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Greening Video Distribution Networks

Energy-Efficient Internet Video Delivery

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Foreword

The concept of the CONVINcE project grew out in 2013 of two observations: the Internet's carbon footprint was expected to exceed in 2020 that of air travel by a factor of two and the Internet traffic will be driven by video. Should people not be convinced of the necessity to reduce carbon dioxide emission, they will need to react to the economic aspect of the problem coming from the price of electricity, which will irremediably increase in the future.

Made up of 16 partners from four European countries, CONVINcE is a Celtic-Plus project addressing the challenge of reducing the power consumption in IP-based Video Distribution Networks (VDN). Partners followed an end-to-end approach, from the headend where contents are encoded and streamed to the terminals where they are consumed, embracing the Content Delivery Networks (CDN) and the core and access networks.

Partners' efforts concentrated on several topics. First on architectures, with a theoretical approach aiming at defining trade-offs between energy consumption and final user's Quality of Experience (QoE). Then, several concrete use cases were studied and some of them implemented. Particular focus was given to energy savings in mobile terminals, edge-cloud and green routing in the core network. Prefiguring tomorrow's networks, virtualization and Software Defined Networks (SDN) were not dismissed, and their influence on power consumption was assessed as well. In order to have accurate measurements of power consumption of devices, hardware and software measurement tools were developed. Industrial partners also conducted a techno-economic analysis with the objective to estimate potential energy savings brought by the project and subsequent gains for service and network operators. CONVINcE project contributed additionally to four different standardization forums: 3GPP, IEEE, IETF and MPEG. In these forums, the project contributed to six different working groups with 38 technical contributions.

An important conclusion of the project is that there is no 'magic solution' solving all consumption issues from the headend to the terminal. Optimization is the sum of several—even small—contributions properly implemented to save energy. Another important result of the project is that you must sometimes accept to consume more energy in one part of the system to save a lot in other parts. This is typically the case where using a new encoding standard HEVC—in the headend increases significantly the energy consumption in this part, but divides by two the bitrate, leading to substantial savings in networks and terminals, with a high positive impact on the end-to-end consumption.

This book is a useful guide for those who want to reduce energy consumption in IP-based VDNs. Most of the chapters are direct results of the CONVINcE project, showing that use of new approaches and technologies can actually reduce the energy consumption in these networks, contributing so to reducing the carbon footprint of the Internet. I would like to thank the authors for their valuable contribution to this huge task.

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Preface

Introduction

Internet video delivery refers to Video Distribution Networks (VDNs). These are networks composed of several parts that together create a chain model from encoding and packaging the content, its transport and distribution to end users and to its consumption in terminals. The most important functionalities in these networks are video encoding/transcoding, adaptive bit streaming, core/metro networks, access networks, Content Delivery Networks (CDNs) and routing protocols.

Given the huge increase in video traffic expected in the next few years, this means one needs to solve associated problems like tempering the significant increase expected in energy consumption and to provide the expected end user Quality of Experience (QoE). For instance, it is mentioned that the European Council has set forth an important target in form of the so-called ‘20 20 by 2020’ initiative, which means the goal is to reduce the greenhouse gases by 20% in European Union (EU) as well as to obtain a 20% share of renewable energies in EU. This further means there is a strong need to consider problems related to this, to study and to solve them.

Reducing energy consumption in VDNs also means addressing topics like software best practices and eco-design as well as power and Quality of Experience (QoE) based design.

Towards this goal, the Celtic-Plus project CONVINcE, financed 2014–2017, with participating industrial and academic partners from four European countries (France, Finland, Sweden and Turkey) brings in important contributions. This book reports an overview of the main research results obtained in CONVINcE.

Organization

The book is organized in a number of ten book chapters and a Foreword chapter that cover several of the most important elements of Video Distribution Networks. Nine book chapters have been written by people involved in the CONVINcE project, working with different elements and aspects of Video Distribution Networks. Furthermore, one more book chapter has been written by researchers at the University of Genoa, Italy and University of Malta. Particular focus has been given to elements like architectures, models, video encoding and decoding, mobile terminals, wireless sensor networking, Software Defined Networking (SDN) and techno-economic aspects.

Features

Based on the information regarding existing literature, one can state that today there is no other similar book. The uniqueness of the results reported in the book combined with the relevance and importance of the topic gives a unique position. Furthermore, it is expected that the experience obtained in the CONVINcE project will open up for other future relevant projects focused on the stringent problem of reducing the energy in Video Distribution Networks.

Target Audience

The book is addressed to several categories of readers: college students, engineers, researchers, networking scientists, computer scientists and industry people. The broad area of topics covered by the book combined with the practical insight creates good premises for opening the interest of many people involved in computer and telecommunication systems.

Karlskrona, Sweden Adrian Popescu

Contents

Abbreviations

3GPP	3rd Generation Partnership Project
ACM	Association for Computing Machinery
API	Application Programming Interface
AVC	Advanced Video Coding
CAM	Video CAmera attached to a Computer
CCN	Content Centric Networking
CDN	Content Distribution Network
Cloud Computing	Internet-based computing
CONVINcE	Consumption OptimizatioN in VIdeo Networks
CPU	Central Processing Unit
DC	Data Center
DNS	Domain Name System
Edge Cloud	Optimizing cloud computing by performing data processing at the edge of the network
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communication
H.323	Protocol for setup, management and termination of a media session
HEVC	High Efficiency Video Coding
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
HTTP-DASH	Dynamic Adaptive Streaming over HTTP
HW	Hardware
I/O	Input/Output
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IoT	Internet of Things
IP	Internet Protocol
IPTv	Internet Protocol Television

IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISO	International Standards Organization
ITU	International Telecommunications Union
LLN	Low-Layer Network
MPEG	Moving Picture Experts Group
MVC	Multi-View Coding
NFV	Network Function Virtualization
OTT	Over The Top
PSNR	Peak Signal-to-Noise Ratio
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RBG	Red/Blue/Green
SDN	Software-Defined Networking
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SVC	Scalable Video Coding
TCP	Transport Control Protocol
TV	Television
UHD	Ultra-High-Definition television
VDN	Video Distribution Network
VDS	Video Data Specification
VoD	Video on Demand
VoIP	Voice over IP
VPN	Virtual Private Network
VQM	Video Quality Model
WAN	Wide Area Network
Wi-Fi	Technology for Wireless Local Area Networking based on using IEEE 802.11 standards
WLAN	Wireless Local Area Network
WMSN	Wireless Multimedia Sensor Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

Chapter 1
Video Distribution Networks: Architectures and System Requirements

Adrian Popescu, Yong Yao and Dragos Ilie

1.1 Introduction

Video Distribution Systems (VDS) are basically a set of audio and video devices, peripherals and equipments for interfacing, switching, routing, and distribution of audio, video, and picture signals sourced from multiple devices and distributed to geographically dispersed multiple devices. VDS provide distribution services of different categories like one to many, many to one, and many to many. A set of specifications and design guidelines are used to define these systems. Technical solutions with business value are expected to provide good mixture of performance, repeatability, and easy-to-use facilities. Because of this, VDS have today almost completely moved from switched networks to IP networks, also combined with the use of IP-capable endpoints and H.323 that defines the protocols to provide audiovisual communication sessions on any packet network. At the same time, the enterprise voice over IP (VoIP) environment continues the massive transition to Session Initiation Protocol (SIP) for functions like call setup, management, and termination of multimedia sessions, also requiring interworking with H.323-based video endpoints.

The current Video Distribution Networks (VDNs) and the Internet are today under big pressure to provide exponential growth in bandwidth demands, mainly because of very large traffic demands associated with TV services like IPTV as well as the appearance of new streaming services like Netflix and Skype-like video communications. At the same time, the Internet has democratized the processes of creation, distribution, and sharing of user-generated video contents through services such as YouTube and Hulu. The situation is further complicated by new developments in the form of adoption of new better video formats, requesting more

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bandwidth like, e.g., the Ultrahigh Definition (UHD) defined and approved by the International Telecommunications Union (ITU).

The video traffic increase associated with the streaming services is dramatic. For instance, the so-called Cisco Visual Networking Index (VNI) indicates that today, the video traffic amounts to 90% of the global consumer traffic and also that most data communication is expected to become wireless by 2018 [1].

Another important development is the emergence of versatile apps for TV. Users are expecting a rich mixture of Video on Demand (VoD), live, and other advanced video services to be provided on an increasing number of mobile devices like smartphones and tablets, anywhere, anytime, any device, also with minimum energy consumption. At the same time, content providers are expected to be able to seamlessly operate across mobile and TV networks through app-like interfaces. The interplay between services and TV hardware is expected to increase. New facilities like voice and gesture recognition and hyper personalization are expected to become popular as well. Furthermore, the appearance of new bandwidth-demanding video streaming services like Netflix further complicated the situation.

To cope with the bandwidth growth, the shift to wireless, and to solve other issues (e.g., security), new architectures have been suggested to support a wide range of services, but unfortunately no focus has been given yet to video distribution. This is clearly observed at new suggested architectures like Content-Centric Networks (CCN) [2] and content-based extensions to Software-Defined Networking (SDN) [3]. The conclusion is that there is need for sustained research and development activities on IP-based VDN.

Connected with this, several important questions need to be answered regarding, e.g., future architectures for video delivery with reduced energy consumption, provision of real-time guarantees for live and interactive video streams, subjective, and objective metrics for performance measurement and evaluation, and performance optimization [4].

The book chapter is organized as follows. Section 1.2 presents the high-level architecture of a video distribution system. Section 1.3 presents the main categories of Low-Layer Network architectural solutions. Section 1.4 presents Content Distribution Networks (CDN). Section 1.5 presents the video distribution networks. Section 1.6 presents some of the most important video applications. Section 1.7 presents the middleware used to control the video architectures. Finally, Sect. 1.8 concludes the book chapter.

1.2 High-Level Architecture

High-level architecture of a system is defined to be a general-purpose architecture that describes the system considered for study. The goal is to define a common framework to support analytical studies, simulations, experiments and interoperability. That means such architecture must provide elements for, e.g., analytic simulations, test, and evaluation. Among others, the high-level architecture of a system must provide information about the system model and also information about requirements, assumptions, and different constraints. In a larger perspective, aspects related to business models and deployment elements may become relevant as well.

1.2.1 Basic Operations

The creation of video content and the distribution over IP networks is a sophisticated process that follows a chain model from the acquisition at the video source, through the production and packaging of the content to the final element of distribution to viewers [5]. A video distribution system contains therefore several parts, which are about media contribution, the primary distribution, and the secondary distribution.

Video contribution refers to functions like capturing and initial processing of the video content as well as the initial transport prior to distribution. For example, the video content may be captured at a football stadium and it may be transported to a central broadcast network facility, which is placed in another location. The video streams used in this phase may be compressed or uncompressed, depending upon the particular situation in terms of the existing bandwidth and the particular demands for quality. The distribution video is sent from the central broadcast facility to other broadcast facilities for ultimate transmission to end users. Distribution configurations of type one to one (unicast) and one to many (multicast) are typically used in this case.

There are two categories of distribution systems, the primary distribution and the secondary distribution [1, 5]. The primary video distribution providers are responsible for the transport of video content from the production entity to the secondary distribution entity for ultimate transmission to end users. Primary distribution services are normally using compressed video formats, e.g., MPEG-2 or MPEG-4 or JPEG 2000. The secondary video distribution providers manage the transport of video content from the primary video distribution providers to the end consumers. Examples of secondary distribution services are IPTV, cable TV, and video streaming. Secondary distribution services are normally compressed with MPEG-2 or MPEG-4 standards, with rates of, e.g., 2–4 Mbps for Standard Definition (SD) systems and 8–20 Mbps for high-definition (HD) systems. The distribution configurations can be of type one to one (unicast) and one to many (multicast).

Basic operations done on the video signals along the video distribution chain are video coding and compression, encapsulation, transmission, reception and decapsulation, forward error correction, and decompression. Similar to other categories of service provider networks, video over IP distribution systems are expected to provide services with a good mix of simplicity, scalability, security, manageability and cost-effectiveness. Service-level agreement (SLA) requirements for video are used for parameters like network delay, network jitter, packet loss, availability, and loss recovery.

The requirements for the greening of IP-based video distribution networks further complicate the situation. One needs to take in this case a closer look at the component elements in the primary and secondary distribution networks and to analyze the greening mechanisms used in particular cases. The major components are the access networks (with different categories of technologies of type wired and wireless), core networks, Data Centers (DCs), and storage networks used to provide Web-based services like IPTV, content distribution, and cloud-based services.

1.2.2 Video Distribution Networks

Video distribution networks are distribution networks typically deployed on top of Content Distribution Networks (CDN) and the so-called low-layer networks (Fig. 1.1). These networks are defined to be IP-based networks managed to provide the levels of service and experience, security, interactivity, and reliability as requested by multimedia services like TV, video, and audio [5].

Today, the general practice is to cache the content in major metro areas, with the help of which the performance variability introduced by the Internet transport or core peering relationships is reduced or even eliminated. Beyond the metro delivery to gateway points, the video is delivered to customers on the access networks. Also, the broadcast channels are typically distributed via satellite.

Another important element at video networks is regarding the video distribution in the network. There are two main categories of video distribution systems, which are using the Internet Protocol TV (IPTV) services or using the Over-The-Top (OTT) services [5].

A video streaming network is composed of various components in the form of hardware, software, and network entities. Examples of hardware are headend, routers, switches, and WiFi access points. The software and the network entities are related to the ways used for accomplishing the video streaming from the source side (e.g., headend) to the destination side (e.g., a mobile terminal). Important elements used in this case are video encoding/decoding algorithms, routing algorithms, edge cloud, and software-defined network (SDN).

The diversity of video streaming network solutions and components indicates the complexity existent in the design and development of optimization solutions for these networks. To alleviate such complexity, a high-level architecture model is used as indicated in Fig. 1.1.

As observed in this figure, the high-level architecture is composed of four different layers and a middleware entity used to control things:

- Applications (App)
- Video Distribution Network (VDN)
- Content Distribution Network (CDN)
- Low-layer network (LLN)
- Middleware

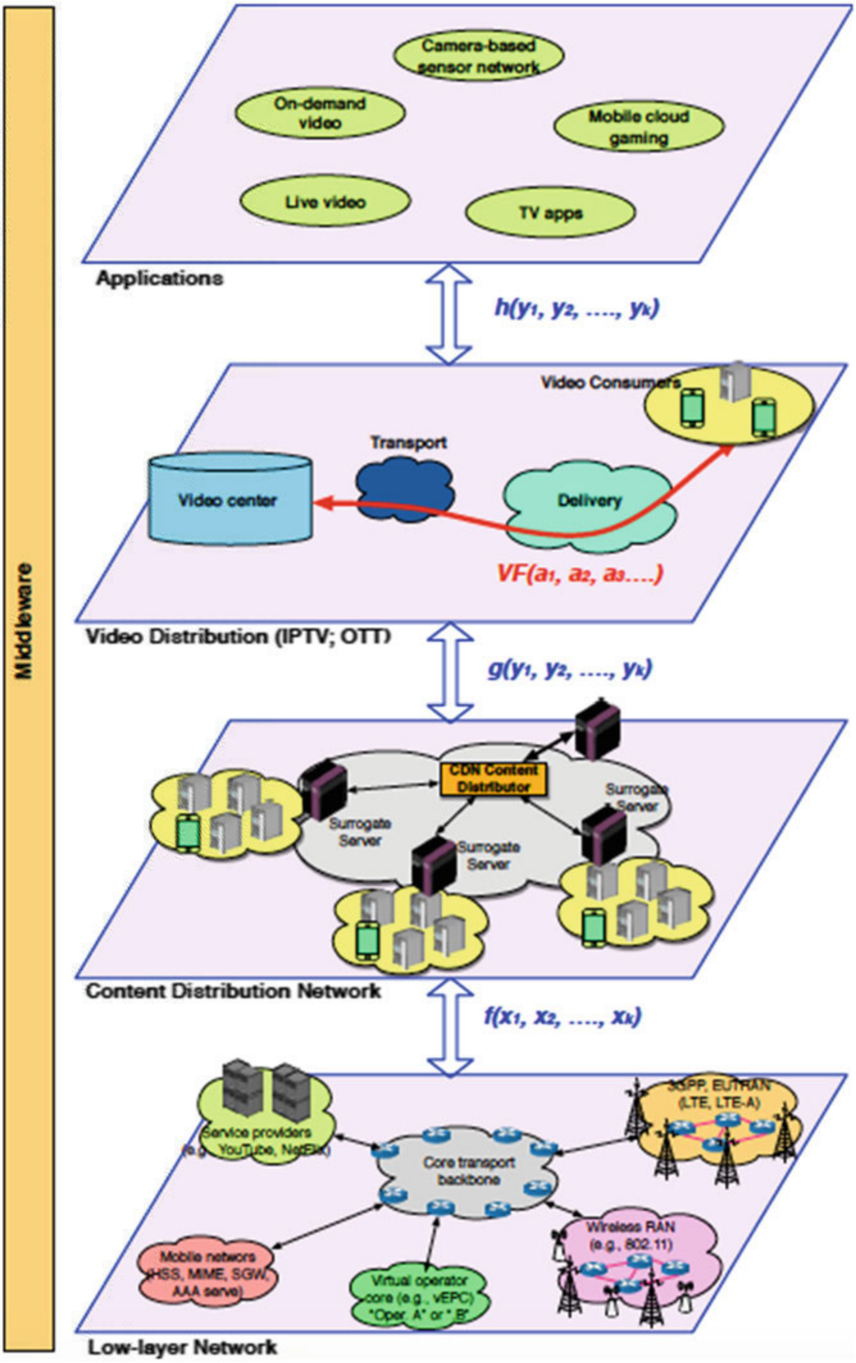

Fig. 1.1 Video distribution networks high-level architecture

As observed in Fig. 1.1, the main characteristics of video distribution networks are diversity and complexity.

A more detailed description of these layers is as follows.

1.2.3 Low-Layer Network

The so-called low-layer network (LLN) refers to L1 (Physical layer), L2 (Data link layer) and L3 (Network layer) in the TCP/IP protocol stack.

Different categories of media and communication systems can be used at low-layer like, e.g., Ethernet, WiFi, coaxial cable, power lines, fiber optics as well as different wireless communications and configurations like WLAN (IEEE 802.11), WPAN (IEEE 802.15), and LR-WPAN (IEEE 802.15.4).

Based on these technologies, different home automation and entertainment services can be offered like Netflix and YouTube.

The most popular architectures are

- Non-cloud-based architecture
- Edge cloud based architecture, and
- Software-defined networking/network function virtualization (SDN/NFV) architecture

Short description of these architectures is as follows.

1.2.3.1 Non-cloud-Based Architecture

The main elements of this architecture (Fig. 1.2) are the video encoding/transcoding entity together with adaptive bit streaming, core/metropolitan networks, routing protocols, fixed and mobile terminals.

Minimizing the energy consumption in this architecture means that the energy is minimized for each individual networking element, typically without giving consideration to other networking elements. Furthermore, transversal solutions can be considered as well like, e.g., software best practices and eco-design.

1.2.3.2 Edge Cloud Based Architecture

The edge cloud based architecture is an architecture, where instead of using a cloud infrastructure at remote, core-deep locations, several small clouds are used at the network edge in partnership with the edge Internet Service Providers (ISPs), as shown in Fig. 1.3. By doing so, the intelligence is shifted away from the network core toward the network edge, also combined with facilities for storage and other

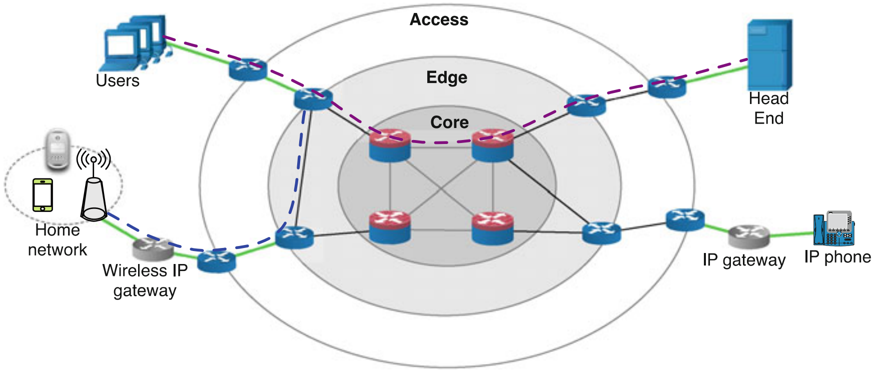

Fig. 1.2 Non-cloud-based architecture

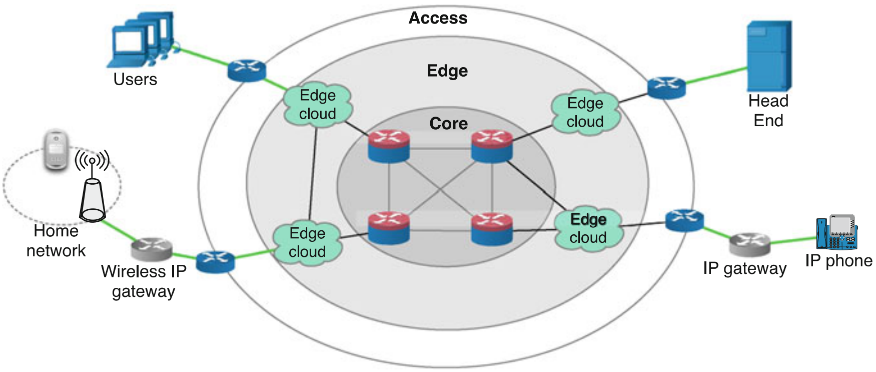

Fig. 1.3 Edge cloud based architecture

functionalities. Important advantages are in the form of offloading energy-intensive operations in access networks, headend, and terminals like, e.g., encoding/transcoding video content, 2D/3D graphical computation, and radio communication in base stations (BSs).

Basically, this architecture is a distributed cloud system complemented with a central cloud to provide services like failback and centralized infrastructure-as-a-service (IaaS) facilities. The distributed cloud system can be used for offloading complex and high energy consuming terminal operations like displaying and communication with the server. The model can be also used as a platform for CDN-like functionality.

Using edge cloud facilities solves several networking limitations like offloading energy-intensive operations in access networks, headend, and terminals. The drawback is because of additional communication needed between terminals and edge cloud, particularly when the communication occurs frequently. This problem can however be solved by finding out appropriated trade-offs among involved parameters [6].

For instance, video transcoding and media processing in edge clouds are an interesting alternative to processing in the central headend multiple streams at different qualities and bit rates, such as to cope with the variety of terminals and the varying QoS in the networks, as it is done today with an Adaptive Bit Rate (ABR) approach. The headend produces in this case a single high-quality stream, which can be further transcoded "on the fly" in the edge cloud. This provides the advantage of less traffic load in the network combined with good stream quality offered to end users. The drawback in this case is because of additional communication introduced between terminals and edge cloud.

Edge computing makes it possible to increase the quality of services by using the so-called context adaptation, which is a way of profiling within a local context, without compromising the privacy. Today, there is a lot of work on this, known under different denominations like, e.g., cloud computing, edge computing, fog computing, and mobile edge computing [7]. The main question in this case is about the best management system for edge resources such as to provide best performance for end users combined with minimum energy consumption. Parameters like resource type and use combined with the particular objectives are considered in this case.

1.2.3.3 SDN/NFV Based Architecture

Software-Defined Networking (SDN) and the associated Network Function Virtualization (NFV) are basically a new networking paradigm where the control and the forwarding data planes in the network are separated. Connected with this, the OpenFlow technology is suggested to standardize the way a controller communicates with network devices [8].

Basically, SDN separates the networking functions into two groups, the data plane (responsible for data forwarding, based on local decisions) and the control plane (responsible for centralized decision-making algorithms that determine optimal paths for data packets). SDN is focused on optimizing the transport of data and programmability facilities used to centrally control traffic flows, to partition the networks as well as to provide application-level QoS. On the other hand, NFV focuses on implementing network functions in software, to support multi-versions and multi-tenancy, to deploy provisioning and control network functions, and to virtualize and streamline the network function deployment. SDN and NFV are combined to create flexible networks, and they are not dependent on each other. SDN allows programmability of the NFV infrastructure to support development and deployment of network functions whereas NFV allows decoupled network capacity and functionality to create network functions that can be dynamically created and deployed.

It is important to distinguish between NFV and network virtualization. NFV focuses on virtualizing traditional network services into entities referred to as virtual network functions (VNFs) and mandates the use of off-the-shell commodity servers and switches. Network virtualization is used to implement logical networks decoupled from the underlying hardware, which provides a new level of flexibility and agility in network management. One can consider NFV as an approach to build up complex network services by chaining VNFs, where network virtualization provides the means to interconnect the VNFs in an optimal way.

Virtualization also applies to video encoding/transcoding. By this, the hardware resources are adapted in a flexible way to encoding/transcoding requests, especially when these resources are in the edge or for live events where picks of connection to video services are experienced.

NFV is used to transform the existing network functions or services into software applications, to consolidate them and to run them on virtual machines based on commercial off-the-shelf hardware. NFV requires carrier-specific virtualization software with high performance on real-time, scalability, reliability, and availability. The problem is that this demands for large investments.

It must be also emphasized that OpenStack and SDN/NFV are not competing solutions, but rather complement each other. OpenStack focuses on cloud orchestration, where the network is just a part of the platform's set of features. This approach is suitable for service providers offering computation and storage services. SDN/NFV aims to bring more flexibility in network management, efficient use of network resources, and target in particular network operators. OpenStack is now able to support OpenFlow and SDN (through the OpenDaylight project [9]) as plug-ins to its network-as-a-service module.

The SDN/NFV architecture provides several advantages like centralized control over the network, quicker network configuration, decoupling of the system that makes decisions from the underlying system that forwards the traffic as well as openings for energy savings in the network. By providing programmability on traffic and devices, increased flexibility and efficiency can be obtained, also with regard to energy savings in the network. Energy saving is particularly relevant for optical fiber networks, which are typically used with Multiprotocol Label Switching (MPLS). By using SDN in a MPLS environment, the complexity of the dynamic control plane is reduced, allowing thus for flexible service creation [8]. For instance, today different control mechanisms are used for operations regarding to find available paths, to reserve bandwidths, to monitor paths, and to maintain guarantees like, e.g., Open Shortest Path Forward Traffic Engineering (OSPF-TE), Reservation Protocol Traffic Engineering (RSVP-TE), Internal Boarder Gateway Protocol (I-BGP), and MultiProtocol Boarder Gateway Protocol (MP-BGP). The routers are requested in this case to provide sufficient CPU capacity and memory to support these protocols, and this is against the well-known end-to-end (e2e) principle used in Internet. On the other hand, the use of SDN and OpenFlow controllers eliminates the need for this. The consequence is also that the applications interfacing to the controller implement the functions provided by the router resident protocol code. The energy requirements are therefore reduced due to lower need for memory and computing capacity, combined with less frequent updates [8].

While the application of SDN to wired/optical scenarios is already becoming a reality, things are more difficult in the case of wireless networks. This is especially because of the large diversity of wireless technologies existing today. Figure 1.4 shows an example of SDN/NFV-based architecture of a mobile network operator, where a dashed line indicates a control plane connection and a solid line indicates a user plane connection [10]. As shown in this example, a mobile telecom operator may own and manage one or more heterogeneous Radio Access Networks (RANs), all of them connected to a common core network. Wireless backhaul networks may be involved as well to connect the base stations (BSs) to a core network. Access and/or core network component elements are enhanced in SDN/NFV with programmability facilities to support multiple functionality levels. For instance, L2 switches and L3 routers can become programmable. Also, multiple operators might physically share the transport core network, the backhaul, or the radio part. Key interfaces are in this case the so-called northbound interface (to virtual operators as well as to service and application providers) and the southbound interface (to physical user plane network entities in the core transport backbone, to physical user plane entities in the RAN as well as to mobile nodes) [11]. It is also important to mention that, besides architectures that assume persistent connectivity to cloud or to edge cloud, ad hoc mobile clouds can be developed as well. These are architectures where the neighboring mobile devices are pooled together for resource sharing.

It is also observed (in Fig. 1.4) the presence of Home Networks (HM). These are particular networks that facilitate communication and interoperability among devices present inside or close to a home. These networks are provided with increased functionalities to provide facilities for interaction and to increase so the quality of life at home. Different categories of media can be used in this case like, e.g., Ethernet, WiFi, coaxial cable, power lines, fiber optics (e.g., fiber-to-the-home

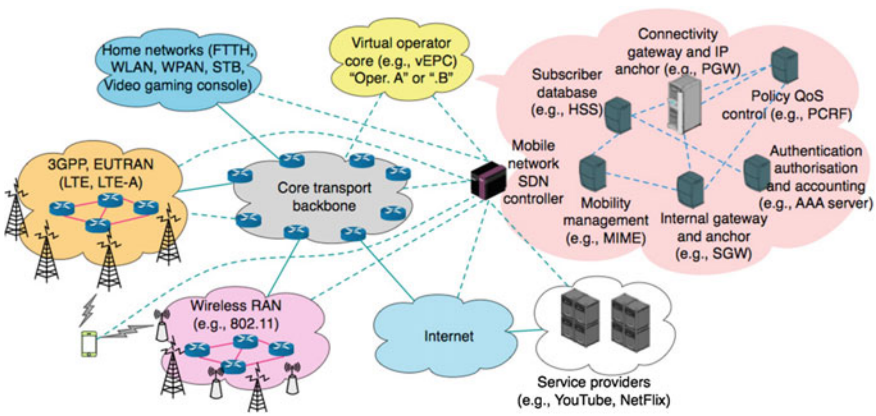

Fig. 1.4 SDN/NFV based network

(FTTH)). Wireless configurations like WLAN (IEEE 802.11), WPAN (IEEE 802.15), and LR-WPAN (IEEE 802.15.4) can be used in the home environment. Based on this, home automation and entertainment services can be offered like, e.g., Netflix and YouTube.

Another important element that must be considered is the so-called *sliced networks*, which is about sharing the network resources among multiple providers. Typically, a user creates in this case a so-called slice and delegates the control to a third party. Every slice is defined to be isolated from other users in terms of traffic, bandwidth, and control. Furthermore, the creation of slices is the requirement needed for opening the network control to more end users to innovate on the network at a time.

1.2.4 Content Distribution Network

On top of the low-layer network, there is the Content Distribution Network (CDN) layer. This is basically a large system of geographically distributed specialized cache servers deployed in different data centers across the Internet, combined with the use of a special routing code to redirect media requests to the closest server, as shown in the example in Fig. 1.5 [11].

CDN is a networking solution where high-layer network intelligence is used to improve the performance in delivering Web and media content over the Internet. An appropriated software architecture is used for this. The main functional elements of CDN are content distribution, request routing, content routing, content processing, authorization, authentication, and accounting. With regard to content delivery, there are three main techniques: HTTP redirection, IP redirection, and DNS redirection (most effective, but need for using DNSSEC) [5].

Furthermore, there are two main categories of content distribution networks, which are based on the way the content is delivered to end user. These are the cache-based CDN and the peer-to-peer (P2P) *C*DN [5].

The cache-based CDN is advantageous for edge cloud architecture, whereas the peer-to-peer CDN solution uses overlay networks and associated routing for content distribution.

The fundamental concept of distributing the content to cache servers located close to end users results in better performance with reference to maximizing the bandwidth, minimizing the latency and jitter, and improved accessibility as well as better balance between the cost for content providers and the QoE for customers. The benefits of using CDN are substantial to Web users, content and application owners as well as network to service providers.

An important issue is to investigate the energy consumption and savings for two distinct cases regarding Data Centers (DCs). These are the case of locating DCs close to end users, which minimizes the transport energy requirements, and the case with centralized DCs, which minimizes the storage energy requirements.