Wireless Network Virtualization: The CONTENT Project Approach

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***Abstract*—Undoubtedly, SDN has the potential to fundamentally change the way end-to-end networks are provisioned and designed. By introducing programmability into networking, the handling of network changes and network provisioning via open software interfaces has become a reality; together with the hardware/software virtualization advances in server systems and software platforms, cloud services can now be rapidly deployed and efficiently managed. The CONTENT project is an EU funded effort for network and infrastructure virtualization over heterogeneous, wireless and metro optical networks, that can be used to provide end-to-end cloud services. In this work we present the wireless network virtualization solution, in the light of the CONTENT technical approach, where a convergent LTE/Wi-Fi network is virtualized and interconnected with an optical TSON metro network. We present our approach in designing and implementing converged virtual 802.11 and LTE wireless networks and the corresponding efficient wireless data-plane mechanisms required, in order to satisfy strict QoS requirements.**

***Keywords*—Network virtualization, inter-domain networking, wireless-optical networks, cloud computing**

I. Introduction

Recent research trends show that convergence of the Wi-Fi and LTE access networks, together with cloud computing technologies, will serve as the backhaul of future wireless heterogeneous networking environments. The reason behind the extreme need for wireless convergence and cloud computing is that based on the current pace of technological innovation, soon enough billions of people will be online, consuming an untold amount of digital content. According to the Cisco VNI forecasts [1] by the end of 2014, the number of mobile-connected devices will exceed the number of people on earth, and by 2018 there will be nearly 1.4 mobile devices per capita. In the same pace, the total needs are exponentially growing thus creating an environment with tremendous needs in wireless network resources and requiring for extreme network efficiency. In addition, wireless traffic offloading is expected to play critical role in the way services are offered. For example 46% of mobile traffic is expected to be offloaded in 2017 in compare with 33% of mobile traffic offloaded in 2012.

Data offloading between LTE and 802.11 networks has been investigated in works like [2] and convergence of virtual LTE-WiFi networks is investigated in projects like CONTENT [3] and CROWD [4]. The former focuses also in the end-to-end network virtualization problem over multi-technology infrastructures, while the latter focuses in virtualized, extremely dense heterogeneous wireless access networks. The goal of the CONTENT project is to provide an end-to-end virtualization system, where physical resources in the wireless, in the optical and the data center domains are virtualized and shared between Virtual Network Operators. The CONTENT solution offers the necessary abstraction mechanisms and the necessary control plane & data plane functionalities, with respect to the SDN paradigm, that pave the way to extend the concept of Mobile Virtual Network Operators (MVNOs) to the concept of Mobile-Optical Virtual Network Operators (MOVNOs).

The CONTENT network architecture can be seen in Fig. 1. Every MOVNO will be able to design and build his own end-to-end virtual network and provision his virtualized resources efficiently, without having to rely on complex abstractions or inter-domain technology dependencies. With a robust, scalable network design every MOVNO is able to support unlimited cloud services and in addition, new business relationships can be established between service providers, physical network operators and Virtual Network operators. For example a physical or virtual CDN provider can establish different business relationships with physical storage providers and MOVNOs [5], in order to provide different charges and discounts for his multimedia content. The potential cloud services that a MOVNO can offer are unlimited.

In the series of papers [3][6] details on the layered architecture of the CONTENT project can be found and in [7] the technical approach of the virtualization of the optical domain, using TSON technology, is described. In this work we present the wireless network virtualization solution in the light of the CONTENT technical approach. Due to page size limitations, we do not provide technical details regarding the TSON Time shared sub wavelength switching technology used to virtualize the optical resources in the metro network. More details can be found in [7] and [6]. In more detail, in this work we present the converged LTE/Wi-Fi wireless network of the CONTENT architecture; the corresponding wireless domain data plane functionality; and the resource allocation and management framework enhancements we developed for interaction with the TSON optical domain. In addition, we present our approach in designing and implementing more efficient wireless data-plane mechanisms, in order to satisfy strict QoS requirements

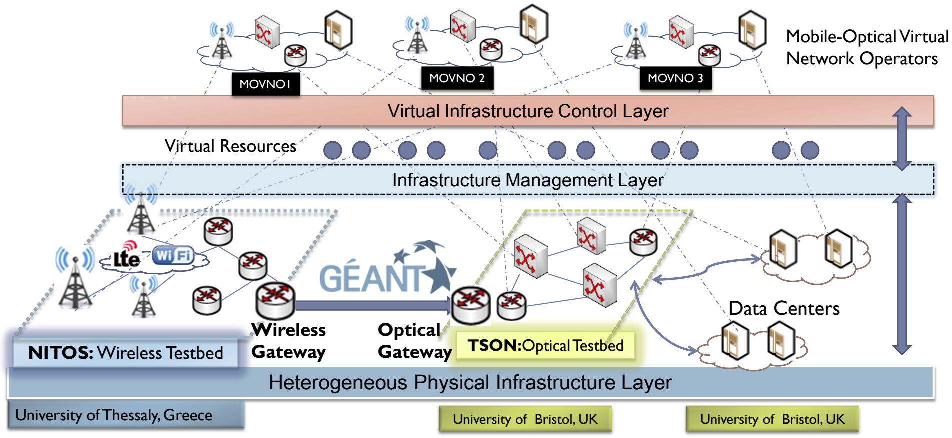

Fig. 1: Service Virtualization (left) and Resource Virtualization (right)

per MOVNO, under the limitations imposed by the wireless medium.

This paper is organized as follows: in section II a description of the CONTENT architecture is made; in section III the wireless virtualization strategy is presented; and section IV concludes this work and presents our future plans.

II. End-to-end Virtualization

Software Defined Networking will be a central part of next generation network architectures; together with NFV, that is adding new network elements centered on the hypervisor or traditional switches and routers, they emphasize the need for advanced control mechanisms regarding network's operations and management. Although the SDN paradigm was introduced in data center operations, there is great need for network virtualization, following the architectural principles of SDN, in end-to-end scenarios. The reason is that end-to-end networks are highly dependable on multi-vendor technologies and interfaces, ISP policies, inter-domain and multi-technology dependencies. CONTENT project tries to meet the requirements set by an end-to-end SDN solution, by building the necessary abstraction mechanisms and the control and management interfaces among Wi-Fi/LTE, Optical-metro networks and the data center infrastructure, while taking into the account the different virtualization models of resource and service based virtualization [8].

End-to-end, multi-domain problems are in the core of very active research made around SDN technology and its applicability. Besides the northbound (eg. REST) and southbound (eg. OpenFlow, Netconf) interfaces, East/West Bound Interfaces (EWBI) and protocols are also investigated by state of the art SDN controllers, like Juniper's Contrail and Opendaylight supported by the Linux Open Foundation. Each network domain, such as access/backhaul network, metro/core IP/MPLS and DC interconnect, may have dedicated controllers in logically centralized, physically distributed designs [9]. Related work on end-to-end virtualization can be seen in works like [10] and [11]. Other concepts relevant to the CONTENT cloud based virtualization approach, are mobile data-offloading ideas [2] and mechanisms to support live WAN migration of Virtual Machines [12] that utilize for example cloud computing platforms connected over VPN based network connections.

A. The CONTENT Wireless Testbed

In the wireless domain the NITOS wireless testbed [13], is used to evaluate the efficiency of the developed approach. The basic components of the NITOS wireless network related to the CONTENT project can be seen in Fig. 2 and are the following:

Wi-Fi access networks: more than 50 operational nodes, equipped with commercial Wi-Fi cards, based on Atheros chipsets that support Linux open source drivers. Through this setup, modification of the MAC and the network layer of the nodes can be achieved and development of new cross layer protocols that are directly compatible and comparable with the IEEE 802.11 commercial products. Each node is equipped with multiple Wi-Fi interfaces.

LTE access networks: The core units are two LTE Access Points (LTE245 eNodeB units) and the SIRRANs LTEnet core network containing the core elements of an EPC (the MME, HSS, S-GW and P-GW).

Wired backhaul network: an OpenFlow based wired packet-core backhaul network responsible to pass the traffic to/from the LTE/Wi-Fi access networks from/to the Wireless Gateway used for the inter-connection, through the GEANT network, with the TSON optical testbed. The *NITOS Gateway* is responsible to handle the ingress and egress traffic from the Bristol network.

Control and Management network: is based on OMF/SFA framework and a new powerful REST API.

B. The CONTENT layered Architecture

In order to provide end-to-end network virtualization capabilities, agnostic to the underlying technological dependencies, the following layering approach is proposed [3] [6]:

(i) *Heterogeneous Physical Infrastructure Layer:* including a hybrid wireless access network (LTE/Wi-Fi) domain, and an optical metro network domain (TSON) [7] supporting frame-based sub-wavelength switching granularity.

(ii) *Infrastructure Management Layer (IML):* This layer offers the necessary resource representation, abstraction, management and virtualization functionalities and is responsible for creation of virtual network infrastructures over the underlying physical resources.

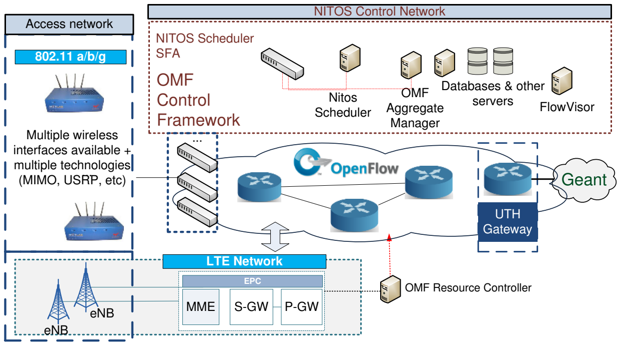

Fig. 2: Wireless Network Architecture

(iii) *Control Layer:* responsible to provision IT and (mobile) connectivity services in the cloud and network domains respectively. The control is made over the IML virtualized resources.

In addition the architecture defines a *Service Orchestration Layer* which is responsible for the efficient coordination of the cloud and network resources, in order to enable the end-to-end composition and delivery of integrated cloud, mobile cloud and network services. We note that the architecture is not bind to a specific controller technology (e.g. NOX, OpenDaylight etc.) or framework (e.g OMF/SFA). The implementation of the complete CONTENT solution in NITOS (in Volos, Greece) and TSON (in Bristol, UK) testbdeds will pave the way towards the adoption of the CONTENT solution by various Wireless and Optical Network Providers, that potentially use different control and management frameworks and are interested in multi-domain, end-to-end software defined networking.

III. Wireless Network Virtualization

At high level, the CONTENT data plane (wired, wireless, optical) will handle incoming datagrams through a series of link-level operations and will be responsible for the fast path forwarding actions, while the CONTENT control plane will be responsible to establish the local data sets used to create the forwarding table entries. In principle, converged Wi-Fi - 3G/4G wireless networks must be able to meet the following challenges: what happens when users switch networks in mid-sessions; how the selection of wireless interfaces is performed; how to perform seamless handoffs; how to automatically authenticate for seamless handoffs; and how to interact with the mobile core for policies and charging.

In addition under the CONTENT end-to-end virtualization concept, we must also investigate the following issues regarding the convergent virtualized LTE/Wi-Fi wireless access network:

1) How the CONTENT virtual wireless networks are defined.
2) Which operations of the data plane and the control/management layers involve their implementation.
3) How the data plane will communicate with the control plane.
4) How the convergent LTE/Wi-Fi networks will be integrated with the TSON domain in the data plane and the control/management planes.

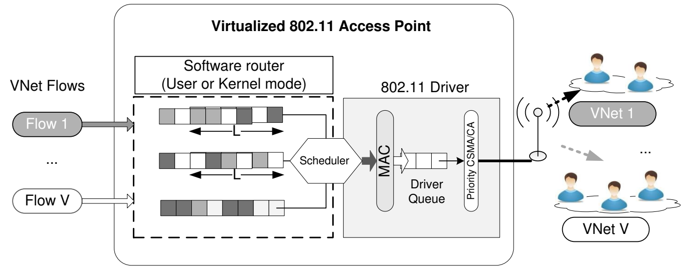

Fig. 3: Virtualized Access Point

5) Which mechanisms will provide service guarantees by means of various metrics (such as throughput, delay etc.).

In principle, virtualization of the wireless access network can take place in the physical layer, the data-link layer (with virtual MAC addressing schemes and open source driver manipulation), or at the network layer. In fact, the capabilities in all the OSI layers of the different wireless technologies considered provide the potential to adopt a very flexible and efficient virtualization solution at this network segment. L2 and L3 network virtualization can take place using technologies such as OpenFlow, while in the Access point resource virtualization technologies like the one proposed in [14] can be used where a single wireless access point is used to emulate multiple virtual access points. The main idea is that clients from different networks associate with corresponding virtual Access Points (APs) though the use of the same underlying hardware. In the MAC layer, Multi-SSID virtualization is investigated in works like [15] and [14] to group users by assigning them to different Virtual APs (VAPs), where each VAP uses different SSID. By mapping each VNet to a different VAP, different handling per VNet is feasible (eg. authentication, encryption and transmission rate etc). We note that although this mechanism is widely used, it is prone to increased channel utilization, due to overhead caused by beacon frames that advertise the multiple SSIDs. In addition, although both resource-based and service-based models enable the support for all the identified requirements, service-based virtualization implementation needs to consider the service granularity, since resources may be unable to be shared among different virtual infrastructures in some cases, due to proprietary MAC protocol implementations.

A. The virtualization Approach

1) Resource Virtualization: A major enhancement performed in the NITOS testbed, in order to be compatible with the CONTENT IML solution, is a new REST API regarding resource abstraction and resource reservation. The NITOS testbed was already SFA compliant and a resource abstraction/resource XML-RPC reservation mechanism was already available, mainly used for FIRE testbed federation. In a nutshell, the new REST API is responsible to expose the testbed resources and reserve resources of any kind from the testbed's physical network. This REST interface is used to expose the semantics and the capabilities of the physical resources to the Infrastructure Management Layer (IML). IML is overall responsible for the management of the network infrastructure and the creation of virtual network infrastructures, over the underlying physical resources from the all the underlying testbeds. In more detail, the IML functionality includes resource representation, abstraction, management and virtualization. An important feature of the functionalities supported, is orchestrated abstraction of resources across domains, involving information exchange and coordination across domains. In addition, the CONTENT IML supports the main resource abstraction mechanism between the data plane and the control plane.

Although the CONTENT architecture is open for any framework that is able to provide the desired functionality, the initial IML implementation is based on the OpenNaaS [16] framework. The OpenNaaS family of tools, developed by an open community under LGPLv3 license, enables a common Network as a Service (NaaS) software-oriented stack for both applications and services. OpenNaaS platform is based on a lightweight abstracted operational model, which is decoupled from actual vendors specific details and is flexible enough to accommodate different designs and orientations.

2) Virtual Flows and Programmable Data Plane Technologies: Virtual network flows can be distinguished in numerous ways such as the "OpenFlow way" for example, by using VLAN identification or source-destination address pairs. In the CONTENT project we use VLAN identification between the virtual network flows and QnQ service to identify flows over the GEANT network. Every Virtual Network is assigned a VLAN tag that will be the end-to-end identity of the flow. The fact that VLAN technology is supported in both the wired backhaul and the LTE/802.11 access networks, gives us the ability as designers, besides providing network isolation, to apply policies and build QoS mechanisms in various points of the architecture and the ability to sufficiently achieve performance guarantees for each virtual network.

In order to support the CONTENT SDN solution, programmable data plane technologies are utilized at multiple points of the NITOS/wireless architecture. In more detail, we use Software Routers, like the Click Modular Router [17] and Virtual Switches, like OpenVSwitch, at multiple points of the NITOS/wireless architecture. Click modular router is ideal for wireless data plane operations, since it is extremely extensible and can be used to perform actions like packet scheduling, traffic shaping, packet filtering, packet dropping and header rewriting. All these mechanisms are necessary in order to provide service guarantees and handle the unpredictable, stochastic nature of the wireless medium. In addition, it offers for fast prototyping, while there are already available plug-ins for multiple operations (eg. openflow plugin).

802.11 data planes and QoS guarantees: Similarly to [14], we use programmable data plane technology, [17] to program forwarding operations in 802.11 Access Points. In a native 802.11a/b/g AP, the queueing structure is a single FIFO queue implemented in the driver. In our proposed scheme (see Fig. 3) the sophistication of the policies is entered through queueing and scheduling operations performed in a layer between the IP and the MAC. We use the Click Modular software router to implement advanced queue structures and perform advanced scheduling decisions, in order to provide service guarantees. For example as shown in Fig. 4 we demonstrate how sophisticated scheduling decisions (GPS/WFQ variations, Credit-based scheduling, Dynamic Weighted Round Robin etc.) can provide different throughput share (different number of transmitted bytes) to each virtual flow, without requiring knowledge of the channel conditions or a priori knowledge of the arrival process. The figure presents a stochastic control approach developed in [18], where multiple Virtual Network flows get a predefined portion of the transmission capacity.

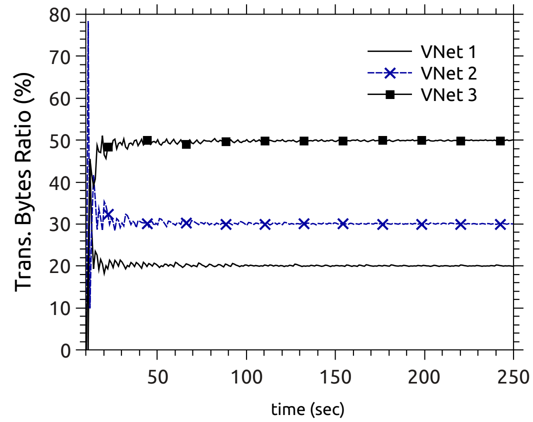

Fig. 4: Throughput share guarantees

In order to enhance the ability of 802.11 access points to support service differentiation between competing Virtual Wireless Networks and at the same time provide improved throughput, we also explored and utilized the dynamic frequency selection (DFS) and the rate adaptation techniques [19]. The combination of these schemes are exploiting the impact of channel width on throughput, range, and power consumption using different combinations of activated antenna elements in Multiple Input Multiple Output (MIMO) enabled systems, such as the 802.11n.

LTE QoS guarantees: In the CONTENT project we heavily rely on the concepts of bearers and the relative service guarantees that the LTE / LTE-A provide, through QCIs identifiers. For every VLAN flow (virtual flow, data pipe, application etc), dedicated bearers (GBR type) are configured and are responsible for the quality of the flow. In more detail in order to provide guarantee QoS to every virtual flow, we rely on the concept of mapping different VLANs to different APNs (subscriber group) and set the desired flow characteristics per VLAN.

3) Data Plane & Control Plane Communication: Following the SDN paradigm, the CONTENT control plane establishes the local data set used to create the forwarding table, for state exchange and updates on topology changes. The CONTENT data plane uses the forwarding table entries to forward traffic between ingress and egress ports. Southbound interfaces (APIs) are used to communicate between the controller in the control plane and the switches and routers of the network (data plane) and facilitate control over the network, in order to dynamically make changes according to real-time demands. The use of programmable data planes, like OVS and the Click modular router, while also the use of switches with native support for OpenFlow in the NITOS backhaul network, allow for easy adoption of many types of SDN controllers and southbound interfaces to be used. We note that the control signaling is made over the IML level of abstraction, so the SDN controller southbound interfaces, communicate indirectly with the data-plane through the IML.

4) Seamless handoffs: Although a lot of modeling work already exists on offloading decision making and policies for inter-network handoffs [2] and various mobility models exhibit the characteristics of temporal dependency, spatial dependency and geographic constraint mobility [20], very few results exist on the actual way we can implement the handoff procedures in SDN over the converged infrastructure. From the end user perspective, enhanced user equipment (UE) is required in order to provide seamless handoffs between various access technologies. Our motivation and inspiration comes from the OpenFlow-Based Vertical Handoff over Wi-Fi and WiMAX made in the Orbit Testbed [21], where a way to make vertical handoffs between multiple wireless interfaces is presented, using OpenVSwitch (OVS) and OpenFlow protocol. Following the analysis presented there, we are able to provide seamless handoffs between multiple interfaces, meaning that the application does not need to be aware that the handoff takes place. We note that similar handoff procedures (basically bridging interfaces at demand) can be also performed by using the Click modular router or a software router that can program the node data plane. Additional techniques like Access network discovery and selection function (ANDSF) are of high interest for the aims of CONTENT project and will be exploited. ANDSF is an entity within an evolved packet core (EPC) and can be used to assist user equipment (UE) to discover non-3GPP access networks (like Wi-Fi in the CONTENT case) that can be used for data communications in addition to the LTE access network.

IV. Conclusions & Future work

The CONTENT project is an EU funded effort for network and infrastructure virtualization over heterogeneous, wireless and metro optical networks, that can be used to provide end-to-end cloud services. In this work we presented the wireless network virtualization solution, in the light of the CONTENT technical approach, where a convergent LTE/Wi-Fi network is virtualized and interconnected with an optical TSON metro network. Virtual flows are defined the "openFlow way", by using VLAN identification and QnQ technology, while advanced programmable data plane technologies are used in 802.11 networks and mapping of subscriber groups to different VLANs in the LTE side in order to provide guarantee QoS to every virtual flow. Current plans include the build of necessary plugins for the efficient interaction of the IML with the SDN controllers and the build of the CONTENT end-to-end prototype solution, while research on the field of the service guarantees in the virtualized wireless field and deployment of cloud services over the CONTENT convergent network, are planned for future work.

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