# Quality of Service Assurance in Multi-domain Content-Aware Networks for Multimedia Applications

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***Abstract* —Content Aware Networking is a "light" variant of Information Centric Networking (ICN) architectural solution, responding to the significant Internet orientation to content and multimedia. The contribution of this paper is focused on the implementation and new experimental results validating previously designed solutions for Virtual Content Aware Networks (VCAN), QoS enabled, built over multi-domain, multi-provider IP networks, in the framework of an ecosystem offering multimedia services. A multi-domain pilot is shortly described, and QoS related experiments are shown, demonstrating the benefit of provisioned VCANs dedicated to transport media flows with QoS guarantees.**

***Keywords — Content-Aware Networking, Network Aware Applications, Multi-domain, Quality of Services, Multimedia distribution, Future Internet.***

## I. INTRODUCTION

A significant Internet trend is its stronger information/content-centric orientation [1]-[5]. Related to this, a high increase in media traffic amount is seen, driven by media oriented applications. On the other side, several current Internet limitations have been emphasized, related to the needs of today communication. Consequently, changes in services and networking have been proposed, including modifications of the architectural basics. The *Information/Content-Centric Networking (ICN/CCN),* [3][4], approaches propose revision of some main concepts of the architectural TCP/IP stack. In parallel, evolutionary solutions emerged, as Content-Awareness at Network layer (CAN) and Network-Awareness at Applications layers (NAA), seen as a light ICN solution. This approach can create a powerful cross-layer optimisation loop between the transport, applications and services.

The European FP7 project, "Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", ALICANTE, [10]–[13], adopted the NAA/CAN approach. It defined a multi-domain architecture, and then specified, designed and implemented a Media Ecosystem, on top of multi-domain IP networks, to offer media services for business actors playing roles of consumers and/or providers. The solution adopted as main principles the content-type recognition at network level and light virtualization (separated Data Plane virtual networks, but a single management and control plane). This solution is believed to offer seamless deployment perspectives and tries to avoid the scalability problems, while are still open research issues, of the full ICN/CON approaches.

In this paper, the "environment" denotes a generic grouping of functions working for a common goal, which vertically span one or more several architectural (sub)layers. Several cooperating environments are defined, including business entities/actors: *User Environment (UE),* containing the End-Users; *Service Environment (SE),* containing High Level Service Providers (SP) and Content Providers (CP); *Network Environment (NE),* where a new CAN Provider exists (CANP - managing and offering Virtual Content Aware Networks- VCANs); traditional Network Providers (NP/ISP) - managing the network elements at IP level.

A VCAN is constructed at request of an SP, to a CAN Provider, based on Service Level Agreement (SLA) spanning one or several independent network domains, and featuring different levels of QoS guarantees. The CANP offers to the upper layers enhanced connectivity services, VCAN-based QoS enabled, in unicast and multicast mode, over multi-domain, multi-provider IP networks. The VCAN resources are managed quasi-statically by provisioning and also dynamically, by using adaptation procedures for media flows. In the Data Plane, content/service description information (metadata) can also be inserted in the media flow packets by the Content Servers and treated appropriately by the intelligent routers of the VCAN.

This paper continues a previous work dedicated to system architecture, design, and algorithms for resource management. Section II makes a short overview of related work. Section III summarizes the overall system architecture. Section IV and V contain the main novel contributions of this paper, presenting the experimental pilot structure and few samples of validation results, extracted of a large set, [12] performed during overall system validation. Section VI contains some conclusions and future work outline.

## II. RELATED WORK

The current challenges and research on content/information networking for the Future Internet are well presented in [1][2]. Information/Content Centric Networking (ICN/CCN), or Content Oriented Networking (CON) [3]–[5] change the traditional TCP/IP stack concepts (with agnostic network layer) by putting more intelligence

 **ISBN: 978-1-61208-349-0** 

in the network nodes, which primarily process the data, based on *content objects* recognition and not based on *location address*. However, full ICN/CCN poses significant problems of scalability and seamless deployment possibility [6].

"Light" approaches are Content-Awareness at Network layer (CAN) and Network-Awareness at Applications layers (NAA) [10]. Here, only content-type of data are recognized by network nodes and treated accordingly. Thus the full ICN scalability and complexity problems are avoided and a. seamless field deployment is possible. The approach brings new benefits for both, Service and Application Layer and Network layer, thus creating a powerful *cross-layer optimization loop*.

Network virtualization is an important set of tools to overcome the ossification of the current Internet [7]-[9]. In our system [10]–[13], a light virtualization is adopted, by creating VCANs as parallel Internet planes [14], each one being content aware and QoS capable. The virtual logical slices (VCANs) exist and are separated in the Data Plane only, while the Management and Control (M&C) Planes are unique at system level. To solve the QoS guarantees, each VCAN has associated a QoS class or meta-QoS class as in [15][16], but in a more powerful way, given the content awareness of the VCANs.

## III. ALICANTE SYSTEM ARCHITECTURE SUMMARY

### A. *General Architecture*

The general ALICANTE architecture is already defined in [10][11][13]. The traditional business actors are SP, CP, NP - Providers and End-Users (EU). A novel actor is the CAN Provider (CANP) which offers virtual layer connectivity services. The EUs are connected to VCANs via home and/or access networks. Note that VCANs do not control access networks resources, given their large variety of technologies. Home-Boxes (HB) – may exist, partially managed by the SP, the NP, and the end-user, located at end-user's premises and gathering content/context-aware and network-aware information. The HB can also act as a CP/SP for other HBs, on behalf of the EUs. Correspondingly, two novel virtual layers exist: the CAN layer and the HB layer.

The novel CAN routers are called *Media-Aware Network Elements (MANE)* to emphasize their additional capabilities: content and context - awareness, controlled QoS/QoE, security and monitoring features, etc.

The CAN layer M&C is partially distributed. It supports CAN customization to respond to the high level services needs, including 1:1, 1:n, and n:m communications and also performs efficient network resource exploitation. The interface between CAN and the upper layer assures *cross-layer optimizations* interactions. A hierarchical monitoring subsystem (at user, service, CAN and respectively network layer) supervises several points of the service distribution chain and feeds the adaptation subsystems with appropriate information, at the HB and CAN Layers.

Figure 1 presents a partial view on the ALICANTE architecture (complete description is in [11]), with emphasis on the CAN layer and management interaction. The network contains several Core Network Domains (CND), belonging to NPs (they can be also seen as Autonomous Systems - AS). The Access Networks ANs are out of scope of VCANs. One *CAN Manager* (CANMgr) exists for each CAN domain to assure the consistency of VCAN planning, provisioning, advertisement, offering, negotiation installation and exploitation. Each domain has an *Intra-domain Network Resource Manager* (IntraNRM), as the ultimate authority configuring the network nodes. The CAN layer cooperates with HB and SE and offers CAN services to them.

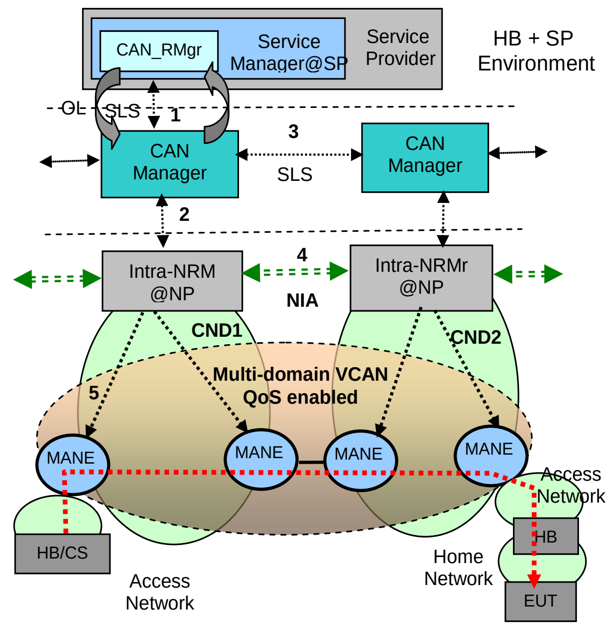


Figure 1: High level ALICANTE architecture: multi-domain VCANs and main management and control interactions

Notations: RM – Resource Management; HB - Home Box; CS - Content Server; EUT - End User Terminal; OL - Optimization Loop; NIA - Network Interconnection Agreements; SP, NP – Service, Network Providers

### B. *VCAN Management*

The VCAN Management framework has been defined in [13]. *A short summary is recalled here only for sake of clarity.* At the Service Manager SM@SP, the CAN Network Resources Manager (CAN_RMgr) performs, on behalf of SP, all actions needed for VCAN support: *VCAN* planning, provisioning (i.e. negotiation with CANP) and then VCAN operation supervision. The *CANMgr@CANP* performs, at the CAN layer, VCAN provisioning and operation. The two entities interact based on the SLA/SLS contract initiated by the SP. The interface implementation for management is based on Simple Object Access Protocol (SOAP)/Web Services.

The M&C contracts/interactions of SLA/SLS types (Figure 1) are: *SP-CANP(1)*: the SP requests to CANP to provision/ modify/ terminate VCANs while CANP replies

 ISBN: 978-1-61208-349-0 

with yes/no; *CANP-NP(2)*: CANP negotiates resources with NP; *CANP-CANP(3):* negotiations might be needed to extend a VCAN upon several NP domains; *Network Interconnection Agreements (NIA) (4)* between the NPs or between NPs and ANPs; the latter are not novel functionalities, but are necessary for NP cooperation. After the SP negotiates a desired VCAN with CANP, it will issue the installation commands to CANP, which in turn configures, via Intra-NRM (action 5), the MANE functional blocks (input and output).

The content awareness (CA) is realized in three ways:

(i) by concluding a SP - CANP SLA concerning VCAN construction. The Content Servers (CS) are instructed by the SP to insert some special *Content Aware Transport Information (CATI)* in the data packets. This simplifies the media flow classification and treatment by the MANE; (ii) SLA is concluded, but no CATI is inserted in the data packets (legacy CSs). The MANE applies packet inspection for data flow classification and assignment to VCANs. The flows treatment is still based on VCANs characteristics defined in the SLA; (iii) no SP–CANP SLA exists and no CATI. The flows treatment can still be CA, but conforming to the local policy at CANP and IntraNRM.

The DiffServ and/or MPLS technologies support splitting the sets of flows in QoS classes (QC), with a mapping between the VCANs and the QCs. Several levels of QoS granularity can be established when defining VCANs, by using one of the implemented QCs: EF, AF1, AF2 or BE. The QoS behavior of each VCAN (seen as one of the parallel Internet planes) is established by the SP-CANP.

Generally a 1-to-1 mapping between a VCAN and a network plane will exist. Customization of VCANs is possible in terms of QoS level of guarantees (weak or strong), QoS granularity, content adaptation procedures, degree of security, etc. A given VCAN can be realized by the CANP, by combining several processes, while being possible to choose different solutions concerning routing and forwarding, packet processing, and resource management.

The mapping between multiple domain VCANs and network resources are developed in [17]. Special combined novel algorithms for multi-domain QoS enabled routing, resource reservation (at aggregated level) and VCAN final mapping have been designed and implemented as to assure VCAN QoS capabilities.

## IV. EXPERIMENTAL PILOT INFRASTRUCTURE

Figure 2 presents a part of the ALICANTE pilot, i.e. an island deployed in Bucharest, UPB. It is a hybrid diagram showing both physical network infrastructure and some architectural elements.

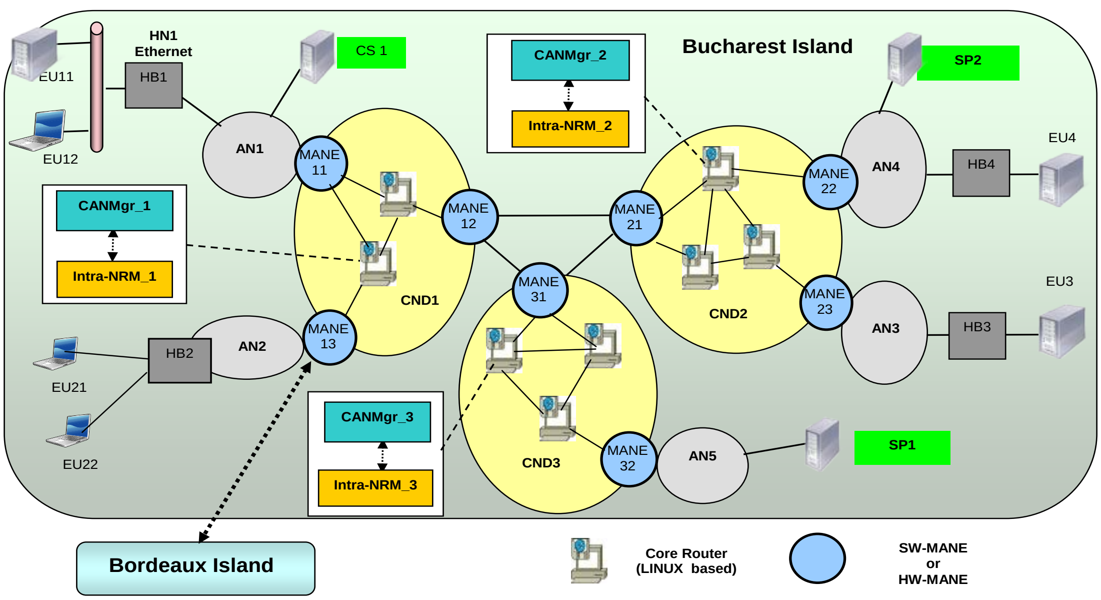


Figure 2: Bucharest Island – general network Infrastructure and architectural elements

The island is also connected via international links to other islands. Here, a summary only emphasizing some specific aspects is given. Its objectives are to validate and demonstrate the capabilities of the overall system for: CAN and network environment (CNE) transport capabilities; CAN and networking support for High-level services. Several Use Cases have been defined in the project to validate high level services capabilities: UC1 - "Distribution of User Generated Content", UC2 - "High Popularity Video on Demand" and UC3 - "Multicast Live TV".

The UPB island is composed by three Core Network Domains and several access networks (ANs). The infrastructure allows multi-domain and multi-provider experiments to be performed locally and also in multi-island environment (e.g., Bucharest - Bordeaux). Specifically, the pilot supported the validation of the following: CAN functionality (mono and multi-domain

 ISBN: 978-1-61208-349-0 

experiments); High-level services scenarios UC1, UC2, UC3 (local/local-remote experiments, mono and multi-domain). In the local demonstration, all business entities (EUs, HBs, SP, CP/CS entities) are placed within, and connected to the UPB island network infrastructure. In the multi-island demonstrations, a part of the service related entities resides in the UPB island and others are connected to the other pilot islands. The roles of the ALICANTE entities are detailed in [11].

The MANE edge routers are content-aware while the interior routers are core regular routers, DiffServ and MPLS capable. The core routers were implemented on Linux machines. The MANE is based on HW + SW configurations provided by the ALICANTE project. The CAN Managers and Intra-NRMs run on Linux based PC machines. The HBs, SP and CP Subsystem's entities (SP or CP servers, Content Servers (CS), Service management entities, Service Registry, etc.) run also on Linux based PC machines. Access Network and Home networks are based on Ethernet technology.

Details on the tests performed in the project pilot, and complete sets of validation results are described in [12].

## V. VALIDATION RESULTS

This section presents a few samples of the experimental results performed to validate the system.

In particular the following example shows a VCAN created, to demonstrate its ability to protect unicast media traffic. It has two logical channels (pipes): one inter-domain pipe, starting in Domain 2 and ending in Domain 1, and a second intra-domain located in Domain 1 – see Figure 3. This test shows that traffic belonging to the VCAN pipe is protected against traffic with low priority, in this case, best effort traffic. A video stream is sent through the inter-domain VCAN's pipe, from MANE 22 to MANE 11. The bit rate for the video stream is around 2.5Mbps. A high rate data flow, streamed from node e.134 to node e.131, will be used as "noise" traffic. The data rate for the "noise" traffic is sent using *iperf* application. It is UDP traffic and it is sent with a data rate of 1Gbps. The results obtained with and without VCAN installed will be presented below.

The VCAN's pipes have a Committed Information Rate (CIR) of 4Mbps and a Peak Information Rate (PIR) of 6Mbps.

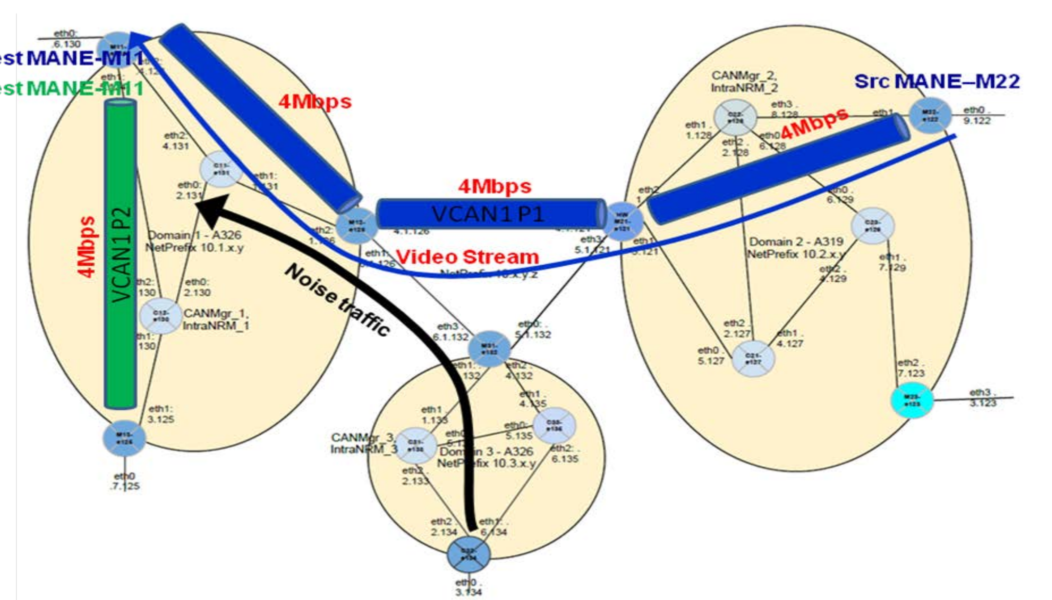


Figure 3: Sample of VCAN topology installed for unicast oriented tests.

The system has been fully implemented for its M&C and data plane components. In Figure 4, the queues of the Hierarchical Token Bucket (HTB) for Traffic Control Filters (TC) filters installed on the MANE 12 node (e.126) are shown. The HTB filters shown belong to the interface eth2, which represents the output interface for the VCAN pipe 1. Appropriate classes are created as a result of the VCAN Create request, issued by the Service Provider. In the left figure, the "noise" traffic is not present, that's why only the queue associated with the VCAN 1 traffic has traffic in it. The data rate measured for this queue is around 2.5 Mbps, which corresponds to the movie's bit rate. In the right figure, the queues belonging to the same filter are shown, but in this case, the "noise" traffic is sent through the e.126 node. It can be seen that, in the default queue for the best effort traffic, the "noise" traffic is present. Its rate is around 40Mbps, because it is reduced by the HTB filter.

 ISBN: 978-1-61208-349-0 

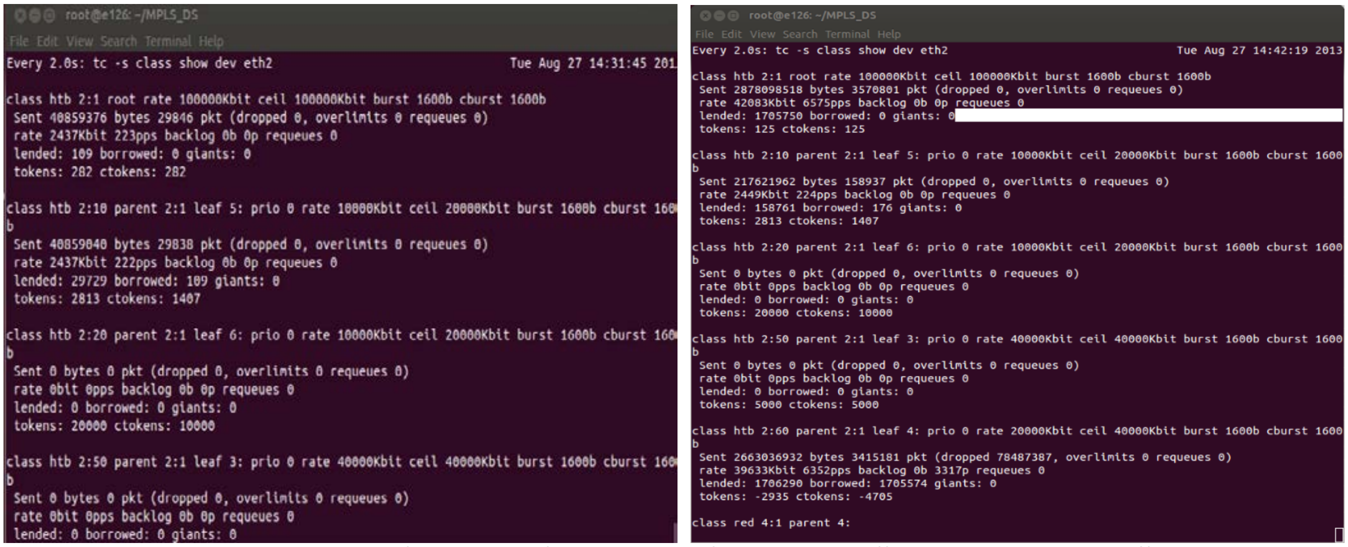


Figure 4: The queues of the HTB TC filter on *e.126*: left - no "noise" traffic; right - with "noise" traffic

Several complex test campaigns have been performed to fully validate the functionality and measure the system performance, [12]. Given the limited space of this paper a qualitative example is given below.

In this test, two movies were continuously streamed at a constant bitrate, the left one is protected by the installed VCAN, and the right one is sent best-effort. In Figures 5 and 6, a snapshot of the videos received at the output of the VCAN pipe is shown. Both snapshots are taken with one VCAN configured and installed. Figure 5 corresponds to the case when the background noise is not present and both movies transmitted are running fine. Figure 6 is taken with background noise flowing active. The movie protected by VCAN will have good quality because its flow is prioritized and protected against low priority traffic, while the best effort movie is very affected by noise. The conclusion is that VCAN has a provisioning effect for QoS protection of dedicated flows.

## VI. Conclusions and Future Work

The paper presented experimental results, validating the solutions for a Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", developed over multiple IP network domains. The architecture and implementation has been fully validated, giving the possibility for multiple providers to cooperate by creating overlay networks over multiple domains.

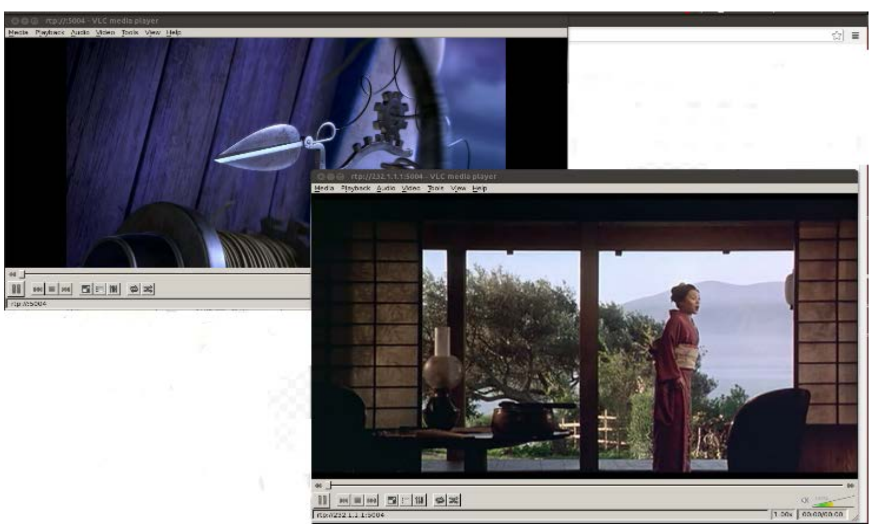

Figure 5: Received video stream with VCAN installed, and no background noise

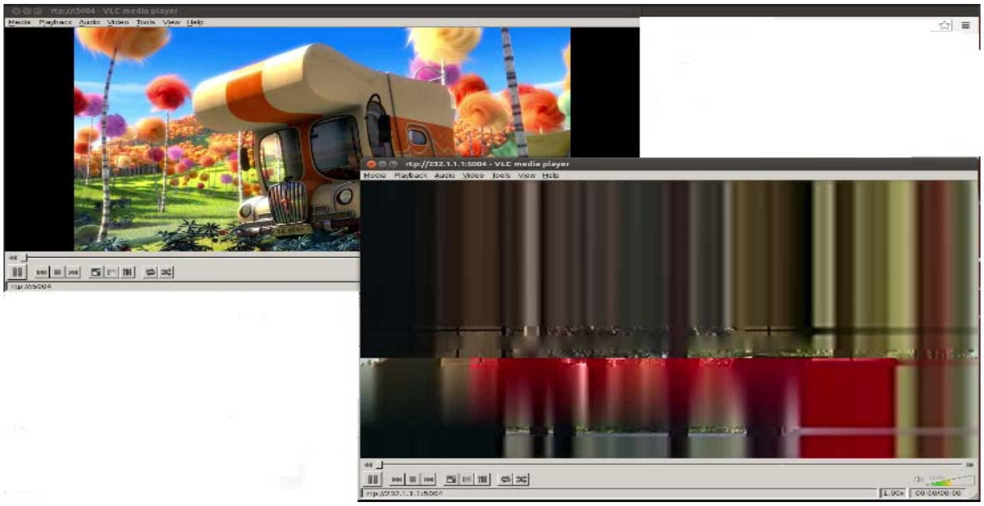

Figure 6: Received video stream with VCAN installed and network loaded with background "noise" (left: protected traffic flowing through VCAN pipe; right: unprotected traffic)

We emphasize the main merit of the system, which provides the possibility of creation of parallel multi-domain VCANs customised for different classes of services, with content type awareness in edge routers, while the QoS supporting technologies can be diverse (e.g. DiffSErv, MPLS, combinations).

The VCANs, provisioned as overlays by the CAN providers, at Service Providers requests, can serve properly the media flow transportation in different conditions of the network load. The system still admits best effort traffic, thus preserving network neutrality.

Future work will be done to extend the functionality of the system towards Software Defined Networking, given that the proposed architecture fulfills the main SDN concepts – decoupling between the Control and Data Plane, partial centralization and programmability of network level forwarders.

## ACKNOWLEDGMENTS

This work was supported partially by the EC in the context of the ALICANTE project (FP7-ICT-248652) and partially by the project POSDRU/107/1.5/S/76903.

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 ISBN: 978-1-61208-349-0 