Software Enabled Future Internet – Challenges in Orchestrating the Future Internet

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Software Enabled Future Internet – Challenges in Orchestrating the Future Internet

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Abstract. This position paper presents SoftINTERNET an initiative for a service-aware and management-aware network control infrastructure for heterogeneous networks (i.e., wired and wireless) that uses software driven features for the elaboration, development, and validation of networking concepts. The proposed infrastructure aims to optimally integrate the connectivity and management layers. It operates across multiple network environments and on top of private and public network clouds utilising fixed and mobile virtual resources, OpenFlow enabled network devices like switches and routers, and networks of Smart Objects. In this position paper, we discuss the motivation, architecture and research challenges for such a promising concept.

Keywords: Software Defined Networks, Software Enabled Networks, Virtualization, Orchestration

1. Introduction

1.1 Background

In this paper we present an initiative to integrate heterogeneous networks, including wired/wireless networks and smart-objects, from both the service and management and control viewpoints, considering them as crucial aspects of Future Networks. The intention is to define a service-aware control and management architecture which provides a service infrastructure and an on-demand programmable network, along with dynamic and global resources, and self-management capabilities that are based on interoperable connectivity protocols and open interfaces.

The initiative presented in this paper is named SoftINTERNET (i.e., Software Enabled Networks Connecting and Orchestrating the future Internet of people, content, clouds [51], devices and things) [1]. SoftINTERNET aims to integrate, orchestrate, and map control enablers as embedded capabilities into Software-Driven

Network infrastructures, in order to make them service-aware and management-aware, as a natural evolution of the software-defined network initiatives (i.e., see section 2). The mapping of these enablers into virtual infrastructure and physical resources involves an aggregation of connectivity, computation and storage resources.

Our approach to this challenge is through the deployment of a flexible and programmable network infrastructure supporting software driven network features that can be instantiated on-demand. These instantiations will be addressing the changing service requirements and resource constraints, yet scalable across multiple services and multiple domains, that can maintain QoS for the end-users of a service, and that provide a level of isolation and security from one service to another.

SoftINTERNET targets and addresses requirements for Future Networks [55] including:

• Software Driven Networking – Future Networks should support the following design goals: Functional Programmability and Elasticity; Integrated Virtualisation of Connectivity, Storage and Processing Resources, including the limited resources in Smart Objects and mobile devices; personalized services and embedded In-Network Management. This we call 'Software Driven and Enabled Networks as a Service'

• Interworking – Future Networks are represented by the interconnection, interoperation and orchestration of heterogeneous networks (i.e. fixed and mobile) that are sharing their virtualised resources. Processing, Storage and Communication Resources spanning over multiple network domains are being aggregated to provide services in a simple and pervasive manner

• Service Provider Access – Future Networks should offer unrestrictive access to different service providers by supporting qualified access mechanisms to a set of network-embedded resource-facing services, and by providing scalable, personalized and self-managed inexpensive networking infrastructures on demand.

• Service Provisioning – Future Networks can support the complete lifecycle of complex services by combining existing elements in a new and creative ways that were often not efficiently interoperable before. QoS and security guarantees are pivotal for the management of the services' lifecycle.

This paper is organized as follows. Related work is presented in Section 1.2 which is followed by the motivation for the SoftINTERNET concept as presented in Section 2. The architectural model is presented in Section 3. Section 4 presents the research challenges of SoftINTERNET. Section 5 provides concluding remarks of this paper.

1.2 Related Work

The areas related to the SoftINTERNET concept are summarized in this Section. These areas include future Internet architectures, programmable networks, open networking, and infrastructure and mobile clouds.

1.2.1 Future Internet Architectures

Architectural changes of the Internet have been promoted by several initiatives. In USA, there are several significant initiatives. NeTS [4] (Networking Technology and Systems) was a program of the National Science Foundation (NSF) on networking research with the objectives of developing the technology advances required to build next generation networks and improve the understanding of large, complex and heterogeneous networks. NetSE [5] proposes a clean-state approach to properly meet new requirements in security, privacy and economic sustainability. GENI [6] (Global Environment for Network Innovations) is a virtual laboratory for network experimentation, based on a 40 Gbps real infrastructure. Stanford Clean Slate [7] proposes a disruptive approach by creating service platforms available to the research and user communities. In Europe, Future Internet initiatives mostly try to develop platforms to support services and applications by utilizing the current Internet infrastructure. G-Lab [8] (Design and experiment the network of the future, Germany), which is the German national platform for Future Internet studies, includes both research studies of Future Internet technologies and the design and setup of experimental facilities. GRIF [9] (Research Group for the Future Internet, France) and Internet del Futuro [10] (Spain) promote cooperation based on several application areas (e.g. health) and technology platforms. Moving towards modern content-aware networking, we can highlight DONA (Data-Oriented Network Architecture) [11] and TRIAD [12] approaches, where content providers can publish content and users request named data from the network.

In the clean-slate Future Internet design track and building on wireless and mobile background, the 4WARD project [13] proposes four main architecture pillars: network virtualization, in-network management, new path abstraction (Generic Path) and networking of information. The SAIL [14] project builds around the concepts of the network of information, cloud networking (for managing and controlling computing, storage and connectivity resources by automatically moving or scaling up or down the resources required by the applications and open connectivity services for providing efficient multi-path/multi-layer/multi-domain transport and routing.

Other projects working in the area of Future Internet include: a) NEBULA [15] with focus on secure and trustworthy cloud computing; b) eXressive Internet Architecture [16], with emphasis on an architecture that inherently supports communication between diverse entities, provides for intrinsic security and includes a pervasive minimal functionality that needs to be present in network nodes for functions like trust management, access to services, hosts and content, and interaction among users, ISPs and content providers; c) PURSUIT [17], which builds on the results of PSIRP [18] and aims at changing the routing and forwarding fabric of the global internetwork so as to operate entirely based on the notion of information according to the publish/subscribe communication model; d) FI-WARE [19], which is developing a platform providing all the necessary technologies to support Future Internet service delivery and provisioning; and e) AKARI Project [20] of Japan, which advocates the use of virtualization as the basis of the Internet architecture in the next generation [21], extending the idea of isolated virtual networks to (1) Transitive virtual networks - cooperation and/or communication between virtual networks, and (2) Overlaid virtual networks-one virtual network over the other.

1.2.2 Programmable Networks

Many projects use virtualization to support programmability [49], [52], [22]. The physical switch interfaces are abstracted and partitioned into so called switchlets, which allow a shared use of the physical switch resources. Different research projects address the virtualization of various network components and their programmability. From switches and links [23] to switchlets [22], active nodes [24] and routelets [25].

The dynamic deployment of new services includes the composition of complete network architectures as virtual networks [26], [27], [25]. Projects like Netscript [28] or Tempest [27] support the notion of Virtual Active Networks [26] over IP networks or virtual networks using safe partitioning over ATM respectively.

Motivated by concepts introduced in the RESERVOIR project [29], providing isolation between the physical infrastructure, and the virtual environment using an overlay network, our goal is to provide a managed network virtualization infrastructure that is based on the SoftINTERNET approach. Thus, instead of reproducing the control complexity and overhead associated with existing networks, we create an abstraction layer, based on a common network model, enabling multiple independent and isolated network applications run over a single physical network infrastructure, dealing with the network logical functionality and its control aspects.

1.2.3 Open Networking

Stanford University has developed a solution for Open Networking, with the aim to: (1) separate data and control planes and define a vendor agnostic API/protocol between the two; (2) design a logically centralized control plane with an open API for network applications and services and (3) virtualize the network infrastructure. The OpenFlow protocol [30] has been proposed for the communication between the network nodes and the centralized network controller, and the FlowVisor [31] framework has been proposed for resource virtualization in this context. The interest on the Open Networking approach and on the OpenFlow protocol is growing worldwide, and in March 2011 the Open Networking Foundation [32] was created with the aim to promote the Open Networking approach and to standardize the OpenFlow protocol.

Specifications of OpenFlow version 1.3.1 have been published in September 2012. Several manufacturers have already developed network nodes supporting OpenFlow, and several open source OpenFlow controllers are available (i.e. NOX [33], Beacon, Maestro, etc.). A lot of works in the area of OpenFlow are in place worldwide in order to extend its field of applications, from LAN to WLAN [34], and even core and GMPLS networks. In addition several EU FP7 projects are dealing with OpenFlow, like OFELIA [35], OpenLAB [36], SPARC [37] and with Open Networking in general SAIL [38]. The main objectives of these projects are to provide testing facilities based on the OpenFlow protocol, and to investigate and propose possible extensions to it in order to overcome its main limitations, in particular related to scalability. Moreover, the FI-WARE project [39] is taking into consideration the OpenFlow technology as a mean to provide open APIs to control and monitor networks and network nodes. Even if several OpenFlow controllers have already been proposed to control and manage open networks,(see NOX, Maestro, Beacon, etc.) there does not exist a clear reference architecture for them. SoftINTERNET aims to define a reference structure for an Open Network controller, able to support virtualization and programmability for this kind of networks.

1.2.4 Infrastructure and Mobile Clouds

Server virtualization technology commonly used in data centres and clouds raises new challenges for both the research and the industry community. In such environments, not only the number of network endpoints is significantly large compared to the physical network infrastructure (due to the fact that each physical server can host dozens of virtual servers), but these endpoints are dynamically created, terminated, and migrated from one physical server to another. One approach to provide data networking in a virtual environment, extending the physical network into the virtual server domain using L2 virtual switches such as Cisco Nexus 1000 or openVSwitch, may be based on the IEEE 802.1qbg [40] standard, in which virtual machines are considered as clients of the physical network. It has the limitation associated with the dynamic nature of such an environment, and the fact that typically it should serve more than one independent tenant. A recent approach to deal with these challenges is by creating an overlay network used to connect the virtual servers (see [41, 42, 43]). Following this approach, virtual networks are no longer considered as clients of the physical infrastructure, thus reducing the network complexity and the dependency between the virtual environment and the physical network infrastructure.

The research area of Mobile Cloud Computing (MCC) is relatively new and there is no consensus even for basic definitions yet. For example, Cisco defines the mobile cloud as mobile services and applications delivered from a centralized (and perhaps virtualized) data center to a mobile device such as a smartphone [44]. The Mobile Cloud Computing Forum [45] defines MCC as an infrastructure where both the data storage and the data processing happen outside of the mobile device. Alternatively, MCC is defined as a combination of mobile web and cloud computing [46][47][48].

2. Motivation for the SoftINTERNET Approach

The integration of the Internet, software technologies and traditional telecommunications and communication technologies, has been always a challenge for network and service operators, as far as service deployment and management [53], [54] is 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 next generation of Software Defined Networks (SDN) needs to move from being merely *Defined* by software to be *Driven* 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. The three key stages of this technological synergy for the main Software Driven Network concepts are depicted in Fig. 1.

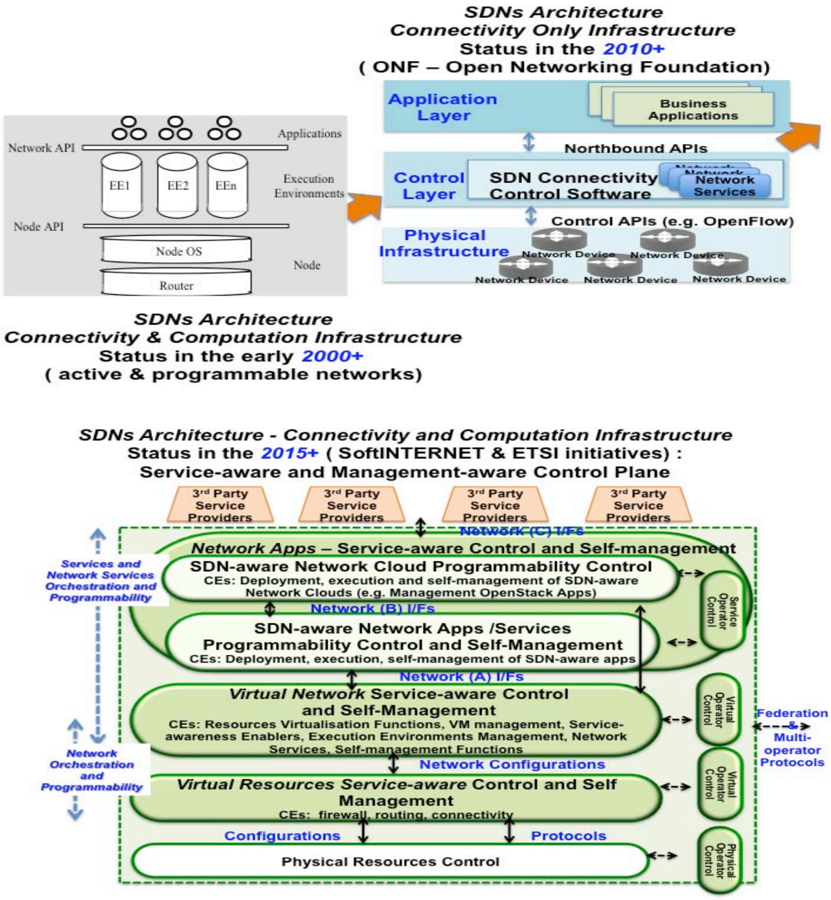

Fig.1 - SDN Evolution - Conceptual View

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 (e.g. first architectural state of the SDN Conceptual View). Advances in programmable networks have been driven by the industry adoption of Open-Flow and a number of requirements that have given rise to a new business model of the same telecom business actors, and roles (e.g. *second architectural state of the SDN Conceptual View:* ***Software-Defined Networks***). 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, while customers may select and customize services according to their needs (e.g. *third architectural state of the SDN Conceptual View: **Software Driven/Enabled Networks**).*

The next generation SDNs are engineered 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.

SoftINTERNET elaborates on programmability in the context of different examples of virtual networks (i.e., clouds, virtualized wireless/mobile networks and open networks). Using virtualization on network components allows multiple independent networks to coexist on the same physical substrate. Additionally, as virtualization provides an abstraction from the underlying hardware, it allows a simplified way for network programmability.

The fundamental difference between the envisaged SoftINTERNET concept and previous SDNs [50] 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.

All these initiatives including SoftINTERNET would result in OPEX reduction for the telecom and cloud operators. SoftINTERNET focuses on the service orchestration and the additional systemic opportunity of additional revenue creation that is enabled by the service-aware and management-aware control plane (e.g. rapid and on-demand service deployment, activation, management and programmability [1]).

3 SoftINTERNET Architectural Model

In SoftINTERNET, the focus is on the service-aware control and management plane, the details of its operation, and the APIs which make it operate. As SoftINTERNET 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) [56], Network Operating System and Network Orchestration, which are manly targeted to ONF 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 SoftINTERNET 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 OpenFlow which does not decompose network layers into functional blocks.

One key component of the SoftINTERNET architecture is the description of services provided by each layer using building blocks defined by an abstract model. SoftINTERNET 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, SoftINTERNET 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 SoftINTERNET 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 SoftINTERNET 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 SoftINTERNET 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 SoftINTERNET is a systematic approach, The overall SoftINTERNET architecture is split into layers depicted in Fig. 2 according to the functionalities described hereafter.

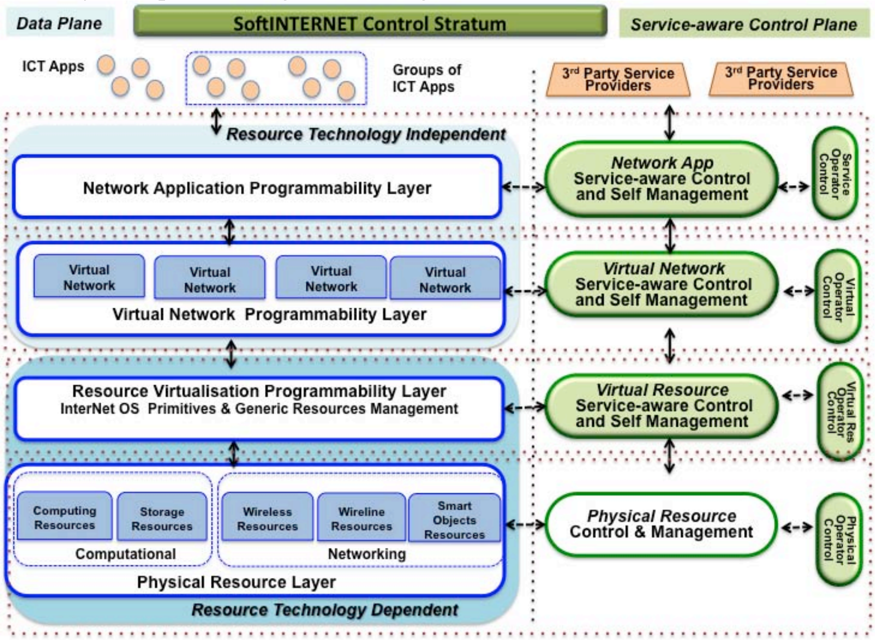

Fig. 2 - The SoftINTERNET Architecture

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 (a kind of 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 SoftINTERNET solution in case of distributed management implementation. The Physical Resource Layer exposes some functions to other layers, for example there is monitoring and controlling of resources used by other layers. The monitoring information provides not only the information about the resource health and usage but also about the power consumption, which makes the SoftINTERNET 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 SoftINTERNET 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 are enabled to interact with services and application and communicate among themselves and with the environment by exchanging data and information about the environment, while 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.

From the underlying physical resources, a set of virtual networks can be created using the mechanisms of the *Virtual Network Programmability Layer*. These virtual networks have different properties according to specific needs. As in case of the physical resources, the virtual networks have embedded self-managed mechanisms. Moreover, they can control and monitor the underlying physical resources. 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 creation of virtual networks can be programmable using the SDN paradigm. It is assumed that there can be multiple virtual networks operators. All of these facilities aid in the scalability of a SoftINTERNET 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 (firewall, transcoder, load-balancers) instantiated at specific points in his virtual network. The SoftINTERNET 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 SoftINTERNET 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 (for example OSGi [2]) or distributed.

The scalability of the proposed architecture is enabled by the scalability for 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.

4 Research Challenges of the SoftINTERNET Approach

SoftINTERNET 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 are graphically depicted in Fig. 3 and they are described hereafter.

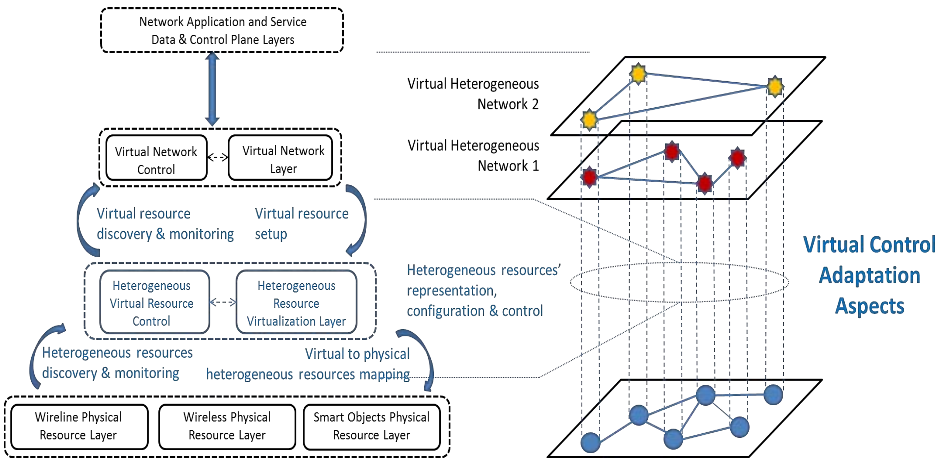

Fig. 3 – SoftINTERNET's Virtual Control Adaptation Aspect

4.1 Mechanisms to control virtual resources for wireless environments

This challenge refers to the necessary technology-dependent tactical 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 reallocation 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. Additionally, the provisioning and utilization of the programmable resources are not to be limited to the network resources only, but also to storage and processing resources, to provide a complete set of programmable resources for the applications.

4.2 Mapping virtual to physical resources for wireless environments

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. 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.

4.3 Mechanisms for controlling virtual resources for wireline environments

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. These include e.g. virtual resource remapping in case of resource scarcity, increased resilience through transparent resource migration in case of hardware failure or energy saving using adaptive virtual resource consolidation.

4.4 Mapping virtual to physical resources for wireline environments

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.

4.5 Mechanisms for controlling 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 SoftINTERNET 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.

Regarding the management and control of the smart object substrate, this challenge includes investigating relevant mechanisms both for substrates with integrated control and data planes (current practice) and for substrates with a Software Defined (e.g., OpenFlow-based) type of control. The latter approach, recently proposed in [3], is based on a clear separation between control and data forwarding. It has the potential to provide the necessary abstractions and to ease management needed for supporting multiple applications over smart object networks and results in better utilization of the physical infrastructure resources. With respect to this, this challenge deals with the adaptations that are required to support the Software Defined Networking concept on smart object virtual networks taking into account the limited capabilities of the nodes and focusing on the need to manage the control overhead.

4.6 Mapping virtual to physical resources for Smart Objects

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 SoftINTERNET 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 develops 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.

The aforementioned operations should remain transparent to the upper layers, meaning that individual virtual networks should be agnostic to any reconfigurations taking place at the physical level and avoiding performance deterioration.

4.7 Energy management and optimisation

This challenge deals 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. 4 below we have identified and outlined the new closed control loop functionality, which is applicable to energy saving technologies. Fig. 1 shows those logical functions, the information base, and their interactions.

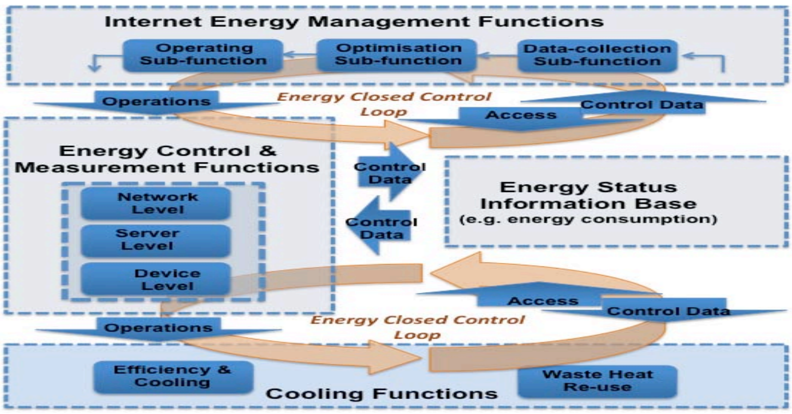

Fig. 4 – Internet Scale Energy Closed Control Loops

4.8 Mature and deployable Autonomic and Optimised Management Integrated feature and qualities

This 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.

4.9 Scalable Programmable delivery infrastructures as systems of Inter-orchestration for Big Data and Service Networks

This challenge deals 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.

5 Concluding Remarks

This position 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 Driven and Enabled 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.

This paper presents SoftINTERNET an initiative for a service-aware and management-aware network control infrastructure for heterogeneous networks that uses software driven features for the elaboration, development, and validation of networking concepts. The proposed infrastructure aims to optimally integrate the connectivity and management layers. It operates across multiple network environments and on top of private and public network clouds utilising fixed and mobile virtual resources, OpenFlow enabled network devices like switches and routers, and networks of Smart Objects.

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