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Inter-domain Peering and Overlay Topologies Support for Content-Aware Networks Dedicated to Multimedia Applications

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Abstract — **The Content Aware Networking (CAN) is an emerging architectural solution, responding to the significant increase in Internet content orientation. In particular media flows distribution can be well supported by virtual CAN oriented networks, aiming to control and assure the quality of services desired for such real-time services. In case of multi-domain spanning VCAN an inter-domain peering problem has to be solved, to create the VCAN overlay. This paper is a continuation of a previous work and refines a management framework for inter-domain peering in overlay VCAN, QoS enabled, built over multi-domain and multi-provider IP networks. An overlay inter-domain topology service and negotiation protocols are defined in this paper, based on cooperation of the CAN Managers belonging to network domains. Alternative solutions are proposed for VCAN topology creation and their usage is outlined. The scalability and efficiency is preliminary analyzed.**

Keywords — Content-Aware Networking, Network Aware Applications, Multi-domain, Inter-domain peering, Management, Multimedia distribution, Future Internet.

I. INTRODUCTION

The current Internet limitations are recently recognized, related to the increasing needs of today world and the global spread of this technology. Intensive research efforts are spent in order to find some enhanced architectural solutions or "clean slate" ones, to solve the limitations thus leading to the Future Internet (FI) architectures. Sample of works are presented in [2]-[8][14]. The work [14] emphasizes the strong orientation of the FI towards content and services and shows the importance of management. Network virtualization is seen as an important "tool" to overcome the ossification of the current Internet [2]-[5]. The overview paper [6], identifies the inefficiency of the current Internet for content delivery and analyses new solutions based on *Content Oriented Networking* (CON) with decoupling of content and location identification at networking level. A major idea in recent proposals is the shift from the traditional TCP/IP stack concepts, based on traditional IP network layer to more sophisticated solutions that insert more intelligence in the network nodes. The new network nodes will process the data packets/content_chunks, based on *content type* recognition or, even more, treating the data objects based on their *names* and not as in traditional TCP/IP stack, i.e., based on *location address*, [6][7]. The TCP/IP stack is changed, in the sense that IP is no longer the thin waist, of the stack [7]. Thus the routing and forwarding paradigms are significantly changed being based on *content names* rather than on destination *IP address*. Also caching content will be available in network nodes, thus giving the possibility to have the content replicas closer to the requester and so, shorter routes between content sources and consumers.

The revolutionary approaches are often referred to as *Information-Centric Networking (ICN)*, which is used as an umbrella term for related concepts such as *Content-Oriented Networking (CON)* and *Content-Centric Networking (CCN)*, [5][6][7][8]. Apart from novel from routing and forwarding functions, the ICN routers have caching capabilities, [7][9], thus shortening the paths between content sources and consumers. These and other reasons (not detailed here), lead to the conclusion that ICN/CCN/CON approach has some strong open issues related to scalability, security, etc. and also needs significant changes of the current Internet deployments and protocols. Last but not least, the complexity of this approach makes necessary to apply autonomic management principles as described in [10].

Therefore, still evolutionary (or incremental) other approaches have been developed in parallel, such as *Content-Aware Networking (CAN)*, which aim to create a *content - awareness* by building upon existing Internet network layers. The new concept actually has two aspects: the *Content-Awareness at Network* layer (CAN) and *Network-Awareness at Applications* layers (NAA). These evolutionary solutions are hopefully offering a better support to the development of the networked media systems and also to the market orientation towards content, while being open to future migration to full ICN/CCN. The CAN/NAA approach is claimed by many studies to bring new benefits for both, Service and Application Layer and Network layer, thus creating a powerful *cross-layer optimization loop* between the transport and applications and services layers, while still allowing a seamless deployment. The network service can better adapt itself to the content which is transported, while the applications and services may take benefit from (limited) information about the network service.

A CAN/NAA architecture has been proposed in the European FP7 ICT running research project, "Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", ALICANTE, [11][12][13]. It defined an architecture, and then specified designed and now is currently implementing a Media Ecosystem, on top of multi-domain IP networks, aiming to offer a large variety of services for different business actors playing roles of consumers and/or providers. Architecturally, this is a "middle-way" solution: it adopted content-type recognition at network level and light virtualization (separation in the Data Plane of the virtual VCANs but has defined a single management and control plane). This solution offers seamless deployment perspectives and tries to avoid the scalability problems of the full ICN/CCN/CON approach.

Several cooperating environments are defined, including several 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. By "environment", it is understood a generic grouping of functions working for a common goal and which possibly vertically span one or more several architectural (sub-) layers.

A Virtual Content Aware Network - VCAN as assumed in this study is *media oriented* in the sense that the network services offered by this *logical data plane* to the upper layers are optimized for media flows requirements expressed by the Service Provider. However regular IP traffic can be as well accepted. A VCAN can span several network domains, where each one is managed independently (a realistic business constraint), while offering different levels of QoS guarantees for media flows needs. Therefore decision regarding the architecture has to be taken, on how to manage the peering, first at the level of the *Data Plane* (including inter-domain routing) and second, in the *Management and Control Plane* (M&C signaling) in order that they cooperate to the realization of a shared VCAN. This is the subject of this paper. Several solutions are analyzed for Management&Control Plane (*cascade, hub, mixed*) and finally the so called "hub model" has been selected. A M&C negotiation protocol is proposed to run between domain managers. The scalability aspects are preliminary discussed.

The Content Aware Network Provider offers to the upper layers enhanced VCAN-based connectivity services, unicast and multicast (QoS enabled) 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. The management is based on vertical and horizontal Service Level Agreements (SLAs) negotiated and concluded between providers (e.g., Service Provider-Content Aware Network Provider). 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.

The multimedia hifgh level services for which such a system can be used as platform are mainly related to content distribution in real and non-real time (Video on Demand streaming, IPTV, etc.) with several level of QoS guarantees at Service Provider requests. The VCANs are custotized for a given content type.

In [1] an overlay inter-domain topology service and negotiation protocols are defined to serve the multi-domain VCAN mapping. It was based on cooperation of the CAN Managers belonging to network domains. The paper [15] studied the mapping the overlay VCANs onto real network resources in a multi-domain context, while satisfying QoS constraints. In that approach the VCAN resources are first logically reserved; later when installation is requested by the SP, they are really allocated in routers. A basic mapping algorithm has been developed.

This paper integrates the results of the previous work [1][15], and brings additional contributions. It refines further the management framework for inter-domain peering in overlay VCAN, QoS enabled, built over multi-domain and multi-provider IP networks. A new variant with global optimization is proposed as different from the basic mapping algorithm presented in [15]. The one-step solution and two step solution for VCAN mapping algorithm are compared and experimental results are presented. Implementation results of the combined algorithm (constrained routing, admission control, QoS reservation and final VCAN mapping) are presented. Scalability is also discussed.

The paper is organized as follows. Section II presents additional samples of related work. Section III recalls the overall architecture. Section IV shortly presents the content awareness features of the system and QoS assurance solutions. Section V is dedicated to the peering solution selected and associated negotiations aiming to extend a VCAN over several domains. Section VI discusses variants of solutions in terms of complexity, scalability and other considerations. Section VII shows how the overlay topology is used in VCAN mapping, and experimental results are presented and discussed. Section VIII contains conclusions and future work outline.

II. Other Related Work

The objective of the paper is to develop management solutions to govern the construction of Virtual Content Aware Networks, QoS spanning several independent network domains which should be peered aiming to assure guaranteed QoS enabled transport of real-time and media traffic.

For inter-domain QoS enabled domain peering, there exist basically two kinds of approaches. The first one

[16][17], proposes QoS enhancements for the Border Gateway Protocol (BGP). The BGP advertises QoS related information between network domains – seen at limit as autonomous systems (ASes), and then a QoS aware routing table is built. However, the notion of content awareness at domains level is absent there.

The work [18] discusses creation and routing of/in Content Addressable Network Virtual Topology which is a partially similar with our idea to extend the inter-domain network matrix in a new one with few intra-domain details. They pick a uniform hash function that maps an object to a point in $[0,1]^d$. They divide the d-cube into zones and assign a node to a zone and store (object, location) pair in the zone that owns the zone for the hashed value of the object. The neighbors of a zone are defined as those nodes whose zones overlap over d-1 dimensions. If a node i wants to find out where object j is stored, it computes h(i) and then sends a lookup message to its neighbor that is closest to h(j); this continues until the message reaches the node that owns h(j); it then returns the location for object j.

Boosted by the increasing demand for multimedia applications over Internet, the problem of finding routing paths satisfying QoS constraints has been extensively studied by the research community. Representative examples of such QoS constraints are related to bandwidth, delay, jitter and packet loss [19]. Even if the e-2-e delay is often a metric of interest for multimedia content distribution the authors from [19] prefer to minimize delay, maintaining only optimal rate. They proposed an overlay model that represents the real network topology; essentially, it is a regular overlay graph, except the links are not weighted by numbers; instead, the link capacities are variables, and a set of linear capacity constraints express the constraints placed on overlay links by shared bottlenecks. In their model, every node selects d neighbors to which it has links with the highest bandwidth. In a similar mode of establishing the bandwidth capacity uploaded Intra-NRM (Intra-Network Resourge Manager) to its associated CAN Manager (CANMgr) for each asked domain, in [19] is used a term of predicted bandwidth. In their work, the highest-bandwidth multicast tree is obtained by a greedy algorithm modified to take linear capacity constraints into consideration.

We have to note that the acronym CAN might create confusion, given that it is used in different texts with several semantics. As an example, the paper [20], introduces the concept of a *Content-Addressable Network (CAN*) as a distributed infrastructure that provides hash table-like functionality on Internet-like scales. It is shown that the CAN is scalable, fault-tolerant and completely self-organizing. However the *Content-Aware Networks* concept considered here has not as fundamental property the addressability based on content names but the adaptation of the transport characteristics to the type of content, mainly in order to assure the required quality of services.

Other solutions for inter-domain QoS peering and routing are based on the overlay network idea [21][22][23][24]. An overlay network can be defined, which first, abstracts each domain with a node, represented by the domain resource manager, or more detailed with several nodes represented by the ingress-egress pair routers from that domain. There exist protocols to transport QoS and other information between nodes and, based on this information, QoS routing algorithms are used to choose the QoS capable path. In [21] a *Virtual Topology (VT)* is defined by a set of virtual links that map the current link state of the domain without showing internal details of the physical network topology. Then *Push* and *Pull* models for building the VT at each node are considered and analyzed. In the *Push* model each AS advertises its VT to their neighbor ASes. This model is suited for small topologies. In the Pull model the Virtual Topology is requested when needed, and only from the ASes situated along the path between given source and destinations; the path itself is determined using BGP.

After routes are found, a negotiation protocol should be run [1][15][23], to establish inter-domains Service Level Specification (SLS) agreements (note that the SLS is the SLA technical part) containing the reciprocal commitments of the parties and in particular clauses for QoS guarantees.

The inter-domain peering in the management and control plane is related on what topology the domain mangers discuss with each other. Several solutions are examined and compared (cascade, hub, mixed-mode) [21][22][23]. However, neither solution considers the content awareness capabilities of the multiple domain infrastructure, nor the virtualization aspects. This paper takes these into account. The architecture proposed here realizes parallel Internet planes as in [25], but additionally associates to each plane a VCAN (Virtual Content Aware Network). Over the overlay topology determined, VCANs will be mapped and then finally the VCANs are mapped onto real network links. This achieves cooperation between the network layer and applications and services layers, thus realizing a powerful optimization loop (OL), similar to [26].

III. ALICANTE System Architecture and VCAN Management

A. General Architecture

The general ALICANTE architecture is already defined in [11][12][13]. A set of business actors is defined, composed of traditional Service Providers (SP), Content Providers (CP), Network Providers (NP) and End-Users (EU). New business actors are introduced: CAN Provider (CANP) offering virtual layer connectivity services and the Home-Box (HB) - partially managed by the SP, NP, and the end-user. It is 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 *Content Aware Network layer* and the *Home Box 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 Management & Control Plane is partially distributed; it supports CAN customization to respond to the Service Environment needs, including: topology, different communication modes like unicast, multicast, broadcast, or even peer-to-peer (P2P), traffic control and QoS constraints, etc. and also allows efficient network resource exploitation. The interface between CAN and the upper layer supports *cross-layer optimizations* interactions in several ways: dynamically provisioning and modification of VCANs as to serve several SPs requirements (only this is the subject of this paper); individual or aggregated media flow adaptation to the current network conditions and terminal context based on Scalable Video Codec technologies; may offer network distance information to Home Boxes to improve their collaboration in P2P style, [26]. A hierarchical monitoring subsystem supervises several points of the service distribution chain and feeds the adaptation subsystems with appropriate information, at the Home Box and Content Aware Network Layers. Fig. 1 presents a partial view of the ALICANTE architecture, with emphasis on the CAN layer and management interaction. The network contains several Network Domains (ND), belonging to NPs (they can be also seen as Autonomous Systems - AS) and access networks (AN).

Note that the Access Networks (AN) are out of scope of VCANs. This decision has two reasons: the access technologies are numerous, with more or less well defined resource management; the scope of the ALICANTE project has been initially and intentionally limited to core network only.

One *CAN Manager* (CANMgr) exists for each IP domain to assure the consistency of VCAN planning, provisioning, (based on negotiation), offering, installation, exploitation termination and advertisement. Each domain has an *Intra-domain Network Resource Manager* (IntraNRM), as the ultimate authority configuring the network nodes. The Content Aware Network layer cooperates with Home Box and Service Environment by offering them CAN services. This solution associates a Content Aware Network Provider component to each Intra-Network Resource Manager component and gives the possibility to an Intra-NRM to upgrade its functionality and become CANP.

B. VCAN Management

The Virtual Content Aware Network Management framework has been already defined in [11][12][13]. Here only a short summary is recalled for the sake of clarity.

Several design decisions among several solutions, have been taken as a trade-off between complexity, optimality and scalability. Some details on the selection are given in the corresponding sections.

- M&C plane and virtualisation degree: light virtualisation (separate virtual Data Planes only); Full virtualisation (all virtual Planes, i.e., Data, Management and Control are separate).

Decision: the light virtualisation model based on a single management and control plane has been adopted in ALICANTE, given less complexity, seamless development capabilities in real networks and still possibility to offer good transport services for media flows.

- Relationships between Content Aware Network Provider (CANP) and Service Provider (SP) concerning the VCAN services : Static SLA between CANP and SP; Dynamic SLA between CANP and SP:

Decision: Dynamic SLA, aiming at higher flexibility and dynamicity

- Multiple domain capable VCANs – establishment procedure : each CAN Manager manages only one VCAN spanning a single domain; any CAN Manager can initiate and coordinate multi-domain capable VCAN construction

Decision: second choice, given the flexibility

- Support of Content-awareness provided by SP to the CAN layer : CAN layer does not get any support information on content provided by SP; CANP gets content related information from SP via the control plane; SP provides content related information via the control plane and data plane

Decision: all three are adopted to get flexibility. If no information on Content Awareness (CA) from SP, then CAN layer is free to choose its own degree and behavior – related to CA, and therefore selects the methods to enforce CA in the VCANs.

- Inter-domain negotiation style between CAN Managers for multi-domain VCANs establishment: hub Model; cascade/mesh model;

Decision: Hub model, given more control on the VCAN for the initiating CAN Manager

At the Service Manager SM@SP, the CAN Network Resources Manager (CAN_RMgr) performs all actions needed for VCAN support on behalf of SP. It performs, at SP level, *VCAN* planning, provisioning (negotiation with CANP on behalf of the SP) and then VCAN operation supervision. The *CANMgr@CANP* performs, at the CAN layer, VCAN planning, 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 contracts/interactions of SLA/SLS types performed in the M&C Plane are shown in Fig. 1. The management interactions are described as follows*:*

(1) SP-CANP: the Service Provider (SP) requests to CAN Provider (CANP) to provision/ modify/ terminate VCANs to which the CANP will finally say yes/no; also CANP might advertise existent VCANs to SP; Actually the CANP is represented by a single CAN Manger which is the initiator of the VCAN construction. The role of an initiator can be played by any CAN Manager.

(2) CANP-NP: CANP negotiates resources with NP;

(3) CANP-CANP– negotiations are needed between CAN Mangers if the VCAN spans several NP domains;

(4) Network Interconnection Agreements (NIA): between the Network Providers or between NPs and CANPs; 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 Intra-NRM (action 5), the MANE (Media Aware Network Element) functional blocks (input and output).

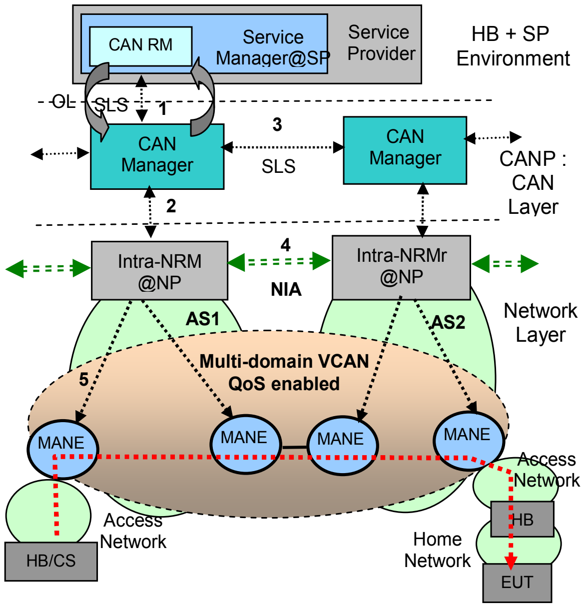

Figure 1 High level ALICANTE architecture: multi-domain VCANs and main management and control interactions

Notations: OL - Optimization Loop; SLS – Service Level Specification; NIA - Network Interconnection Agreement; RM – Resource Management; SP – Service Provider; CANP Content Aware Network provider; NP - Network Provider CS- Content Server; Intra-NRM – Intra domain Network Resource Manager; HB-Home Box; EUT- End User Terminal; MANE – Media Aware Network Element ; AS – Autonomous System

IV. CONTENT AWARENESS AND QOS AT CAN LAYER

The Content Awareness (CA) is realized in three ways:

(i) by concluding a SLA between the Service Provider and CAN provider (SP –CANP) concerning different VCAN construction. The Content Servers (CS) are then instructed by the Service Provider to insert (if they are able to do it) some special *Content Aware Transport Information (CATI*) fields in the headers (e.g in the Real Time Protocol header)of the data packets. How to optimize this insertion is not in the scope of this paper. This CATI simplifies the media flow classification and treatment by the MANE;

(ii) SP-CANP SLA is concluded, but no CATI can be inserted in the data packets (this is the case of legacy Content Servers). The MANE applies *deep 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. However, the flows treatment can still be processed in content aware style, but conforming to the local policy at CANP and IntraNRM.

The networking technologies to support QoS enabled VCANs are DiffServ and/or MPLS. The sets of flows are splitted in QoS classes (QC), with a mapping between the VCANs and the QCs. Several levels of QoS granularity can be established when defining VCANs. The QoS behavior of each VCAN (seen as one of the parallel Internet planes) is established in the SP-CANP SLA contract.

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 CAN Provider, by combining several processes, while being possible to choose different solutions concerning routing and forwarding, packet processing, and resource management.

The definitions of local QoS classes (QC) and extended QCs and meta-QoS classes were adopted in ALICANTE, [16][17][23][25] to allow capturing the notion of QoS capabilities across several domains. Each domain may have its local QoS classes and several local QCs can be combined to form an extended QC. The types of VCANs defined for different QoS granularities based on QoS Classes are VCANs based on meta-QCs [16], VCANs based on local QC composition and hierarchical VCANs based on local QC composition. The last case is the most efficient but also the most complex. Inside each VCAN, 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.

The definition of QoS classes makes the system robust to traffic overload with protection of desired flows against such overloads. Actually the QoS support for the real-time traffic in the VCANs are assured by :

- QoS constrained routing and logical reservation of traffic trunk pipes (provisioned at SP request);
- installation of them in the network (unicast or multicast mode);
- traffic enforcing rules in the Data Plane.

For unicast VCAN the supporting QoS technology is MPLS cooperating with Differentiated Services (E-LSP solution). For multicast case QoS constrained trees are computed, resource reservation is done and then in the Data plane Diffserv is enforced.

V. CAN Multi-Domain Peering

A. Horizontal M&C VCAN Negotiation

A given VCAN may span one or several IP domains. In a multi-domain context, one should distinguish between two topologies (in terms of how the domains are linked with each others): *Data plane topology* and *Management&Control plane (M&C) topology*. The first can be of any kind (depending on SP needs and including the domains spanned by a given VCAN). In a general case, one may have a mesh/graph of domains. The *M&C topology* defines how the CAN Managers associated to different domains inter-communicate for multi-domain VCANs construction. The VCAN initiating CANMgr has to negotiate with other CAN Managers. There exist two main models to organise this communication at management level: *hub* model and *cascade* model, see [16][17][23][25].

The *hub model* was selected for this study; it has the advantage that initiating CAN Manager(CANMgr) can know, each VCAN component (network) and its status. A drawback is that each CAN Manager should know the inter-domain topology (complete graph) of network domains. They could be of lower tier grade or be Autonomous Systems (AS), involved in a VCAN. Given the tiered hierarchy of the Internet, the number of Network Domains (ND) involved in an E2E chain is not too high (actually is lower than 10, [8]), scalability problem is not so stringent. Two functional components are needed: (1) inter-domain topology discovery protocol; (2) overlay negotiation protocol for SLA/SLS negotiations between CAN Managers.

The *cascade* model, [17][23] is more advantageous for initiating CAN Manager if a chain of domains is to form the VCAN. However, for an arbitrary mesh topology of the NDs composing the VCAN, and for multicast enabled VCAN, this model offers less efficient management capabilities.

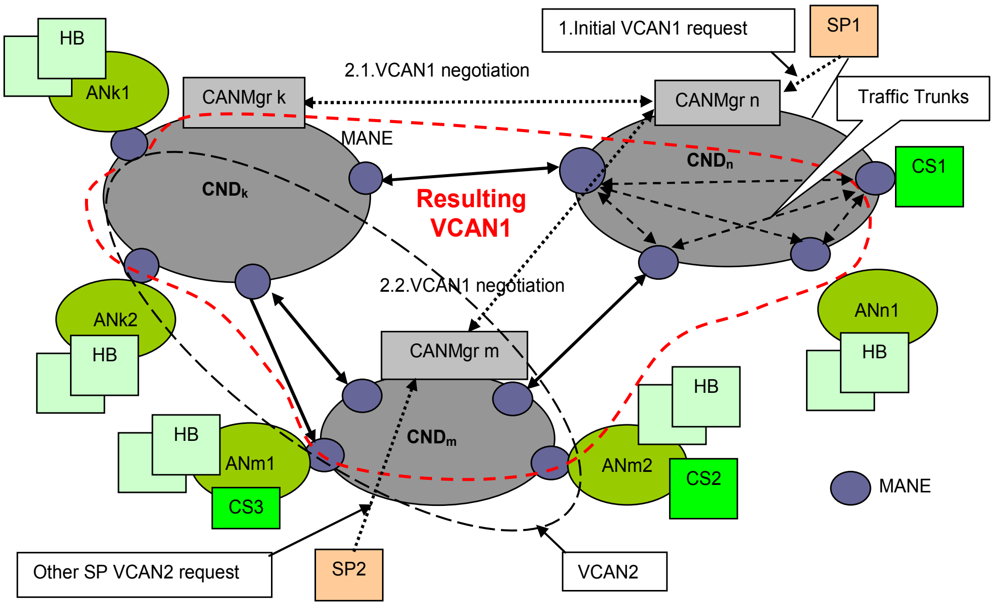

Figure 2 Example of multi-domain VCANs and negotiation signalling for VCAN1(hub model for management plane)

SP – Service Provider; HB - Home Box; CS - Content Server; CND – Core Network Domain; CANMgr – CAN Manager VCAN – Virtual Content Aware Network – logical virtual plane; AN – Access Network; MANE – Media Aware Network Element ;

Fig. 2 shows an example of a multi-domain infrastructure and two VCANs, i.e., VCAN1 and VCAN2. It is supposed that the inter-domain discover protocol has already produced its results, so each CAN Manager knows about the inter-domain graph and have inter-domain routing information, including link capacities and QoS related capabilities. The SP1 asks for a VCAN1 to a CANMgr (Initiator) – see action 1. It was supposed that the SP knew the edge points of this VCAN1, i.e., the Media Aware Network Elements IDs where different sets of HB currently are, or they will be connected. The initiator *CANMgr_n* determines all network domains (ND) involved (from the SP information and its inter-domain knowledge). The initiator CANMgr splits the overall SLS parameters (the VCAN1 is multi-domain), e.g., determining ingress-egress points, bandwidth, delay, etc. needed for each domain. Then the initiator CAN Manager negotiates in parallel with all other CAN Managers (actions 2.1, 2.2) to establish the VCAN1 = {VCAN1n U VCAN1m U VCAN1k}, where the three components are mapped onto the networks CNDn, CNDm, CNDk. In a successful scenario, the multi-domain VCAN1 is agreed and then it is later instantiated in the network.

The system allows several Service Providers, each one may ask one or several VCANs. In Fig. 2 it is given an example of SP2 wanting a VCAN2 spanned over CNDk, CNDm.

B. *Overlay Virtual Topology*

Constructing VCAN over one or multiple domains is one of the main task of the CAN Manager. Each Core Network Domain (CND) has complete autonomy w.r.t. its network resources including network dimensioning, off-line traffic engineering (TE), and dynamic routing. The Content Aware Network Manager (CANMgr) cooperating with Intra-Network Resource Manager (Intra-NRM) is supposed to know about its network resources.

Given that in ALICANTE each CND has associated the Intra-NRM and CANMgr, one could abstract both under the name of Network Domain Manager (NDMgr). This entity should have an abstract view of its network domain and output links towards neighbors in a form of a set of virtual pipes (called *Traffic Trunks*). A set of such pipes can belong to a given QoS class. As already stated, a multiple domain VCAN should also belong to some QoS class and therefore inter-domain QoS aware routing information is necessary in order to increase the chances of successful SLS establishment, when negotiating the multi-domain VCAN. The multi-domain VCANs deployment needs knowledge on a virtual multi-domain topology.

Each Core Network Domain (CND) can assure QoS enabled paths towards some destination network prefixes while implementing its own network technology: DiffServ, MPLS, etc. Also, each CND can be seen in an abstract way as an *Overlay Network Topology (ONT)* expressed in terms of *TTs (traffic trunks)* characterized by of bandwidth, latency, jitter, etc. One TT is belonging to a given QoS class QCi.

We define an *Overlay Network Service (ONS)* responsible for getting the ONTs related to CNDs belonging to a multi-domain VCAN. The CANM Managers will then inter-negotiate the SLS contracts in order to reserve VCAN resources and finally ask installation of them. The overlay topology can be hierarchised on several levels.

Fig. 3.a presents a first level (inter-domain) Overlay Network Topology, in which, each domain CND is seen as a node. The overlay graph of the CNDs belonging to the VCAN is composed of the nodes CNDk, CNDn, CNDm. Then, a second order ONT can be defined for one CND. Fig. 3.b shows the ONT for the domain CNDk, composed of Traffic Trunks, each one characterized by a bandwidth and a delay. If the initiating CAN Manager knows the ONT graph of the CNDs involved, then provisioning of QoS enabled VCANs can be done.

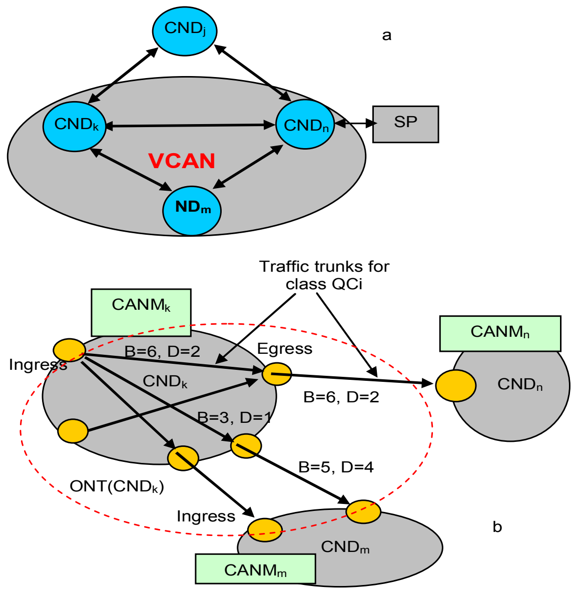

Figure 3 a. Inter-domain overlay network topology (ONT); b. ONT of the domain CNDk (B= bandwidth, D= max delay- generic figures)

The Overlay Network Service can collect the topology information in two ways (see also [21]): a *proactive* (*push*) mode and a *reactive* (also called *pull* or *on demand*) mode in order to obtain the overlay (virtual) topologies of other NDs.

In the *proactive case*, every CND advertises its Overlay Network Topology (ONT) to other CNDs without being requested for. The advantage is the same as in IP proactive routing protocols: the ONTs of other CNDs are already available at a given ND because they are periodically or event-triggered advertised among CND managers. The advertisement can be executed at an initiative of each CND manager, so this model allows promotion of some routes to other domains. This can be subject of policies. The dynamicity is high (event driven advertisements), but the complexity is also high. Scalability problems exist, because of high control traffic volume and also flooding the neighbor CNDs with (maybe) not needed information.

In the *reactive* (*on-demand*) mode the ONTs are obtained on demand by an Core Network Domain (CND) interested to reach a given destination prefix. The CND will query each domain of a given path to get the ONTs. No advertising mechanism is necessary. The scalability is higher because only the ONTs of the chosen routes will be obtained. Studies [8] show that the mean End to End (E2E) communication in the Internet usually involves few domains (less than 8). Therefore, the number of domains to be queried to obtain the ONTs is small. The pull model latency is higher (need time for queries and calculations). The updates of ONT knowledge is not event driven w.r.t. other CNDs, because lack of advertisements. For our purposes we have chosen the reactive model.

If a CAN Manager wants to build an ONT it will query its directly linked (at data plane level) neighbor domains (i.e., the corresponding CAN Managers). It is supposed that it has the knowledge of such neighbors. There are two possibilities of a query: *a. non-selective query/demand*- i.e., the asking CANMgr wants to know all neighborhood of the asked neighbors; *b. selective demand*- the asking CANMgr wants to know answers only from those neighbor domains which have paths to a given set of destinations.

1) Non-selective query

The interrogating CAN Manager receives from SP the IDs of the ingress-egress points of a future VCAN. So, it can determine to which domains it belongs (mapping details between Ingress-egress IP addresses and network domains are out of scope of this paper). Therefore the initiator CAN Manager can know which domains *must* participate to the VCAN. It should also determine what other transit domains also must participate. The process of topology discovery can end when a contiguous graph containing the "must" domain is obtained. Note that non-optimal solution can be obtained if the process is limited to a minimal graph containing the desired ingress-egress-points. The information on reachability of a given point from a domain can be obtained in two ways: by consulting a BGP data base, or based on interrogating the neighbors and so on, until information is obtained.

Example:

1. The SP issues a requests for VCAN (I1, O1, O2, O3) to CANMgr2, assume that this is the VCAN initiator (where Ik, k= 1,2, ….., On, n= 1, 2, … are the ingress and egress points of traffic flows (actually these are IP addresses of edge MANE routers).

2. CANMgr2 determines that CND1, CND4, CND5, CND6 *must* participate to the VCAN, because the ingress and egress points {I1, O1, O2, O3} belong to them.

Each queried CANMgr can return – in a first most simple approach only its list of neighbors. At receipt of such information, the interrogating CANMgr updates its topology data base.

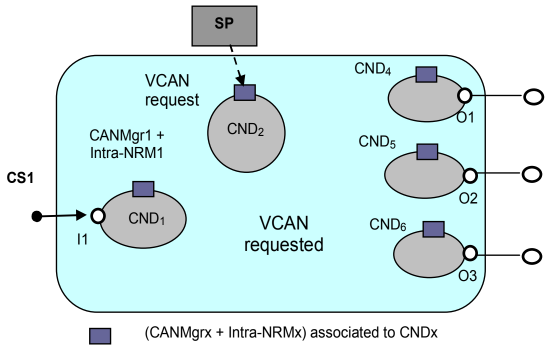

Figure 4 Example of a requested VCAN (I1, O1, O2, O3)

Then it queries the new nodes learned and so on. The process continues until the interrogating node CANMgr learns the whole graph of "international" topology of interest for it. How large is this network zone? The scope of such a zone can be limited by and determined in two ways: by local policies and by considering the request from SP for a given multi-domain VCAN.

Because the events that change the topology structure are not very frequent (hours, days, weeks, months), the topology construction process could be run at large time intervals (once per hour, for example). Consequently the amount of messages used to build the Overlay Network Topology will not overload significantly the network.

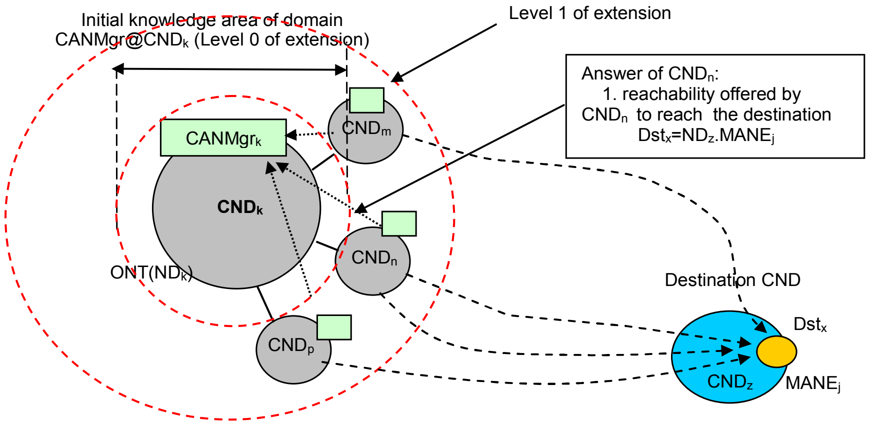

Figure 5 Different areas of ONT knowledge for NDk (Level 0, Level 1, …) in selective –query mode

2) Selective querry

The query process is similar, but the answers will be selective, i.e., , filtered conforming the required set of destinations. The area of knowledge desired by a given CANMgr can be also determined by the SP request (proposed VCAN span) and by local policies; it can be enlarged if needed. Fig. 5 shows such an area for two levels of extension.

We summarize the selected design decision- most appropriate to our objectives: *on-demand model based on overlay network topology service; based on non-selective* *and selective queries and simple answers (i.e., reduced ONT topologies obtained from the domains).* Advantages of this solution consist in less complexity, less overhead, and preserving privacy and autonomy of intra-domain routing information.

VI. VARIANTS OF SOLUTIONS AND SCALABILITY ISSUES

The complexity, scalability and signaling overhead of the inter-domain peering and ONT information collection depends also on the variants of the VCAN mapping. Even if the detailed discussion of the algorithm of VCAN mapping is not the objective of this paper, we present below some considerations on possible solutions. We consider the general case of multi-domain VCAN.

The VCANs should serve Fully Managed (FM), Partially Managed (PM) and Unmanaged Services (UM)- seen from the QoS level of guarantees, [11][12] point of view. The most demanding in terms of QoS are the FM services. Therefore QoS enabled routing is needed both intra and inter-domain. Given that QoS assurance is required the metrics used for network distances should reflect these requirements. Also constrained routing will be used in order to maximize the chances to successfully conclude the SLSes associated to VCANs.

A. One step VCAN Mapping

In this case the initiator CAN Manager completely maps a mono/multi-domain VCAN (requested by SP) onto the network infrastructure, by using the complete ONT represented as *Resource Availability Matrices* (RAM) (containing topologies + available capacities) *for both inter-domain and intra-domain.* The RAM is delivered to the CAN Manager by its associated *Intra-Network Resource Manager* (i.e., RAM is uploaded by the associated Intra-NRM, for its network domain) and other *CAN Managers* concerning the summary of available connectivity resources of the respective domains (Overlay Network Topology - ONT for each domain).The pros and cons in this case are:

Pros:

- Intra-NRM (Intra Network Resource Manager) is not requested to run mapping algorithms but only to dimension its network conforming local policies (more simple functioning);
- It is a more simple solution for unicast VCANs based on MPLS paths - e.g., Intra-NRM establishes a matrix of MPLS pre-provisioned paths, conforming its own policy and offers them to a CAN Manager in abstracted form as intra-domain ONT;
- The CAN (Content Aware Network) Manager has stronger control on VCANs. It can also run a global optimization algorithm when doing VCAN mapping.
- Optimal global solutions can be obtained in terms of resource reservation.

Cons:

- More complexity for the CAN Manager, given that it should collect the complete ONT and also run at inter-domain level the combined algorithm for QoS routing, Admission Control (AC), Resource reservation and VCAN mapping
- Higher signaling overhead;
- Periodic or event triggered or on-demand updates are necessary to refresh the CAN Manager knowledge on the network resources matrix for the network domain to which it is associated;
- Less dynamicity at network level: MPLS paths are pre-provisioned, before knowing the actual SPs requests;
- Not applicable solution for multicast enabled VCANs (i.e VCANs wher one has a tree of traffic trunks); the *intra-domain tree* should be constructed - *on demand* of the CAN Manger addressed to its associated Intra-NRM (the tree cannot be pre-provisioned) and mapped onto real network paths.

B. Two steps VCAN Mapping

The Initiator CAN Manger only collects the first level ONT, i.e., obtains a graph containing only the domains abstracted as nodes (see Fig. 3.a). So, the Intra-NRMs and consequently the other CAN Managers (apart from initiator) do not have to deliver to the initiator CAN manager any ONT. The initiator CAN Manager runs the VCAN mapping algorithm on a graph where each core network domain is represented as a node and the edges of the graph are inter-domain links. Then each Intra-NRM performs actually the mapping of VCAN requested resources on its network resource matrix (i.e., intra-domain ONT) for the part of VCAN spanning that domain, by running a similar algorithm.

Pros:

- Intra-NRM does not disclose to the CANP (Content Aware Network Provider) any intra-domain topology (neither detailed nor ONT) except the ingress and egress points; this is a good solution from business point of view;
- More scalable solution for both ONT topology determination and VCAN mapping algorithm based on two hierarchical levels: CAN Manager runs the combined VCAN mapping algorithm at inter-domain level for the first time. Secondly, the CAN Manager of each selected domain as being

part of the path will run again the algorithm for the intra-domain topology;

- Each Intra-NRM having total knowledge on its network resource matrix, runs the combined VCAN mapping algorithm at intra-domain level;
- Suitable solution for multicast capable VCANs (the mapping of the tree onto networks paths is done by the Intra-NRM on demand from CAN Manager and not provisioned in advance;
- More simple solution for CAN Manager in terms of algorithm complexity;
- Less amount of signaling between CAN Managers.

Cons:

- No global optimisation of the multi-domain multicast tree is assured, given that selection process of the inter-domain path does not consider any information boaut6 so0me possible intra-domain bottlenecks;
- Overload of the Intra-NRM with VCAN mapping algorithm;
- Need to establish dynamically MPLS paths - so more complexity (Label distributiuon protocol is needed).

Considering the *pros* and *cons* of the above solutions, we adopted both of them have been: the first solution for unicast VCANs (one level mapping algorithm running at CAN Manager level) and the second solution for multicast VCANs (two levels - combined algorithm).

C. Summary of VCAN Mapping Solutions Selection

For *inter-domain routing,* a combined algorithm and protocol is proposed to perform jointly *QoS routing, admission control, VCAN mapping and logical resource reservation*, while using the multi-domain graph of the network, available resources (per QoS class) containing the following information: topology, where a domain will be represented as: a node – for unicast/MPLS VCANs; - summary of ONT (Overlay Network Topology) for multicast VCANs; - link capacities for each edge of the graph. For *intra-domain routing* the same combined algorithm and protocol is proposed but only for multicast VCANs, while using the intra-domain graph of the network (per QoS class), containing the following information: intra-domain topology; link capacities for each edge of the graph.

Specifically we have:

Unicast VCANs (mono or multi-domain), supported by MPLS provisioned paths at each network domain level: one level planning and VCAN mapping performed at CAN Manager based on applying the combined algorithm on an inter-domain graph composed of inter-domain links and summary of the domain topologies of the network domains (delivered as RAM – Resource Availability Matrix by Intra-NRMs) to the CAN Manager.

Multicast VCANs (mono or multi-domain), supported by hybrid multicast trees: a hierarchical two-levels approach for VCAN mapping onto multi-domain network infrastructures. The two levels are: inter-domain VCAN mapping, intra-domain VCAN mapping.

D. Routing Metric

A QoS constrained routing is performed over the ONT. A combined metric was proposed [15] for a link, considering the bandwidth request, the bandwidth available, targeting to choose the widest path. The cost of an inter-domain link (i,j) in the ONT can be *C(i,j) = Breq/Bij* , where Bij is the available bandwidth on this link. Note that this cost is not a static one: it depends on the amount of requests and on the capacity available on the link for that class of service .

The simplest cost of the full path will be: *Sum (link costs).* Additionally one can use*: Sum (link costs) * NHF (path)* where Number of Hops Factor NHF (path) is a weight factor approximately proportional to the number of CNDs crossed by this path. This solution will try to reduce the number of transited domains.

The ratio also can be interpreted as link utilization factor; that is why an alternative notation can be used: C(i,j) = U_{link_ij}. The constraint is: *(Breq/Bij < 1).* Therefore in each action of path search the branches not satisfying this constraint should be not considered.

VII. COMPUUTATION AND USAGE OF THE OVERLAY TOPOLOGY TO MAP VCANS

A. Operational Phases

This section describes how the overlay topology information is used to map the multi-domain VCANs. The VCAN mapping algorithm is actually a combined one, making jointly a *QoS routing*, *admission control* (considering the bandwidth requests of the SP), *resource reservation* for virtual paths and *VCAN mapping* on these paths. For details of this algorithm one can consult [15]. In order to be more specific the example presented in Fig. 4 is considered.

Supposing that the VCAN initiator CAN Manager learned the inter-domain overlay network topologies (ONT) and inter-link capacities, it can negotiate with SP an SLS contract and to conclude this contract it has to try to map VCANs onto network resources. The VCAN mapping can be done on a single level (jointly inter and intra-domain) or separately on two hierarchical levels: inter-domain and intra-domain. We present here the first solution , i.e., single level VCAN mapping.

We suppose the initiator CAN Manager has knowledge on ONT as presented in Fig. 3.a, i.e., it knows the graph of inter-domain topologies but it does not know anything about intra-domain traffic trunks.

The VCAN mapping problem is the following: given an inter-domain graph and a Traffic Matrix (TM is contained in the SLS produced by SP), how to map the TM onto real network graph as to respect some minimum bandwidth constraints and also optimize the resource usage. The simplest form for TM is expressed as a matrix having entries {(input, output, bandwidth) ….} for different traffic trunks belonging to the desired QoS class. Note that in a more complex approach several QoS parameters can be considered, e.g., delay, but here we treat the simplified case of only capacity (bandwidth).

We continue the example given in Fig. 4. It is supposed that the desired VCAN has a tree topology. We assume that steps 1 and 2 have been already performed. The following steps follow, ending with a complete VCAN mapping onto real network topology.

3. CANMgr2 (knowing the inter-domain graph) determines that Core Network Ddomain1 (CND1), ..CND6 should participate to VCAN. In particular it adds CND3 to the list in order to reach CND6
As a result, CANMgr2 knows an abstracted graph as in Fig. 6.
4. CANMgr2 determines possible input points and output points (border routers I/Fs IDs) for each domain by using the inter-domain graph. Note that it does not know yet the inter-domain paths. Several solutions might exist. Fig. 7 shows this graph.

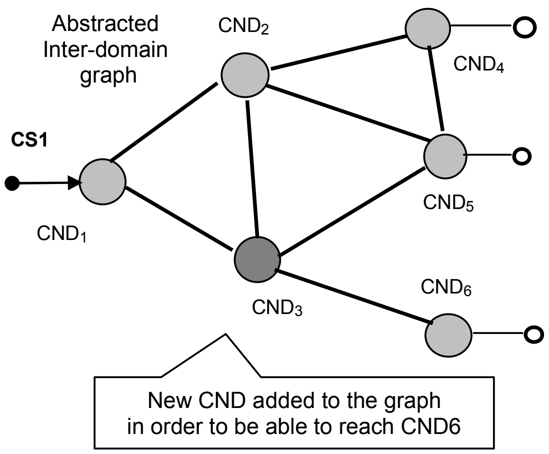

Figure 6. First abstraction of an inter-domain graph determined by CANMgr2 able to realise VCAN spanning

5. CANMgr2 asks the ONT information from each domain in the form of Resource Availability Matrix (RAM). The paramters of the requests have entries like (input, output, bandwidth) for all ingress-egress pairs of points of that domain. This RAM returned is actually the summary overlay topology and capacities of each domain. In this way each domain has not to disclose its actual topology and capacities to a third party.

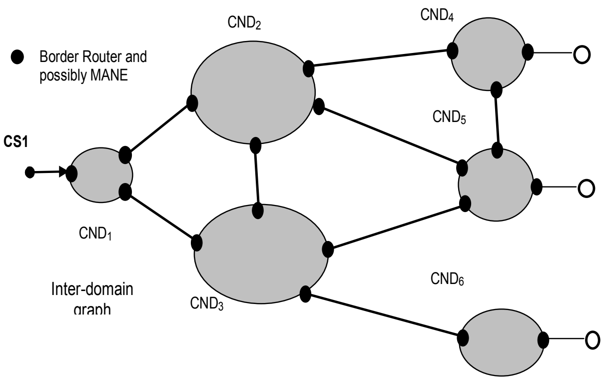

Figure 7 Inter-domain graph known by CANMgr2 with ingress-egress points specification

6. CANMgr2 receives the ONTs and capacities, i.e., the RAMs from all CANMgrs and its Intra-NRM and constructs a detailed graph of available links.
Note 1: that each domain is free to return whatever RAM is wants depending on its own policy. This process is depicted in Fig. 8.
Note2: the CANMgrx does not know yet the capacities needed by VCAN initator, simply because CANMGr2 does not know yet what to request from CANMgrx. CANMgr 2 only asks for RAM.
7. CANMgr2 computes (modified and combined algorithm based on Dijkstra one) and determines VCAN mapping and the allocation of resources (Fig. 9).
8. CANMgr2 communicates back to each CANMgr and also to its Intra-NRM what resources have been used on intra-and inter-domain links.
9. Each CAN Manager communicates to its Intra-NRM what resources have been booked as reserved, on behalf of this domain.
10. Each CAN Manager and Intra-NRM map internally the portion of the VCAN on some real network paths (e.g., MPLS label switched paths. Note that the solution already exists because at step 5 the RAMs expressing the internal ONT of the domain) have been communicated to the initiator VCAN manager.
11. The RAMs are adjusted accordingly at each domain.
12.The new VCAN is registered in all Data Bases of different CAN Managers.
13. Confirmations are returned to the CANMgr2.
14. CANMgr2 registers this VCAN in its Data Base.
15. CANMgr2 returns response to the Service Provider.

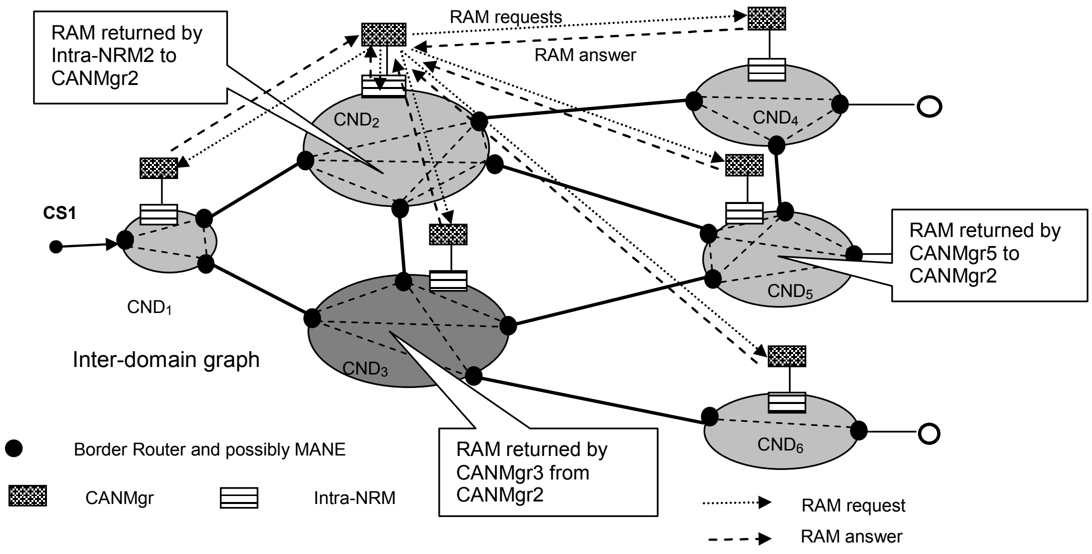

Figure 8 CANMgr2 collects the internal ONT from other CAN Managers by issues RAM requests and getting answers

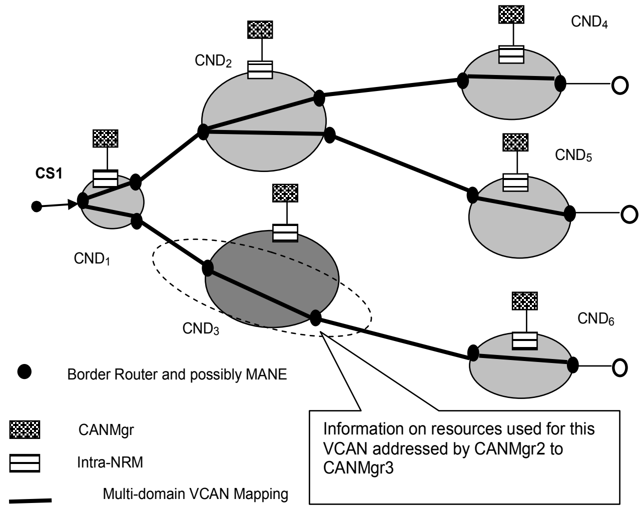

Figure 9 Computed VCAN (tree in this example)

B. VCAN Mapping Algorithm Implementation and Experiments

This section presents an implementation variant and then some numerical examples and experimental results for the procedure proposed in the above sub-Section A.

The VCAN mapping algorithm has been implemented in C, using Visual Studio C++ Express Edition as development environment. The hardware platform used, relevant for the obtained results (especially the average processing time), is a device equipped with Intel(R) Core(TM)2 CPU T5600@1.83GHz processor and 2,00 GB installed memory (RAM) on a 32-bit OS.

A complete implementation of the CAN Manager and Intra-domain Network Resource Manager and Servcie Provider software are currently in progress and detailed results will be reported soon.

The multi-domain network is supposed to contain several Core Network Domains CND A, CND B, .. CND F.

The Initiator CAN Manager is supposed to collect the overall ONT composed from inter-domain and intra-domain parts (steps 2-6). Note that in this example to keep it simple, we did not specify exactly who the initiator CAN Manager is. Actually it can be any of them.

Initially the first level inter-domain abstracted ONT (Overlay Network Topology) is collected – expressed in a graph containing only the domains (abstracted as nodes) and inter-domain link capacities (similar to Fig. 6). Then after finishing step 6 of the procedure the inter-domain graph plus each domain ONT is obtained (Fig. 9).

In this example, the first level ONT (image of the network graph) is presented in the Fig. 10 as a matrix M1 where A,B,C, ..F correspond to indexes 0, 1, 2, ..5 of rows and columns. To simplify the presentation, the numbers (entries) stand for generic bandwidth units (capacities) on the inter-domain links (a zero entry value means no link between the corresponding nodes). Here each domain is abstracted as node numbered with an index belonging to the set {0, 1, …, 5}.

$$M1 = \begin{matrix} 0 & 15 & 21 & 0 & 0 & 0 \\ 15 & 0 & 16 & 18 & 43 & 0 \\ 21 & 16 & 0 & 0 & 23 & 30 \\ 0 & 18 & 0 & 0 & 12 & 0 \\ 0 & 43 & 23 & 12 & 0 & 0 \\ 0 & 0 & 30 & 0 & 0 & 0 \end{matrix}$$

Figure 10 Inter-domain first level non-oriented graph (ONT) example represented as a matrix

After having the first image of the inter-domain ONT, the Initiator CAN Manger performs the steps 3-4-5-6 of the procedure. The result is getting a completed ONT collected from the CND A, …, F. The complete inter-domain graph is presented in Fig. 11, where the ONTs for the domains A, B, …, F are also represented (see step 6 in the procedure described in sub-section A).

In Fig. 11, the values attached to the middle of each link represent the segment capacity and the 1 to 6 numbers are the exit point's indexes from a CND (Core Network Domain). For example between CND B and CND D there is a link with 18 bandwidth units' capacity and the exit point from CND B is the one with no 4. The dotted lines inside each CND represent the ONT of each domain, i.e., Resource Availability Matrix - RAMs returned by each Content Aware Network Manger of the domains A, B, … to the initiator CANMgr. The continuous lines together with dotted lines form the complete inter-domain network graph where each domain is summarized by its ONT.

The graph of Fig. 11 can be represented as a matrix (Fig. 12) and this will be the input to the VCAN mapping algorithm. In the matrix the value 0 means no link between adjacent nodes and other value different from 0 signify that there is a link with the correspondent capacity.

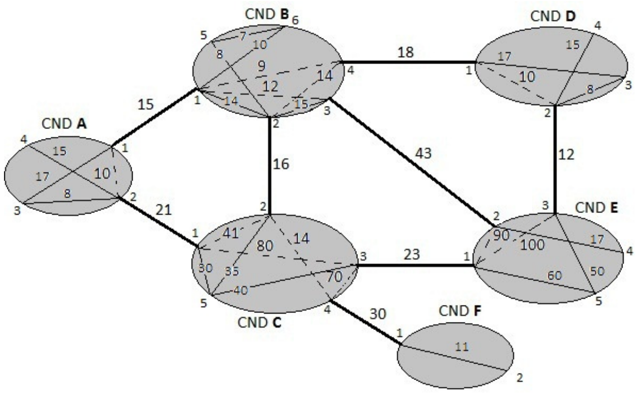

Figure 11 Inter-domain network graph (non-oriented) and summary of domains' ONT collected by the Initiator CABN Manger after finishing the step 6

M2		A		B				C				D		E			F
		A1	A2	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	E1	E2	E3	F1
A	A1	0	10	21	0	0	0	0	0	0	0	0	0	0	0	0	0
	A2	10	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0
B	B1	21	0	0	0	12	9	0	0	0	0	0	0	0	0	0	0
	B2	0	0	0	0	0	14	0	16	0	0	0	0	0	0	0	0
	B3	0	0	12	0	0	0	0	0	0	0	0	0	0	43	0	0
	B4	0	0	9	14	0	0	0	0	0	0	18	0	0	0	0	0
C	C1	0	19	0	0	0	0	0	41	80	0	0	0	0	0	0	0
	C2	0	0	0	16	0	0	41	0	0	14	0	0	0	0	0	0
	C3	0	0	0	0	0	0	80	0	0	70	0	0	23	0	0	0
	C4	0	0	0	0	0	0	0	14	70	0	0	0	0	0	0	30
D	D1	0	0	0	0	0	18	0	0	0	0	0	18	0	0	0	0
	D2	0	0	0	0	0	0	0	0	0	0	18	0	0	0	12	0
E	E1	0	0	0	0	0	0	0	0	23	0	0	0	0	90	100	0
	E2	0	0	0	0	43	0	0	0	0	0	0	0	90	0	0	0
	E3	0	0	0	0	0	0	0	0	0	0	0	12	100	0	0	0
F	F1	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0

Figure 12 The inter-domain graph (ONT) –used as input for VCAN mapping algorithm.

The detailed description of the VCAN mapping algorithm (combined QoS routing and reservation - proposed by the same authors) is not in the scope of this paper. For details one can see [15]. However, for completeness of the example presentation, a short description is given below.

The Service Provider request for a VCAN (Virtual Content Aware Network) can be expressed in the simplest form as a Traffic Demand Matrix (TDM) having entries (input_Id, output_id, bandwidth_requested). , i.e., source of request, the destination and the capacity requested.

The primary objective of the algorithm is to select paths based on the criterion *of largest capacity (bandwidth) possible* and then make resource reservation on those paths.

AS an example, Fig. 13 represents the Traffic Demand Matrix

$$\mathrm{Re}\, q = \begin{matrix} 1 & 12 & 5 \\ 4 & 15 & 7 \\ 8 & 11 & 9 \end{matrix}$$

Figure 13 Traffic Demand Matrix example

The indexes of the representation (A1, A2,…) correspond to the extended matrix (where the numbers 0, 1, 2, …, 15 represents A1, A2, …., respectively F1).

The results obtained after running the algorithm for M2 matrix are shown in Fig. 14, where the computation time, a total cost of the solution and the degree of request satisfaction is also presented.

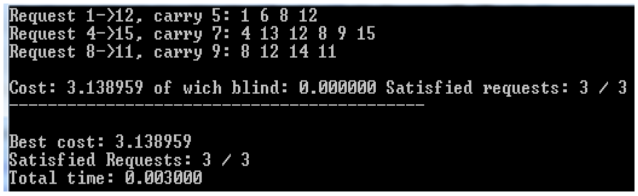

Figure 14 VCAN Mapping algorithm results – simple example

The VCAN system has been implemented as part of ALICANTE work and installed on a pilot testbed. It consists in three fully meshed core network domains, with all nodes as Linux routers (MANE routers and Core Routers in each domain). Each domain has a CAN Manager and and Intra-domain Network Resource Manager. The implementation is made in C under Linux, Unicast VCANs and multicast VCANs have been experimented and validated on this testbed. Results are already submitted to be published in additional papers.

The main blocks of the VCAN Manager implemnetd have been: CAN Planning, CAN Provisioning, CAN SLS negotiation Protocols, CANMgr interfaces – vertical and horizontal ones.

VIII. Conclusions and Future Work

The paper proposed a management solution for inter-domain peering, to support Content Aware Networks for a multi-domain and multi-provider environment. The management is based on horizontal SLAs negotiated and concluded between CAN providers (represented by CAN Managers) the result being a set of parallel VCANs offering different classes of services to multimedia flows, based on CAN/NAA (Content Aware Network/Network Aware Application) concepts. The inter-domain approach is to develop an overlay topology service to support VCAN construction, thus obtaining several parallel QoS planes. A CAN Manager is initiating the multi-domain VCAN realization by using the overlay topology service. Two solutions are proposed for topology collection in multi-domain environment: one and two steps. The optimization solution in one step is anew contribution of this paper. Pros and cons are discussed related to complexity, scalability, signaling overhead and business point of view and it is conclude that each solution can be better in some scenario: one-step solution for unicast VCDANs and two-step solution for muklticat VCANs.

A numerical example and samples of implementation results are given for the one-step algorithm.

Algorithm experimentation for large topologies is in progress and results are already submitted for publication.

The system is currently under complete design and implementation in the framework of the FP7 research project ALICANTE. Further validation and extensive performance evaluation results will be shown in a future work.

Acknowledgments

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