Softwarization of Future Networks and Services -Programmable Enabled Networks as Next Generation Software Defined Networks

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Abstract— **The Software Defined Networks (SDNs) and Network Functions Virtualisation (NFVs), as recent separate research and development trends have the roots in programmable / active network technologies and standards developed a decade ago. In particular, they are associated with the decoupling of forwarding from control and hardware from networking software, using open interfaces to connectivity resources. The next phase of R&D would involve novel integration and use of all connectivity, storage and processing resources under new management and control systems for provisioning of on-demand networking and services with continuous update of features. This brings into focus a relatively new and key topics for the next decade: what and how to create the conditions for effective and continuous updating and changing the networking functions without reinventing each time architectural aspects and related components (e.g. Softwarization of Future Networks and Services or Programmable Enabled Networks). This paper presents some of the key challenges in realising such programmable enabled networks.**

Keywords—Programmable networks, softwarization of Future Virtual Networks and Services

I. Background and Context

The current developments in Software Defined Networks (SDNs) and Network Functions Virtualization (NFVs) are highlighting new and critical R&D topics related to what and how create the conditions to effectively and continuously update and change the networking functions (e.g. Softwarization of the future networks and services or *Programmable Enabled Networks - PENs*) without reinventing every time the network architectures. Key software features of the future networks and services are already identified and elaborated in the ITU-T recommendation Y.3001 [4, 5]. These software features include: service diversity, functional flexibility, virtualisation of resources, energy consumption, service universalization, network management, mobility, optimisation, identification, reliability and security would need to be realised as part of the future network services and continuously updated.

The integration of the Internet with software infrastructures and traditional communication / telecommunication technologies has been always a challenge for network and service operators, as far as service deployment and management [7, 8, 9, 11] are concerned.

Different frameworks and architectural approaches have been proposed in the research literature and in commercial work. New approaches and technologies are causing a paradigm shift in the world of network architectures. The motivation behind this shift is the still-elusive goal of rapid and autonomous service creation, deployment, activation, and management, resulting from ever-changing customer and application requirements.

Research and development activity in this area has clearly focused on the synergy of a number of concepts: programmable networks, network virtualization, self-managing networks, open interfaces and platforms, and increasing degrees of intelligence inside the network.

The future networks and services need to move from being merely Defined by software to be Programmable by software and must be capable of supporting a multitude of providers of services that exploit an environment in which services are dynamically deployed and quickly adapted over a heterogeneous physical infrastructure, according to varying and sometimes conflicting customer requirements.

At least three key stages of this technological synergy for the main Software Driven Network concepts could be identified as presented in Figure 1 & 2:

• Programmability in network elements (switches, routers, and so forth) was introduced over a decade ago as the basis for rapid deployment and customization of new services (i.e. first architectural state of the SDN Conceptual View: *programmable networks*) [6].

• Advances in programmable and virtual networks have been driven by the industry adoption of Open-Flow & NFV and a number of requirements that have given rise to a new business model of the same telecom business actors, and roles (i.e. second architectural state of the SDN Conceptual View: *Software-Defined Networks*) [2, 3].

• We are moving away from the "monolithic" approach where systems are vertically integrated toward a component-based approach, where systems are made of multiple components from different manufacturers, interacting with each other through open interfaces to form a service. The result is a truly open service platform representing a marketplace wherein services and service providers compete with each other [12], while customers may select and customize services according to their needs (i.e. third architectural state of the SDN Conceptual View: *Softwarization of networks* or *Programmable Enabled Networks - PEN*) [1].

The fundamental difference between the envisaged PEN concept and previously proposed SDN technologies is the switch to a connectivity and computation infrastructure which is both a service-aware and a management-aware network foundation, where the network elements have direct support for service lifecycle and built-in support for management functionality.

This infrastructure utilizing shared virtualised resources, including those in wire, wireless and resource-constrained mobile devices and smart objects. PENs would need to be engineered [1] to facilitate the integration and delivery of a variety of ICT services, Computing and Network Clouds and to enhance integration of the key enabling technologies: programmability, networks, network virtualization and network function virtualisation and self-management.

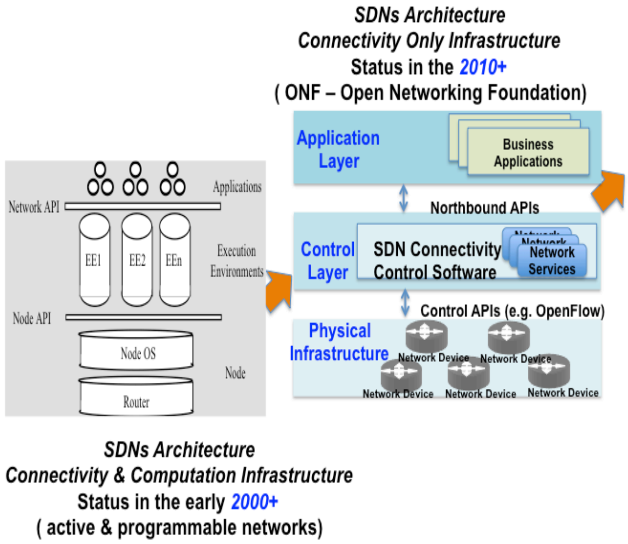

Figure 1 - SDN Evolution - Conceptual View of Networked Systems

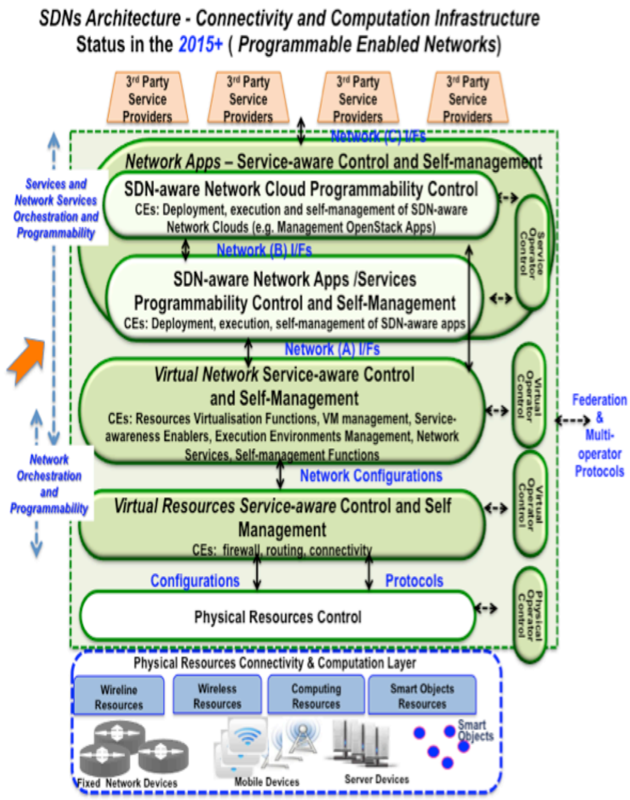

Figure 2 - SDN Evolution (continuation) - Conceptual View of Networked Systems

This paper presents some of the key challenges for realising the Softwarization of Networks / Programmable Enabled Networks (PENs) as the third stage of R&D in SDN.

II. PROGRAMABLE ENABLED NETWORKS (PEN) OVERVIEW AND CHALEENGES

A. PEN Overview

In PEN, the focus is on the service-aware control and management plane, the details of its operation, and the APIs which make it operate. As PEN relies on existing wired and wireless networks and devices, these control elements provide a mapping downwards so there is less emphasis on devising new physical features. This is the main systemic difference to the traditional programmable networks and the recent activities on Network Function Virtualisation Network Functions Virtualisation (NFV) [3], Network Operating System and Network Orchestration, which are mainly targeted to ONF [2] validation. An important feature of the architecture is a cross-layer approach, i.e. interfaces and mechanisms that enable control and exchange of information between different PEN layers: this provides the ability to push requirements from one layer to the next in a configurable and dynamic way. The proposed functional decomposition simplifies the implementation that is driven by the envisioned functionality. It has to be noted that such an approach is completely different from that of Open Flow which does not decompose network layers into functional blocks.

One key component of the PEN design is the description of services provided by each layer using building blocks defined by an abstract model. PEN does not intend to create new models, but rather to examine and reuse well-established ones, e.g. IETF ForCES, ONF's OpenFlow's switch model and YANG (NETCONF). Accordingly, PEN will extend the chosen model to satisfy the requirements in order to depart from their current 'network function' view and get closer to the 'network service' view.

Composition of services using such a methodology will enable the PEN architecture to have a very fine-grained degree of service programmability as well as to encompass any new future layer primitives. The ability to dynamically insert new layer primitives would be empowered to adapt to future needs. In essence the building-block approach will allow PEN to define, deploy and manage, at runtime, new functionalities and services. These functionalities will be published from bottom-up, whereby each layer publishes to the upper layer the functions that it can provide and ultimately the user will be able to see which services are available. They would be able to be pushed from top-bottom, where the user can request one or more specific services which would then have to be created from existing infrastructure or instantiated at run-time and then published to the user.

The PEN concept is developed according to the features mentioned in the third architectural state of the SDN Conceptual View (Fig. 1) based on a Software Driven/Enabled Networks approach. In opposite to SDN proposed by ONF [2] PEN is a systematic approach towards an integrated connectivity and computation infrastructures. The overall PEN architecture is split into layers depicted in Fig. 2 according to the functionalities described hereafter.

The lowest layer, Physical Resource Layer role is to cope with heterogeneous environments. It has two main functions. It provides a uniform view (via virtualization) of different technological network and computational resources (i.e., providing resource abstraction) and it has intrinsic autonomic and programmable management of the resources, which provides a fast-reaction time for management operations and facilitates scalability of the PEN solution in case of distributed management implementation. The Physical Resource Layer exposes crucial functions to other layers, for example there are monitoring and resource control facilities used by other layers. The information monitoring provides not only a view of the resource health and usage but also of the power consumption, which makes the PEN approach energy efficiency ready. It is assumed that such 'physical resources' can be provided by multiple owners/operators across multiple domains. The deployment of the PEN architecture will be in a form of additional control elements to the wired and mobile environments with adaptation to specific physical resources.

It is worth mentioning that Smart Objects are also part of the architecture. IoT and "Smart Objects" are expected to become active participants in information, social, industrial and business processes where they interact with services and applications while communicate among themselves by exchanging data and information about the environment. In parallel, they are reacting autonomously to the "real/physical world" events and influencing it by running processes that trigger actions and create services with or without direct human intervention.

A set of virtual networks utilizing the underlying physical resources can be created using the mechanisms of the Virtual Network Programmability Layer. These virtual networks adapt their properties to the specific needs of customers and services. The virtual networks have embedded self-managed mechanisms that can control and monitor the underlying physical resources, through utilizing in an intelligent manner the lower-level control and monitoring components of the Physical Resource Layer. The self-management operations include self-configuration, performance optimization, and self-healing. The performance optimization deals with efficient usage of physical resources and cross virtual-network optimizations (traffic management). The manipulation of virtual networks can be programmable using the SDN paradigm. It is assumed that there is support for multiple virtual networks operators. All of these facilities aid in the scalability of a PEN solution.

The end-users and application providers can use specific virtual networks according to their needs in order to create high-quality, personalized, QoS-aware, and secure services. It is assumed in the proposed approach that *programmability of end-user services is provided by the Network Application Programmability Layer.* A simple example would be of a user defining the network topology that he requires from the network along with specific functionalities (e.g., firewall, transcoder, load-balancers) instantiated at specific points in his virtual network. The PEN would be able to create this virtual network and instantiate the requested user's functionalities at the required locations to provide the desired QoS, e.g. minimizing network latency.

It has to be noted that the aforementioned programmability and self-management of different layers of PEN requires the ability to send, execute and monitor the execution code and therefore the management operations should be extended appropriately. In order to do that we need an execution environment that can be centralized or distributed.

The scalability of the proposed architecture is enabled by the following architectural elements: virtualisation of all types of physical resources; the separate mechanisms and mappings of virtual resources to wire, wireless and smart objects networks; the control elements of the service-aware and management-aware control layer; the northern APIs as depicted in Fig. 1 and by the use of Virtual Machines for the programmability of the service and network components.

III. PEN CHALLENGES

A number of R&D challenges are identified for the realization of programmable enabled networks with solutions hosted by the architectural blueprint presented in fig. 3.

Performant and Safe Network Execution environments: This challenge refers to the network hosting virtual environments and virtual machines to overcome the problem of having several execution environments implemented in various technologies, and providing different abstractions, interfaces, and so on. Network software features would be realised and activated in the network by the creation of specific to the network of execution environment and groups of virtual machines which are managed (creation, change/update, deployment, migration, orchestration, deletion) as one. The advantage of having an explicit notion of a virtual environment is to provide generic means to manage access and resource control on the node-level. While execution environments support the installation, instantiation, and configuration of services code in various ways, the virtual environment puts a uniform management layer on top. This allows external clients to interact with services through the interface of the virtual environment in a generic way, and the interactions will be mapped to specific interfaces of the execution environments. Several execution environments can be attached to a virtual environment, just the same way as other resources. This leads to another aspect of virtual environments: the partitioning of resources. The network provider can set up virtual environments on selected network nodes, and assign them to a particular service provider, in order to offer a virtual network. Access to the virtual environments will be made available to the respective service provider so that it can manage its own virtual network. The resource partitioning implemented among virtual environments will prevent interference with other service providers and, additionally, allow an accounting per service provider.

Several virtual environments belonging to the same service provider but running on different network nodes will form a virtual network to be used by the service provider to deploy services and make them available to customers. In order to know which virtual environments belong to a particular virtual network, the environments are tagged with special network identifiers.

To summarize, the concept of virtual environments enables several aspects:

- A generic way of deploying and managing services independent of the technology of the underlying execution environment;
- A generic way to manage (i.e., monitor and control) nodes for service providers as well as for network providers;
- Partitioning of resources among several service providers;
- Accounting of resource usage per service provider;
- Delegation of service management to the service providers.

Programmability in Future Networks and Services: This challenge refers to solutions for the fast, flexible, and dynamic deployment of new network services. This is aimed to provide easy introduction of new network services by realizing the dynamic programmability of the network and its devices such as routers, switches, and applications servers. Dynamic programming refers to executable code that is injected into the network element in order to create the new functionality at run time. The basic idea is to enable third parties (operators, service providers and other authorised users) to inject application-specific services (in the form of code) into the network. Applications may utilize this network support in terms of optimized network resources and, as such, they are becoming network aware. As such, network programming provides unprecedented flexibility in telecommunications. However, viable architectures for programmable networks must be carefully engineered to achieve suitable trade-offs between flexibility, performance, security, and manageability.

The key question from the public fixed and mobile operator's and Internet service provider's points of view is: how to exploit this potential flexibility for the benefit of both the operator and the end user without jeopardizing the integrity of the network. The answer lies in the promising solutions for:

- Rapid deployment of new services;
- Customization of existing service features; optimisation of network resources
- Scalability and cost reduction in network and service management;
- Independence of network equipment manufacturer;
- Information network and service integration;
- Diversification of services and business opportunities in particular for virtual environments and clouds.

Federation facilities: This challenge refers to the interactions between the different operators and different domains with the same operator. These facilities would include provisioning of:

- *interfaces* that will allow a networking function to federate. Using this interface, the networking function should be able to cooperate in order to provide Interdomain communication.

- *authentication* for other operators, and the two operators confirm with each other the identity of the two consumers of a particular service.
- *mechanisms for communication and programmability of service modules* deployed by different operators for the same service.
- *mechanisms for end-to-end resource management, monitoring, and accounting* should be provided.

Heterogeneous environments: PEN should cope with heterogeneous environments providing uniform view (virtualization) of different technological networks and computational resources. This functionality is a part of Physical Resource Layer. The research challenges to assess this view with special emphasis on the wireline, wireless and Smart Objects virtual control adaptation.

Control of Virtual wireless resources: this challenge refers to the necessary technology-dependent actions and algorithms for run-time control over local virtual resources in wireless network environments using technology specific operations. This challenge addresses basic configuration functionalities including virtual resource creation, activation, adjustment and termination operations. Dedicated mechanisms and algorithms developed for on-the-fly manipulation of resources in dynamic environments with conflicting requirements according to up-to-date feedbacks from local network monitoring activities are also part of this challenge. These may include adaptive re-allocation of virtual resources according to changing network conditions or service demands. Additionally, this challenge deals with the critical nature of developing autonomous actions that provide network stability and optimizations in absence of higher-level control. This includes for example virtual resource remapping in case of resource scarcity that can be provided internally to the virtual network control.

Mapping virtual resources to the wireless resources: this challenge includes the design and implementation of specific mechanisms and algorithms for optimised mapping of virtual resources onto the physical resources in the wireless environment. Specific optimisation techniques will be developed for efficiently mapping between virtual resources and the physical network infrastructure. In this case of wireless infrastructures, certain characteristics and capabilities have to be considered, e.g. limited bandwidth, processing capabilities, storage, energy (battery), type of interfaces supported of the mobile nodes and mobility, conflicting requirements. As the mapping of virtual to physical resources should be transparent to higher control layers, mechanisms have to be developed that allow the seamless hand-off between different wireless devices. Additionally, algorithms will be identified that optimize the coverage of wireless radio connections to provide access to enough physical resources while avoiding unnecessary energy consumption.

Control of virtual wireline resources: This challenge includes the design and implementation of specific mechanisms and algorithms for run-time control over local virtual resources in wireline environments. OpenFlow environments are considered for representative wireline environments. A major aspect of this challenge is the development of technology-specific methods that enable the provisioning of virtual networks and storage/processing resources over OpenFlow substrate infrastructures. This includes the creation, configuration and tearing-down of virtual resource components, considering both networking and computational/storage resources, e.g. so that link bandwidth or network computation power can be adjusted on-the-fly based on conflicting requirements. By using OpenFlow switch virtualization, networking resources can be re-allocated according to changing network conditions or service demands. Additionally, this challenge considers the development of autonomous actions that provide virtual network stability, performance and optimizations even in absence of higher-level control.

Mapping virtual resources to wireline resources: this challenge includes the design and implementation of specific mechanisms and algorithms for optimised mapping of virtual resources onto the physical resources in wireline environments. Specific optimisation techniques will be developed for efficiently mapping between virtual resources and the physical network infrastructure. Such mapping will involve a wide variety of resources available from the underlying wireline network, including communication, computing and storage capabilities. The mapping will take into account the top-level service/operational requirements such as the demanded QoS requirement and resilience capability to be embedded into the resulting virtual network. By addressing this challenge virtual networks will be customized with optimally allocated capabilities such as virtual nodes (with computing and storage capabilities), virtual links and paths for specific networked services.

Control of virtual resources for smart objects: this challenge will identify and implement the mechanisms required for the discovery, registration and monitoring of virtual and physical resources, configuration and control (including reservation, isolation and release) of virtual resources, and creation of service components in smart objects environments. Taking into account the technology-agnostic requirements of the PEN virtual network control layer, this challenge will identify the technology-dependent control mechanisms needed to meet these requirements.

The control mechanisms will not only be used at this layer/level but they will also need to expose information to the upper layers in order to allow management and control of virtual networks across more than one technology-specific physical domain. It will allow receiving triggers from the upper layers for setting up and tearing resources, as well as adding/removing functionalities and creating service components within the virtual networks which will be accommodated on virtual components residing on smart objects substrates. In this context, an abstract identification model needs to be defined to reference each smart object, as single element or part of a group, for all the control/configuration processes. To realize this, appropriate interfaces need to be defined.

Mapping virtual resources to smart objects resources: this challenge deals with the critical nature of developing the mechanisms and techniques needed to optimize the mapping of virtual resources on physical smart object resources. The objective is to continuously optimize the use of the physical resources (e.g. utilization, energy efficiency) as well as to provide self-organization and self-healing capabilities by appropriately (re)grouping virtual resources and mapping them accordingly to the best set of physical resources. This mapping should ensure that each operation made on a virtual device has to take effect on the physical object. In fact, all the operations allowed by PEN on virtual instances of the smart objects should then be replicated in a tangible way on real objects. To achieve this each real object must exhibit a set of APIs that enable the interaction with the equivalent virtual object.

This challenge also relates to functions for the setup and control of necessary physical object clusters to support, as an entity, virtual resource requirements in a performance and energy efficient manner. Furthermore, the mapping of virtual to physical resources will support different levels of in-network processing which are needed to provide the best trade-off between computational and networking-related energy consumption in energy-limited smart object environments.

Uniform Autonomic and Optimised Management: This research challenge deals with the critical nature of developing the mechanisms and enablers and systems for autonomic management functions applied not only to the physical resources, but also virtual resources located inside the network. In addition, a unification of all autonomic functions should be realised to enable coordination, orchestration, governance and knowledge closed control loops as applied to all autonomic functions. In this approach the management and control functions would be distributed and located or hosted in or close to the managed network and service elements enabling control of CAPEX and significant OPEX reduction.

Scalable Programmable delivery infrastructures as systems of Inter-orchestration for Big Data and Service Networks: This challenge relates with the critical nature of developing the mechanisms for the transition from current systems designed around discrete and static pieces of uncorrelated silos of content centric information or silos of networks to systems which are more programmable with decentralized control of big data and service networks, incorporating technologies which enable associative orchestration and interactions, and which often leverage virtualisation technologies to provide the capabilities to enable those interactions. In order to integrate such delivery systems, as well as offer new systems to support enhanced composition and correlation - which is what systems of Inter-orchestration is all about, in the end appropriate virtual platform technologies will need to be deployed.

Energy management and optimisation: this challenge relates with the critical nature of developing the mechanisms for Energy- cognisant Internet including optimizing the energy consumption within the limits of a single network and/or a network of networks and /or network of Data Centres and Clouds, based on system virtualization plus the optimal distribution of VMs across the set of networks and servers and providing stabilization of the local networks following electricity demand-response loops.

In Fig. 3 below we have identified and outlined the new closed control loop functionality, which is applicable to energy saving technologies in Future Networks. Fig. 3 shows those logical functions, the information base, and their interactions.

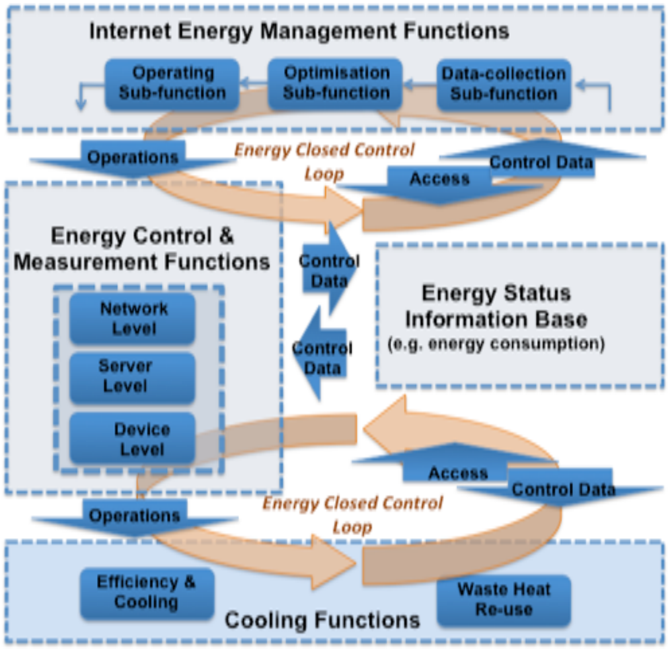

Figure 3– INTERNET SCALE ENERGY CLOSED CONTROL LOOPS

CONCLUDIND REMARKS

This paper discusses the motivation, architecture and research challenges for the next generation Software Defined Networks (SDN). The next generation of Software Defined Networks (SDN) needs to move from being merely *Defined* by software to be *Programmable* by software (e.g. Softwarization of the network) and must be capable of supporting a multitude of providers of services that exploit an environment in which services are dynamically deployed and quickly adapted over a heterogeneous physical infrastructure, according to varying and sometimes conflicting customer requirements.

A programmable enabled network prototype is under development at University College London (UCL) as response to the above new requirements and challenges.

ACKNOWLEDGMENT

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