Network Resources Allocation in Content-Aware Networks for Multimedia Applications

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***Abstract* — Virtual Content Aware Networks (VCAN) constructed as overlays over IP networks, are currently of high interest in the context of Future Internet multimedia distribution. The VCANs mapping onto real topologies while meeting some QoS properties is still an open issue and constitutes the objective of many studies. This paper continues a previous work which defined the management framework of a complex multi-domain networked media oriented system. Here it is proposed a combined set of algorithms and protocols to perform VCAN mapping on real network infrastructures both for intra and inter-domain, while meeting QoS constraints for multi-domain VCANs.**

Keywords — Content-Aware Networking; Network Aware Applications; Multi-domain; Inter-domain peering; Management; Resource allocation; Future Internet.

I. INTRODUCTION

Many research efforts are spent today to find the best solutions (evolutionary, middle-way or revolutionary) for so called Future Internet (FI), [1-5]. Content orientation of the FI is largely recognized and new solutions towards this make have been proposed, [2][6][7][8], to create virtualized *Content Aware Networks* (VCAN) and *Network Aware Applications* (NAA) on top of the IP level. Novel network nodes (routers) will process and forward the data, based on *content type* recognition or, even more, treating the data objects based on their *name* and not based on *location address*, [6][7]. The paper [6], analyses new solutions based on *Content Oriented Networking* (CON) with decoupling of contents from hosts at networking level. The VCANS can be constructed based on virtualization techniques, agreed to be used to overcome the ossification of the current Internet [3-5].

The European FP7 ICT research project, "Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", ALICANTE, [9-13], adopted the NAA/CAN approach. It targets to define an architecture, and then to fully specify, design and implements a Media Ecosystem, on top of multi-domain IP networks, to offer services for different business actors playing roles of consumers and/or providers. It adopted content-type recognition at network level and light virtualization (VCANs separation in the Data Plane but a single management and control – M&C plane). This approach offers seamless deployment perspectives and tries to avoid the scalability problems (still open research issues) of the full CON approaches.

The ALICANTE business entities/actors belong to Several cooperating environments: *User Environment (UE),* containing the End-Users (EU) terminal; *Service Environment (SE),* containing High Level Service Providers (SP) and Content Providers (CP); *Network Environment (NE),* where a new CAN Provider exists (CANP) to manage and offer Virtual Content Aware Networks - VCANs); traditional Network Providers (NP/ISP) - managing the network at IP level. The "environment", is here a generic grouping of functions cooperating for a common goal.

The CANP offers to the upper layers enhanced VCAN-based connectivity services, unicast and multicast (QoS enabled) over multi-domain, multi-provider IP networks. The novel CAN routers are called *Media-Aware Network Elements (MANE)* to emphasize their additional capabilities: content and context – awareness. 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., SP-CANP). 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.

In [12], [13] the general framework is developed, to manage connectivity services offered by the VCANs to the upper layers. This paper elaborates the mapping of the overlay VCANs (as requested by an SP) onto real network resources in a multi-domain context, while satisfying topological QoS constraints, is a challenging issue and is the main subject of this paper, thus continuing the initial work on VCAN presented in [12][13]. During this mapping the VCAN resources are logically reserved; later when the VCAN installation is requested by the SP, they will be really allocated in routers. Note that the content awareness processing is not directly discussed in this paper, but is specified in [11-13].

Section II presents samples of related work. Section III summarizes the overall ALICANTE architecture and VCAN general Management. Section IV describes the inter-domain peering solution. Section V is the paper core, presenting the proposal of an architecture and a joint algorithm which uses the overlay topology information and combines constrained routing and resource reservation aiming to assure the optimum VCAN virtual links mapping onto network paths. Section VI contains some conclusions and future work outline.

II. RELATED WORK

The fundamental problem for virtual networks is their instantiation and finding an optimal allocation of resources offered by a physical IP Network. In order to solve this NP-hard problem, several heuristics have been proposed in literature [4][5][24].

Our specific objective is to develop management solutions to map the QoS capable VCANs, over several independent network domains, in a scalable way to finally assure efficient transport of real-time and media traffic. The approach must take into account the ALICANTE partially decentralized architecture [9-12] : CAN Managers and Intra-domain Network Resources Managers exist – each of them being aware on the status of their resources. Therefore we should consider also the inter-domain QoS enabled domain peering problem. Basically there are two solutions: find some inter-domain paths (without checking the QoS properties mandatory), or find QoS enabled paths. Any solution applied, after paths finding, a negotiation protocol should be run, [9-11] [18][19][21], between domain managers, to establish inter-domains Service Level Specification (SLS) agreements (SLS is the SLA technical part) containing clauses for QoS guarantees. If no QoS constraints are used during routing, there are significant chances that the SLS negotiation will fail. So, it is a better solution to search for QoS enabled paths, [14][15][18][19].

In [18][19], QoS enhancements for the Border Gateway Protocol (BGP) are proposed to add QoS related information to BGP advertisements between network domains. However, the notion of parallel planes (in our case content aware) at domains level is absent there and all process are running at routing level.

Better fitted to ALICANTE needs are the solutions for inter-domain QoS peering and routing based on the overlay network idea, [14-16]. An overlay network is defined, which first, abstracts each domain with a node, represented by the domain resource manager, or more detailed with several nodes represented by the egress routers from that domain. Protocols are needed to transport QoS and other information between nodes and, based on this information, QoS routing algorithms can choose QoS capable paths. In [20] 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.

Related to management signaling for inter-domain, several solutions are examined and compared (cascade, hub, mixed-mode), [18][19][21][22]. However, neither solution considers the content awareness capabilities of the multiple domain infrastructure, nor the virtualization aspects. ALICANTE architecture realizes parallel Internet planes as in [22], but mapped onto VCANs, and additionally achieves cooperation between the network layer and applications and services layers, thus realizing a traffic optimization loop.

The solution adopted in this paper is a combined one, applicable both to inter-domain and intra-domain context: QoS enabled (constrained) routing based on overlay topology, the VCAN virtual links assignment to virtual paths, after admission control check, first at inter-domain level and then negotiation between domain mangers and running similar algorithms at intra-domain level.

III. ALICANTE SYSTEM ARCHITECTURE AND VCAN MANAGEMENT

The general ALICANTE concepts and architecture are defined in [9-11]. Figure 1 shows a mixed, simplified picture, emphasizing the actors and interactions and a multi-domain VCAN.

The network contains several Core Network Domains (CND), belonging to NPs (can be Autonomous Systems - AS) and access networks (AN). The ANs are out of scope of VCANs. The CAN layer M&C is partially distributed: one *CAN Manager* (CANMgr) belonging to CANP exists for each IP domain, doing VCAN planning, provisioning, advertisement, offering, negotiation installation and exploitation. Each domain has an *Intra-domain Network Resource Manager* (Intra-NRM), as the ultimate authority configuring the MANE and other network nodes. The EU terminals are connected to the network through Home Boxes, playing the roles of Residential Gateways. A HB can also act as a CP/SP for other HBs, on behalf of the EUs. The CAN layer cooperates with HB and SE by offering them CAN services.

The VCAN Management framework has been already defined in [12][13]. Here only a short summary is recalled for sake of clarity. A functional block at Service Manager SM@SP, performs all actions needed for VCAN support on behalf of SP (planning, provisioning, negotiation with CANP, VCAN exploitation). The CAN Manager (*CANMgr@CANP)* performs, at the CAN layer, VCAN provisioning and operation. The two entities interact based on the SLA/SLS contract initiated by the SP. The interface implementation for management is based on Simple Object Access Protocol (SOAP)/Web Services.

The main interactions in the Figure 1 are*: SP-CANP(1)*: the SP requests to CANP to provision/ modify/ terminate VCANs while CANP says yes/no; also CANP might advertise existent VCANs to SP; *CANP-CANP(2)* – negotiations are needed to extend a VCAN upon several NP domains; *CANP-NP(3)* : CANP negotiates resources with NP; *Network Interconnection Agreements (NIA) (4)* between the NPs or between NPs and CANPs; (necessary for NP cooperation). After the SP negotiates a desired VCAN with CANP, SP will issue the installation commands to CANP, which in turn configures, via Intra-NRM (action 4), the MANE functional blocks.

The content awareness (CA) is realized in three ways, [11]:

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

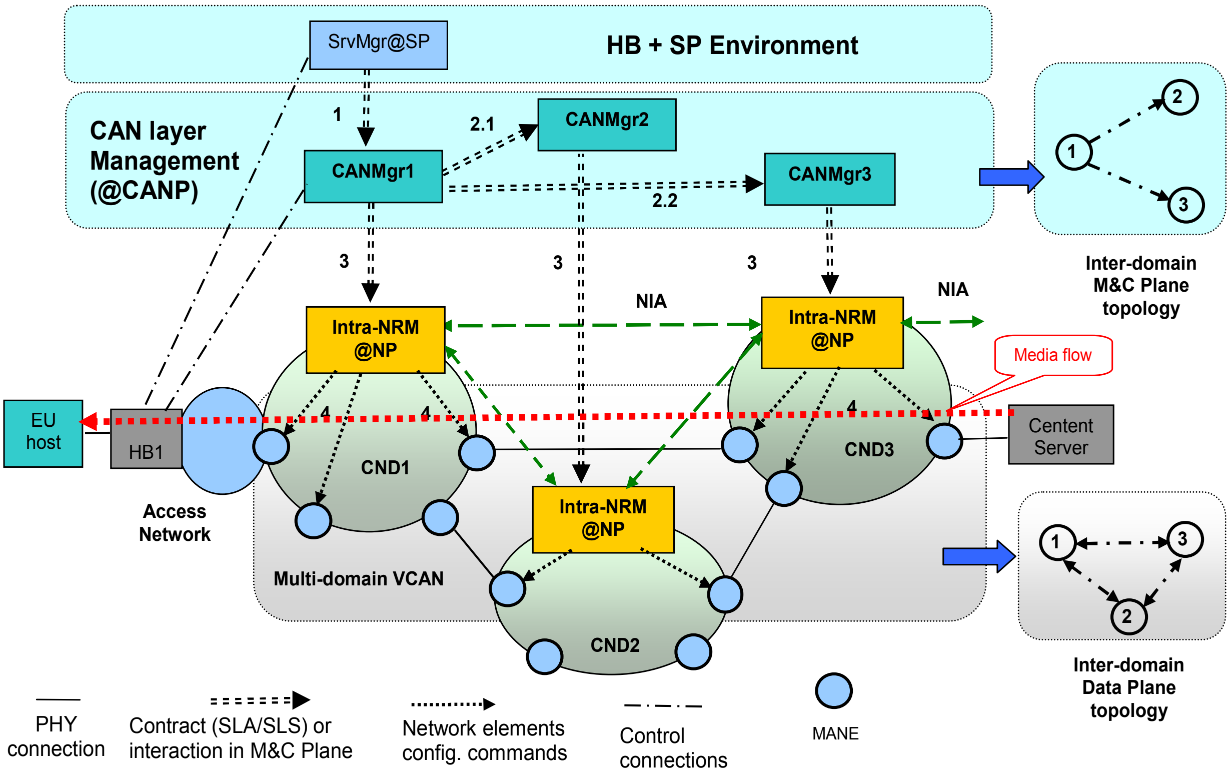

Figure 1 Example of a multi-domain VCAN. Data Plane topology and management interactions

In the CNDs DiffServ and/or MPLS technologies can support splitting the sets of flows in QoS classes (QC), with a mapping between the VCANs and the QCs with several levels of QoS granularities, [18][19]. The QoS behavior of each VCAN (seen as one of the parallel Internet planes) is established by the SP-CANP.

IV. CAN MULTI-DOMAIN PEERING

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 *M&C topology*. The first can be of any kind (including the domains spanned by a given VCAN- see Figure 1- triangle). The *M&C topology* defines how the CANMgrs associated to CNDs inter-communicate for multi-domain VCANs construction. The VCAN initiating CANMgr has to negotiate with other CAN Managers. There exist two main models: *hub* model and *cascade* model, [19][21][22].

The *hub model* was selected; it has the advantage that initiating CANMgr knows, each VCAN component (network) and its status, but it must also know the inter-domain topology. Given the tiered hierarchy of the Internet, the number of CNDs involved in an E2E chain is not too high (actually is lower than 10, [8]), so, *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, [19][21] is better for a chain of domains topologies than for arbitrary ones.

Figure 1 shows an example of a multi-domain VCAN composed of parts of CND1, 2, 3. This VCAN is constructed in the following way. An inter-domain discovery protocol [11], has informed each CANMgr about the inter-domain graph where each CND is abstracted as a node (the inter-domain links capacities are also learned, supposing that each CANMgr knows its neighborhood). The SP asks for a

VCAN to a CANMgr (Initiator) – see action 1. The SP knew the edge points of this VCAN, i.e., the MANEs IDs where different sets of HB currently are, or they will be connected. The initiator *CANMgr_n* determines all CNDs involved (from the SP information and its inter-domain knowledge) and then negotiates in parallel with all other CAN Managers (actions 2.1, 2.2) to agree and reserve resources for the VCAN. The split of the SLS parameters (if it is the case) should be done at the initiator (e.g., for delay). In a successful scenario, the multi-domain VCAN is agreed and then it will be later instantiated in the network.

Each CND has complete autonomy w.r.t its network resources including network dimensioning, off-line traffic engineering (TE), and also dynamic routing. The CANMgr and Intra-NRM have together an abstract view of its CND and output links towards neighbor domains in a form of a set of virtual links (called *Traffic Trunks*). A set of such links can belong to a given QoS class. A multiple domain VCANs 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, between CANMgrs. The multi-domain VCANs deployment needs knowledge on a virtual multi-domain topology. Acquisition of this information is performed by an inter-domain protocol, which offers to CANMgrs an *Overlay Network Topology Discovery Service* (ONTS) similar to that described in [20]. Therefore in the following sections we suppose that this information is known by each CANMgr. Details on the protocol performing the ONTS for the benefit of given CAN managers are out of scope for this paper.

V. VCAN MAPPING AND RESOURCE RESERVATION

A. CAN Provisioning at SP

The functional block at SP for this is the CAN Provisioning Manager at SM@SP. It performs the SP-CANP SLS processing - subscription (unicast/multicast mode) in order to assure the CAN transport infrastructure for the SP. After some VCAN planning the SP requests to the CAN Manager associated with its home domain, to subscribe for a new VCAN. 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 Intra-NRM, and overbooking is an option, depending on the SP policy.

B. CAN Negotiation

A negotiation protocol (SP-CANP-SLS-P) has been developed in ALICANTE (not detailed here) to support the negotiation process between several pairs of managers like *CANProvMng@SM* as a client and *CAN Manager* as a server. The main usage of this protocol is for establishing *SLS* contracts, but it should have all the necessary properties of a general negotiation protocol, and could be adapted/used to serve CAN invocation. The SP-CANP-SLS-P supports one of several negotiation actions: establishment/ modifications/ termination of SLS contracts.

C. Inter-domain CAN Planning and Resource Management

The *CAN Planning* first task is to perform the inter-domain resource management and then prepare the intra-domain similar actions. QoS capable VCANs are envisaged here. The idea of this paper is to combine the constrained QoS routing with admission control and VCAN mapping, on two levels: inter-domain and then intra-domain. This split solves partially the scalability and also administrative problems of a multi-domain environment. The planning objectives are: using the ONT information and SP request to determine the domains participating to a given VCAN requested by SP; apply a constrained routing algorithm admission control and VCAN mapping; based on routing information the SLS splitting between domains is computed.

To make the functional steps more readable, consider the Figure 2 example, containing several network domains CND1, CND2, … CND8. SP has requested a VCAN-0 construction, whose parameters are embedded in an SLS request. The CND1 is supposed to have its CAN Manager as initiator of the VCAN. The required VCAN should assure guaranteed services in a given QoS class, services, i.e. guaranteed traffic trunks (TTs) starting from the Content Servers CS1, CS2 up to different client HBs, denoted as HBc1…HBc7. SP requests the VCAN-0 and a delivers a Traffic Matrix (TM) associated to it, containing (at minimum) the requested bandwidth of the TTs.

The following actions are performed:

1. SP issues a VCAN-0 request to initiator CANMgr1 (at CND1) i.e. an SLS request (topology, traffic matrix, QoS guarantees, …etc.).
2. The CANMgr1 obtains from ONTS the inter-domain level ONT (topology graph, inter-domain link capacities, etc.). The ONT is sufficiently rich to cover the required VCAN.
3. The CANMgr1 determines the involved domains in VCAN-0 by using the border ingress-egress point's knowledge (actually MANE addresses) indicated in the SLS parameters (Figure 2.a).
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 Figure 2.a this new VCAN is represented by dotted line). In VCAN-1 graph, some new additional transit core network domains need be included, e.g., CND4, CND5 (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. Optimisation techniques can be applied in this phase.
5. The initiator CAN Manager should make the first split 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 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 *ouputs* are the Traffic matrices for each CND composing the VCAN.

To do this, the CANMgr1 will run a constrained routing algorithm. A combined metric is proposed here for a link, similar to [14], considering the bandwidth request and the bandwidth available, targeting to choose the widest path.

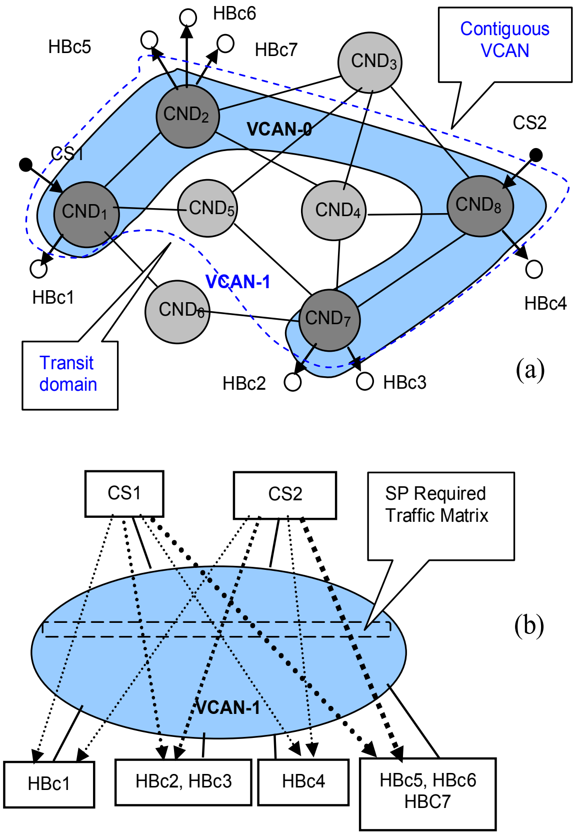

Figure 2. Example of a multi-domain requested VCAN (VCAN-0 is requested by SP).

Note that the final solution will also contain delay-constrained routing and introduce delay in the metric. This is possible, given that ALICANTE system has a powerful monitoring plane capable to perform delay measurements and compute averages both intra and inter-domain. In the example below we only consider bandwidth only in the metric defined.

The cost of a inter-domain link (i,j) in the ONT can be $C(i,j) = Breq/Bij = Breq/Bavail$, where Bij is the available bandwidth on this link and *Breq* is the bandwidth requested for that link. Another useful interpretation of this ratio is as link utilization factor ; that is we the alternative notations will be used: $C(i,j) = U_{link\_ij}$. The metric should be ≤1, this representing the bandwidth constraint applied to the algorithm. The metric is additive, so one can apply modified Dijkstra algorithm to compute the *Shortest Path Trees (SPT)* for each ingress node where the traffic flows will enter. Given that *Breq* is different for each branch of the tree the additive metric used for SPT computation is 1/Bij. The mapping is to be done jointly with the routing process.

The summary pseudo-code of the combined routing, admission control (AC) and mapping algorithm (not yet optimized) is described below. The notation ;/text after pseudo-code lines represents explanatory comments.

```
1. Split the requested TM in several trees, one for each ingress node ( I1, I2, ...In);/See the Figure 2.b having two trees
2. On the current graph, repeat for 1 to n:
    {2.1. Compute the DJ_SPT (root_I1) where DJ means Dijkstra algorithm;/Routing
     2.2. Select the TM branches that can be satisfied ( i.e., Bij > Breq for that direction);/Mapping and AC
     2.3 Reserve capacities for these branches by subtracting the respective capacities from the graph;/ thus obtaining a reduced graph
     2.4. Compute the overall utilization for each path reserved as $U_{path} = Sum_{links} (Breq/Bavail) * NHF(path)$;
     2.4 List the unsatisfied branches; /it may happen to not be able to satisfy all requests of TM
    }
3. Aggregate the results for all inputs, for satisfied and not satisfied branches and compute the overall VCAN utilization by summing over all paths mapped onto the real graph;
```

Notes:

1.The cost of a full path could be *Sum (link costs) * NHF(path)* where Number of Hops Factor NHF(path) is a weight factor approximately proportional with the number of CNDs crossed by this path. This cost will optimize the solution by reducing the number of transited domains

2.AS shown above, the ratio *Breq/Bavail* computed on a link can be interpreted as the link utilization factor $U_{link} = Breq/Bavail$ of that link. Summing for all links we can get the path utilization. Summing the utilizations for all paths one gets the overall network utilization U_{VCAN} for that VCAN.

3. We assume that only bandwidth is considered in the above metric and the procedure is: select the widest path ; however this will usually also assure the smallest transfer delay, [14].

4. In the simplest form the algorithm keeps only the best path satisfying the constraint. In an advanced version, several inter-domain paths satisfying the constraint may be retained. Knowledge of the path allows that the domains involved in this TT are determined. This solution could be useful for load balancing and it will be analysed in a future work.

5. If priorities are assigned to the TTS in the traffic matrix by SP, then these will be considered in the order of computations done in Step 2.

D. VCAN Mapping Optimisation and Scalability

The optimal mapping of overlay virtual networks onto real network substrate resources is shown to be a NP-hard problem, [24]. We try here to find a pragmatic solution, based on the fact VCAN construction actions have no strong real time constraints for computations. The solicitation of a CANP to construct VCANs is rather not frequent (intervals of days, weeks, etc.).

Normally the NP would like that for a given traffic matrix associated to a VCAN, the best mapping would be that one having the least overall utilization. Therefore a straightforward optimization method is to compute the step 2 of the algorithm several times, for other order of inputs given by the bijective function f(I1, ..In) -> {Ik1, Ik2, ..Ikn} which creates actually permutations of the set {I1, ..In}. The function is random. The best allocation is that one having the least overall utilization. Note that for large n, the solution is not scalable (we would need n!) computations. Therefore in practical cases one can stop repetitions of the step 2 after some computations if the overall utilization fulfill some enough good thresholds fixed by local CANP policy.

Other optimization procedure is possible if the CANP policy looks for an optimal mapping that leaves the greatest amount of resources available. Then the same algorithm can be applied, while the metric for a link will be not U but $1/(1-U)$.

Scalability of the solution is assured by: splitting the problem hierarchically in inter-domain and intra-domain similar problems; grouping the requests in sets of trees and avoiding of individual mapping; exploiting Internet tiered hierarchy in order to minimize the number of transit domains in a VCAN.

E. Numerical Example

Figure 3 presents a numerical example of inter-domain path computation, in order to finally determine the splitting of the overall SLS into parameters sets, each one associated to a different domain. The links are denoted with values representing the available bandwidth. Note that, depending on the policies, these bandwidth values can be used for any QoS class, based on FIFO policy of resolving the SLS requests, or might be assigned offline for given planned QoS classes.

The paths utilizations in the Figure 3 example are:

$U(path\_1) = (1/5 + 1/3 + 1/4) *4 = 0.78*4 = 3.12$

$U(path\_2) = (1/2 + 1/6 + 1/3) *4 = 1.0 *4 = 4,$

therefore the *path_1* is better, given that it has a lower path utilization factor.

Given the resource reservation assured by provisioning in the M&C plane (accompanied by policing in the data plane), the value of the bandwidth already booked is subtracted from the available one, on each link, before analysing other TT paths. The SLS splitting results of this computation step are:

TT(CND1) : Input_CS1---> Output_CND2, Breq= 1;
TT(CND2) : Input_CND1---> Output_CND4, Breq= 1;
TT(CND4) : Input_CND2---> Output_CND8, Breq= 1;
TT(CND8) : Input_CND4---> Output_HBc4, Breq= 1;

After splitting in this way the overall SLS, a set of parameters are available for each domain. Then, separate negotiations can be done by CANMgr1 with each other CAN Manager involved in the VCAN for that SLS.

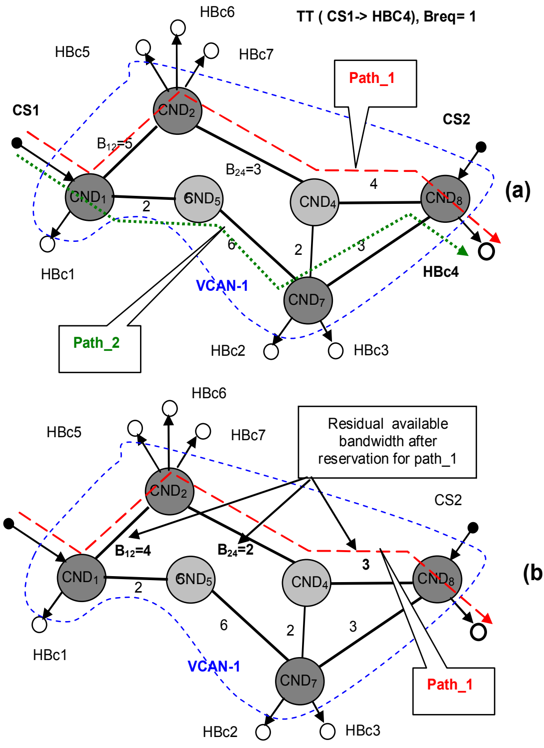

Figure 3. Connectivity graph of the extended VCAN (requested by SP SLS domains and the transit ones)

a. Inter-domain path computation (constrained routing) and implicit inter-domain resource reservation

b. Adjustment of the ONT graph after selecting *path_1* as good.

The algorithm has been preliminary implemented using Visual Studio C++ Express Edition as development environment. The hardware platform was equipped with Intel(R) Core(TM)2 CPU T5600@1.83GHz processor and 2,00 GB installed memory (RAM) on a 32-bit OS. The preliminary results have shown computation times between 10-100 ms for network graphs having 5-80 nodes. It was also observed a dependency between the number of solved requests and the number of edges in a graph with the same number of vertices. Further results will be reported in a future work.

F. Intra-domain CAN Planning and Resource Management

In ALICANTE a two level hierarchy has been selected for VCAN mapping: inter and intra-domain. Essentially, to map a VCAN portion onto a given CND network graph for the intra-domain case, *the same algorithm can be applied by the CAN Manager in cooperation with Intra-NRM.* The knowledge of the intra-domain graph is obtained by Intra_NRM in the link-state style (similar to Open Shortest Path protocol- OSPF). The details will be studied in a future work. The actual placement of functions inside CAN Manager or Intra-NRM depends on policies and degree of trust between these two entities. Actual locations of mapping functions depends on 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 to the CANMgr can be adjusted by Intra-NRM to improve the traffic engineering performances.

VI. CONCLUSIONS

This work proposed the architecture and a combined set of algorithms and protocols to manage network resources, in order to solve the mapping of a Virtual Content Aware Network overlay plane, onto network infrastructure resources, while respecting the QoS requirements issued by the Service Provider which is exploiting VCANs. The inter-domain part of the problem has been treated in more details, by combining an overlay topology approach with an inter-domain constrained routing and admission control. Scalability and optimization aspects have been discussed. Note that the solution discussed is currently in the phase of detailed design, evaluation and implementation inside the FP7 ALICANTE project. Consequently in the near future, complete evaluation results both formal and experimental of this solution will be published.

Acknowledgments

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