Video Delivery over Next Generation Cellular Networks

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***Abstract*—The rapidly increasing use of mobile devices, such as smart phones and tablets, as well as the high popularity of mobile applications and especially video streaming incur an increasing traffic demand on mobile cellular systems. The cloud computing and the software defined networking (SDN) paradigms constitute suitable tools for mobile networks to efficiently handle the increasing video traffic. In this paper, we focus on content and, in particular, video delivery services on top of emerging and next generation cellular networks which employ SDN in their core, mainly from a business standpoint. We analyze the stakeholders and their business interests and relationships, also providing a value network and business model analysis for both existing and emerging use cases of interest.**

Keywords—Content delivery; Video; Software defined networks; Cloud computing; LTE; Business models

I. INTRODUCTION

The increasing use of mobile devices, such as smart phones and tablets, has been phenomenal the last years, resulting at an extremely competitive market for mobile connectivity and services. At the same time, the increasing user demand for services puts an increasing traffic demand on mobile cellular systems [1], is mostly due to the increasing demand for infotainment services and in particular video. According to multiple studies, the majority of data traffic comprises of video of typically short duration [3], [4], [5]. Video traffic will continue to grow heavily, especially on mobile devices. In particular, mobile data traffic caused by Netflix has doubled during the past 12 months in North America [1]. Also, 69% of global consumer Internet traffic, i.e. traffic generated by consumer and not business broadband connections, is expected to be Internet video in 2017 [2].

Consumer usage behavior and technology utilization trends are also changing. In [2], the global mobile data traffic is forecasted to be 13 times more in 2017 than in 2012. In addition, an increasing amount of traffic is delivered through content delivery networks (CDNs), especially video content, while CDNs are estimated to carry almost two-thirds of all video traffic in 2017. Business-wise, actors creating mobile terminals (e.g. Apple, Samsung) and platforms/ecosystems (e.g. Apple Store for iOS or Google's Play Store for Android), or video services (e.g. Google's YouTube) attain high profits. This is in sharp contrast to network operators, whose profits are constantly eroding, while facing increasing network investments and operational costs in order to cope with the increasing video traffic [6], [7].

On the other hand, cellular systems are currently highly centralized and not optimized for such high-volume and bandwidth-intensive applications like video streaming and gaming, which are expected to be dominant in LTE (Long Term Evolution) and other 4G (4^{th} generation) cellular technologies. Mobile network operators (MNOs) typically use centralized network architectures that lead to long communication paths between end-users and servers, waste of network resources and increased delays [8]. Distributed mobile network architectures are needed to avoid bottlenecks, to utilize available resources in a more efficient manner, and to

This work has been performed partially in the framework of the EU ICT Project SmartenIT (FP7-2012-ICT-317846) and Celtic Project SIGMONA (CP2012/2-5).

improve end-users' quality of experience (QoE). The cloud computing model and, especially, software defined networking (SDN) can be applied in such mobile cellular systems to solve this issue by offering decentralized computing, flexible storage, and on-demand, elastic, pay-as-you-go services to third party operators and end-users, which can serve as a cost effective way of supporting video services.

In this paper we focus on content and, in particular, video delivery services on top of emerging and next generation cellular networks where virtualisation of the mobile core network is employed by use of new concepts such SDN, mainly from a business standpoint. This is motivated and justified by the increasing importance of video delivery services in terms of revenue and traffic growth. In Section II, we discuss the related technical and traffic engineering (TE) issues and in Section III, we overview the related work. Then, in Section IV, we present the stakeholders and briefly overview the methodologies adapted for the analysis done in Section V of video delivery over next generation cellular networks; the latter includes the business interests and relationships of the stakeholders, also providing value network and business models analysis for both existing and emerging use cases of interest. Finally, in Section VI, we summarize our findings and provide some concluding remarks.

II. NEXT GENERATION CELLULAR NETWORKS

Networks rely on the quality of the services they provide, and thus require a fine degree of traffic management and optimum use of network resources to enhance their competitiveness and ensure their cost-efficient operation.

This can be achieved with the help of SDN. SDN is expected to be the key enabler in developing telecommunication infrastructure for the growing needs of the mobile networks. SDN is a networking paradigm in which the control plane is decoupled from the data plane (and therefore vendor-specific hardware), and it is assigned to a software application named controller.

The feature of SDN (e.g. via a well-defined API such as OpenFlow [9]) regarding simplifying routers and switches by moving the control plane to a centralized or distributed server(s) should: i) improve data throughput via simplifying switches' functionality and ii) reduce congestion via traffic management and optimized resource allocation applied by the controller. The SDN technology will allow enabling a set of new usage scenarios in mobile networks as follows:

- Segregation of traffic flows individually to share available resources supporting various Mobile Virtual Network Operators (MVNOs),
- Optimal redirection of flows to video servers closer to the end-users and dynamic load balancing,
- Efficient management and usage of resources; in particular, dynamic re-allocation of flows to free some routers and switch them off for energy optimization.

Mobile networks consist of physical and logical layers [10]. The physical layer is formed by network switches (L2), routers (L3) and physical links employing different topologies and technologies. The logical layer consists of network elements (e.g. eNodeB, Mobility Management Entity (MME), Serving/ Packet GW (S/P-GW), Home Subscriber Server (HSS), etc.) that perform the attachment, mobility and transport of data from mobile devices across the mobile network. The physical layers (L2 and L3) provide the required connectivity and transport functionality to the logical layers that implement the mobile specific control plane.

The integration of SDN with LTE network elements either as part of MME or as part of S/P-GW will allow keeping current IP based networks and include SDN-based flexibility. The SDN-based switches will improve the LTE network architecture to support video delivery by dynamically optimizing routing to access video streaming servers. Fig. 1 describes the scenario where an SDN controller is integrated with MME to dynamically change the routing based on end-user's mobility. In addition, SDN can improve caching after dynamically changing policies based on end-user's location and traffic congestion.

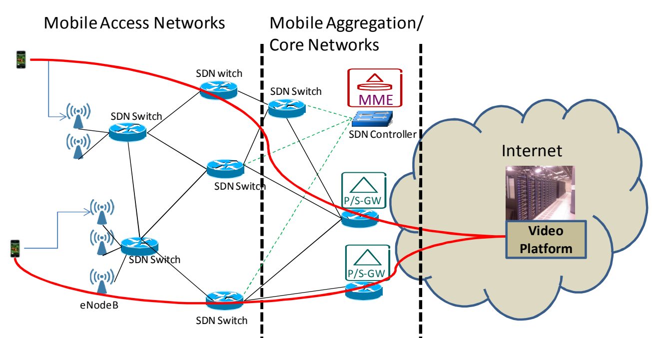

Fig. 1. Integration of SDN with MME for optimal video streaming.

As shown in Fig. 1, the SDN controller has complete visibility of the traffic and topology of the network. Therefore, the SDN controller can dynamically decide most suitable routes and select proper S/P-GW as the point of attachment to public Internet for accessing the video streaming servers. The LTE architecture already separates control from data plane which facilitates the virtualization of network elements and integration with SDN. The MME manages the mobile attachment, registration and handover control procedures together with the eNodeB. The S/P-GW manages the data plane through tunneling from the eNodeB after the MME indicates to the S/P-GW that the mobile has completed the attachment and registration. Therefore, to avoid cross traffic the LTE control plane i.e. MME should be integrated with the SDN controller. This allows the MME to have full visibility of the SDN switches through the controller and apply the proper policies regardless whether the MME is virtualized and moved to different locations. Moreover, the controller can perform load balancing over the P/S-GW to optimize the access to public Internet from the mobile network. The controller can select the optimal route when end-user moves to avoid congested paths and provide better quality of service (QoS). In addition to optimal routing, SDN promises optimal content access based on in-network caching management to concentrate the traffic in certain location, thus reducing overall mobile network congestion.

III. Related Work

In a mobile network, a video application can be realized through different paths through core and access networks, which can influence the end-user's QoE, because of the lossy nature of the wireless channel [11] and the available rate for video delivery [12]. Nevertheless, the acceleration of mobile video is crucial for operators as delay significantly influences QoE of the subscribers in mobile networks. Many solutions have been proposed to reduce content delivery latency and enhance subscribers' QoE in mobile networks. For instance, in [13], the focus is on wireless performance analysis for 3G, 4G, and WLAN while taking into account video coding and efficient placement of video servers.

In [14], a comprehensive survey of most relevant research activities for content delivery acceleration in mobile networks has been presented. In [15] an optimization framework to achieve the best video performance considering QoE has been proposed. This framework combines three different approaches that can act simultaneously, i.e. path selection, traffic management and frame filtering. Alternatively, mobile CDN can enable the optimization of the content delivery to end-users on any type of wireless or mobile network. For example, [16] proposed a mobile streaming media CDN (MSMCDN) as a network overlay to the mobile infrastructure for video delivery over a time-varying channel. In addition, the MEDIEVAL project [17] developed an intelligent video aware mobile network architecture that implements CDNs to increase end-users' QoE for video services. The proposed solution integrates the CDN with mobility management and a cross-layer optimization entity.

Other studies focus on cross-layer, application-aware, or QoE-aware content delivery, such as the video pacing scheme proposed in [18]. In turn, network resource allocation framework considering the mean opinion score has been proposed in [19]. Another approach described in [20] proposes an adaptive streaming algorithm for 3GPP networks to improve QoS in varying network conditions by means of changing the media rate. Such adaptation depends on the available codec profiles and associated coding bit rates. The deployment of mobile CDN serving point nodes in a mobile CDN infrastructure is motivated in [21] by listing benefits for a mobile network operator who wishes to employ a mobile CDN system in their existing mobile network architecture.

Existing cellular networks suffer from inflexible and expensive equipment, and complex control plane protocols. In [22], authors argue that SDN can simplify the design and management of cellular data networks and inter-operation with other wireless network technologies and other operator networks, while enabling new services. The paper presents also some new challenges that future SDN architectures should address in cellular environment, such as supporting many subscribers, frequent mobility, fine-grained measurement and control, and real-time adaptation of, e.g., video quality, based on cell tower congestion, device type, and the subscriber's service plan.

In [23], the OpenRadio idea is presented, that provides modular and declarative programming interfaces across the entire wireless stack. OpenRadio's programmable cellular data plane enables the network operator to program the network stack for traffic subsets by specifying packet processing behavior expected from the network for different traffic classes. The similar idea called SoftCell has been presented in [24]. The architecture supports fine-grained policies for mobile devices in cellular core networks. The SoftCell controller realizes high-level service polices by directing traffic over paths that traverse a sequence of middle-boxes, optimized to the network conditions and end-user locations.

Moreover, in [25], the integration of OpenFlow with LTE control plane is proposed. The authors advocate in favor of using the OpenFlow protocol for setting up GTP tunnels. Another approach, called OpenFlow Wireless [26] focuses on virtualizing data path and configuration.

Finally, a new architecture called C-RAN (Cloud Radio Access Network) has been proposed in [27]. The goal of the solution, endorsed by China Mobile and several industry stakeholders, is to provide low cost and high performance green network architecture to operators. The C-RAN architecture adopts core technologies, such as centralized baseband pool, collaborative radio and real-time cloud computing, to build a clean radio access network. In turn operators will be able to deliver rich wireless services in a cost-effective manner for all concerned. Authors argue that through enabling the smart breakout technology in C-RAN, the growing internet traffic from smart phones and other portable devices, can be offloaded from the core network of operators. The proposed solution reduces back-haul and core network traffic and latency to the end-users as well as differentiates service delivery quality for various applications.

IV. Stakeholders and Methodology

This section presents the stakeholders and the methodologies used for the analysis of video delivery over next generation cellular networks. These methodologies have been enriched and adapted to cover the present analysis needs.

A. Stakeholders

In today's Internet marketplace, the Internet service layer stakeholders are those providers that buy and sell Internet services, namely connectivity or network service providers (NSPs), information providers, and end-users. NSPs that offer connectivity on Layers 3 and below include: access network providers or edge NSPs, and transit NSPs. The information providers include cloud providers, CDNs, application service providers, content providers, Internet retailers and communication service provider, commonly referred to as over-the-top providers (OTTs) - and also market places.

On the other hand, the end-users may be classified as residential and business, while in the recent years, end-users have been seen to become also content producers by uploading to video platforms like YouTube home-made videos and other material, the so-called user-generated content (UGC). In our analysis below, we choose not to focus on this new role of the end-users though for simplicity.

A NSP (e.g. a Tier-1, 2, 3 network operator) would normally own its own network, and be responsible for the provisioning of its functionalities. An NSP having as customers solely end-users is referred to as an Edge NSP. In cellular networks an Edge NSP with own network infrastructure is also called a Mobile Network Operator (MNO), while a wireless communication service provider not owning wireless network infrastructure, but instead leasing it from an MNO is named Mobile Virtual Network Operator (MVNO). A NSP selling wholesale Internet connectivity to other NSPs is commonly referred to as a Transit NSP.

Due to the erosion of NSPs' profit margins, the NSP and CDN business tend to converge, e.g. Level 3 in the US, although pure CDNs still exist, e.g. Akamai which is dominant in the CDN market. Nowadays, many NSPs deploy their own IPTV/video-on-demand (VoD) and CDN solutions, as an additional product offering, revenue source and a means of strengthening their presence in a highly competitive market.

Nevertheless, the roles of these stakeholders might change with the introduction of a new technology such as SDN in the considered scenarios, as discussed in Section V.B.3).

B. *Methodologies*

1) *Industry Architecture Notation*

The role configurations and the actors that control the critical roles as well as their interactions can be illustrated with the industry architecture notation shown in Fig. 2. The notation takes into consideration the technical architecture and functionalities, which defines the roles that actors control. Each actor can control several roles, but the responsibility of each role cannot be divided between the actors. The value of the notation lies in the ability to have several role-actor configurations for the same technical architecture. For a detailed description of the methodology, please refer to [28].

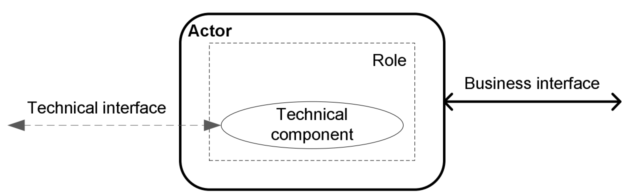

Fig. 2. Notation for industry architecture.

2) *Business Model Framework*

Business modeling provides the required understanding of the way the business entities transform their input to monetizable output; thus, elaborating on how business is conducted and instantiating the actors' interactions in the market. In this paper, we use an **adaptation** of the business model framework of [29], encompassing the key strategic choices an actor can make. In the adapted framework, key strategic choices are mapped to a set of key variables, for each of which a value range is defined. Note that the key variables and value ranges used in our study are based on those of [29] but are not identical to them so as to serve this analysis needs. These variables are grouped in 3 areas:

- *Value Proposition*: what is offered in the market to whom and via what resources
- *Value Network*: decisions on key partners and level of integration in the value network
- *Financial Configuration*: revenue and cost streams

This methodology is applied in Section V for the business modeling of video delivery over cellular networks. The reader may refer to [30] for additional information on the business model framework.

V. Video Delivery over Next Generation Cellular Networks

This section presents the basic scenario for video delivery over cellular networks and use cases of interest, providing the value network configurations and business models depicting the actors' interaction on the business and technology layers.

A. *Scenario definition*

As already mentioned, our basic scenario is video delivery and, specifically, VoD over next generation cellular networks. In this scenario, end-users utilize the VoD service at the retail market, which is mapped to the session layer in terms of traffic. The content consumed in the retail market is made available via business agreements in the wholesale market, i.e. among the cellular Edge NSP (MNO or MVNO) and the Content Provider or a CDN, possibly with the intermediation of some Transit NSP.

The content can be either on-net, i.e. provided by the Edge NSP itself, or off-net, i.e. outside the Edge NSP, while additional stakeholders are involved in the value chain and service composition process for its efficient delivery to the end-users of the cellular Edge NSP. These issues are investigated in the remainder of this section by means of distinguishing a basic use case focusing initially on the on-net VoD market and an additional one depicting the additional complex interactions required when (at least some part of) the content is off-net. This separation allows a better understanding of the business interactions on two complementary parts of the value chain, i.e. from the Edge NSP to the end-user and from the content origin to the Edge NSP respectively.

1) *Use case: On-net Video on Demand*

VoD service over a (virtualized) LTE network is illustrated in Fig. 3 with the right part depicting the on-net video traffic.

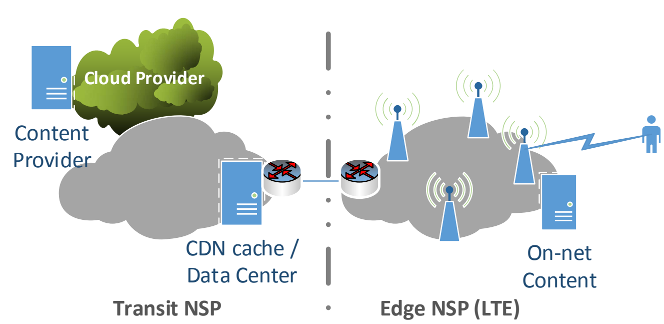

Fig. 3. Video-on-Demand delivery over an LTE cellular network.

Its respective analysis in terms of business and technology interactions is provided in Fig. 4: The Edge NSP offers its own video service that the end-users can request on an on-demand basis. The content is stored in the Edge NSP's video platform and the Edge NSP controls the access to the video service through end-user subscriptions, i.e. SIM cards. The content ownership is omitted from the figure for simplicity; however, the content can be produced by a third party content provider or by the NSP itself. The Edge NSP may also utilize caching for better performance and QoE for the end-users.

For full Internet connectivity, the Edge NSP buys network capacity from the Transit NSP, which is separated into the hardware component and the control component by a network virtualizer. The access network can also be virtualized and the radio resource allocator can be controlled by a MVNO. However, in this work, the Edge NSP is defined to include both the MNO and the MNVO variants, since this distinction has limited impact on the VoD service; indeed, typically MVNOs lease a part of the MNO's radio access network (RAN) and probably some support functionality (e.g. accounting) via static wholesale agreements acquiring a fraction of the MNO's RAN frequencies.

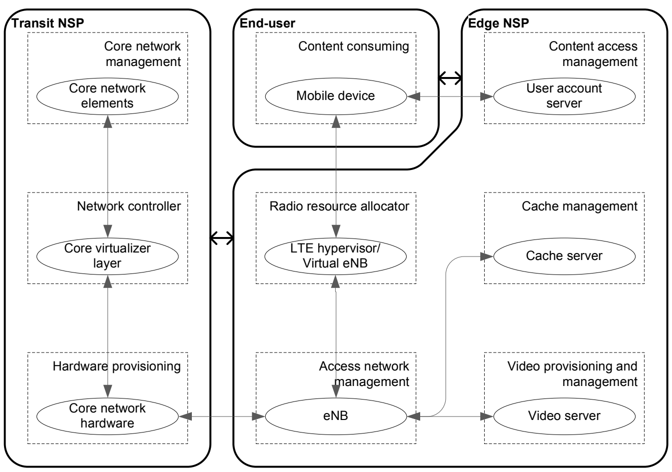

Fig. 4. On-net Video-on-Demand use case.

2) Use case: Off-net Video on Demand

A similar use case of VoD service over an LTE network is illustrated in Fig. 5, where the video delivery is performed off-net, i.e. hosted outside the domain of the cellular Edge NSP. This use case requires one additional actor in the value chain, who is either a) a CDN (e.g. Akamai, Google), as is the typical present case, or b) a cloud operator providing IaaS or PaaS to content providers. Again, the actor/role of content ownership and provisioning are omitted for simplicity.

Note that the new entity may also represent multiple instances of CDNs or Clouds, such that interactions and business agreements can be assumed also between them. For instance, a federation of cloud operators, an emerging market trend, or CDNs can be considered in this case. Thus, this use case is compatible to the recent developments in the front of CDNi (CDN interconnection) [31], where multiple typically small CDNs collaborate to aggregate content and form a federation which essentially serves as a large virtual CDN, capable of attracting demand from large content providers.

In this use case, a sufficiently large Edge NSP could establish a direct peering link with the CDN or cloud provider, so as to serve that CDN/cloud's content over a dedicated link of controllable QoS characteristics, possibly bypassing congested parts of the Internet, to reach the end-users of the Edge NSP. The efficient provisioning of the service to the end-users requires business coordination at the wholesale market among the aforementioned stakeholders, which are responsible for a part of the end-to-end service composition process.

This implies the presence of wholesale business agreements and Service Level Agreements (SLAs) with the typical model of bilateral cascading agreements: an SLA defines the performance for a fraction of the end-to-end service, e.g. between the content provider and the cloud provider; such a SLA would then be integrated by the next stakeholder in the chain (i.e. the Transit NSP) to his own product offering (to the Edge NSP) so as to construct the end-to-end service with acceptable QoE for the end-user. This model has the advantage of simplicity in delegation of responsibility and limited accounting overhead for the involved parties.

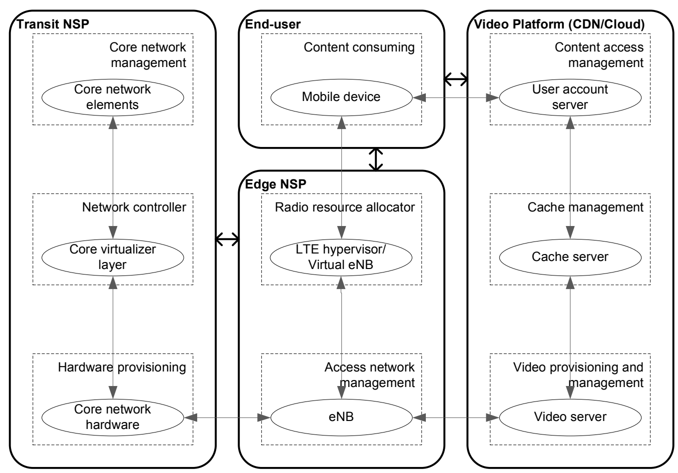

Fig. 5. Off-net Video-on-Demand use case.

B. *Value Networks, Revenue flows and Business Models (MD)*

We now proceed to apply the reference framework to the paper's basic service scenario prescribing that the Edge NSP wants to deliver VoD services. Our focus is on the business interactions, the market power and competition issues, as well as on the impact of the SDN paradigm on the market. We can realistically assume that the content is owned by a content provider (e.g. a studio), who is accessible either directly or via the intermediation of a CDN, such as Akamai, a cloud or even a data center federation that has been delegated the responsibility of pushing the content provider's content close to the Edge NSPs, and thus, the end-users.

We begin our analysis with the first area, the **Value Proposition**, and we apply its basic parameters to this market.

Product/Service Delivered: Custom TE products at the wholesale level (among NSPs and OTTs) support premium transfer of (video) content from the content server to the end-user, who can be possibly paying at the retail level his serving NSP in order to watch premium content at high quality. In particular, the aforementioned network connectivity products are provided by the Edge NSP(s) via TE to ensure that he can deliver the desired quality via smart traffic engineering in their network (wholesale level). This might entice large content providers to purchase these dedicated network paths so as to increase the consumption of the content by the end-users (or alternative subsidize via advertisements). Thus, at the retail level, we can envision micropayments coming from the end-user's session layer, e.g., via subscription for the content purchased.

Target Customer: The NSP's target customer is the content provider or CDN, who is providing premium quality services to end-users (e.g. via some portal, where end-users subscribe). This could include, e.g., studios owning movies, who may wish to provide their services on top of the network as a cost-effective means compared to other alternatives.

Customer Value: Quality guarantees on video service. This renders the service a valuable market good of high quality, increasing its market potential and value in the market.

Resources and Competencies: The NSPs and other stakeholders utilize their resources and competencies in their core business, i.e. remain technology-oriented. The stakeholders do not necessarily invest in technology competencies and infrastructure to other domains; instead they design, implement and offer services that attempt to attract demand from other stakeholders whose main competency is in complementary service segments that as a whole support the end-to-end video delivery. The introduction of the SDN approach is expected to further intensify this trend by virtualizing and making available as a service the requited market segments, while stakeholders invest in their core business so as to remain competitive in this emerging market of services.

Next, the **Value Network** theme parameters are provided.

Vertical Integration: It is likely that NSPs perform vertical integration by aggregating the roles of CDN, Transit NSP and even possible Edge NSP. This could be the case for substantially large NSPs. Vertical integration is a good way to strengthen market position and exploit existing business ties in one market to push complementary products in complementary relevant markets. The virtualization that SDN brings can further intensify this trend, allowing stakeholders, whose core business is not that of networks (e.g. hypergiants, such as Google, or federations of data centers/CDNs), to control the end-to-end quality that the end-users of their services experience, via purchasing the right to reach the end-users with certain quality, defined in a SLA.

Customer Ownership and Relationship: There is some initial end-user interaction with some content web portal/server in order to trigger the video delivery. This portal creates an intermediated relationship and indirect revenue flows across the infrastructure and Internet service layer, i.e. the layer of wholesale basic infrastructure and that of high-level services that end-users are aware of. Wholesale agreements are bilateral and exploit existing business relationships. The SDN paradigm may further enforce the market position of large content providers, whose profits are constantly increasing as opposed to those of NSPs, further commoditizing the bit transfer market, even over the cellular infrastructure.

Interconnection Modality-Business Agreements: End-users may have a contract with the CDN/content provider (e.g. NetFlix or Disney portal) for the services it provides. This can be a long-term contract (e.g. monthly fee for being able to stream certain number of movies per day) or on-demand. For the agreements among the NSPs and CDNs involved in the service provisioning, wholesale transit-like agreements are envisioned.

Content-Data Delivery Model: The CDN model is the dominant one, which can be emulated also by a federation of interconnected Data Centers (or cloud providers). This is mostly due to the fact that the price dynamics of storage remain more cost effective than those of bandwidth, also combined with the higher multiplexing gains attained by caching: each bit cached in a CDN is reused resulting in bandwidth savings for the operators and QoE improvement for the end users. NSPs provide the required network infrastructure to connect the caches to the end-user in a way that the end-to-end customer QoE requirements are met.

Last, the parameters of the **Financial Configuration** theme are investigated.

Revenue model, revenue sharing, charging issues and money flows: The services can be subsidized by advertisement and also possibly paid per-view by the end-users who subscribe to those services e.g. via a VoD portal. This subscription could either be explicit (pay per-view case) or implicit (subscription is bundled in the end-user's contract paid by the end-user to his provider). For the management of the aggregate traffic flows, it is expected that the purchaser of the involved traffic contracts will have to compensate the involved networks (if any) for carrying this traffic on top of their network and reaching the end-users (the "eyeballs"). Thus, there are two distinct charging layers with separate/co-existing money flows: the aggregate level traffic charging at the network layer (NSP charging) and the per-session based charging at the application layer (end-user payments).

The current revenue model in the NSP world is that small networks (i.e. Edge NSPs) compensate upstream NSPs (i.e. Transit NSPs) for Internet connectivity. However large Edge NSPs, some of which are also active in the transit business, often succeed to attain some revenue from large content providers, e.g. Google, in order to guarantee high quality for certain services, e.g. YouTube. Those agreements are bilateral, typically confidential and implemented via private interconnection of the two parties and custom TE solutions in the Edge NSP network. The virtualization that the cloud and SDN paradigm bring may further intensify this trend, rendering the dynamic leasing and control of part of the Edge NSP resources a new product to be purchased by the Content and Application Service Providers.

It is, thus, important to note that the retail market (end-users paying for video) and wholesale market (among NSPs, CDNs) coexist and complement each other. The wholesale part of the market is not exposed to the end-user, who typically establishes a business relationship with the content owner (e.g. VoD portal) and the Edge NSP. The increased flexibility in the traffic management brought by the SDN paradigm may decrease the dependency of the core NSP and the end-user to an Edge NSP, possibly leading in the long term to an Edge-as-a-Service paradigm, where access to services will be purchased over a completely virtualized mobile access market, in extremis opaque to the end-user. This is a clear difference between the mobile and fixed edge network cases, as in the latter one usually there is only a single edge NSP owning the last mile (cooper or fibre) to the end-user.

In the case of federations of clouds and CDNs, some revenue sharing scheme must be decided by the involved parties. We envision that these federations will be highly specialized; addressing a specific target market and service (e.g. video delivery) and their operations will be regulated by common business policy rules that are unanimously approved by the federation members,. Well known mechanisms for revenue apportionment, such as Shapley values or even auction-based stock market-like mechanisms for the dynamic allocation of resources (e.g. storage and content), comprise potential candidate solutions.

Cost Model: The NSPs must invest to compete for the content-generated traffic; investments are expected to be individual, i.e. on a per-stakeholder basis, while federations and alliances, e.g. in the form of capacity and network deployment sharing, are also possible as complements. Also interconnection costs for the creation of new network routes and cache deployments may arise. The smart management of the traffic flows may also impede costs to the NSPs. A long-term agreement between the Edge NSP and the content provider (or CDN) is also likely, possibly complemented with a bandwidth-on-demand spot market for demand spikes. The cloud and SDN paradigms will allow increased awareness over the different costs over different parts of the network, thus, serving towards sustainable market prices and efficient serving of end-users' needs.

3) Discussion

The SDN-enabled separation of data plane from control plane allows streamlining of current IP network elements after removing the control logic. This can lead to price erosion in the long term, since after removing control logic/intelligence from current IP switches and routers the only solution to improve competitiveness is by increasing throughput based on new technologies. On the other hand, the current IP network element manufacturers (e.g. Cisco, Juniper) can start selling new products including inbuilt LTE and SDN functionality, while virtualization can result in significant cost gains.

The mobile network manufacturers might continue to deliver the full end-to-end system, acquiring the SDN based network equipment from IP network element vendors together with the control logic that now is separated into independent software components. This separation of the data and control logic can lead to new entrants that can easily focus on the production of mobile network elements and deliver those as software components that IP network element manufacturers can deliver with their products.

Therefore, the tight integration of data and control plane that current MNOs are delivering as a complete product is now decoupled. This leads to totally new business models, where both IP network elements and mobile network manufacturers might be reducing their operational margins that can be captured by new entrants. Concerning the new entrants, in addition to the independent software component vendors mentioned above, new players, such as data center providers (e.g. Google, Amazon, etc.), can take a more active role as service integrators. These new players can become network providers by acquiring and integrating the products from IP network elements and mobile network manufacturers.

In the previous sections we have elaborated on the business agreements, the potential business models and respective money flows. An existing market trend, also related to the on-going net neutrality debate, is that for the management of the aggregate traffic flows, it is expected that the purchaser of the involved traffic contracts will have to compensate the involved networks (if any) for carrying this traffic on top of their network and reaching the end-users (the "eyeballs"). This has to some extent been the case between same-sized networks, where asymmetry in the bilateral exchange of traffic leads to establishing paid peering relationships. The increasing demand for video delivery services over next generation cellular networks is likely to intensify this trend with the price serving as the proxy for the quality of the service (segment) purchased.

Furthermore, we foresee this trend also to the NSP-content provider market, due to the increasing "opening" of the networks whose usage is no longer limited to the operator that deployed the respective infrastructure; instead this traditional monolithic paradigm is increasingly replaced from that of network infrastructure as a service via virtualization and abstraction of network resources and functions.

The increased virtualization brought by the SDN paradigm may decrease the dependency of the end-user to an Edge NSP, possibly leading in the long term to an Edge-as-a-Service paradigm. In particular, access to services may soon be purchased over a completely virtualized mobile access market, in extremis on-demand on a per-session basis and the selection process may be automated and opaque to the end-user, thus further decoupling the network connectivity and services layer. To this end, alliances of the de-facto competing network and application service providers, whose scope may range from technical standardization, i.e. similar to the WiFi Alliance [32], to joint business, i.e. similar to the airline industry alliances, are also likely to emerge in an effort to achieve critical mass, cost reductions via increased resource usage, economies of scale, are also likely. Therefore, complex cooperative business agreements and horizontal or vertical integration market attempts are also likely to emerge in the coming years, further enriching the ecosystem business agreements and the resulting service offerings.

VI. SUMMARY AND CONCLUSIONS

We investigated the potential and impact of content and, in particular, video delivery services on top of emerging and next generation cellular networks that use cloud and SDN, from a business standpoint. This is motivated by the increasing importance of video delivery services in terms of revenue and traffic. We have studied the emerging market trends, business agreements, potential business models and money flows.

We argue that the next generation cellular networks promise a higher degree of virtualization, multiplexing, cost reduction, openness, competition and efficiency gains at the network layer. A prerequisite for this promise to be realized is to enforce the BEREC-supported principled of transparency and competition throughout the content delivery value chain. This will greatly contribute to the market competitiveness and the health of the ecosystem, enabling advanced content/video delivery of high quality and thus value for the users.

Additionally, considering the existing willingness to pay of users for content and applications (ranging from ringtones to gaming and video), it is expected to the enrichment of the ecosystem with new services and the diversification of existing business models in the video content delivery market, also highlighted in this paper. We believe that though we have focused on video delivery over next generation cellular networks in this qualitative analysis, much of the findings and conclusions drawn are applicable to a wider and richer set of services and markets, including gaming, rich communication services, and video conferencing.

ACKNOWLEDGMENT

The authors would like to thank all SIGMONA and SmartenIT partners for useful discussions on the subject of the paper.

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