Connectivity Services Management in Multi-domain Content-Aware Networks for Multimedia Applications

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***Abstract*—This paper proposes a new framework, for connectivity services management in overlay Virtual Content Aware Networks (VCAN) built over multi-domain, multi-provider IP networks. The framework is part of a Future Internet-oriented Multimedia networked architecture developed inside a FP7 European ICT research project, ALICANTE. The VCAN new concept is a stronger coupling between network and applications. The VCANs are managed by CAN Providers, and the high level services by Service Providers (SP). The CANP offers to SPs enhanced connectivity services, including unicast, multicast, in a multi-domain networking context. The management framework is based on vertical and horizontal Service Level Agreements(SLA) negotiated and concluded between providers and possibly also on content/service description information (metadata) inserted in the media flow packets by the servers.**

Keywords—Content-Aware Networking; Network Aware Applications; Connectivity services; Management; Multimedia distribution; Future Internet

I. INTRODUCTION

The Future Internet has a strong orientation towards services and content, [1][2][3]. A new solution to make the Future Internet more content oriented [3][4][5][6], is to create virtualized *Content Aware Networks* (CAN) and *Network Aware Applications* (NAA) on top of the flexible IP. Additionally to routing, the CAN routers are optimized for filtering, forwarding, and transforming inter-application messages on the basis of their content and context.

The work of this paper is part of an activity performed in the framework of a new European FP7 ICT research project, "Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", ALICANTE [7] [8][9]. The following inter-working multi-actor environments are defined: *User Environment (UE)*, to which some end users belong; *Service Environment (SE)*, to which Service Providers (SP) and Content Providers (CP) belong; *Network Environment (NE)*, to which the Network Providers (NP) belong. *Environment* is a generic name for a grouping of functions defined around the same common goal and which possibly vertically span one or more several architectural layers.

We propose a new framework, for connectivity services management in overlay VCANs built over multi-domain, multi-provider IP networks. The VCANs are managed by a CAN Provider (CANP), and the high level services by SPs. The CANP offers to SPs enhanced connectivity services including unicast and multicast. The management framework is based on vertical and horizontal SLAs negotiated and concluded between providers and possibly also on content/service description information (metadata) inserted in the media flow packets by the servers.

The paper continues the starting work on VCAN management presented in [8][10]. It is organized as follows. Section II presents samples of related work. Section III summarizes the overall ALICANTE architecture. Section IV presents the content awareness features of the system and QoS assurance solutions. Section V describes the peering approach to extend a VCAN over several domains. The proposed CAN management architecture and functionalities is presented in Section VI. Section VII contains some conclusions and future work outline.

II. RELATED WORK

A higher coupling between the Application and Network layers was recently proposed in order to make the IP network more adapted to content and services. In the framework of rethinking the architecture of the Future Internet, the concepts of CAN and NAA are proposed. CAN adjusts network layer processing based on limited examination of

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the nature of the content, and NAA implies processing the content based on limited understanding of the network conditions. The work presented in [1] emphasizes the strong orientation of the FI towards content and services and shows the importance of management. CAN/ NAA can offer a way of evolution of networks beyond IP, as presented in [6]. The implementation of such an approach can be supported by virtualization as a strong method to overcome the ossification of the current Internet [2][3][4][5].

The work in [11] discusses the content adaptation issues in the FI as a component of CAN/NAA approach. The CAN/NAA approach can also offer QoE (Quality of Experience) and QoS capabilities of the future networks, [6][12]. Context awareness is added to content awareness in [13]. However, the CAN approach requires a higher amount of packet header processing, similar to deep packet inspection techniques. The CAN/NAA approach can also help to solve the current networking problems related to the P2P traffic overload of the global Internet [14]. The Application Layer Traffic Optimization (ALTO) problem studied by IETF can be solved by the cooperation between the CAN layer and the upper layer. The management architecture of the CAN/NAA oriented networks is still an open research issue.

III. ALICANTE SYSTEM ARCHITECTURE

The main concepts and general ALICANTE architecture are defined in [7][8][9]. The business model is defined, composed of traditional SP, CP, NP - Providers and End-Users (EU). A new actor is the CAN Provider (CANP) offering virtual layer connectivity services. A new entity is also defined: Home-Box (HB)- 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. Two novel virtual layers exist: the CAN layer for network level packet processing and the HB layer for the actual content delivery, working on top of IP. The virtual 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 SE [8] uses information from the CAN layer to enforce NAA procedures, in addition to user context-aware ones. Apart from VCANs provisioning, per flow adaptation can be deployed at both HB and CAN layers, as additional means for QoS, by making use of scalable media resources.

The management and control of the CAN layer is partially distributed; it supports CAN customization as to respond to the upper layer needs, including 1:1, 1:n, and n:m communications, and also allow efficient network resource exploitation. The rich interface between CAN and the upper layer allows cross-layer optimizations interactions, e.g., including offering distance information to HBs to help collaboration in P2P style. At all levels, monitoring is performed in several points of the service distribution chain and feeds the adaptation subsystems with appropriate information, at the HB and CAN Layers. Fig. 1 presents a partial view on the ALICANTE architecture, with emphasis on the CAN layer and management interaction. The network contains several NP domains (Autonomous Systems - AS) and access networks (AN). Each domain has an Intra-domain Network Resource Manager (IntraNRM), as the authority configuring the network nodes. The CAN layer cooperates with HB and SE by offering them CAN services. One CAN Manager (CANMgr) exists for each IP domain to assure the consistency of CAN planning, provisioning, advertisement, offering, negotiation installation and exploitation. However, autonomous CAN-like behavior of the MANE nodes can be also offered in a distributed way by processing individual flows.

The following contracts/interactions of SLA/SLS types performed in the Management and Control Plane and the appropriate interfaces are shown in Fig. 1:

SP-CANP(1): the SP requests to CANP to provision/ modify/ terminate new VCANs and the CANP to inform SP about its capabilities; *CANP-NP(2)* - through which the NP offers or commits to offer resources to CANP (this data is topological and capacity-related); *CANP-CANP(3)* - to extend a VCAN upon several NP domains; - *Network Interconnection Agreements (NIA) (4)* between the NPs or between NPs and ANPs; these are not new ALICANTE 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 IntraNRM (5) the MANE functional blocks (input and output).

IV. CONTENT AWARENESS AND QOS ASSURANCE AT CAN LAYER

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

(i) by concluding an SLA between SP and CANP, concerning different VCAN construction. The content servers are instructed by the SP to insert some special Content Aware Transport Information (CATI). This simplifies the media flow classification and treatment by the MANE.

(ii) the SLA is concluded, but no CATI information is inserted in the data packets. The MANE applies deep packet inspection for data flow classification and assignment to VCANs. The treatment of the flows is based on VCANs characteristics defined in the SLA.

(iii) no SLA exists between SP and CANP. No CATI is inserted in the data packets. The treatment of the data flows can still be CA, but conforming to the local policy established at CANP and IntraNRM.

An important issue related to multimedia flow transportation is the QoS assurance. The DiffServ philosophy can be applied to split the sets of flows in QoS classes (QC), with a mapping between the VCANs and the QCs.

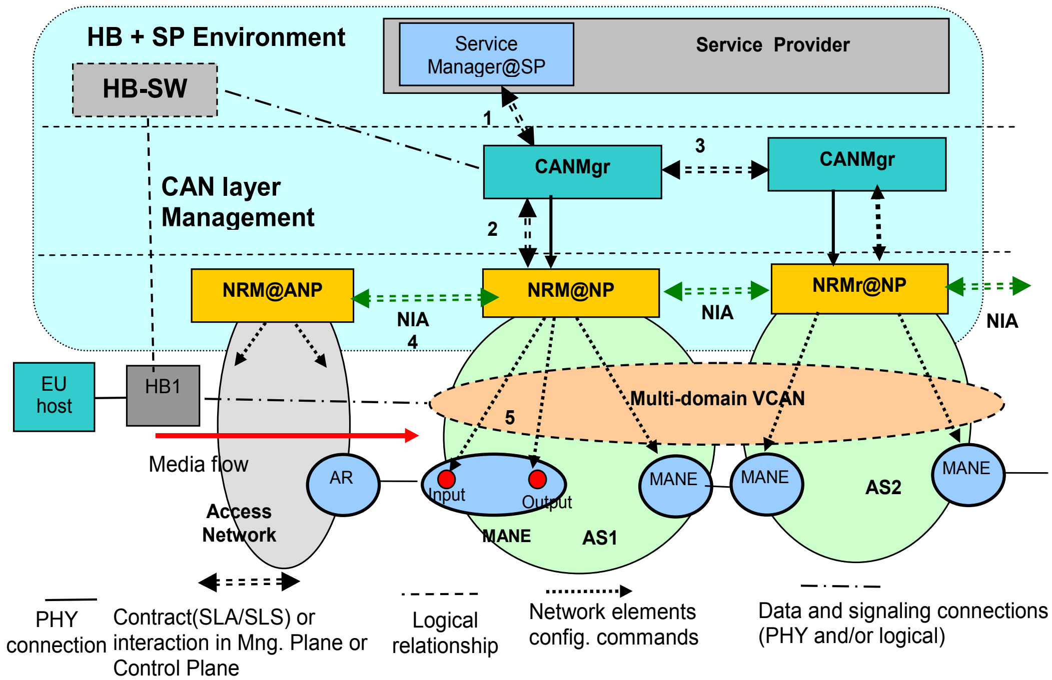

Figure 1. ALICANTE architecture: CAN management interactions

Several levels of QoS granularity can be established when defining VCANs. The QoS behavior of each VCAN is established inside the SLA between SP and CANP.

Actually, the CAN layer may offer to the SP, several parallel internets (PI) [15], specialized in different types of application content. We adopt the PI concept, enriching it with content awareness. A PI enables end-to-end service differentiation across multiple administrative domains. The PIs can coexist, as parallel logical networks composed of interconnected, per-domain, Network Planes. A given plane is defined to transport traffic flows from services with common connectivity requirements. The traffic delivered within each plane receives differentiated treatment, so that service differentiation across planes is enabled in terms of edge-to-edge QoS, availability and also resilience.

In ALICANTE, generally a one-to-one mapping between a VCAN and a network plane will exist. Specialization of CANs may exist in terms of QoS level of guarantees (weak or strong), QoS granularity, content adaptation procedures, degree of security, etc. A given network plane or VCAN can be realized by the CANP, by combining several processes, while being possible to choose different solutions concerning some dimensions: route determination, data plane forwarding, packet processing, and resource management.

The definitions of local QoS classes (QC) and extended QCs were adopted, to allow us to capture the notion of QoS capabilities across several domains [16][17][18]. For a simplified design, we also used the concept of Meta-QoS-Class [16]. A meta QC captures a common set of QoS ranges of parameters spanning several domains. It relies on a worldwide common understanding of application QoS needs. Foir example, VoD service flows need similar QoS characteristics whatever AS they transit. The meta QC concept offers the advantage that the existence of well known classes greatly simplifies the inter-domain signaling in the sequence of actions needed to establish domain peering in the multi-domain context. This concept simplifies the peering of different domains inside the same VCAN.

The types of VCANs for different QoS granularities based on QCs are described in [9]. In short, the following use cases have been defined for multi-domain VCANs: VCANs based on meta-QC, VCANs based on local QC composition, hierarchical CANs based on local QC composition.

The last case is the most efficient but also the most complex. Each domain may have its local QoS classes. Several local QCs can be combined to form an extended QC. Inside each CAN, several QCs are defined corresponding to platinum, gold, silver, etc. In such a case, the mapping between service flows at SP level and CANs can be done per type of the service: VoD, VoIP, Video-conference, etc.

V. CAN MULTI-DOMAIN PEERING

A given CAN may span one or several IP domains. Thus a peering problem appears: how to determine the intermediate and terminal domains to be chained in the resultant VCAN. The hub model is proposed, in which a CAN Manager is communicating with other managers in order to establish the multi-domain CANs.

A drawback is that each CAN Manager should know the complete graph of AS candidates to participate in every possible VCAN (overhead). However, given that the number of ASes involved in a VCAN communication cannot be high, and that they can be localized in an Internet region, the scalability problem is not so stringent.

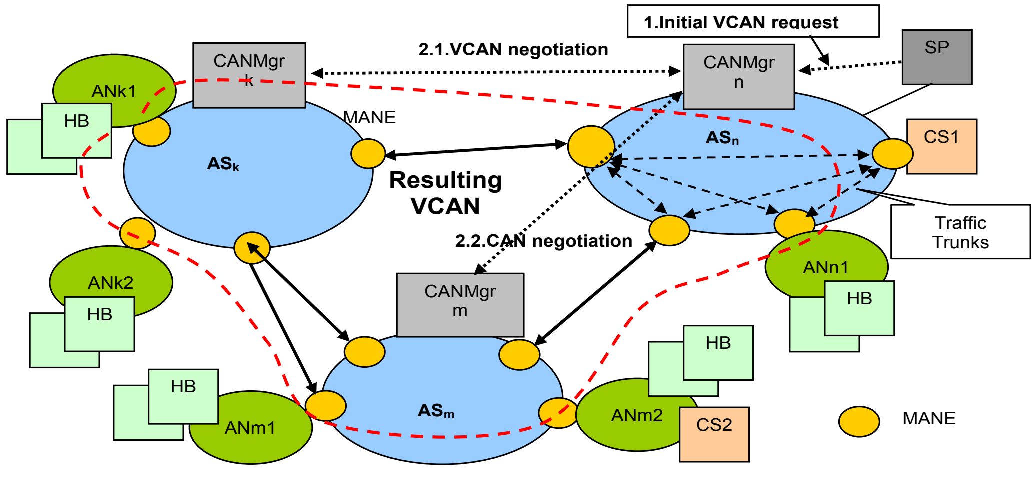

Figure 2. Example of a multi-domain CAN (hub model)

The initiator CAN Manager should discuss/negotiate with all other CAN Managers in order to establish the "international" VCAN = {CAN1 **U** CAN2 **U** CAN3 …}. The split of the SLS parameters should be done at the initiator (e.g. for delay).

Fig. 2 shows an example of a multi-domain VCAN. The infrastructure is composed of three domains AS*n*, AS*k*, AS*m*, each having a CAN Manager. Several Access Networks are connected to these domains, containing Home-Boxes or/and Content Servers (CS). The latter are controlled by the SP. The SP is requesting a CANMng *n* to construct a CAN, spanning several domains, i.e. AS*n*, AS*k* and AS*m*. It is supposed that the SP knows the edge points of this CAN, the MANEs where different sets of HB currently are, or they will be connected. Based on its inter-domain routing information, the CANMng_*n* determines that the components of the VCANs are AS*n*, AS*k*, AS*m*. Therefore, it negotiates in actions 2.1 and 2.2 the appropriate VCAN capabilities with CANMng_*k* and respectively CANMng_*m*. In a successful scenario, the multi-domain CAN is agreed and then it is instantiated in the network.

VI. CAN Resource Manager Architecture at Service Provider and CAN Provider

Fig. 3 presents the proposed architecture for CAN Management. This is a continuation and development of the one presented in [10]. At the Service Manager SM@SP level, the CAN Network Resources Manager (CAN_RMgr) component performs all the actions needed to assure the CAN support to the SP, in order to deploy its high level services in unicast or multicast mode. It is responsible to negotiate with CANP on behalf of the SP and perform all actions necessary for *VCAN* planning, VCAN provisioning and VCAN operation.

CNMgr@CANP performs at the CAN layer all actions related to VCAN provisioning and operation. The two entities interact based on the SLA contract initiated by the SP. The technical part of these contracts is the Service Level Specification (SLS).

Several points of view should be considered when defining/planning the services, planning the CAN and respectively when defining CAN_RMgr functionalities: the commercial optimization needs of the SP, CANP resources, CAN network engineering and implementation.

The CAN_RMgr interacts with the following modules supposed to exist and belonging to the SM:

Service Forecast and Planning - an *offline process* performing service predictions and their associated plans of deployment, considering the business as input.

Service Deployment Policy - can contain (in a data base) predefined rules for service planning. This information is derived from the high-level business interests of the SP and significantly influences the planning.

CAN_RMgr@SM contains the following functional blocks: CAN Planning, CAN Provisioning and CAN Operation and Maintenance, as main functional blocks. A CAN Repository data base keeps all data related to VCAN provisioning, installation and current status. Policies can intervene to guide the other blocks through the module *CAN Deployment and Operation Policies*.

Fig. 3 also shows the interfaces, defined below. Where possible, the interface implementation for data transport will be based on SOAP/Web Services interfaces, used for SOAP requests and responses.

1. CAN Planning at *CAN-RMgr@SM* - to - Service Forecast and *Planning@SM* at Service Life Cycle block. This input interface to CAN_RMgr delivers information from the service forecast module and from the policy block, to allow the high level CAN Planning.

2. CAN Operation and Maintenance at *CAN-RMgr@SM* - to - Service Life Cycle block. This interface delivers the current status data on active CANs to the Service Life Cycle block.

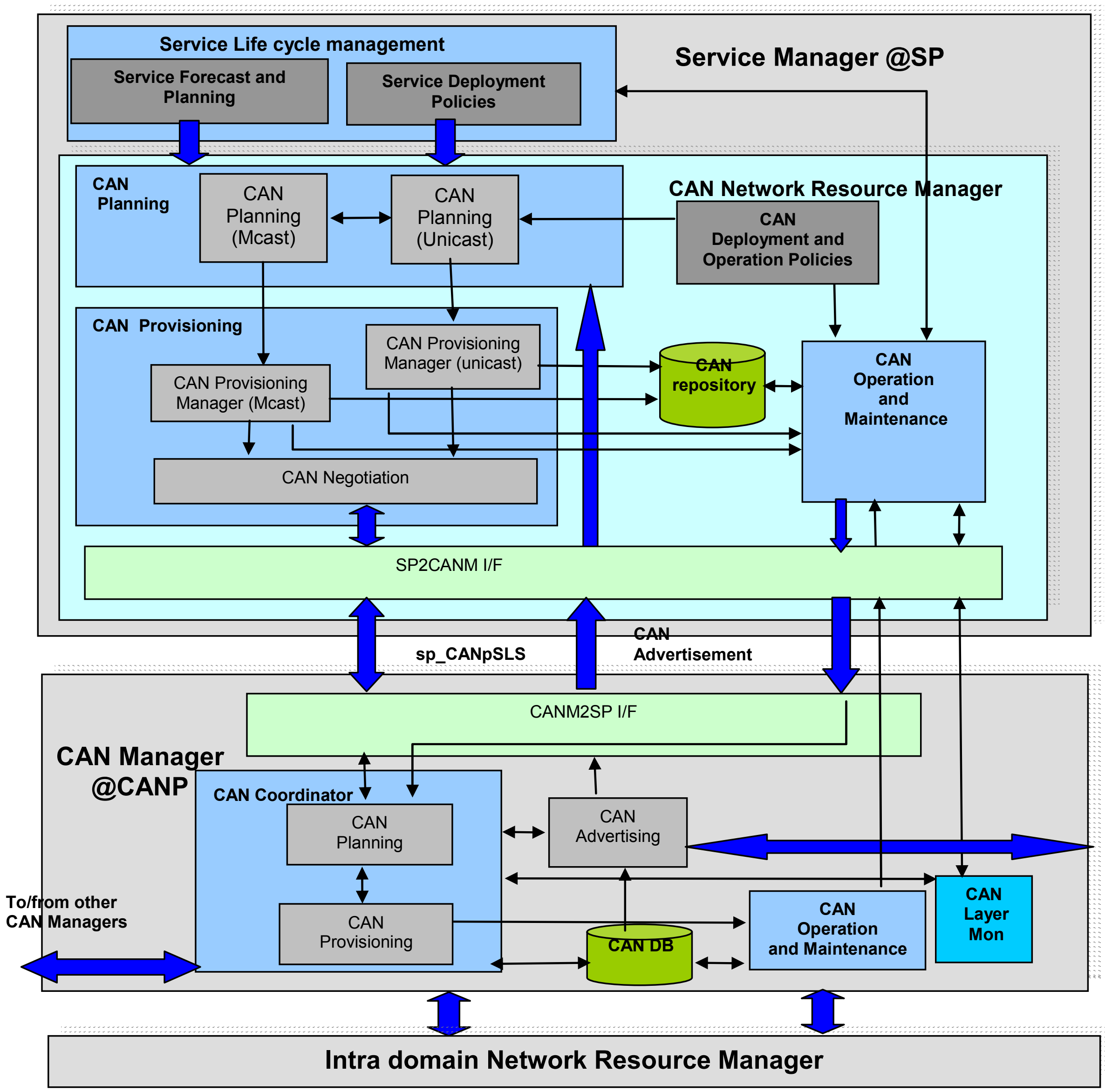

Figure 3. Architecture of the CAN Network Resource Manager at SP and CAN Manager at CAN layer

3. CAN-RMgr@SM – to – CAN Manager. This is a multiple interface necessary for CAN_RMgr at SM@SP to perform the following:

- request the CAN Manager to negotiate VCANs and perform negotiation (SLS contracts will be concluded for VCAN subscription, based on a negotiation protocol);
- command VCAN installation (invocation)
- receive advertisement information about available CANs constructed at the CANP's initiative
- request modification and/or termination of a CAN: according to the current situation and the evolution of the forecast, the SP can re-negotiate the network resources with CANP, which will imply to add/modify/delete VCANs;
- receive status and monitoring information about the active VCANs.

A. *CAN Provisioning*

The functional block for this is the CAN Provisioning Manager at SM@SP. The *CANProvMng@SM* has several main functions shortly presented below.

It performs all *sp_CANpSLS* processing - subscription (unicast/multicast mode) in order to assure the CAN transport infrastructure for the SP. For CAN subscription, the *CANProvMng@SM* receives requests for a *sp_CANpSLS* contract dedicated to a given CAN from *CAN Planning.* Then, it requests to the CAN Manager associated with its home domain, to subscribe for a new CAN. It negotiates the subscription and concludes an SLS denoted by: *SP-*

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CAN_SLS-uni_sub for unicast, or *SP-CAN_SLS-mc_sub for* multicast*.* The results of the contract are stored in the *CAN repository.* Note that CAN subscription only means a logical resource reservation at the CAN layer, not real resource allocation and network node configuration.

The CAN subscription action may or may not be successful, depending on the amount of resources demanded by the SP and the available resources in the network. Note that at its turn the CAN Manager has to negotiate the CAN subscription with IntraNRM, and overbooking is an option, depending on the SP policy.

B. CAN Negotiation

The basic version of this negotiation protocol (SP-CANP-SLS-P) can support the negotiation process between several pairs of managers like *CANProvMng@SM* as a client and *CAN Manager* as a server. The main usage of this protocol is for establishing *sp_CANpSLSs* contracts, but it should have all the necessary properties of a general negotiation protocol, and could be adapted/used to serve CAN invocation.

The SP-CANP-SLS-P protocol is a client-server, 1-to-1 protocol, where the client initiates the negotiation sessions. In order to be able to serve the c/pSLS negotiations, it is completely distinct from the negotiation logic*,* which is located a layer above the protocol and acts as a user of the protocol. For SLS negotiation between SP/CANP, the logic is represented by the combined roles of: Service Provisioning and an SLS Request blocks at the client-side; SLS Request Handler and SLS Subscription Admission Control blocks as the server-side. The SP-CANP-SLS-P supports one of several negotiation actions: establishment/ modifications/ termination of SLS contracts.

The management system described is currently in the design phase in ALICANTE project. Validation and implementation results will be published in the near future.

VII. CONCLUSIONS AND FUTURE WORK

The paper proposed an architectural solution for connectivity services management, in Content Aware Networks for a multi-domain and multi-provider environment. The management is based on vertical and horizontal SLAs negotiated and concluded between providers (SP, CANP, NP), the result being a set of parallel VCANs offering different classes of services to multimedia flows, based on CAN/NAA concepts. The approach is to map the QoS classes on virtual data CANs, thus obtaining several parallel QoS planes. The system can be incrementally built by enhancing the edge routers functionalities with content awareness features. Further work is going on to design and implement the system in the framework of the FP7 research project ALICANTE. A preliminary implementation and performance evaluation will appear in [19].

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