Resource Management in Multi-Domain Content-Aware Networks for Multimedia Applications

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***Abstract*—The significant orientation of the current Internet towards information/content determined the appearance of new solutions and concepts among which the Content Aware Networking is a significant one. Virtual Content Aware Networks (VCAN) constructed as overlays over IP network substrate is considered an efficient solution to incrementally introduce content awareness at network level. This paper continues a previous effort to define and develop a new framework for connectivity resources management in overlay VCANs, built over multi-domain, multi-provider IP networks. The VCANs are created and managed by novel business entities called CAN Providers and they offer enhanced connectivity services to high level Services Providers (SP), including unicast, multicast, and P2P in a multi-domain networking context. The paper develops the management system and procedures to negotiate and allocate the connectivity resources in different network domains, independently managed, but cooperating to create VCANs. 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; CAN 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, is to create virtualized *Content-Aware Networks* (CAN) and *Network-Aware Applications* (NAA) on top of the flexible IP [3][4][5][6]. 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] and is a continuation and extension of the work presented in [10] and [11]. 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.

Note that in this text the Service provider is actually a High Level Service Provider, offering high level services (Video on demand, VoIP, conference services, etc.). It is not mandatory the owner of the network and transport resources, but may uses such capabilities hired from the network owners named here Network Providers (NP). This approach defines a flexible business model. In practice the same commercial entity can play several roles (e.g. CP+SP+ NP), but they can be as well, separated.

We propose a new framework, for management of the resources necessary for connectivity services management in overlay VCANs built over multi-domain, multi-provider IP networks. The VCANs are created and managed by a CAN Provider (CANP), at the request of high level Services Providers which exploit these networks to the benefits of their individual users. These requests are actually "provisioning actions" in the sense that the SP have some forecasted traffic and services data on the future needs and decides to construct some new "networks", for the future.

The traffic and services forecast is not in the scope of this paper. However our solution is neither a static provisioning nor an over-provisioning one; the VCANs can be established, modified in terms of their capabilities and terminated dynamically, given 1) the support of several negotiation protocols existing between the managers (i.e dynamic SLAs (Service Level Agreements) can be established any time, by negotiation); 2) an integrated monitoring system exist covering all environments, capable to offer measurement data on traffic load and thus permitting to the managers to take appropriate decision about resource (re)allocation for different VCANs.

The CANP offers to SPs enhanced connectivity services including unicast, multicast and peer-to-peer (P2P). The management framework is based on vertical and horizontal SLAs defined in the Management and Control (M&C) Plane negotiated and concluded between providers and possibly also on content/service description information (metadata) inserted in the media flow packets (Data Plane) by the servers.

The paper continues the starting work on VCAN management presented in [8][10][11].

Note that this complex system is still under development, therfore some final and evaluation results will be presented in future papers. This paper 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 discusses the scalability aspects of the system. Section VIII contains some conclusions and future work outline.

II. Related Work

A higher coupling between the Application and Network layers was recently proposed as a new approach 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 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 Future Internet (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 [12] 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] [13]. Context awareness is added to content awareness in [14]. 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 [15]. The Application Layer Traffic Optimization (ALTO) problem studied by the 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.

Virtualization, including its management and control is seen as a key method in the FI, to increase the flexibility and collaboration capabilities among network and SPs. The challenges are to develop:

- Virtual networks creation, abstracting the subset of network resources (link bandwidth, element processing power, etc.). Parallel logical slices can be defined, based on mechanisms independent or dependent on technology [16][24]. Virtualization based on overlays have been proposed in [3][4][5][21][25].
- Flexible management to create virtual network services on-demand (e.g., security, content-awareness) offered to upper layers, i.e., in [25], by defining a VNet Provider and VNet Operator. Such entities provide the VNet planning / advertising/ discovery/offering, negotiation, provisioning, operation (installation, modification, manipulation, monitoring, termination) while cooperating with IP network layer, [16][23][24][25].
- Support for VNets across multiple network domains based on inter-domain peering conforming to certain SLA/SLSs (Service Level Agreement/ Service Level Specifications), while preserving each domain's resource management independency [16][23][24][25][26]. Inter-domain QoS-enabled routing based on Virtualization is proposed [21][22][30].
- Support of unicast and multicast services on top of the virtual networks. The CURLING [23] architecture is content-centric using a multicast-style receiver-driven service model, but does not address content adaptation, mapping to native IP multicast, or QoS. In [27] a support for multicast streams adapted to each terminal's needs is proposed, by encoding media in multiple Scalable Video Coding (SVC) layers, and defining independent multicast trees for each layer, but it only supports overlay multicast.

Multi-domain Network Resource Management and QoS Support: there are limitations of existing work that are related to management and control. The *Management and Service-aware Networking Architectures* (MANA) Group [28] evaluated several issues either not yet solved, or having limitations. Among them, one can identify some issues related to the area of CAN/Network Environment:

- Guaranteeing availability of service according to Service Level Agreements (SLAs) and high-level objectives; facilities to support Quality of Service (QoS) and SLAs;

- Mobility of services;
- Facilities for the large scale provisioning and deployment of both services and management; support for higher integration between services and networks;
- Facilities for the addition of new functionality, capability for activating a new service on-demand, network functionality, or protocol (i.e., addressing the ossification bottleneck);
- Support of security, reliability, robustness, context, service support, orchestration and management for communication and services' resources.
- Multi-domain QoS support: the [16][17][24][26] projects are examples of architectures supporting end-to-end QoS across multiple domains. However, they do not specifically address media content.
- Dynamic assignment, provisioning and interfacing of customizable multi-domain network services to upper layers (e.g. SPs): this challenge is tackled in [16][24][26]. However, the aforementioned works do not address the cross-layer optimisation between the network layer and upper layers.

Specific comparisons between previous work presented in various research project are given below. The ALICANTE approach for network management versus other research project solutions is compared (The list is not exhaustive). Correlating their scope with ALICANTE's objectives, the selected projects' solutions are (partially) media and content oriented, including end-to-end QoS, and consider multi-provider, multi-domain, multi-technology architectures; they also cover (partially) the integrated management of both high-level services and networking resources. The scope and limitations of the proposed solutions are identified, in order to clarify the ALICANTE design choices and/or progress with respect of these solutions.

The FP6 project MESCAL "Management of End-to-end Quality of Service Across the Internet at Large" project [17][18][19], proposed an evolutionary, scalable architecture, enabling flexible delivery flows over multi-domains, with QoS. The main actors are: Service Providers (SPs), IP Network Providers (INPs), Physical Connectivity Providers (PCPs) and Customers. MESCAL has a complex management system mainly focused on resource management and traffic engineering (offline and online) intra and inter-domain. It does not have a multimedia orientation as a main design direction.

While applying sophisticated techniques for traffic engineering intra and inter-domain MESCAL has no concept of parallel planes as ALICANTE VCANs. However ALICANTE will use the MESCAL concepts of QoS classes (local, extended, meta-QC) in a multi-domain environment, but fitted to VCAN oriented architecture. ALICANTE proposes a joint algorithm for QoS constrained routing , admission control and resource mapping and reservation, both in inter and intra-domain.

The FP6 project ENTHRONE "End-to-End QoS through Integrated Management of Content, Networks and Terminals" [26][29], proposed an evolutionary architecture on top of IP, to cover an entire Audio/Video (A/V) service distribution chain (content generation, protection, distribution across QoS-enabled heterogeneous networks and delivery at user terminals). ENTHRONE targeted primarily multimedia distribution services.

ALICANTE offer as well as Enthrone QoS enabled paths on top of a multi-domain, but its management at network level is more powerful, being able to create VCAN parallel planes.

The FP6 project AGAVE "A liGhtweight Approach for Viable End-to-end IP-based QoS Services" [16][24], aims to solve the E2E provisioning of QoS-aware services over multi-domain IP networks. The Service Providers (SPs) and the IP Network Provider (INPs) cooperates. The INP offer enhanced connectivity services across multiple domains, by extending a Network Plane (NP) to A Parallel Internet (PI) spanning several domains
In AGAVE the NPs implement local virtual network segments while PIs can be seen as end-to-end "virtual network segments", each PI exposing specific performance characteristics. The NPs are built by specific Traffic Engineering (TE) techniques applied in each INP domain. AGAVE suggests an incremental solution for network virtualization. However, it does not create virtual network segment as slices "for sale" to SPs or peer network providers. It manages the complexity of performing the Connectivity Provisioning Agreements (CPA) concluded between SPs and INPs, aiming to the provisioning and delivering of different types of traffic in multi-domain context. The NP and PI notions are said to be internal to INPs, and their definition and realization, through TE, while the SPs sees only the CPA. The AGAVE authors state that "the definition of NPs and PIs and their engineering are hidden from SPs. AGAVE does not consider content-aware aspects at network level.

The novelty in ALICANTE is that it creates VCANs which are known to SPs. However, ALICANTE benefits from, and extends the AGAVE concepts of PIs, by offering the VCAN as an enhanced equivalent of Network Planes. This is done in the framework of a more complete architecture, of the proposed Media Ecosystem.

This paper further develops previous work of the same group of authors. The work in [8] is only a first description of concepts and high level description of the ALICANTE system architecture, with no details on functional capabilities. The paper [10] is the first approach description of the CAN management architecture. The work in [11] is focused only on QoS aspects of the system. While parts of these works are present or referenced here, this work is a step forward in integrating the various components into the system assembly.

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 (Service Provider), CP (Content Provider), NP (Network Provider) 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 the 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 uses information from the CAN layer to enforce NAA procedures, in addition to user context-aware ones [8]. 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. Figure 1 presents a partial view on the ALICANTE architecture, with emphasis on the CAN layer and management interaction. The network contains several Core Network Domains (CN); each of them can be extended up to Autonomous System – (AS), the main idea being an unified management of each domain. Therefore, each domain is supposed to have an Intra-domain Network Resource Manager (IntraNRM), as the authority actually configuring the network nodes. Access Networks (ANs) also exists, connected to the core domains; however the ALICANTE VCANs do not cover the ANs. This design decision has been taken because the heterogeneity of AN technologies in terms of managing and guaranteeing the QoS capabilities. On the other side, from the business point of view, the Access Providers have complete independence on "if" and "how" to control the access network resources. 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 Figure 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.

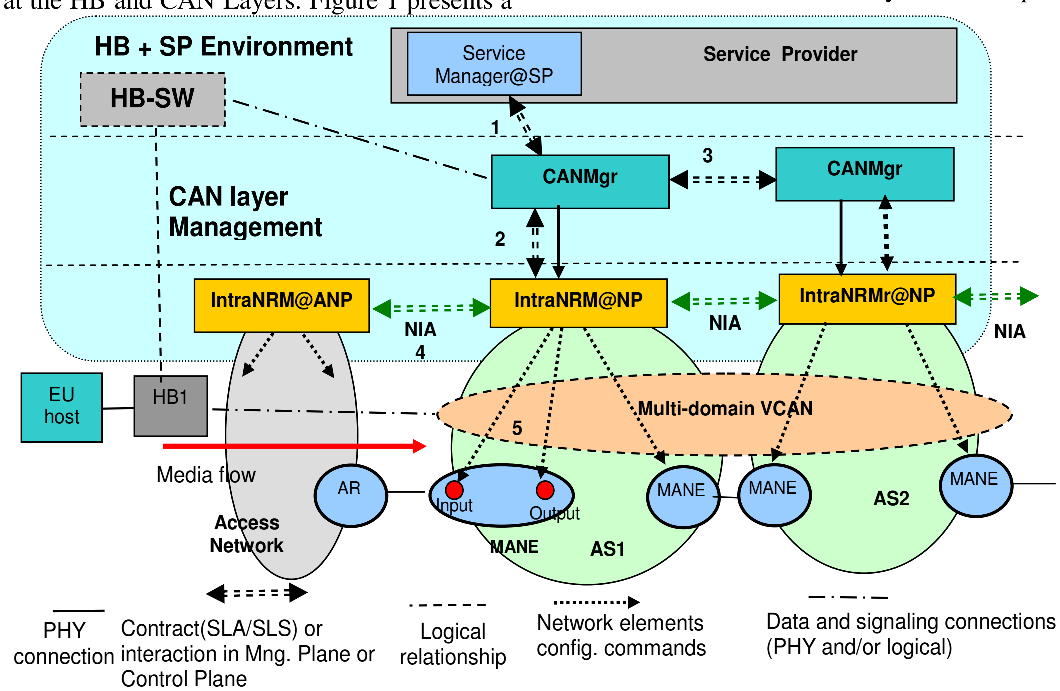

Figure 1. ALICANTE architecture: CAN management interactions

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:

- 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.
- 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.
- 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.

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), specialized in different types of application content [16]. 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 [17][18][19]. For a simplified design, we also used the concept of Meta-QoS-Class [17]. 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. For 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.

Note that in ALICANTE architecture, apart from resource provisioning at CAN layer, there is another subsystem, performing per flow adaptation (e.g. for flows generated by Scalable Video Codecs in several layers) [8][9]. This adaptation can adjust the numbers of layers received by a given HB or EU terminals depending on terminal capabilities and network status. For reasons of dimension and focus, this adaptation subsystem is not described in this paper.

V. CAN Multi-Domain Peering

A 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* and *Control (M&C) topology.* The first can be of any kind, e.g a heterogeneous graph representing a partial mesh (depending on SP needs and including the domains spanned by a given VCAN). 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 [16][17][18][24][26].

A. VCAN Negotiations

The hub model supposes that an initiator VCAN Manager is discussing in hub style with other managers in order to negotiate multi-domain CANs. With this respect, the *CAN Manager is supposed to have inter-domain topology information.* The advantage is that allows a complete control of the VCAN because the CANMng initiating the VCAN knows all network domains participating to this CAN. A drawback is that each CAN Manager should know the complete graph of domain candidates to participate in every possible VCAN, which creates a signaling overhead. However, the number of domains (ASes) involved in a VCAN communication is rather low, given the hierarchical tiered structure of the Internet [23]. Usually a group of domains of interest for a VCAN are localized in an Internet region, so the scalability problem is not so stringent.

The initiator CAN Manager should discuss/negotiate with all other CAN Managers in order to establish the VCAN = {VCAN1 U VCAN2 U VCAN3 …}, where U represents union action. Split of the SLS parameters should be done at the initiator (e.g. for delay).

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 would be more advantageous for initiating CAN Manager if a chain of domains is to form the VCAN [16][26][30]. 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 shows an example for hub-style signaling adopted in ALICANTE for a multi-domain VCAN. The overall infrastructure is supposed to have four core network domains CNDk, CDNj, CNDn, CNDm, 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 Content Provider (CP). The SP is requesting a *CANMgr_k* to construct a VCAN, spanning several domains, e.g CNDk, CNDj, CNDn, and CNDm. It is supposed that SP knows the edge points of this VCAN, i.e. the MANEs where different sets of HB are (currently) or will be connected.

The *CANMgr_k* determines (based on its inter-domain topology knowledge) that the components of the VCANs are CNDn, CNDj, CNDm. Therefore, it negotiates SLSss in actions represented by 2.1, 2.2 and 2.3 notations. The negotiations target to achieve appropriate VCAN capabilities from *CANMgr_j CANMgr_n* and respectively *CANMgr_m.* Each CANMgr has to check in its domain if sufficient resources are available (by negotiating with Intra-NRM and concluding an SLS). These actions are not represented in Figure 2. In a successful scenario, the multi-domain VCAN is agreed on (logical resource reservation only) and then it is installed in the network upon request of the SP and executed by CANMGr_k (at its turn it requests this to *CANMgr_j*, *CANMgr_n* and *CANMgr_m).* Then, each CANMgr instructs its associated Intra-NRM to install the appropriate configurations in the edge MANE routers and interior core routers.

B. *Overlay Virtual Inter-domain Topology*

The problem leading to consideration of the inter-domain topology comes from the following needs:

- a multi-domain VCAN should be constructed by the initiator CAN Manager spanning several core network domain CNDs;
- each CND has complete autonomy w.r.t. its network resources including off-line network dimensioning, traffic engineering (TE) and also internal routing. Each CND can assure QoS enabled paths towards some destination network prefixes, by using its own network layer technology like DiffServ, MPLS, etc. and also can control the QoS on its out links. Consequently, each CAN Manager associated to a CND will decide upon accepting or rejecting a proposed SLS for this domain;

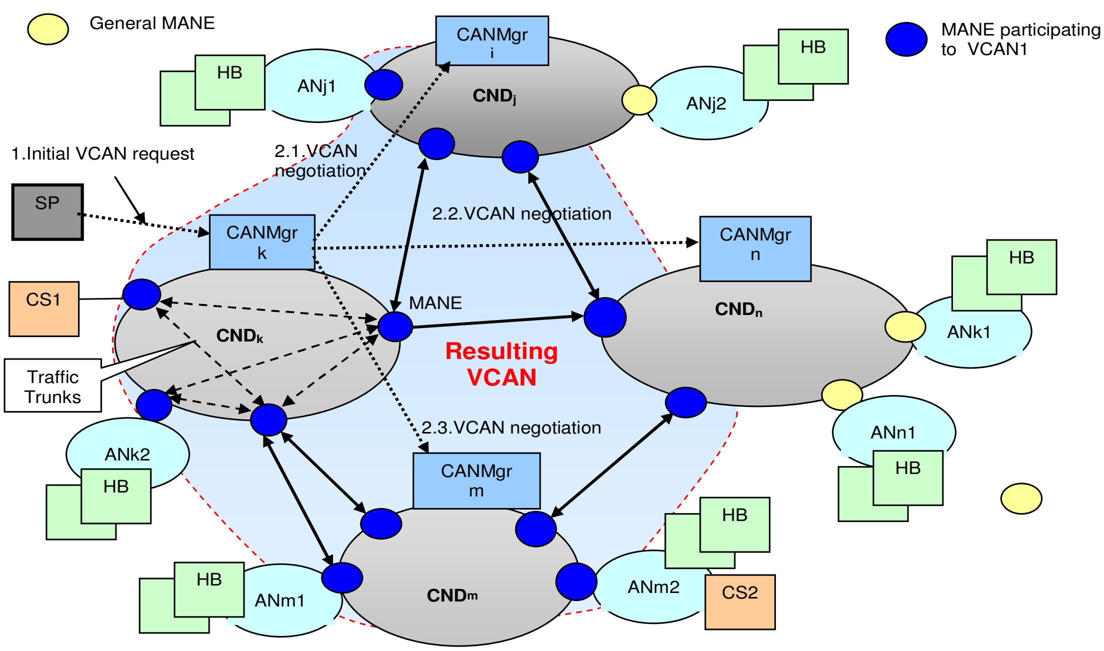

Figure 2. Example of a multi-domain VCAN and hub model for management communication between CAN Managers

- inter-domain QoS- enabled routing should be solved;
- internal topological and capacities information (real or even in abstracted form) of a CND can be non-public for other CNDs;
- the VCAN initiator CAN Manager should determine which CNDs will compose a requested VCAN and split the connectivity requirements among these CNDs, in order to prepare the negotiations described in the previous section. Therefore, the multi-domain VCANs deployment needs knowledge on multi-domain topology and has to solve also a constrained inter-domain routing problem;
- the solution should be scalable, by avoiding one CAN manager be burdened with computations which are related actually to other CND internal business.

The ALICANTE solution is to develop a special service, *Overlay Network Topology Service (ONTS*), able to support multiple VCAN construction while meeting the above constraints. This is explained shortly below and more detailed in Section V.

Note: the subsystem composed by a CAN Manager and its corresponding Intra-NRM will be optionally called CND Manager (CNDMgr). This will simplify the description of overlay topology concepts applied to ALICANTE (without considering the amount of information given by the Intra-NRM to CAN Manager about its topology and capacities).

Each CNDMgr has at least an abstract view of its network 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. Each multiple domain VCAN should also belong to some QoS class and therefore inter-domain QoS aware routing information is necessary in order to construct this VCAN, i.e. to establish SLSs, when negotiating the multi VCAN. Usage of the standard *Border Gateway Protocol (BGP)* to provide knowledge on inter-domain paths would require no modifications in the edge routers, however no QoS information is carried in BGP advertisements. Therefore the establishment of the SLSs between CANMgrs, tried on BGP-indicated routes, might have high probability of failure.

A solution which better fits the ALICANTE purposes is to determine an inter-domain Overlay Network Topology (ONT) by developing a special ONT Service (ONTS), running at the level of CAN Managers. This is partially similar to those described in [21][22], while abstracting the physical network details of each CND. The ONTS delivers to the CAN Manager the information on the inter-domain graph linking different CNDs in a zone and capacities of the inter-domain links. Using the information on this topology (which abstracts the domains), the initiator CAN Manager can determine which domains could compose a requested VCAN. Then, one can apply an inter-domain QoS-aware and constrained routing algorithm to find inter-domain paths satisfying the SLS constraints.

Actually, the determination of the inter-domain ONT can be split in two parts: (1) determination of the inter-domain connectivity graph; (2) determination of the capacities of the inter-domain links. The algorithms and mechanisms to determine the ONT constitute the subjects of other work.

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

Figure 4 presents the proposed architecture for CAN Management. This is a continuation and development of the one presented in [11]. 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 to 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 an SLA contract 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.

A. CAN Management at Service Provider

The CAN_RMgr@SP 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*.

Figure 5 also shows the interfaces, defined below. Where possible, the interface implementation will be based on SOAP/Web Services, 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.

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

- request the CAN Manager VCANs, and to this aim it performs negotiation (SLS contracts will be concluded for VCAN subscription, based on a negotiation protocol);
- command VCAN installation (invocation)
- receive advertisement information about available VCANs constructed at the CANP's initiative
- request modification and/or termination of a VCAN: 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.

B. CAN Provisioning at Service Provider

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 VCAN transport infrastructure for the SP. For VCAN subscription, the *CANProvMng@SM* receives requests for a *sp_CANpSLS* contract dedicated to a given VCAN 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-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.

C. Negotiation Protocol

This section will define the specifications for a general SLA/SLS negotiation service and protocol, *AL-SLA/SLS-NP*, valid for several ALICANTE usages and actor pairs. Negotiation protocols must be available at the interfaces: CANMgr – SP to establish SP-CANP SLA; CANMgr – CANMgr to negotiate CAN extension to other NP domains). Negotiation is also needed between CANP and Intra-NRM to negotiate resource commitments by IntraNRM. The *AL-SLA/SLS* is partially a new protocol, i.e. the service primitives and negotiation styles are designed for ALICANTE purposes. This protocol will be implemented over Web Services framework.

The *AL-SLA/SLS-NP* runs at the subscription time to negotiate an agreement between two parties: a customer (requesting the SLA/SLS) and a provider (offering the SLA/SLS). The negotiation can also happen in practice at service invocation periods, provided that subscriptions are immediately followed by invocations. The qualitative and quantitative parameters of the SLS can be specified in a special data structure, known as the *Service Subscription Data Structure (SSDS).* This is to be defined for different usages of the protocol, depending on the type of the SLS required.

The *AL-SLA/SLS-NP* has features of a general negotiation protocol. It has enhanced/new features if compared to other negotiation protocols like SrNP (MESCAL, [18][19]) while being adapted to the ALICANTE environment. It is a client-server half-duplex negotiation protocol between two entities. The cases considered in ALICANTE are:

(1) Service Provider = client, CANP = server- for VCAN contracts

(2) CANP = client, Intra-NRM = server- for contracting the VCAN network resources of core network domain

(3) CANP = client, other CANP = server - for contracting the VCAN resources from other domains (the negotiating entities are CAN Managers and they might belong to the same CANP)

(4) HB = client, Service Provider = server – for individual contracts between HB and SP in order to access media services form SP.

In a particular negotiation session, one party can only be a client or a server but not both at the same time. Concerning the reliability and security of the services offered by the *AL-SLA/SLS-NP*, several choices have been considered: UDP fast transport, having the drawback of non-reliability, or reliable and secure negotiation service offered to the negotiation entities. Given the importance of this signaling in ALICANTE, a reliable and secure negotiation service has been adopted by implementation on top of Web services.

The following assumptions (these can be considered also as detail design decisions) are valid: the parties (Negotiation Logic – NL modules) are the "users" of the protocol. They know the identity of each other; the objects under negotiation can be described as a document whose syntax and semantics is known by the NLs; the NLs know to build, extract, and manipulate the information in the document; the negotiation objective is to conclude a contract between the parties regarding the document content (negotiation is performed upon the values of the parameters in the document and not upon the types of these parameters); AAA processing related to negotiation aspects is not performed by *AL-SLA/SLS-NP* (it concerns the NL); *AL-SLA/SLS-NP* uses the services of a reliable and secure transport protocol; the *AL-SLA/SLS-NP* is transparent to the policy used by NL to make decisions on the negotiated objects (therefore the NL logic complexity is irrelevant for the negotiation protocol).

D. Negotiation Functional Blocks

AL-SLA/SLS-NP is a *transactional protocol* (1-to-1), between two negotiation service interfaces (AL-SLS-NP/NL). Figure 3 shows the negotiation functional architecture. It is seen that the NL can have several active transactions in the same time interval. Figure 3 also presents the generic interfaces involved in negotiations.

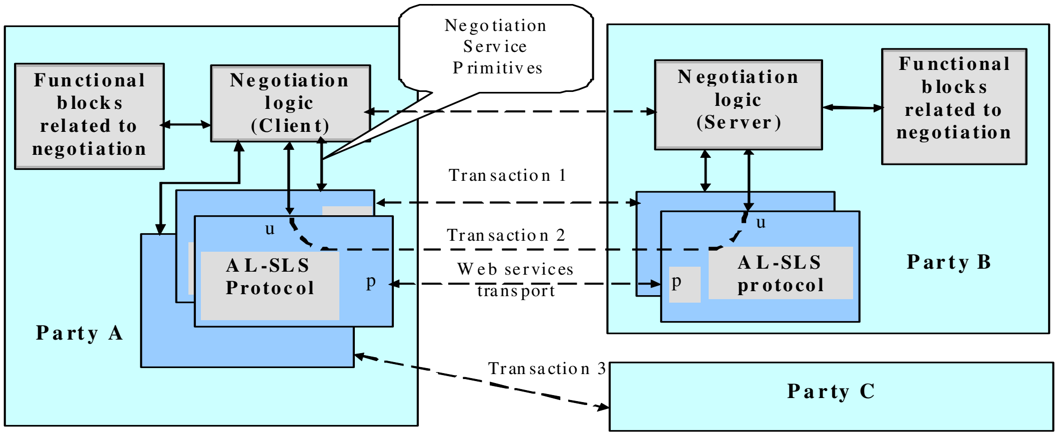

Figure 3 AL-SLA/SLS negotiation architecture

Note: AL-SLS is a short notation for *AL-SLA/SLA-NP* protocol.

AL-SLA/SLS-NP is an *application-layer*, *negotiation session/transaction-oriented* protocol. Each transaction allows to establish/modify/delete an SLS related contract (agreement). It performs contract establishment/modification or termination session. For the negotiation itself, several styles may be applied: simple two steps negotiation (one negotiation object); multiple steps negotiation (one negotiation object). An advanced feature could be: multiple steps negotiation with several negotiation objects in responses.

E. *CAN Management at CAN Provider*

The Functional architecture of the CAN Management and Control along with CAN Resource Management at CANP is illustrated in Figure 4.

a) Static CAN Services Management

The static CAN services management means that the VCANs containing aggregated multi-domain pipes are subscribed in advance (statically) to actual data transfer, based on SP forecasted data. The VCANs spans from CS locations (known) up to the regions of the access routers in the AN where potential HBs are located, based on a non frequent planning, at SP initiative; the network dimensioning is done infrequently in so called Resource Provisioning Cycles; the multicast trees are established statically over multiple domains. The above functions might be policy based influenced.

b) Dynamic CAN Services Management

The dynamic characteristics of the CAN service management are related to: policy based SLS dynamic invocation handling; possibility of modifying the VCAN invocation; multiple invocation per the same subscription; inter-domain dynamic resource optimization; multicast trees dynamically adjusted at the edges; cooperation between adaptation and provisioning.

c) CAN Manager Main Functions

The main functions of the CAN Manager are: VCANs resources planning, negotiation and provisioning (at SP request or at its own initiative); VCANs advertisement, offering; VCANs installation and exploitation. The mapping CANMgr – per NP domain – allows the horizontal architectural structuring. A single CANMgr can control one or several VCANs deployed in its domain or, initiate the construction of a multi-domain VCAN.

One CAN Manager (CANMgr) is associated to each core IP domain This per-domain mapping exhibits important technical and business advantages: (i) allows for a horizontal structuring of the architecture and creates the possibility of horizontal negotiations between CAN Managers; (ii) creates the possibility that CAN Manager SW to be an extension of the Intra-NRM; (iii) enables each NP to become a CAN Provider; (iv) limits the network area controlled by a single CAN Manager, thus contributing to the scalability of the solution, as the management and control overhead is concerned.

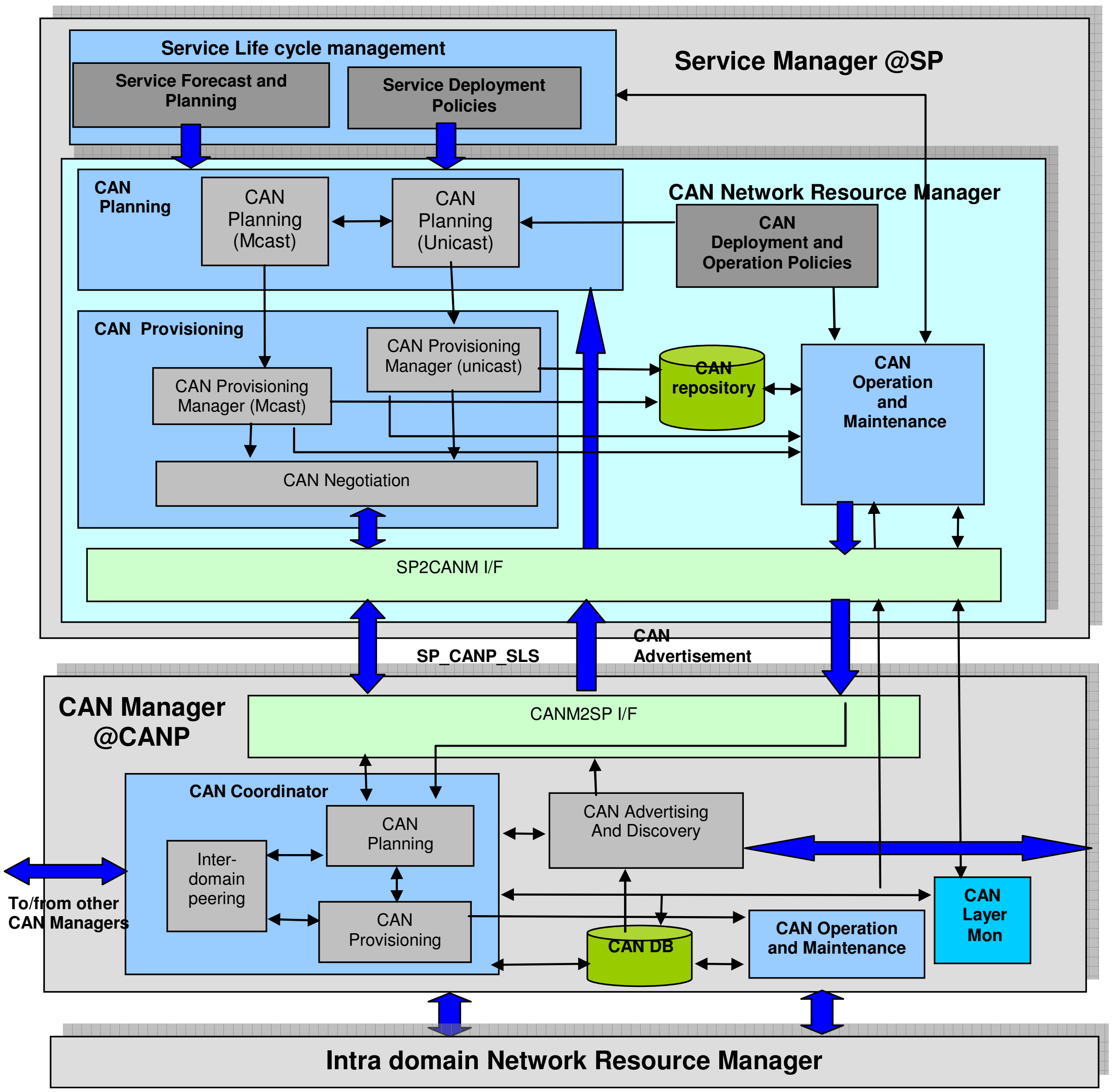

Figure 4. Architecture of the CAN Network Resource Manager at SP and CAN Manager at CAN layer

d) CAN Management Layer External Interfaces

- **North (Upper) I/Fs**

CAN Provider – Service Provider: This I/F of CAN Manager to CAN Network Resource Manager at SP (component of the Service Manager) has the role to assure cooperation between SP and CANP in order to negotiate VCANs (at SP initiative) and install, maintain and exploit, modify, and terminate the VCANs. The second role of this I/F is to assure vertical communication for the cross-layer monitoring framework. Moreover, this I/F will support advanced features like VCAN advertisements made by the CANP to SPs, in order to offer them the existing VCAN resources.

- **Horizontal I/Fs**

CAN Manager – Home Box: this I/F has the role to instruct HBs how to use the VCANs and also to deliver to HBs network distances (based on static and dynamic monitored information) between different edge MANEs.

- **South (Lower) I/Fs**

CAN Manager- Intra-domain Network Resource Manager: this I/F has the role to support negotiation between CANP and NP related to assuring network resources for VCANs and to transport the messages to control the installation and operation of the VCANs; to exchange of monitoring information between the Monitoring module at network layer and Monitoring module at CAN layer; to assure the transport of flow adaptation policies from CAN Manager to the MANEs via Intra-NRM.

f) Horizontal Interfaces between CAN Managers

The following I/Fs are defined between the CAN Managers associated to different Core Network Domains: negotiation I/F for SLSs between the CAN Managers in order to extend the VCANs over multi-domains; I/F to exchange messages for inter-domain peering,

g) CAN Manager Functional Modules

- CAN Planning, Provisioning and Security
  - *CAN Planning:* this is the highest level decision block at CANMgr, determining what, when and where the VCANs are to be constructed and controls all VCAN life cycle for unicast/multicast VCANs. It cooperates vertically with SP and horizontally with other CAN Managers. Internally to CAN Manager, the CAN Planning instructs the CAN Provisioning block about VCAN negotiations and subsequent related actions.
  - *CAN Provisioning:* performs the lower level actions related to VCAN life cycle by preparing the individual SLSs and conducts horizontal negotiations with other CAN Managers and also with local Intra-NRM.
  - *CAN Security:* controls and performs authentication and authorization functions at CAN Layer including the relationship with SP, and manages the security related policy distribution. The security architecture and functions will not be discussed in this paper
- *Inter-domain Peering:* determines the inter-domain topology and capacities by using an overlay topology service developed among the CAN Managers. This service gets the Overlay Network Topology (ONT), in cooperation with other CAN Managers and then is used by the CAN Planning in order to determine which domains can belong to a given VCAN to be constructed.
- *CAN Operation and Maintenance (CAN_OM):* commands the VCANs installation upon request of the CAN Operation and Maintenance @SP (if the VCAN has been ordered by SP) or from the CAN Provisioning (if the VCAN has been ordered by local CANMgr). This is called *CAN invocation*. The installation actions are implemented as commands given by CAN_OM to the Intra-NRM of the local domain and also to other CAN Managers (horizontally) through the path: CAN_OM –> CAN_Prov –> other CAN Managers. The CAN_OM controls the modification and termination of the VCAN. CAN_OM controls the Monitoring operations at CAN layer related to the SLSs associated to a given VCAN or to the discovery of the Network Distance when requested by the HB.
- *CAN Layer Monitoring:* performs measurements at CAN layer, conforming to the instructions given by the CAN_OM; returns reports on traffic measured and stores them in the CAN DB; communicates with the upper layer of monitoring.
- *CAN Data Base:* contains all data on static and dynamic information related to the CAN Layer. CAN Manager modules read and write information in this database which is the main component through which all other functional blocks interface.
- *Advanced functionalities*:
  - *CAN Policies:* local policies defined at level of this CAN Manager will be defined and guide the VCAN planning and deployment.
  - *CAN advertisement and discovery:* informs horizontally other CAN Managers about existing VCANs and respectively discover other CAN Managers VCAN resources.

F. Basic Signaling for VCAN Resource Provisioning

Figure 5 shows the signaling diagram at CAN layer, in order to construct a multi-domain VCAN, spanning three core network domains CND1, 2, 3. The picture presents a case of successful establishment of a SLS and finally the installation of the VCAN in the network. This is considered as step 0 in a sequence of steps during VCAN cycle. The other steps are not presented in this paper.

The messages exchanged are generically described without details on parameters. The initiator of this VCAN construction is SP which issues a request to CANMgr1.

The latter determine the other CAN Managers involved, i.e. associated to other domains, splits the SLS in particular SLSs particular to each domain involved (these details are not shown in the diagram) and then negotiates with them. In the example, CANMgr2 and CANMgr3 are dialogue partners for CANMgr1. Each CANMgr at its turn negotiates resources with its associated Intra-NRM. Finally, in a success scenario, the SP receives a confirmation about VCAN resource reservation, via VCAN_rsp_neg (ok). Later, at SP will the VCAN is installed in the network by the respective CAN Mangers and Intra-NRMs.

G. CAN Planning at CAN Provider

Before performing VCAN signaling with other CAN Managers, the VCAN initiator CAN Manager should perform the VCAN planning, done by the CAN Planning functional block. Details on the planning algorithm will be presented in another work. Here a summary is presented. The objectives of this planning are: 1. to determine the domains participating to a given VCAN requested by SP; 2. inter-domain (links) resource management; 3. apply a constrained routing algorithm based on ONT acquired by the Initiator CAN Manager; 4. based on routing information, the SLS splitting between domains is computed.

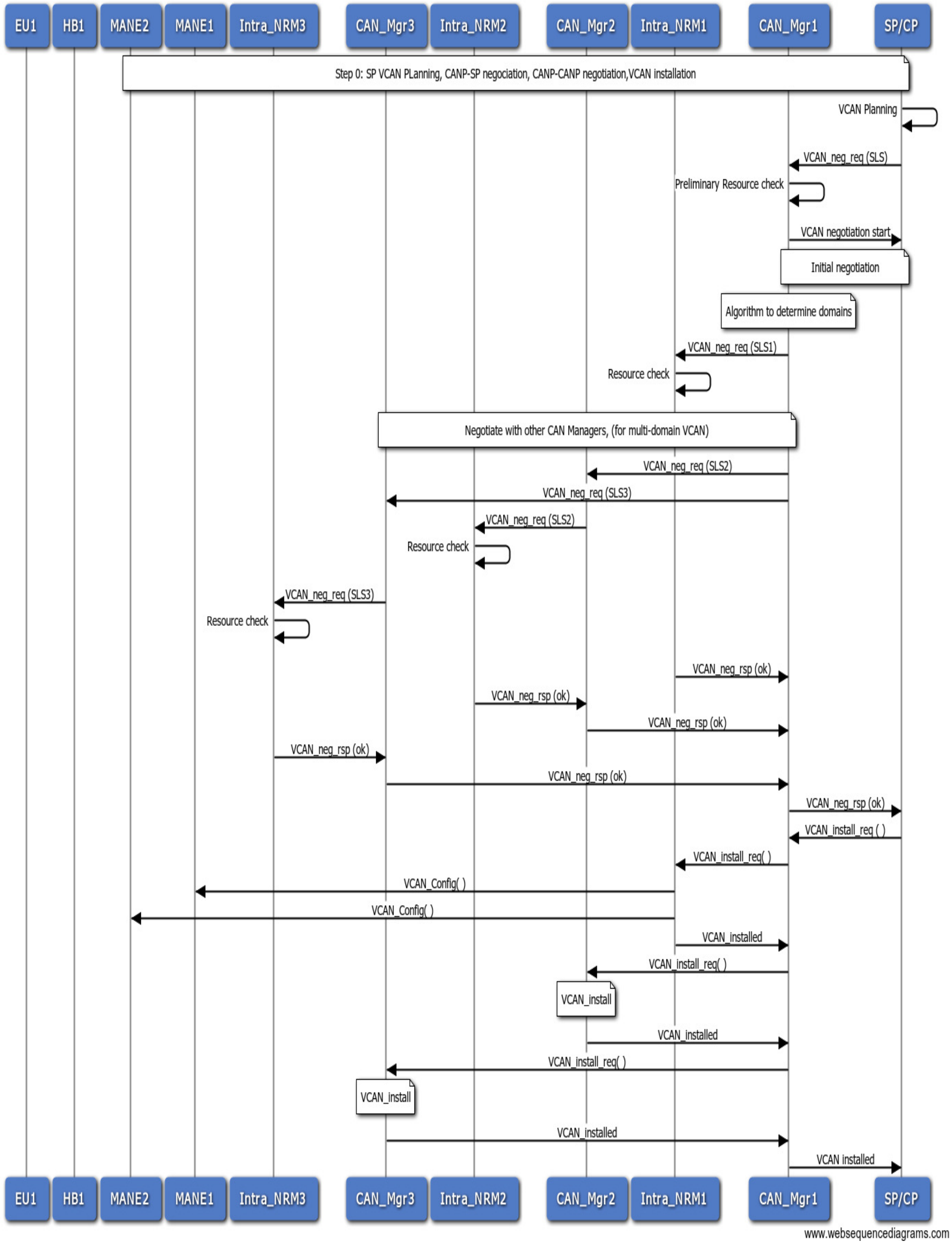

Figure 5. Basic signaling diagram for VCAN establishment (multiple network domain case)

Inter-domain planning

A summary of actions set is the following:

1. SP issues a VCAN-0 request (this will be mapped onto a given QoS class), i.e. an SLS request (topology, traffic matrix, QoS guarantees, etc.)
2. The initiator CANMgr obtains from ONTS (this service is assured by the Inter-domain Peering block) the inter-domain level ONT (topology graph, inter-domain link capacities, etc.). The ONT is sufficiently rich to cover the required VCAN.
3. The initiator CANMgr determines the involved domains in VCAN by using the border ingress-egress point's knowledge (actually MANE addresses) indicated in the SLS parameters
4. The initiator CANMgr determines a contiguous inter-domain connectivity graph (each CND is abstracted as a node) resulting in an extended VCAN-1. In VCAN-1 graph, some additional transit core network domains need be included (it is supposed in the most simple version that these new core network domains added are also VCAN capable). Therefore a contiguous new VCAN-1 is defined. Optimization techniques can be applied in this phase.
5. The initiator CAN Manager should make the first split of the initial SLS among core network domains. This means to produce the set of SLS parameters valid to be requested to each individual CND. The inputs: are: ONT graph, abstracting each CND (domain) by a node; QoS characteristics of the inter-domain links (bandwidth, delay); Traffic Matrix (and other QoS information) of the SLS proposed by SP. The outputs are the Traffic matrices for each CND composing the VCAN.

In order to perform this, the Initiator CAN Manager will run a constrained routing (modified Dijkstra algorithm) based on a composite additive QoS-aware metric. This will be described in a future work. Finally the CAN Planning has determined the sets of SLS parameters to be negotiated with each CAN Manager of the domains participating to VCAN.

H. Intra-domain CAN Resources Provisioning

An essential functional aspect related to the VCAN mapping onto network resources in a core network domain is the relationship between CANMgr and Intra-NRM with respect to:

(1) the style for Intra-NRM to upload information to CANMgr about its available resources : on demand (OD) or in proactive (P) style (at Intra-NRM initiative);

(2) amount and depth of information uploaded by Intra-NRM on network resources (graph, capacities, etc.). Note that for every variant, and depending on monitoring information at network level the Resource Availability Matrix (RAM) uploaded can be adjusted by Intra-NRM to improve the traffic engineering performances.

These variants are shortly discussed below.

Proactive style*:* At initiative of Intra-NRM, (periodically or event triggered) the RAM, i.e., either full connectivity graph and capacities or only a summary similar to ONT information is uploaded to CANMgr. Advantages are that the Intra-NRM is the most qualified to know when it is appropriate to deliver network information to CANMgr, e.g. every time when network re-dimensioning is performed. Also, CANMgr has at every moment all information about network resources.

The disadvantage is that CANMgr can be overloaded with more information than it really needs at a given time; it may keep or discard some information, depending on its local policy at CANMgr level.

On demand style: the RAM of the Intra-NRM is obtained on demand of the CANMgr when it needs it, in order to appropriately answer SP requests. The advantages are that the CANMgr decides when it wants RAM information from Intra-NRM, and it is a possibly better usage of CANMgr DB space. Another plus is that Intra-NRM is released from informing the CANMgr.

The cons are that this approach incurs a higher delay in servicing the SP requests, because CANMgr should first acquire RAM in order to respond appropriately based on updated RAM information.

In the real networks world the NPs are usually reluctant to disclose information on their networks (topologies, traffic load, etc.) to external parties. However the approach of this paper supposes a strong cooperation betwen the CAN Procvider (CANP) and Network Provider (NP) in order to construct the VCANs. Therefore, several degrees of "trust" between such entities should be analysed.

The depth of information uploaded by the Intra-NRM to CAN Manager depends on the degree of trust between these two entities and is of course, policy determined. We might have several situations:

- High trust (HT): Intra-NRM uploads to CANMgr its full connectivity graph;
- Medium trust (MT): Intra-NRM uploads to CANMgr an overlay RAM based on traffic trunks (similar to ONT);
- Low trust (LT): Intra-NRM does not upload/disclose any topology and resources to CANMgr, but only ingress-egress points Ids and Yes/No answers to a SLS request

Depending on the actual routing and mapping algorithm (to map the matrix traffic requested for this domain), the real graph will be placed at the level of CAN Manger (case HT) or Intra-NRM (case MT or LT).

From the architectural and also business point of view, the MT and LT solutions are more appropriate, in order not to outsource the important task of configuring the network elements to third parties. In such a case, the CAN Manager has only to decide on mapping of the Traffic Matrix onto TTs reported by the Intra-NRM. Decision P/OD can be an implementation option. The solution HT is actually one in which the CAN Manager functionalities are constructed as an additional software on top of the IntraNRM, and in such a case one has a single integrated entity (IntraNRM +

CANMgr) belonging to the business actor which is now (NP + CANP).

VII. Scalability aspects of Management and Control

The ALICANTE system targets large network configurations. Scalability in such cases is important and is shortly discussed in this section, with focus on M&C.

A. *VCAN Planning and Provisioning*

The following features assure a good scalability of the architectural solution:

- The full centralized solution for VCAN management is avoided, given that each Core Network Domain has associated a CAN Manager; the initiator CAN Manager should negotiate in hub style with other CAN Mangers. However, this approach does not create difficult scalability problems, given that the number of domains actually involved in a multi-domain chain is rather small (less than 10) due to tiered structure of the Internet. On the other side these signaling are not real time ones. The advantage of this solution is that the initiator CAN Manager has always an overall image of a multi-domain VCAN and can respond to some SP possible complaints about different events. No per-flow signaling between CAN Managers exist in M&C.
- The VCAN SP–CANP negotiation are done per VCAN, described in terms of aggregated traffic trunks
- The SP negotiates its VCAN(s) with a single CAN Manager, irrespective if it wants a single or a multi-domain spanned VCAN
- A hierarchical overlay solution is applied for inter-domain peering and routing, where each CAN Manager knows its inter-domain connections. The CAN Manager initiating a multi-domain VCAN is the coordinator of this hierarchy, without having to know details on each domain VCAN resources
- The monitoring at CAN layer and network layer will be performed at an aggregated level.

B. *Multicast Management and Control*

- The management system described work as well for unicast or multicast capable VCANs. However, the multicast detailed management is not described in this paper, given that the general signaling actions are the same in unicast or multicast case. Multicast hybrid solution has been envisaged, with usage of IP level multicast intra-domain wherever is possible;
- VCAN multicast capable, i.e., multicast aggregated trees can be constructed, usable by multicast sessions having similar QoS characteristics;
- The multicast solution is combined with P2P (used by the HBs), thus assuring a better scalability for multicast distribution.

C. *Routing and Forwarding*

In the case of multi-domain VCANs, the broadest paths will be selected, thus optimizing the network resource usage. The length of the paths can be minimized by using higher layer tiers domains when necessary.

The length of the paths between HBs working in P2P mode, or between HBs and CSs, will be minimized by delivering network distances information to HBs to help the peering process.

D. *Management of Configurable Types of VCANs*

The amount of processing in the Data Plane affects the scalability of the system. In order to be flexible with respect to different SP needs, and not to reach a very rich granularity if no need for it exists, the CAN layer may offer several types of VCANs seen as parallel planes. The M&C can configure the VCANs (at request of the SP), to offer gradual scalability properties and QoS differentiation capabilities:

- VCANs based on Meta-QoS-Classes – mostly scalable (lower processing tasks for the data flows) but with rough granularity in terms of VCAN QoS properties
- Multi-domain VCANs based on an inter-domain combination of local (per-domain) QoS classes (LQC) – having medium scalability and higher degree of service/flows differentiation
- Multi-domain hierarchical VCANs based on local QC composition, but where each domain may have its local QoS classes.

VIII. Conclusions and Future Work

This 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 of the main network element (MANE router) supposed to be managed by the described framework of this papaer appeared in [20].

Future work is also necessary to solve the mapping of the overlay VCANs (as requested by SP) onto real network resources in a multi-domain context, while satisfying QoS constraints. The VCAN resources are first logically reserved; later when installation is requested by the SP, they will be really allocated in routers.

Finally use cases (Video on demand, IPTV media streaming will be experimented on four testbeds (Portugal, Bordeaux, Bucharest, Beijing) in order to to validate the overall functionality. These results will be presented in future papers.

ACKNOWLEDGMENTS

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