. Technically there is no constraint to support simultaneous use of both accesses, but the use cases documented in [8] and [12] did not consider that option.

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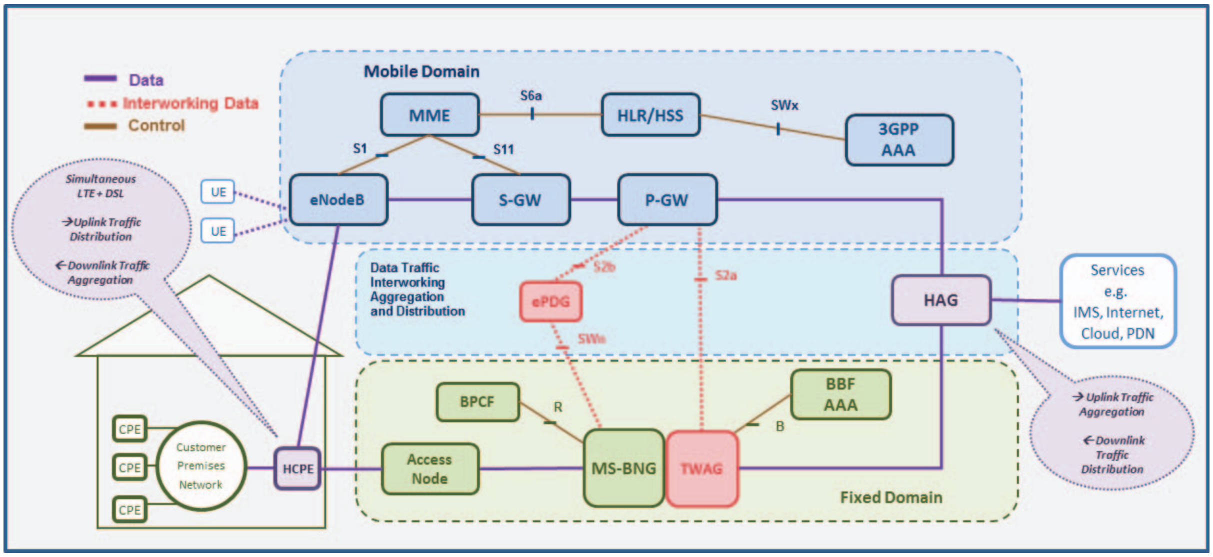

Figure 2. Convergence and Interworking of the User Plane.

There are advantages on using more than one access simultaneously. Fixed access service providers looked at this paradigm as a fast-lane to: speedup service deployments, in areas where DSL or fiber is still under deployment; enhance coverage and capacity, by combining both access links and boosting the available bandwidth; and increase network reliability, as demanded by some enterprise business models. All these use cases where actually discussed in several standardization bodies and finally documented in the BBF in late 2014. This was the motivation for the BBF TR-348, as the Hybrid Access Broadband Network Architecture, the first released specification for Hybrid Access [17].

The most visible architectural enhancement is the definition of two new logical nodes responsible for the aggregation of user plane traffic: the Hybrid Customer Premises Equipment (HCPE); and the Hybrid Access Gateway (HAG).

The HCPE is a fixed access CPE typically a DSL router, switch or residential gateway enhanced with a second WAN interface connected to a 3GPP access network, e.g. 3G or LTE access. This logical box is responsible to provide network access to the customer premises, distributing upload traffic among the simultaneously connected fixed and mobile links, and aggregating traffic that comes through both links in the downlink direction. Having two access network links it can be simultaneously connected to the LTE eNB through its radio link and connected to the fixed access node (e.g. DSLAM).

Placed in the opposite side of the operators network is the HAG. The HAG is a logical function placed in the operators core network that can be a standalone node or co-located with the gateway (e.g. the 3GPP PGW or the fixed BNG), depending on its implementation deployment. It has the responsibility of aggregating a subscriber uplink traffic that comes from the fixed and mobile core before being forwarded to the external network, and distributing downlink traffic between the two domains towards the subscribers HCPE direction. The new nodes described are represented in Figure 2, contextualized within 3GPP and BBF network architectures.

In Hybrid Access, traffic transportation and distribution schemes may differ according to the deployment scenario. If a layer 4 packet distribution mechanism is required, the Multipath TCP (MP-TCP), although not originally designed to support Hybrid Access, is an IETF-based standard mechanism that can serve as building block for future enhancements [18]. Another alternative could be layer 3 overlay tunneling mechanisms, as such PMIPv6 [19] or GRE-Tunneling [20]. Finally, and considering that one of the paths would be on a 3GPP link, then a layer 3 native network tunneling could also be explored, re-using the GPRS Tunneling Protocol (GTP) for this purpose, exploring what has been done so far within the 3GPP NB-IFOM working item [21]. Considering that, according to 3GPP initial stage studies, 5G networks and devices should be as more access independent as possible, and that we can foresee future devices having simultaneous access to different access network links, then the Hybrid Access paradigm can be the operators first approach to a truly converged network. Hybrid Access technical motivations, implementation and deployment scenarios and standardization status are explored in deeper detail by [22].

Enhancements would be needed to enable and adapt traffic distribution schemes on the device and the core network gateway to the new and demanding applications and services. In fact, to achieve the ultimate goal of deploying a programmable, and automated network where services would be turned on and off on-demand, or the core network would be sliced per device or service type, operators are relying on the toolbox provided by Network Function Virtualization (NFV) of some access and core network functions and network programmability and automation technologies to deal with the challenges to the traditional charging and

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billing mechanisms which are even more complex in a true converged network scenario [6].

4. Convergence 2.0: The road towards 5G

5G systems imply a revolution in the way telecom networks are actually implemented. The target of 5G is to provide the technology foundation for the deployment of high-quality and reliable end-to-end services not only to humans, but also devices, serving as ultimate enabler for the new generation of the Internet-of-Things (IoT). Therefore access agnosticism, always-on connectivity, and common core network are key concepts by most of 5G-targeted services.

Multi-access interworking and convergent technologies, and the standardization efforts described in the previous sections, are necessary building blocks towards the definition of a 5G network. These aspects were actually considered in the Stage 1 studies of 3rd Generation Partnership Project (3GPP) for the New Services and Markets Technology Enablers (SMARTER), i.e. basic building blocks for the definition of the new 3GPP-based 5G systems. Although primarily targeting the support of a new radio access, it was set as potential service requirement that the new 3GPP system is expected to support at least: inter-access mobility between mobile and other access types (e.g. WLAN, fixed broadband access, Bluetooth, etc); different access selection; simultaneous access connectivity; and 3GPP-based authentication for different access types. System requirements for the 5G system development are explored by 3GPP in the TR 22.891 [23], including convergence-related requirements, as described, but also evolutionary network paradigms like Network Functions Virtualization (NFV), network programmability and automation.

When considering these new network deployment paradigms in the context of Fixed Mobile Convergence (FMC), it is possible to define a Convergence 2.0 network model for the 5G era. The highlights of such Convergence 2.0 network model can be summarized looking into each of such networking implementation paradigms: NFV and Network Programmability and Automation.

4.1. Network Functions Virtualization

Defined by ETSI [24], NFV provides a framework for the virtualization of telecom applications, enhanced with management and orchestration capabilities. A network node becomes then a Virtualized Network Function (VNF), decoupled from the actual hardware (HW) resources, which are provided by an infrastructure service. A VNF is then a software application (SW) whose needs on computing, memory, or storage, are handled (and, in a certain way, hidden) by such infrastructure service.

In addition, NFV provides a standardized management and orchestration system, which is the responsible for making the VNF resource instantiation towards the infrastructure service. That enables common Operation & Management (OAM) procedures, including service onboarding, scaling, upgrade, VNF management or decommissioning, for the complete set of the deployed VNFs.

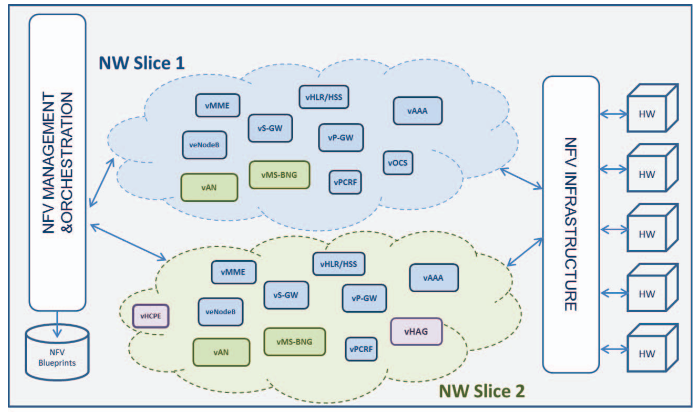

Figure 3. NFV enabling the deployment of network slices.

The NFV paradigm invites network architects to reconsider the strategies towards convergence followed in classical networks, and described in the previous sections of this paper. A deployed VNF is just a SW instance of a network entity, not a network node. Specialized VNFs of the same function can be then actually deployed.

4.2. Network Programmability and Automation

In addition, a VNF is expected to support auto-configuration, auto-scaling dynamically whenever it is needed, and capable of self-healing in case of VNF failure (that is without human interaction). That implies smaller, easier and predictable VNFs. This is again a different view on what the classical convergence has done, mainly focused on the definition of complex network node entities capable of managing several traffic scenarios

NFV, plus network programmability and automation, allow the implementation of network slices, a concept that proposes to deploy a complete (and affordable) network subset, dedicated to a specific business segment. That increases the number of potential telco providers, from the classical telecom service providers dedicated to niches (e.g. basic but affordable connectivity for young people) to companies (enterprises) with no experience or expertise in such area but that requires enough telco-based connectivity to outsource a telco network slice (e.g. electrical companies that have to deal with massive M2M devices communications).

Figure 3 represents NFV-enabled network slices, serving different network deployments and different tenants. In slice 1, the operator deploys both fixed (in green) and mobile (in blue) virtual network functions serving a subset of its subscribers that have both mobile and fixed subscriptions, for example; and in slice 2 the operator deploys a subset of virtual network functions for Hybrid Access subscribers (in violet). In both examples the virtual AAA function is deployed serving all subscriber types (fixed, mobile and hybrid).

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4.3. A Network of Software Functions

NFV, network programmability and automation including network slicing mean that the network, which has been a network of nodes, becomes a network of SW functions or VNFs. Consequently, the standardization of a Convergence 2.0 network model within the 5G era might follow a new archetype, a novelty in the telco industry standardization. It consists of standardizing by SW implementation, through Open Source Communities (OSC) and their ways of working and methodologies. Classical standardization, as the definition of architectural frameworks, network entities and reference points, is considered still necessary, but in very tight collaboration and alignment with the new SW implementation activities of the OSC, as already indicated by some SDOs [25].

Facing this scenario, it is much more feasible for an operator to distribute and instantiate network functions that finally tailor a network slice. Convergence 2.0, makes the instantiation of those components access-type independent. Novel business models may appear from this paradigm, like for example the association of a specific slice (and consequent vertical) to a specific network access type.

5. Conclusion

Fixed-Mobile Convergence (FMC) has been a trending topic in the last decade, being that reflected in the different Standard Development Organizations (SDOs) dealing with the different access networks and core networks, with special focus within the 3rd Generation Partnership Project (3GPP) and the Broadband Forum (BBF). This paper describes the standardization work done in this area based on the work done in 3GPP, BBF and IETF.

With the 5G network (radio and core) being designed by the time of writing of this paper, the FMC-related work done so far is described and analyzed in the context of its suitability to fulfill all the 5G-based service demands. This comes at a time where classic SDOs, like the BBF and 3GPP SA2 Working Group make plans to re-engage on joint discussions following past successful collaborations on FMC, but now focusing primarily on the common 5G core network architecture[26].

This paper however, goes beyond the classic SDOs paradigm and refers also to new network deployment paradigms like Network Function Virtualization (NFV), network programmability and automation that enable network slicing. It describes how the combination of existing FMC toolbox with the new network deployment paradigms might fulfill and satisfy some of the main requirements, which motivated the convergence work developed in the past.

Even though standardization will continue to play an important role in the network functions evolution, the Convergence 2.0 concept proposed in this paper builds upon the development of SW pieces. Those SW pieces cannot be considered as closed and frozen, but continuously refined as part of their own evolution. As a result, Open Source fora (e.g. OpenStack) join the classic SDOs in the leadership of the new Convergence 2.0 standardization for the 5G era.

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