Evolving Future Internet Clean-Slate Entity Title Architecture with Quality-Oriented Control Plane Extensions

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***Abstract*—Due to the technological evolution, growth and various new service demands requiring new solutions to support novel usage scenarios, current Internet has been confronted with new requirements in terms of network mobility, quality and scalability, among others. New Future Internet approaches targeting Information Centric Networking, such as the Entity Title Architecture (ETArch), provide new services and optimizations for these scenarios, using novel mechanisms leveraging the Software Defined Networking (SDN) concept. However, the current ETArch approach is equivalent to the best-effort capability of current Internet, which limits achieving reliable communications. In this work, we evolved ETArch with both quality-oriented mobility and resilience functions following the super-dimensioning paradigm to achieve advanced network resource allocation integrated with OpenFlow. The resulting framework, called Support of Mobile Sessions with High Transport Network Resource Demand (SMART), allows the network to semantically define the quality requirements of each session to drive network *Quality of Service* control seeking to keep best *Quality of Experience*. The results of the preliminary performance evaluation of SMART were analyzed using Mininet, showing that it allowed the support of mobile multimedia applications with high transport network resource and quality demand over time, as well as efficiently dealing with both mobility and resilience events.**

Keywords–Future Internet; SDN; ICN; QoS and QoE.

I. INTRODUCTION

The Internet is constantly evolving, motivated by its natural growth and by the introduction of new services and applications to fulfill emerging needs. New requirements are being placed over its architecture, such as mobility, security and scalable content distribution. To cope with this new set of requirements, several enhancements are being defined, increasing the complexity of the overall Internet architecture, with many core components reaching their limit, and hindering further evolutions [1]. In addition, the current Internet still cannot address many of today's and emerging requirements adequately, such as efficient transmission of content-oriented traffic and effective congestion control. As a result, clean-slate attempts are being carried out as the next step towards an efficient Future Internet approach.

Information Centric Networking (ICN) [2] is one of such proposed approaches focusing on content access and delivery beyond current host-to-host communications. Content has a more central role in the network operations, motivated by the need to meet data-intensive applications. This paradigm shift leverages in-networking caching and replication, improving efficiency, scalability and robustness.

However deploying ICN capable nodes into current networks would require the update or replacement of existing networking equipment and protocols. *Software Defined Networking* (SDN) [3] emerges as a promising solution to overcome this, since it could not only facilitate the deployment of ICN functionalities in current networks without requiring new clean-slate designs, but it could also improve and enhance current and future Internet network management mechanisms.

The *Entity Title Architecture* (ETArch) [4] is an emerging Future Internet clean-slate approach which shares the vision of content-oriented paradigms, where entities request content by subscribing to it, triggering the network to dynamically configure itself in order to provide the users with the intended content. The content is delivered trough a channel that gathers multiple communication entities, called *Workspace*, allowing communicating entities to express their requirements over time. Despite its innovative approach, ETArch does not consider reliable communications provisioning in its design, and omits important factors to determine the connection, such as the quality requirements of demanding applications and the level of quality of the network nodes. Thus, ETArch lacks quality-oriented mechanisms for establishing workspaces, which means that network control functions seriously restrict data dissemination over the best-effort transport model of the current Internet. Moreover, ETArch operates in a per-flow driven way, and it is well known that such signaling approach overloads the system performance with the increasing session-flow admissions, mainly in terms of signaling and processing overheads [5]. As a result, the entire system can reveal increasingly high latency (network processing) and bandwidth use (exceeding signaling), which may increase energy consumption levels while degrading users perception.

This way, it is evident that ETArch is unable to accommodate bandwidth-intensive mobile session flows (e.g., real-time multimedia) guaranteeing both *Quality of Service* (QoS) and *Quality of Experience* (QoE) over time, in terms of setting workspaces connections with limited delay, error and loss

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rates experience. This drawback seriously restricts the scope of ETArch in Future Internet scenarios, especially when is taken into account the fact that traffic forecasts predict that 80% of the total data flows will stream multimedia content by 2017 [6]. In view of this, the session setup control functions of ETArch must take into consideration quality parameters to guide quality-oriented sessions, specially real-time ones, where losses above 5% generally lead to very poor effective throughput [7]. This diversity of applications makes the current ETArch approach of offering the same "best-effort" service to all applications inadequate.

The limitations described above motivate our work in the sense that there is a need to extend the control plane of legacy ETArch with quality-oriented functions to improve the session admission mechanism. First of all, it is required to define the application session requirements that will semantically describe the quality demands that must be fulfilled over time, by defining the minimum quality requirements of each mobile session flow (bitrate, tolerance to packet delay/loss/error, etc.). We claim that adopting both QoS-connectivity over-estimated provisioning capabilities and QoS-oriented mobility would benefit ETArch system to establish personalized multiparty sessions while improving the system scalability. For this reason, this paper proposes a new network architecture, denoted as Support of Mobile Sessions with High Transport Network Resource Demand (SMART), which redesigns the legacy ETArch with advanced QoS and mobility control functions to accommodate bandwidth-intensive mobile sessions over truly reliable and robust communication channels, while optimizing the network control plane. The SMART approach will act as a communication service provider with the following main innovations: (i) clean-slate Future Internet network architecture with new addressing methods, group-based connectivity, QoS-oriented mobility and resilience controls; (ii) IEEE 802.21 compliant signaling approach to control device handover; (iii) over-provisioning paradigm based automated, systematic and dynamic network resource allocation integrated with OpenFlow; (iv) OpenFlow extensions to provide QoS support.

The results of the preliminary performance evaluation of SMART were analyzed using Mininet, demonstrating its superior benefits with regard to the original configuration in the network and user perspectives in terms of QoE and delay.

The remainder of the document is organized as follows: Section II presents the background for this work, highlighting not only the supporting technologies, but also other related approaches. Section III presents the proposed framework, evaluated in Section IV, where results of its implementation are presented. Finally, Section V presents some concluding remarks.

II. BACKGROUND

The Entity Title Architecture [4] is a clean-slate network architecture, distinguished over other Future Internet initiatives by its topology-independent naming, addressing and semantically driven designation scheme, that uniquely identifies each entity, and by the definition of a channel that gathers multiple communication entities, called *Workspace*. A key component of this architecture is the *Domain Title Service* (DTS), which deals with all network control-plane aspects. The DTS is composed of *Domain Title Service Agents* (DTSAs), which maintain information about entities registered in the domain and the workspaces that they are subscribed to, aiming to configure the network devices to implement the workspaces and to allow data to reach every subscribed entity.

The operation of ETArch, on which the DTSA entity centrally controls the behavior of the forwarding plane, materializes the SDN paradigm through OpenFlow. OpenFlow [8] is an instantiation of SDN already available in a number of commercial products and used in several Future Internet research projects. It separates the data plane from the control plane of the network, allowing the OpenFlow Controller to manage and control the underlying data plane, and to configure the forwarding table of the switches, via a well-known service-oriented API. This approach enables switches to be (re)configured on the fly, enabling flexible and dynamic network management [3].

The adoption of OpenFlow is mainly focused on core/wired networks. However, the support of QoS in OpenFlow-enabled networks is very limited, relaying on manual external tools to manage queue configuration. Several recent attempts have tried to overcome such limitation, such as QoSFlow [9], that made possible for administrators to manage resources on the controller level.

A. Related work

Regarding QoS, there is a continuing debate on how to evolve the current Internet in order to efficiently accommodate multimedia sessions. Currently, there is no QoS architecture that is successful and globally implemented. Some researchers argue that fundamental changes should be done to fully guarantee QoS, while others think slight changes are enough to have soft guarantees which will provide the requested QoS with high probability. Future Internet requires QoS control approaches beyond current Internet standards, which mainly leverage the per-flow approach to allocate network resources (queues, bandwidth, data paths, etc.). Drawbacks associated to per-flow approaches are well known [5], mainly in terms of network performance (state, processing and signaling overheads), severely jeopardizing system scalability and increasing energy consumption.

Our previous works [10] proposed dynamic super-dimensioned provisioning network resource allocation techniques, deploying a controlled oversizing strategy for both bandwidth and data paths and allowing the admission of several sessions without per-flow signaling exchanges and decisions in the entire network systems. We strongly believe that an optimized network control approach enabled by the over-provisioning technique will allow the evolution of ETArch towards a truly efficient and robust Future Internet network system in comparison to what it is available in the literature.

Several works have explored QoS control and OpenFlow integration in Future Internet architectures, as follows. B. Sonkoly et al. [11] focus on enhancing OpenFlow switches and OpenFlow testbeds with advanced QoS and virtualization capabilities, in order to make them capable of running QoS related experiments, but does not propose any specific QoS control model. In the other hand, H. Egilmez et al. [12] propose a per-flow driven approach, while our focus is to conceive QoS control mechanisms beyond IP and per-flow regular approaches.

In [13], key research topics in the area of future Internet architecture are investigated. The most relevant research projects from United States, European Union, Japan, China, and other countries are introduced and discussed, aiming to draw an overall picture of the current research progress on the Future Internet architecture. Among all of them, only the Japanese proposal AKARI briefly mentions QoS in the design principles of one of its sub-architectures. Not only clean-slate proposals are not focusing on QoS (neither QoE), but most of them are not even taking it under consideration.

The analysis of the related work justifies our work, since none of the proposals taken into consideration fulfills the requirements in providing a Future Internet clean-slate SDN system supporting truly reliable and robust bandwidth-intensive transport capacities.

III. SMART PROPOSAL

The SMART has as main objective to enhance ETArch with new mechanisms supporting advanced network control capabilities aiming to enable QoS-guaranteed mobile multimedia applications over time. Quality requirements are semantically defined for each session in order to guide SMART functionalities, supported by an extended OpenFlow approach to support QoS control.

The SMART envisions enabling a new integrated Future Internet clean-slate SDN system embedding new mechanisms to support advanced routing, resource reservation, admission control and priority queuing functionalities. In order to fulfill the required end-to-end QoS, we designed a dynamic QoS routing super-dimensioned provisioning centric strategy to provision automated, systematic and dynamic network resource allocation for multimedia workspaces.

The innovating aspect of the advanced QoS control adopted in SMART focuses on enabling the integrated use of admission control and over-provisioning centric network resource allocation to achieve a signaling constrained approach. SMART bootstraps the system with oversized network resources, namely surplus workspaces enforced with over-reservations on all network interfaces, and stores such information in the DTSA. As such information is available in advance, the DTSA is enabled to take multiple session admission decisions without any signaling events to enforce neither resource reservations nor forwarding rules in the selected workspace. After the system bootstrap (at the network boot up), SMART only generates signaling events to adjust the over-reservation patterns, in order to over-provision the system again, allowing multiple session admissions with the least amount of signaling.

The SMART framework is presented in Figure 1, emphasizing the new QoS-Manager, which embeds the QoS control-plane additions.

The DTSA acts as the OpenFlow controller of the network. In what concerns its functions as OpenFlow controller, the DTSA is responsible for storing information about the existing entities (Entity Manager), workspaces (Workspace Manager) and handover procedures (Mobility Manager), as well as for performing routing related tasks, implementing the workspaces into the switches. Moreover, these functions are interfaced by a central module (NetConnector), allowing the integration of procedures to optimize several aspects of the network. Lastly, it features a *Media Independent Handover Function* (MIHF) for exchanging IEEE 802.21 information with other nodes and an OpenFlow Channel for communication with the OpenFlow Switches. The IEEE 802.21 is the IEEE standard for Media Independent Handover (MIH) [14]. Its main purpose is to facilitate and optimize inter-technology handover processes by providing a set of media-independent primitives for obtaining link information and controlling link behavior in a heterogeneous way, thus creating an abstraction regarding the link layer.

The EDOBRA Switch consists of an IEEE 802.21-enabled OpenFlow switch. Besides the standard OpenFlow switch capabilities for executing data packet for- warding operations and for storing information on how packets of each workspace should be treated, the EDOBRA Switch is coupled with IEEE 802.21 mechanisms to control aspects of the link interface regarding handover management, such as resource management and/or events about the attachment and detachment of nodes. Lastly, it is coupled with an MIHF for interacting with the Mobile Node (MN) and the DTSA via IEEE 802.21 and an OpenFlow Channel for communication via OpenFlow with the DTSA. The OpenFlow Channel is also responsible for encapsulating DTS messages into OpenFlow messages.

The Mobile Node represents the end-user equipment that establishes connection with the endpoint switches. The MN may be equipped with one or more access technologies, either wired (e.g., Ethernet) or wireless (e.g., WLAN or 3G). The MN deploys an MIHF, allowing higher-layer entities in the device itself (Mobility Manager) or external network entities (e.g., DTSA) to control the links and to retrieve information in an abstract way. In this way, the MN is able to either retrieve link conditions on the current connection or to provide information about other networks in its range. In what concerns DTS procedures (such as register, workspace creation and attachment operations), the MN contains a DTS Enabler that allows it to communicate with endpoint switches via DTS. In addition, the DTS Enabler is also used by applications to send their packets over DTS protocol.

The proposed new sub-components of the QoS-Manager are described as follows:

Advanced Resource Allocator*:* The QoS Advanced Resource Allocator provides support to the QoS management by controlling the usage of the network resources. It is responsible for calculating the new over-reservation patterns, in case none of the available workspaces can possibly satisfy the QoS requirements of a new session; and for the enforcement of the new over-reservation patterns over the workspace switches through the Protocol Manager.

Admission Controller*:* The QoS Admission Controller provides support to the network's QoS management by regulating the access to the network. It is responsible for querying session requirements, candidate paths and their resource availability; and for taking the final decision, either accepting or rejecting the establishment of the workspace. The minimum quality requirements for each mobile session flow (bitrate, tolerance to packet delay/loss/error, etc.) and the current conditions of the candidates workspaces (available traffic classes,

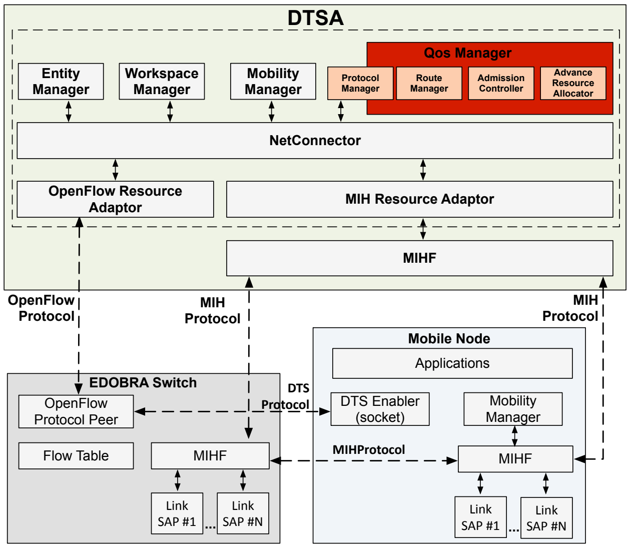

Figure 1: Proposed framework

packet delay/loss/error current rates, link technology, etc.) are taken into account.

The Admission Controller denies a session when the demanded QoS parameters cannot be satisfied (i.e., there is no feasible workspace to accommodate the session), and informs the controller to take necessary actions.

Route Manager: This function is responsible for determining the availability and packet forwarding performance of routers to aid the route calculation. It requires collecting the up-to-date network state from the switches on a synchronous or asynchronous basis. Several routing algorithms, such as shortest path or a dynamic QoS-aware one, can run in parallel to meet the performance requirements and the objectives of different sessions. Network topology information is needed as input along with the service reservations.

Protocol Manager: The QoS Protocol Manager handles communication between the QoS-Manager and the extended OpenFlow API. It is responsible for the setup of the over-estimated reservation patterns across the network through the extended OpenFlow API, for collecting the flow definitions received from the QoS-Manager and for efficient flow management by aggregation.

SMART was designed under the principle of pushing complexity to the network boundary (application hosts, leaf or first-hop routers and edge routers). Since a network boundary has a relatively small number of flows, it can perform operations at a fine granularity, such as complex packet classification and traffic conditioning. In contrast, a network core router may have a larger number of flows, it should perform fast and simple operations. The differentiation of network boundary and core routers was accomplished through workspace aggregation, and it is vital for the scalability of SMART.

A. System Setup

The System Setup is triggered by the DTSA as a consequence of noticing that the underlying network topology has changed. Therefore, DTSA agents unicast an OpenFlow extended message to all OpenFlow enabled switches in the network. On receiving the message, each switch initializes the per-class over-estimated reservation patterns in a way compatible with the underlying QoS approach (for instance, configuring the packet scheduling priorities).

At this stage, the DTSA polls each switch of the network. The current condition of each switch must be taken into account (available traffic classes, packet delay/loss/error current rates, link technology, ect). When the stats request is responded, the DTSA stores all the information in local state tables (unicast workspaces at this time). The generation of multicast workspaces is still a part of the System Setup, which is a fundamental support for the workspace selection. To that, DTSA adopts a combinational algorithm that takes unicast workpace registers to generate all possible combinations between each ingress and all core/egress sequentially.

B. Session Setup

This process is triggered whenever the DTSA receives a workspace attachment entity request.

It is necessary to decide the best-suited path in the core network in order to maintain the established QoS parameters of the multiparty content delivery (as described in Figure 2). An efficient approach to quality-oriented mobility control must always keep the mobile nodes best connected over time, and guarantee that the whole activated mobile session flow meets its quality requirements. The algorithm starts by searching in the internal structures of the DTSA to determine whether there is already a workspace that is being used for the specified flow from the traffic source to the subscriber.

```
Query QoS requirements of the entity attachment request;
Get all workspaces from the traffic source to the subscriber;
for each candidate workspace do
    if workspace able to acommodate QoS reqs then
        Configure workspace flow using OpenFlow in source switch;
        Consigure workspace flow using OpenFlow in dest switch;
        Join the user to the existing workspace;
        break;
for each candidate workspace do
    if readjusted workspace able to acommodate QoS reqs then
        for each switch needed of readjustment do
            Setup new over-reservation patterns(extended OpenFlow)
        Configure workspace flow using OpenFlow in source switch;
        Consigure workspace flow using OpenFlow in dest switch;
        Join the user to the existing workspace;
        break;
Reject the entity attachment request;
```

Figure 2: Session setup algorithm

If there is indeed a workspace able to acommodate the QoS requirements of the new session-flow, it is only necessary to join the user to the existing workspace, which requires no significant signalization overhead (only end switches are notified), as opposed to the original ETArch architecture without the SMART extensions, in which all switches forming the workspace must be signalized.

Considering the case of non-existence of available workspaces to accommodate the demanded session, a suitable workspace may be found by simply readjusting the current over-reservation patterns. The workspace with a greater probability of acceptance is selected and the new over-reservation configuration is calculated, as can be seen in (1).

$$B_{ov}(i) = \frac{B_u(i)}{MR_{th}(i)}(MR_{th}(i) - B_u - B_{rq}(i)) \quad (1)$$

$$\begin{aligned} where\ B_{ov} &: Overreservation\ Bandwidth\ of\ CoS\ i; \\ B_u(i) &: Bandwidth\ Used\ in\ CoS\ i; \\ B_{rq}(i) &: Bandwidth\ Required\ in\ CoS\ i; \\ MR_{th}(i) &: Maximum\ Reservation\ Threshold\ of\ CoS\ i \end{aligned}$$

If the over-reservation patterns calculated by the DTSA are not enough to ensure a suitable path, it is necessary to make a readjustment of the maximum reservation thresholds of all the classes. When none of the available paths are able to accommodate the demanded session (not enough bandwidth in the network) and there is no workspace candidate with probability of acceptance, DTSA rejects the entity attachment request.

IV. EVALUATION

In order to evaluate the feasibility of our framework, we extended the ETArch implementation with the SMART architecture according to the proposals in Section III.

A. Evaluation Scenario

The results of the preliminary performance evaluation of SMART were analyzed by using Mininet [15]. As presented in Figure 3, two different *Mobile Nodes* (MN) were connected to a common OpenFlow Switch.

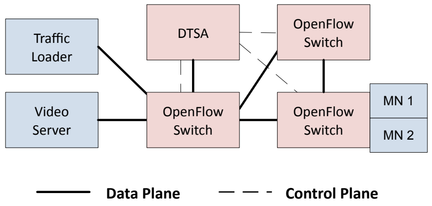

Figure 3: Scenario environment description

The DTSA is connected to the OpenFlow devices using two different connections: one for control and another for data. The MN1, MN2 and the Video Server, on which the DTS applications were run, are the remaining entities that complete the evaluation scenario. The application in the video server is sending a H.264 video stream over two workspaces, one of them being a QoS-enabled workspace, with the MN1 and the MN2 subscribed to each of them in order to receive the video stream. The switches are connected in a triangular shape to have path diversity. The video streaming server and the client are connected to different switches, while the traffic loader inserting cross-traffic into the network is connected to the same switch that the server connects to. Each switch initiates a secure connection to the controller using the OpenFlow protocol (see dashed lines in Figure 3). The controller runs our SMART implementation described in detail in Section III.

In this scenario, MN1 requests a QoS-enabled workspace to receive content from the Video Server, while MN2 requests a normal workspace with no special QoS requirements. Thus, the video packets destined to MN1 are identified as being part of a multimedia workspace by the SMART controller and routed accordingly, while the stream (destined to MN2) is considered as a data workspace which has no QoS support (i.e., best-effort). Finally, in each test, long cross-traffic is sent from the loader to the client continuously.

B. Performance Evaluation

In this section, we evaluate the performance of the proposed framework, comparing it with a deployment of the ETArch without QoS support. Throughout the tests, we used a video sequence having 30 frames per second with the resolution of 1280x720. We then encoded the sequence in H.264 format using the *ffmpeg* encoder (v.1.2.4) to obtain a stream at 1800 kbps (32.55dB).

We decoded the received videos using *ffmpeg* and measured their qualities using *Peak Signal-to-Noise Ratio* (PSNR) and *Structural Similarity* (SSIM) values with respect to the original raw video. PSNR is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. It is widely used to measure the quality of reconstructed transmitted images/videos. The SSIM index is a method for measuring the similarity between two images. It is a full reference metric; in other words, the measuring of image quality based on an initial uncompressed or distortion-free image as reference. SSIM is designed to improve on traditional methods like PSNR and *Mean Squared Error* (MSE), which have proven to be inconsistent with human eye perception. The results are given in Figure 4, which are in terms of received video quality versus time.

Results show that the video with QoS support (SMART enabled) is not affected from the cross traffic and approaches full video quality, while the video without QoS support (ETArch only) has a significant amount of quality loss. In terms of PSNR (Figure 4(a)), the original ETArch framework achieved 19.02±9.03 dB, while the SMART-enabled version achieved 20.97±7.94 dB. SMART achieved optimized bandwidth-guaranteed multimedia transport with a 10% of PSNR improvement. In terms of SSIM (Figure 4(b)), ETArch achieved 0.61±0.16, while SMART-optimized version 0.79±0.14. This implies an improvement of almost 30%. These results were achieved because, during the bootstrapping procedure, switches composing candidate workspaces were initialized with per-class over-reservation patterns. Besides, the video packets destined to MN1 are identified as being part of a multimedia workspace by the SMART controller and routed accordingly, while the stream (destined to MN2) is considered as a data workspace which has no QoS support (i.e., best-effort).

Figure 5 shows random frames picked for both streams. Figure 5(a) corresponds to the traffic subscribed by MN2 (without QoS support), while Figure 5(b) corresponds to the SMART enabled transmission.

C. Forwarding Table Size Analysis

In this section, we study the footprint of the proposed framework, comparing it with a deployment of the ETArch

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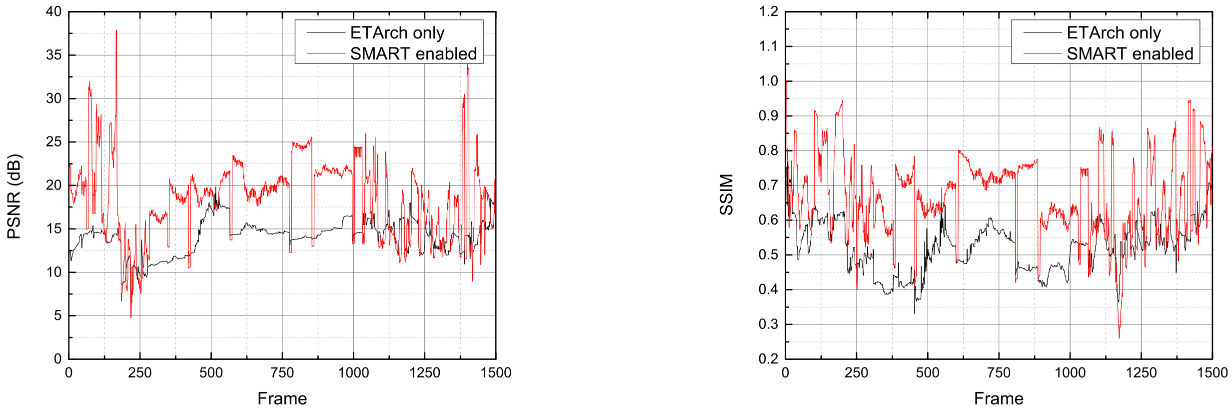
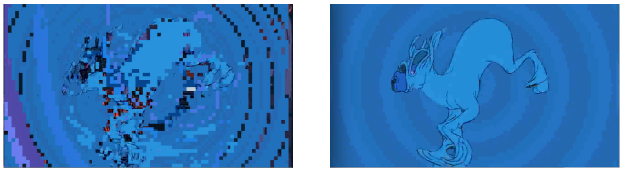


(a) PSNR metric

(b) SSIM metric

Figure 4: QoE metrics for multimedia video streaming



(a) Frame without SMART

(b) Same Frame using SMART

Figure 5: Video snapshot comparison

TABLE I: FORWARDING TABLE SIZES AT CORE ROUTERS

	ETArch with SMART	ETArch only
University of Texas (2011 report)	952	20.000
University of Texas (2013 report)	1.330	40.000
University of Texas (congested scenario)	1.330	80.000

without QoS support. As explained in Section III, SMART was designed under the principle of pushing complexity to the network boundary. Besides, the larger the size of the forwarding table, the worse the performance achieved. Studies show the performance degradation with the increasing number of flows [16].

The results obtained are presented in Table I, showing the number of entries for each protocol generated in the forwarding table for different scenarios. We use real-world scenarios, from different campus networks around the world. According to the 2011 report [17], the architecture of the campus network of the University of Texas consisted of 14 cores and 2 border routers, supporting up to 20.000 simultaneous connections. In 2013, the campus network architecture grew up to 16 cores and 2 border routers. Over 40,000 simultaneous connections spending 36 million hours combined on the system were monitored in spring of 2013. Let's also imagine a congestion scenario with twice as many simultaneous connections (80.000).

Results from Table I show a very significant optimization in the forwarding table size of core routers. However, the number of entries in the forwarding table of SMART signaling scheme does not depend on the number of entities attachments requirements, unlike the original ETArch signaling scheme. Therefore, the relative percentage of the forwarding tables size comparison could be even lower in more saturated scenarios. In what concerns the DTS protocol, no control signaling was required on core switches during the session setup procedure since over-estimated reservations patterns were already initialized during the bootstrapping procedure.

V. CONCLUSION

We have presented a QoS-enabled framework that aims to support mobile multimedia applications with guaranteed QoS and QoE on top of ETArch, a clean-slate SDN-based ICN approach. It allows the dynamic and preemptive reconfiguration of the network resources using over-estimated reservation patterns to achieve optimized bandwidth-guaranteed multimedia transport. Results showed that our framework allows mobile multimedia applications with guaranteed QoS maintained over time, optimizing traffic control and diminishing overhead and forwarding table sizes at core network switches. Moreover, using our framework, applications become semantically capable of defining the quality requirements of each session.

The work presented in this article showcased the integration and growth capabilities of multiple technologies, exposing them to novel scenarios, contribution to the evolution of SDN, ICN, mobility and QoS management procedures operating as a suitable Future Internet framework embodiment.

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