Virtualization of Set-Top-Box Devices in Next Generation SDN-NFV Networks: the INPUT Project Perspective

R. Bruschi***, F. Davoli**, L. Galluccio*, P. Lago***, A. Lombardo*, C. Lombardo***, C. Rametta*, G. Schembra*
*DIEEI, University of Catania, Italy (email: name.surname@dieei.unict.it)
**UNI-GE, Italy (email: name.surname@unige.it)
***CNIT, Italy (email: name.surname@cnit.it)

ABSTRACT
Due to the emergence of Software Defined Networking (SDN) and Network Functions Virtualization (NFV) paradigms, coupled with a hyper-connectivity communication paradigm, the "softwarization" of the Internet infrastructure and of its network management framework is gaining increasing popularity. This is the target of the INPUT platform, a novel infrastructure and paradigm supporting Future Internet personal cloud services in a more scalable and sustainable way, and with innovative added-value capabilities. The INPUT technologies enable next-generation cloud applications to go beyond classical service models, and even replace physical Smart Devices, usually placed in users' homes (e.g., set-top boxes), with their virtual images, providing them to users "as a Service". In this paper we present the Virtual set-top box from both architectural and functional points of view, demonstrating the feasibility of the softwarized SDN/NFV paradigm joined with the fog-computing approach to support personal cloud services.

CCS Concepts
• **Network services→Cloud computing** • **Network services→ Programmable networks**

Keywords
Software Defined Networking; Network Functions Virtualization; Device Softwarization, Fog-computing, Cloud Services.

1. INTRODUCTION
Internet Service Providers (ISPs) are facing increasing customer demands for services that require a lot of bandwidth and very low end-to-end delay. Recent traffic reports show that video delivery on the Internet is registering a tremendous increase and will likely grow further in the coming years [1][2]. According to [3], video streaming determines the second largest transfer volume and is among the top growing traffic classes on the Internet. Two key enabler for this trend are the the new paradigms of Software Defined Networks (SDN) [4] and Network Functions Virtualization (NFV) [5][6], recently introduced to redefine the vision of the Internet, providing network managers with a complete and programmatic control of a dynamic view of the network. The power of SDN is based on its characteristic of decoupling control and data planes, moving the network intelligence to a centralized controller. On the other hand, the emerging technology of NFV introduces an important change in the network service provisioning approach, leveraging standard IT virtualization technology to consolidate many network equipment facilities onto standard servers that could be located in data centers, network nodes and even in the end user premises [5] [7][8][9][10][11].

The combined application of both SDN and NFV is strongly stimulating the interest of Service Providers and Network Operators to make the innovation cycles of networks and services faster and easier, reducing both OPEX (OPerational EXpenditure) and CAPEX (CAPital EXpenditure), thanks to the enormous possibilities of making operation processes (e.g. configuration of network devices) automatic, and network functions and services more flexible and cheaper. Furthermore, NFV enables function and service deployment over the network, in particular toward its edge [12][13][14][15], and represents an enabling factor for a rapid evolution of the dynamic service chain provisioning [16][17][18][19].

Many deployment scenarios of SDN and NFV could be envisioned [20][21][22][23][24][25], depending on the network segments (e.g., core or edge) being addressed. Among them, one of the most appealing use cases for Telco Operators and Service Providers is the so-called Smart Device as a Service (SDaaS), aiming at virtualizing services of both Customer Premises Equipment (CPE) devices and Provider Edge (PE) nodes like, for example, set-top boxes, video surveillance, remote building monitoring and automation, Internet of Things gateways and sinks, etc., providing them on demand as a service. This creates a volume and an economic market that will drive investments outside of the network infrastructure boundary and stimulate the advent of new communications paradigms. In this context, according to the approach of the European INPUT project [26] of virtualizing both network and application functions within the telecommunication network, the main goals of this paper are: the introduction of the concept of virtual private network as an extension of the user's residential LAN, where physical and virtual devices (the above mentioned SDaaS) can coexist and communicate with one another; the provisioning of an architectural and functional description of a virtualized smart device, i.e. the virtual set-top box (vSTB), allowing users to receive and record multimedia contents by only accessing their own virtual private network, independently of their geographical position and their current Internet access point. Thanks to the INPUT approach, specific features can be added in the service chains of a vSTB, like for example video encryption [27][28], video compression [29][30] and transcoding [31][32].

The paper is structured as follows. Section II provides a description of the reference scenario and the network architecture. Section III introduces the virtual set-top box as a service, while Sections IV maps it on the INPUT platform, details its core elements, and explains the concept of personal cloud service as a chain of network functions and service applications running on the user's personal network and providing a service to the end users. Finally, Section V draws some conclusions and discusses about some future work.

2. REFERENCE SCENARIO AND NETWORK ARCHITECTURE
The INPUT platform is compliant with NFV architecture described in [33][34]. It considers a telecommunication Network

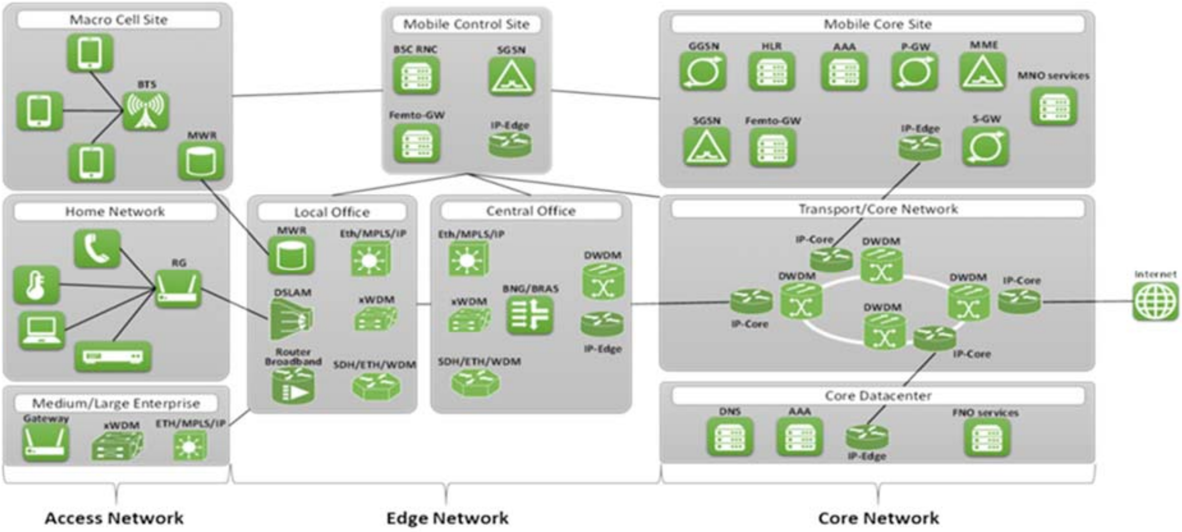

Figure 1. Legacy IP Network architecture.

Infrastructure (NI) with full technological convergence of the mobile and the wireline access. The NI is meant to be constituted by the following segments:

- Core Network (CN): it is the backbone part of the NI. It is characterized by very high capacity links connecting access networks to other networks and datacenters.
- Access Network (AN): it is the access part of the NI, and connects subscribers to their immediate Internet Service Provider (ISP).

Traffic from the AN to the CN is aggregated and routed in the Edge Network (EN) segment, where specific nodes interface end users to the Authentication, Authorization and Accounting (AAA) systems. In today's network (see Figure 1), such nodes are the only devices that are in charge of authenticating Telco customers, authorizing their traffic and services, as well as extracting information for pricing and billing processes. In other words, they constitute the only network nodes in the Telco infrastructure where network services follow a "Personal" paradigm.

Fixed and mobile network convergence requires the interfacing of heterogeneous systems coming from the two technology domains. In this respect, the SDN and NFV technologies can certainly simplify the deployment of a universal central office, which can provide aggregation and AAA services for both fixed and mobile domains (see Figure 2). On one hand, NFV servers can host specific network functions, which today are provided by dedicated equipment; on the other hand, an SDN controller can provide a seamless chain of network functions and configure different virtual networks according to the traffic requirements.

Starting from the envisaged future networks evolution, the INPUT Platform aims at integrating personal cloud services in ENs, where the Network Operator terminates the user network access, and a direct trusting/control on user accounts and services is performed.

In particular, the INPUT Platform introduces/controls computing and storage capabilities in the edge network enabling users and network operators to create and manage private clouds in the network. Thanks to a wide adoption of SDN and NFV paradigms and a vertical integration of cloud services into the network, this allows moving these services closer to end users, so supporting novel latency-sensitive applications.

As a result, the INPUT technologies enable to replace physical Smart Devices (SD), usually placed in users' homes (e.g., network-attached storage servers, set-top-boxes, video recorders, home automation control units, sensors, etc.), with their "virtual images," providing them to users "as a Service" (Smart Devices as a Service – SDaaS).

A *Virtual Image* is defined as a software instance that fully or partially dematerializes a physical network-connected device, and that provides its virtual presence in the network together with all its functionalities.

Moreover, cloud services take advantage of a vertical integration in the network environment, where applications can benefit from the SDN/NFV capabilities to intercept traffic or to directly deal with network setup configurations and parameters.

Provision of INPUT service involves three main stakeholders:

- **The (Telecom) Network Operator:** it is in charge of providing Internet access, accounting and billing to its subscribers, and the infrastructure/platform to support and deploy cloud services.
- **The Service Providers:** they are in charge of **"**interacting" through standard APIs with the INPUT Platform for defining personal cloud services, also specifying their computing and storage requirements and the service level agreement. They can directly create cloud services, and/or allow users to create/configure their own personal cloud network.
- **The Users**: they are individuals or enterprise customers representing the final consumers of the personal cloud services.

Note that the same actors can play different roles at the same time. For example, a Service Developer can be a Service Provider, or even the Network Operator may also coincide with the Service Provider.

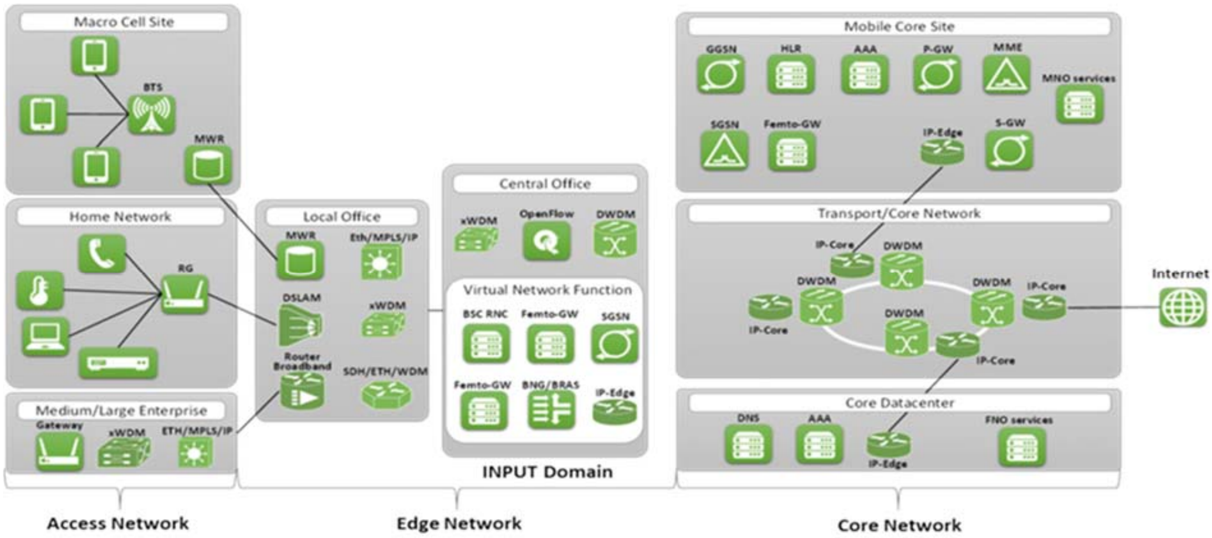

Figure 2. IP Network architecture according to the SDN/NFV paradigm of the INPUT project.

- *Definitions and assumptions*

Before explaining in more details the functioning of the virtual set-top box (vSTB) personal cloud service (PCS), it is important to provide the reader with a set of definitions in order to clarify the rest of the paper.

Inside the INPUT project, the concept of *Personal Network* (PN) has been defined as a secure and trusted virtual overlay network that is able to interconnect the smart devices of a user with standard L2 protocols and operations equivalent to the ones today available in the user's home network, independently of their location (inside/outside the user's home) or their nature (physical/virtual). Personal Networks are designed with the goal of providing the user with the perception of being in the user's home LAN with his/her own (virtual and physical) SDs, independently of the current location. In addition, a Personal Network allows exploiting the same communication protocols (e.g., DLNA - Digital Living Network Alliance, UPnP - Universal Plug and Play, etc.) that are currently implemented in any physical smart and visualization device.

Considering the networking-related capabilities, Personal Networks are realized by virtualizing typical network functions provided by the user's home gateway, and transferring them into software instances (we call them *Net_Functions*) running in commodity computing facilities deployed in the Telco Operator edge network.

A Net_Function is a single software instance that is able to run in commodity servers to provide data- and/or control-plane network functionalities (e.g., IP forwarding/routing, firewall, deep packet inspector, NAT, DHCP, etc.).

On the other side, we define *Service_App* a software instance running in a single "execution container" (e.g., a VM - Virtual Machine) providing application-level services. Starting from these considerations, a cloud service providing virtual SD as a service in general can be deployed in the INPUT infrastructure as a chain of: *Service_Apps*, each performing specific tasks (e.g., user interface, web server, proxy, content caching, storage, computing, encryption/decoding, transcoding, etc.); *User_Apps,* i.e. applications running on users' physical devices such as smart TVs, smartphones, tablets or similar; *DC_Apps* (Data Center Apps), that are applications and services running on remote servers in the cloud. The communication and information messages exchanged among different *Apps* of the same personal cloud service will be handled through the deployment of *Back-End Networks*. With this term we mean a virtual L2/L3 interconnection among a set of *Users/Service/ DC_Apps* (and/or even *Net_Functions*), with the aim of realizing the service chain composing the personal cloud service, and that is separated from the Personal Network. In other words, a Back-End Network is a L2/L3 broadcast network domain built among two or more virtual/physical hosts, whose traffic is isolated from the one carried by the PN or other Back-End Networks.

3. VIRTUAL SET-TOP-BOX SERVICE AT A GLANCE

An example of how it is possible to provide smart services to the users by means of the SDN/NFV approach proposed by the INPUT project is represented by the virtualization of well-known set-top box devices. According to the proposed approach, the STB is not physically present at the user home; rather, it is provided as a Personal Cloud Service (PCS) through the Telco operator infrastructure. In more detail, the virtual STB (vSTB) consists of a services chain of Service_Apps and DC_Apps, created by the Content/Service Provider and deployed into the INPUT infrastructure, and User_Apps running on user's devices (see Figure 3).

The vSTB is instantiated by the Network Orchestrator, trying to use resources as close to the end-user position as possible, in order to maximize his/her perceived QoE.

The vSTB provides the following main capabilities:

1. real-time streaming of multimedia content transmitted from the content provider in one or more local DLNA player devices such as smart TVs;
2. real-time streaming of multimedia content in smartphone and/or tablet players by exploiting the radio access network;

3. recording and playing-out content.

All the above-mentioned capabilities will be managed by using User_Apps for smartphones or tablets. A graphic user interface (GUI) guides the user across the above-mentioned vSTB functions. For the sake of clarity, the GUI permits to choose the action (play live contents, recording and view users' contents) and the target device where to finalize the action, i.e. the player, among the devices connected to the Personal Network. Under this perspective, it appears clear that users do not need to directly connect any STB to their home multimedia players, because it will be provided as a service through the INPUT infrastructure.

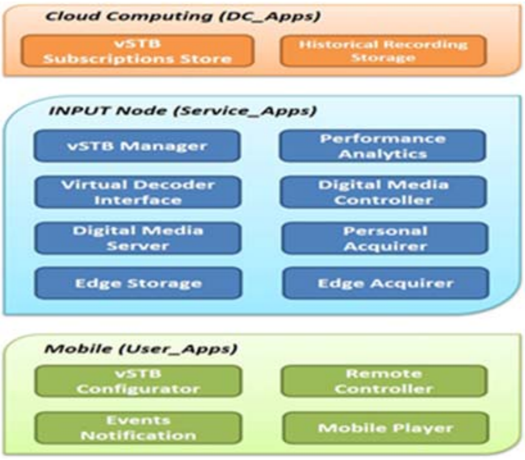

Figure 3. Functional elements composing the vSTB Personal Cloud Service.

The potentiality of the STB virtualization becomes clear when the user moves from his/her own home physical network towards another residential or business physical network. This is obtained thanks to the INPUT platform peculiarity of flexibly extending the concept of "home network" to the more complex idea of Personal Network. When moving toward an external LAN, belonging to the INPUT network, or utilizing his/her mobile devices (smartphone or tablet) under the radio coverage area of the INPUT network operator, the user will be able to: view a real-time or stored content directly on the mobile device and/or migrate/duplicate the vSTB service in the visited network.

In order to minimize the storage space, only one server can be allocated either for the whole Telco network, or for each edge node, in order to serve all the users connected to it. Such approach allows to employ light virtual machines running the Service_Apps composing the vSTB instances and to optimize the copy and migration procedures in case some user moves from the own residential network to the INPUT radio access network or to other residential or business networks.

The same solution can be employed for the video stream receiver, i.e. the functional block that receives all the live contents coming from the content providers and that interfaces with the vSTB to send the user only the required stream (i.e. a live channel, an event, and so on).

4. MAPPING OF THE VSTB TO THE INPUT ARCHITECTURE

As mentioned in Section III, physical SDs such as the set-top boxes are fully virtualized in the INPUT computing facilities through software instances, named Service Applications (Service_Apps), running at different levels of the edge network infrastructure. Starting from these considerations, the whole service, named Personal Cloud Service, is deployed in the INPUT architecture as a chain of Service_Apps, User_Apps, i.e. software elements at the user side, and DC_Apps, i.e. software components hosted at data-center side.

The target of this section is to present all the components of the vSTB PCS. In the following, the different elements inside the framework will be presented together with their functionalities.

- **DC_Apps**
  - *vSTB Subscription Store:* it is a cloud service enabling the subscription of services/channels/events proposed by the Content Provider; a user has to connect to this service every time he wants to change the terms of his subscription.
  - *Historical Recording Storage:* contents saved by users are stored in a storage service within the INPUT infrastructure; when contents become obsolete and, thus, required less frequently, they are moved to a data center storage service, i.e. the Historical Recording Storage.
- **Service_Apps**
  - *vSTB Manager:* it is the Service_App enabling management and configuration of the vSTB device. As will be clear in the following, by means of it users are able to migrate and/or duplicate smart devices in the visited Personal Networks belonging to the INPUT network infrastructure.
  - *Performance Analytics:* it gathers the information about the service KPIs such as latency, delay, delay variation, packet loss rate, throughput and other parameters allowing the measurements of the quality of service/experience of the user. These parameters can be accessed by users by means of this Service_App.
  - *Virtual Smart Device set-top box*: it is the core element of the vSTB service, and represents the virtualization of the common physical set-top box; it consists of four Service_Apps, whose functions and behavior will be detailed in Sub-Section A.
  - *Edge Storage*: it is the Service_App responsible for saving the contents recently recorded and that, therefore, will be requested more likely in the immediate future.
  - *Edge Acquirer*: it is the Service_App receiving the data flows from the Content Provider's servers. It communicates with the users' PAs to publish the content schedule and to transmit the requested multimedia data flow.
- **User_Apps**
  - *vSTB Configurator*: it is the mobile User_App enabling the configuration of the virtual smart device. From this User_App, a user can choose device settings such as, for example, language, subtitles, transcoding (in case the user

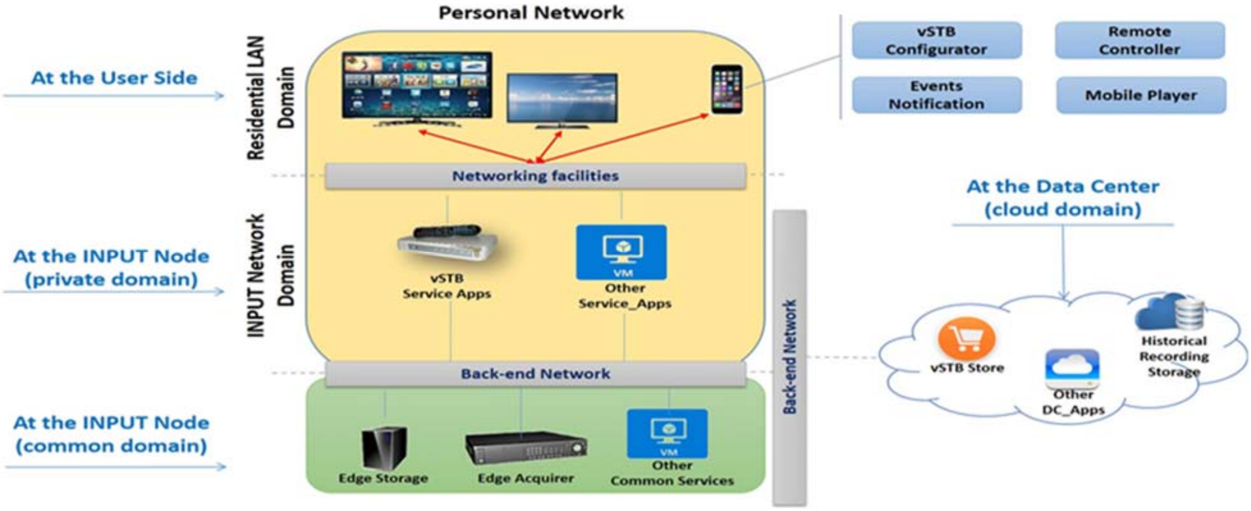

Figure 4. Overview of the vSTB deployment on the INPUT platform.

want to limit the bandwidth for the service, or in the user's players certain audio/video codecs are not available), favorite programs, parental controls, and so on.

- *Remote Controller*: this User_App is a mobile application that the user installs on her smartphone or tablet to remotely control the vSTB device; more in detail, it connects to the VDI Service_App allowing the following actions: access the provider's content schedule, select a real-time or recorded content, and choose the DLNA player.
- *Events Notification:* it allows setting up a notification service to alert users when the requested content is available.
- *Mobile Player*: it is a mobile application that allows viewing content directly on a smartphone or a tablet; it connects directly to the PA and DMS Service_Apps, in order to select between real-time and stored contents.

Finally, Figure 4 shows a high-level overview of the user's Personal Network when the vSTB service has been activated. As already specified, the PN includes both physical and virtual devices. More in detail, we can distinguish physical devices at the user side, i.e. in the user's residential LAN domain, and virtual devices at the INPUT domain, i.e. deployed inside the INPUT network infrastructure, but belonging to the user's private domain. In addition to the above components, there are also other elements deployed within the network infrastructure, but that can be considered in the common domain; that is, they are employed for a number of users and do not belong to a specific PN, like the *Edge Acquirer* and the *Edge Storage* Service_Apps in the case of vSTB PCS.

4.1 VSTB core elements

The virtual set-top box device implementation consists of four Service_Apps, as represented in Figure 5. It is compliant with the DLNA standard, that is, it is able to communicate with DLNA-compliant devices. Each component of it will be described in the following.

1. **Virtual Decoder Interface (VDI)**: this component represents the interface between the user's app and the functional components of the virtual decoder. By using an app (Android, iOS, Windows Phone or other frameworks) the user can select an action among: *view live contents*, *record incoming or future events transmitted by the provider*, *view a recorded content from the own digital library*. Furthermore, the VDI communicates with the Digital Media Controller to select the digital media player to be used to view the multimedia content, and with the Personal Acquirer, with the aim of selecting one of the proposed contents or enabling the recording of a selected event.
2. **Digital Media Controller (DMC):** according to the DLNA standard, the DMC maintains the list of the DLNA players in the network and communicates with the DMS to know the list of the contents as they are exposed by the PA.
3. **Digital Media Server (DMS):** also this element is compliant with the DLNA standard; it maintains and updates the list of contents exposed by both the PA and the Edge Storage.
4. **Personal Acquirer (PA)**: it receives commands from the VDI enabling the live streaming of contents or the recording of a selected content. It communicates with the Edge Acquirer at the Edge Node of the network requiring the multimedia content selected by the user, or indicating that a specified event has to be forwarded to the edge storage to be recorded. The PA has also the task to expose live contents to the DMS.

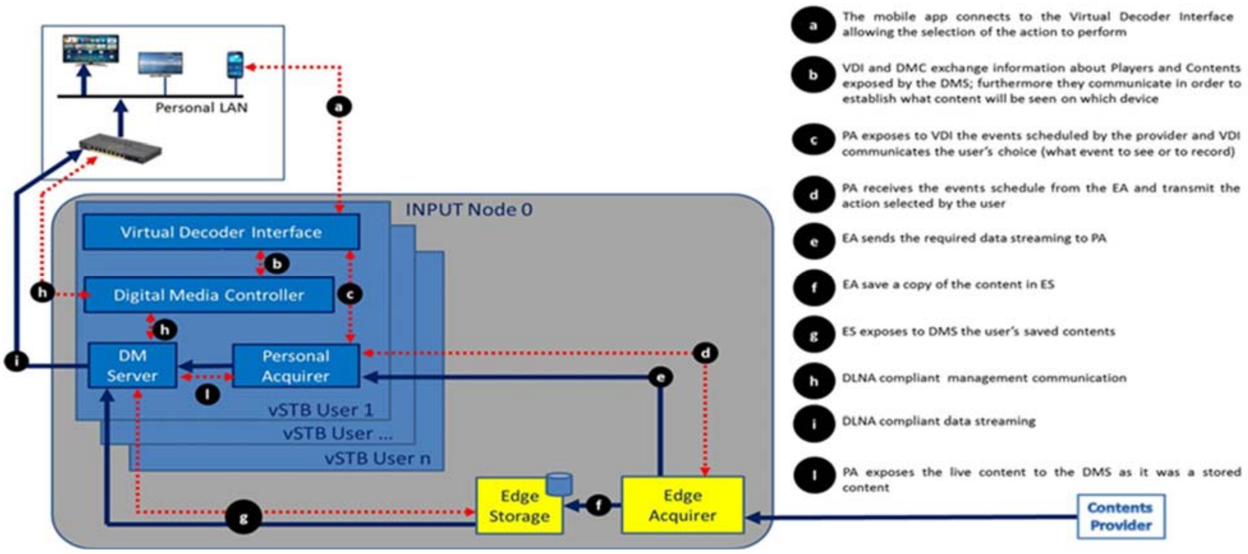

Figure 6. Data and signaling messages exchanged among the vSTB core elements and the physical devices attached to the user's residential local area network.

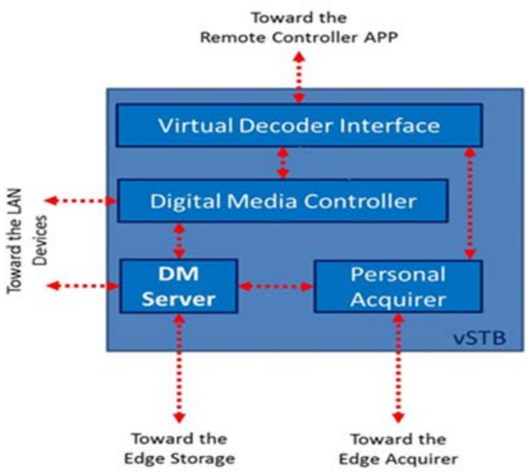

Figure 5. vSTB core elements.

In addition to the functional blocks that constitute the vSTB, the framework is based on the presence of two more elements within the network edge node, i.e. the ***Edge Acquirer*** and the ***Edge Storage***. The first one receives data streams directly from the Content Provider; furthermore, it exposes the event scheduling to the connected vSTBs, and sends required data streams to the PA. Finally, when required, it saves multimedia contents in the ES. The Edge Storage, on the other hand, is a Network Attached Storage where users can save contents on demand. Saved contents, thus, are made available to all those users who have requested registration. Fig. 6 shows an overview of data and signaling messages exchanged among the above core elements and the physical devices attached to the user's residential LAN.

4.2 *Service chains and physical distribution of the functionalities*

A PCS such as the virtual set-top box is deployed in the INPUT architecture as a chain of DC_Apps, Service_Apps and User_Apps elements, each of which performs specific tasks (e.g., user interface, web server, device manager, events notification, data analytics, storage, encryption/decoding, etc.). In Fig. 7 we report the service chains, i.e. the sequence of DC_Apps, Service_Apps and User_Apps involved during some of the most relevant actions characterizing the proposed PCS. For the sake of clarity, in green boxes we will represent User_Apps, running on the user's mobile devices; blue boxes refer to Service_Apps hosted in the INPUT network infrastructure; orange boxes represent DC_Apps; finally, the user's devices involved to finalize the action, i.e. the DLNA players, are shown in grey boxes.

- *Viewing a content on a smart TV*

When a user wants to watch a multimedia live content (refer to Figure 7.a), he/she accesses the *Virtual Decoder Interface* (VDI) by using his/her User_App *Remote Controller*. The *VDI* Service_App is connected to the *Digital Media Controller* (DMC) and to the *Personal Acquirer* Service_Apps. Thanks to them, it is possible, respectively, to select the destination DLNA player among the devices connected to the user's personal network, and to connect to the *Edge Acquirer* Service_App to request the desired multimedia content scheduled by the content provider.

Likewise, when a user wants to watch a recorded content, he/she accesses the *VDI* by using the User_App *Remote Controller*. The *DMC* is connected, besides the DLNA Players, also to the *Digital Media Server* (DMS) to retrieve the recorded content. The latter can be stored in the local *Edge Storage*, if it has been recorded recently, or in the *Historical Recording Storage* DC_App, if it is older than a given time threshold.

- *Viewing a content on a mobile device*

The user wants to receive the service directly from a Smart Client that is connected to the user's Personal Network through a mobile connection (refer to Figure 7.b). The applications involved in this action are the Mobile Player User_App, the Virtual Decoder Interface, the Digital Media Server and the Personal Acquirer, coupled with the Edge Acquirer Service_Apps, as concerning the

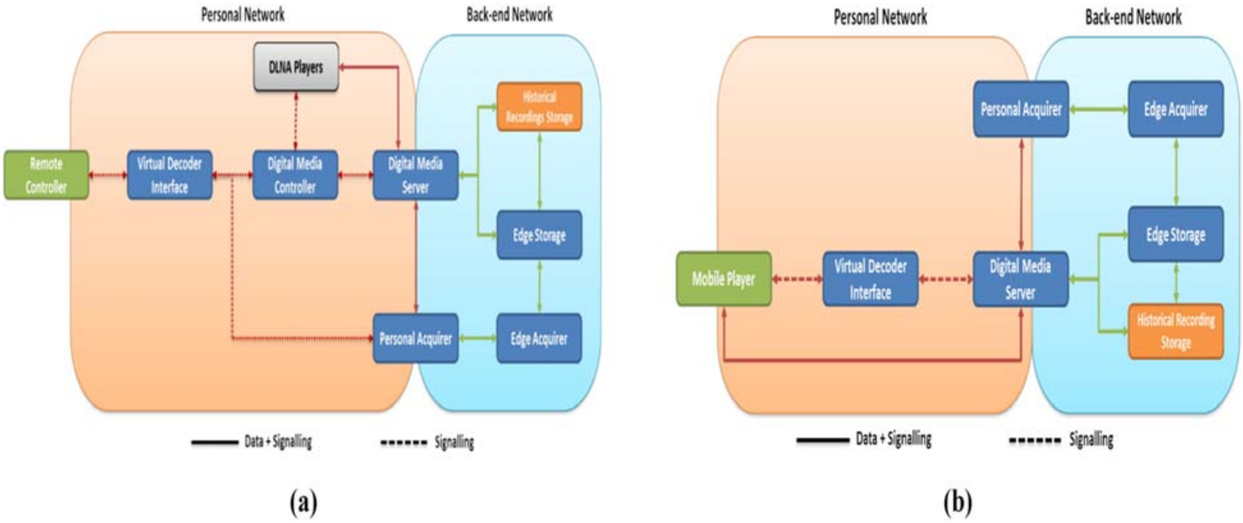

Figure 7. Service chains for live multimedia content view on (a) smart TV and (b) mobile device.

view of a live content from the content provider. Instead, as far as the view of a stored content is concerned, the involved applications are the Digital Media Server and the Edge Storage Service_App, or the Historical Recording Storage DC_App.

5. CONCLUSIONS AND FUTURE WORK

This paper provides an overview of how the European INPUT project aims at realizing a full SDN/NFV convergent network, including fixed cabled and wireless radio access networks, and extends the concept of user's local area network to the more complex and flexible concept of personal network, that is, a network able to follow the users during their movements. In addition, the paper shows how the INPUT platform enables easy and fast deployment of smart devices as a service. One of the possible applications of the architecture has been proposed; namely, the virtual set-top box, illustrating its functional and architectural design as a chain of applications running at the user side, in the INPUT network facilities and in the cloud, i.e. in data centers. As future work, we are considering the implementation of the service on a first network prototype and the development of an orchestration engine for the provisioning, deployment and management of the Service_Apps inside the network, according to the service requirements in terms of quality of service/experience.

6. ACKNOWLEDGMENTS

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