Hybrid Multicast Management in a Content Aware Multidomain Network

Eugen Borcoci
Telecommunication Dept.
University Politehnica of Bucharest
Bucharest, Romania
e-mail: eugen.borcoci@elcom.pub.ro

Gustavo Carneiro
INESC Porto, Faculdade de Engenharia,
Universidade do Porto
e-mail: gjc@inescporto.pt

Radu Iorga
Telecommunication Dept.
University Politehnica of Bucharest
Bucharest, Romania
e-mail: radu.iorga@elcom.pub.ro

Abstract—**This paper proposes an architectural management solution for a multicast hybrid infrastructure optimised to transport real time multimedia flows. The multicast capabilities are offered to the upper layers as connectivity services by an overlay multi-domain Content-Aware Network. The overall system is based on new concepts like Content-Aware Network and respectively Network Aware Application. A hybrid multicast framework, Quality of Services capable is proposed, where IP intra-domain multicast is combined with inter-domain overlay multicast. The management aspects of this infrastructure are discussed. The design, validation and implementation of a system based on this architecture are currently under development in the European FP7 ICT research project, ALICANTE.**

Keywords - multicast; overlay multicast; content-aware nertworking; network aware applications; multimedia distribution; quality of services; Future Internet.

I. INTRODUCTION

The multicast transport service has received more attention in the last years, in the context of increasing of group communication needs and also of real time flows and content/media distribution to large groups of users like IPTV, Video on demand (VoD), peer-to-peer (P2P). The traditional IP multicast (IPM) despite its two decade age[1], is not however globally deployed [2][3] , due to problems related to group management, needed router capabilities, inter-domain issues and QoS problems. On the other hand, Overlay Multicast (OM) has received increased attention in the last decade, including tree based and P2P solutions. OM [4][5][6], has lower efficiency and speed, but it is quickly implementable, due to not relying on network layer multicast capabilities. A hybrid approach (IPM + OM) can be an attractive trade-off, both in terms of scalability, efficiency and flexibility. One can benefit from intra-domain IPM where it exists, and use OM outside the IP multicast area. Therefore, in this paper, a hybrid solution is considered.

For the Future Internet (FI) it is generally accepted that it will be [8][9] strongly service-content oriented and media oriented. A new concept proposes to increase the coupling between the transport/network and application layer, resulting in Content-Aware Networks (CAN) and Network Aware Application (NAA). Such CANs can be constructed as overlays, on top of traditional IP networks using partial or full network virtualization (VCAN). Note that virtualization is seen as a main way to make the Internet more flexible [10],[11]. Compared to the traditional ones, the CAN routers have additional tasks such as content/context-based classification and filtering, QoS processing, routing/forwarding, adapting and transforming the packet flows.

This paper considers the multicast service realization in a CAN/NAA context. The work is performed inside the European FP7 ICT research project, “Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments”, ALICANTE, [15]-[19]. An architectural management solution for a multicast hybrid infrastructure, QoS capable is proposed here, optimized to transport real time multimedia flows. The multicast services are offered to the upper layers by the VCANs. The solution is based on hybrid multicast (H-Mcast) framework, QoS capable, where the IP intra-domain multicast (if available) is combined with inter-domain overlay multicast. The management aspects of this infrastructure are explored.

The paper is organized as follows. Section II presents samples of related work. Section III summarizes the overall ALICANTE architecture. Section IV is focused on the multicast hybrid framework. The multicast management solution is proposed in Section V. Section VI contains some conclusions and outline of future work.

II. RELATED WORK

The new approach CAN/NAA is currently investigated in many studies, targeting better performance (for multimedia) but without losing modularity of the architecture. The CAN and NAA are studied in the framework of Future Internet architecture discussions.

The CAN/NAA approach can naturally lead to a user-centric FI and telecommunication services, as described in [8],[9],[12],[13]. The works [12][13] consider that CAN/NAA can offer a way for evolution of networks beyond IP. The capability of content-adaptive network awareness is exploited in [13]. The CAN/NAA approach can also offer

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QoE/QoS capabilities of the future networks, [12]. The architecture can be still richer if, to content awareness we add context awareness [13]. To provisioning methods for QoS assurance one can add content adaptation as another set of methods [14][18]. The CAN approach, on the other hand, requires a higher amount of packet header processing in the CAN elements, similar to deep packet inspection techniques; therefore, new methods are needed to minimize this processing task. Organizing the Internet in VCANs is a solution that fits naturally into the concepts of Parallel Internets [20]: each plane can be associated to a VCAN and to different QoS classes having different granularities, as described in [20], [22].

The approach of this paper is to enhance the VCAN capabilities with a powerful multicast service, QoS-enabled CAN, and multi-domain capability.

III. SUMMARY OF ALICANTE SYSTEM ARCHITECTURE

The ALICANTE main concepts and general architecture has been already described in [15]-[19]. Here, a summary only is inserted to allow the next presentation of the multicast framework as shown in Figure 1.

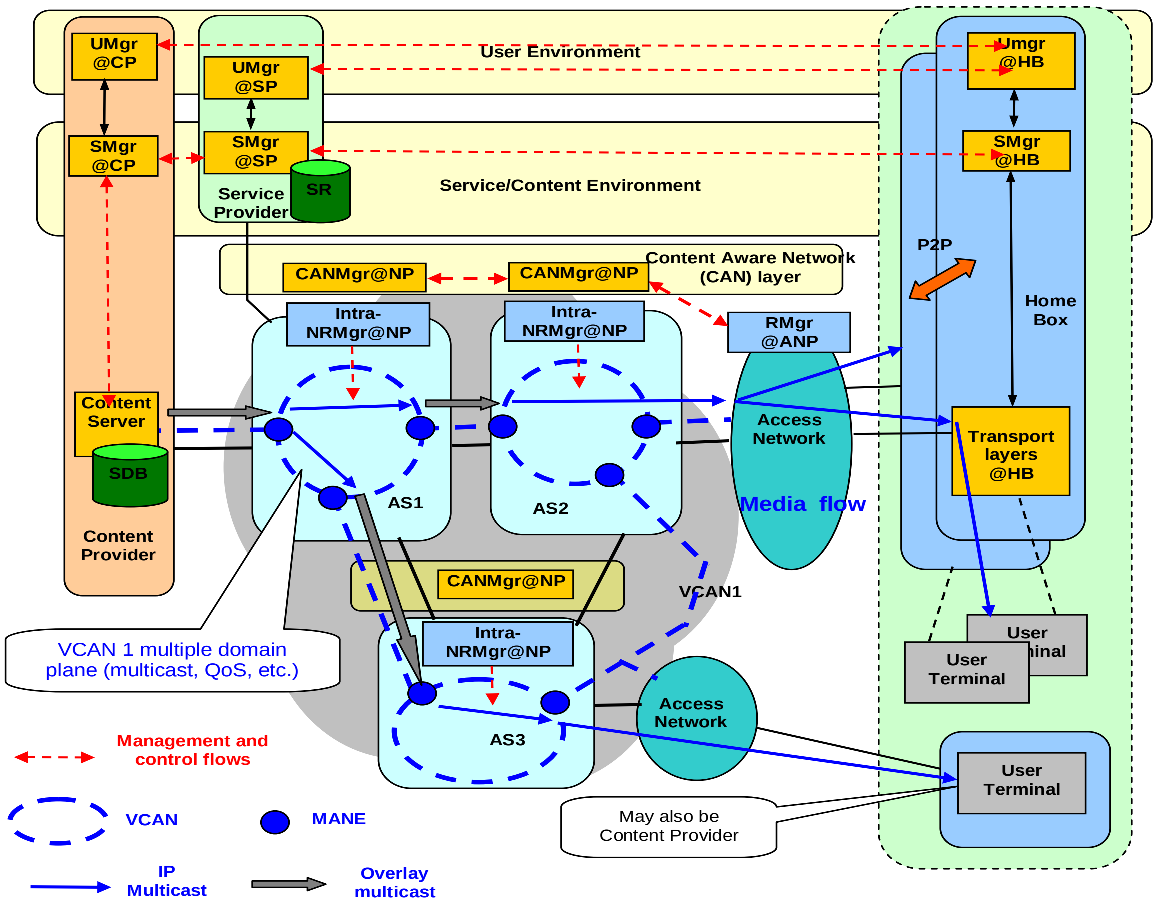

Figure 1 The ALICANTE Overall Architecture

Notations: UMgr, SMgr, CANMgr, NRMgr, RMgr – are respective managers at user, service, CAN and network levels. MANE – Media Aware Network Element; SR Service Registry; SDB- Server Data Base

ALICANTE proposed a new *Media Ecosystem*, comprising business entities, having roles of consumers and/or providers. It defines inter-working environments, [15], [16]: *User Environment (UE)*, to which End-Users (EU) belong; *Service Environment (SE)*, to which Service Providers (SP) and Content Providers (CP) belong; *Network Environment (NE)*, to which the Network Providers (NP) belong. The business model contains a new actor - *CAN Provider (CANP)* which is the virtual layer connectivity services provider seen as an enhanced NP and offering VCAN services. A new entity is also defined: *Home-Box (HB)*, partially managed by the SP, the NP, and the EU. The HB is located at end-user's premises and manages *content/context-aware and network-aware* information. The HB can also act as a CP/SP for other HBs, on behalf of the End User (EU). The HBs cooperate with SPs in order to distribute multimedia services (e.g., IPTV) in different modes (e.g., native multicast or Peer to Peer -P2P).

Two novel virtual layers [15],[16] exist: CAN layer for network level packet processing, working on top of IP and HB layer for the actual content delivery, in the user proximity. The HB layer hosts the service adaptation,

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service mobility, security, and overall management of services and content. The CAN routers are called *Media-Aware Network Elements (MANE*) having additional capabilities: content/context - awareness, controlled QoS, security, monitoring, etc. The CAN/MANE approach offers advantages over conventional routing/forwarding, but raises several challenges given more tasks to be performed by the MANE.

The CAN layer offers to the SP, *Parallel Internets* specialized for different types of applications/content, including multicast services. One or several CANs with different capabilities can be defined, installed and offered by each domain. They also can be chained in order to obtain multi-domain spanned CANs. The CAN data operations are performed by MANEs which are installed at the domains' edges (scalability reasons). The MANEs process the flows according to the content properties derived from the data flow and depending on VCAN network properties and its current status. The flows are classified in MANE based on *Content Aware Transport Information (CATI)* inserted by the content servers in the data packets, or *packet headers analysis* or information derived by *on-the-fly content-type statistical analysis.* The Management and Control Plane supports contracts/interactions [19] of SLA/SLS type (appropriate protocols are developed in ALICANTE): *SP-CANP*- through which the SP requests to CANP to provision/ modify/ terminate VCANs; *CANP-NP* - through which the NP offers or commits to offer resources to CANP; *CANP-CANP* – for multi-domain VCANS; *Network Interconnection Agreements (NIA)* between the NPs or between NPs and ANPs (these are not new ALICANTE functionalities but are necessary for NP cooperation).

In Figure 1, a VCAN1 is configured, spanning AS1, 2, 3 and offering multicast services. IP multicast is used inside ASes (if available) and overlay multicast between domains. The MANE is both IP multicast and OM capable.

IV. HYBRID MULTICAST OVERLAY

This section describes the multicast functionalities provided by the CAN, first at intra-domain level, and then expanding the scope to cover multi-domain multicast via VCANs.

A. MANE Multicast Functionalities

For intra-domain multicast, ALICANTE will use Protocol Independent Multicast – Sparse Mode or Source Specific Multicast (PIM-SM/SSM), [5],[7]complemented with QoS assurance mechanisms. For the first phase of system development, PIM-SM has been selected as an existing mature solution. In case that a given domain has no IPM capabilities, still the H-Mcast system can extend the OM to transit the respective domains.

The inter-domain links between MANEs will transport UDP packets containing a header and the multicast data. Thus, in the case of native multicast traffic generated by the CP server, an Overlay Module (OMd) inside the MANE, encapsulates the native multicast packet or payload into a unicast one and send it to the next domain. The latter will strip the outside header and, based on OMd header, CATI, or SVC[24] layer information and then forwards the multicast data to the HBs that are subscribed to it, using transport method selected for that session in that domain.

MANEs can also contribute to P2P intra-domain multicast [17][18]. In such scenarios, the MANE is first instructed to forward the content as unicast flows, one flow per HB. Later, if a few more HBs subscribe to the content, in order to save bandwidth, switch to P2P distribution mode is triggered by the CAN Manager. Therefore, from the MANE point of view, only unicast sending is necessary. The P2P management and control actions will be done by the CAN Manager and HBs. The MANEs are supposed to be both IPM and OM capable. MANE has a *multicast data plane module (MDPM)*. It receives an input packet and retransmits it in a number of replicas as required. The MANE receives instructions of how to multiply and forward multicast traffic (forwarding table), from CAN Manager via Intra-NRMgr.

The details of the MANE multicast functionality will be presented in a future paper. A short description is inserted here. The MDPM has two input drivers, one for multicast and another for unicast input, a high-level Multicast Bridge/Switch (MB) sub-module, and two output drivers, one for multicast and another for unicast. The MB contains a *Forwarding Table* storing the tree information of that MANE. As an example, for the case of an SVC application flow there will be associated a multicast tree for each SVC layer [18]. This is also done by the LOLCAST protocol [23], but it only supports OM, and not H-Mcast as is proposed here. The input driver receives packets from a network interface and analyzes them to extract the parameters {VCAN_ID, Layer#}. The input module delivers to the MB the original full packet, plus VCAN_ID, Layer# information. The MB generates the replicas to the output ports, in native multicast mode or unicast mode depending on the next device/network which follows that MANE.

B. Multi-domain VCAN Multicast Trees

An H-Mcast tree is composed of several MANE nodes (H-MCast nodes) distributed in several NP domains. Each one may assume one or more of the following roles: *root node*, *intermediate node*, and *leaf node*. The latter are usually located at the ingress of ANs. Intermediate MANE nodes are capable of making an interface between the IPM and OM parts of the tree.

A domain peering problem appears in multi-domain VCAN cases: how to determine the domains to compose the VCAN. The hub model has been proposed in ALICANTE, [19]. The SP contacts an initiating CAN Manager, which in turn determines and negotiates with other managers in order to establish the multi-domain CANs. The initiating *CAN Manager is supposed to have inter-domain topology information* (it should know all AS domains participating to this VCAN). The advantage of this approach with respect to others (e.g., cascade model) is that one has complete control of the VCAN, but knowledge on inter-domain topology is needed. However, the number of ASes involved in a CAN communication is low (< 10), and they can be localized in an Internet region, therefore the scalability problem is not so stringent.

Figure 2 shows an example of a multicast VCAN spanning three autonomous systems AS1, 2, 3, 4. The AS1 and AS4 network routers are PIM-SM capable, while AS2 and AS3 are not (except MANE). A multicast capable VCAN is constructed having a tree topology, with root in AS1 and leaves in other domains. The left side MANE routers in AS1 and AS4 plays also the role of *Rendezvous* Points *(RP)*[7] for the PIM-SM protocol. The thin lines of the tree in the picture represent the unicast links composing the overlay part, while the thick ones the IPM part. The leaf MANEs play also the role of Designated Routers for PIM-SM protocol. The HBs can subscribe to the multicast tree by using the *Internet Group Management Protocol IGMP*. The construction of such tree will be described in the following sections.

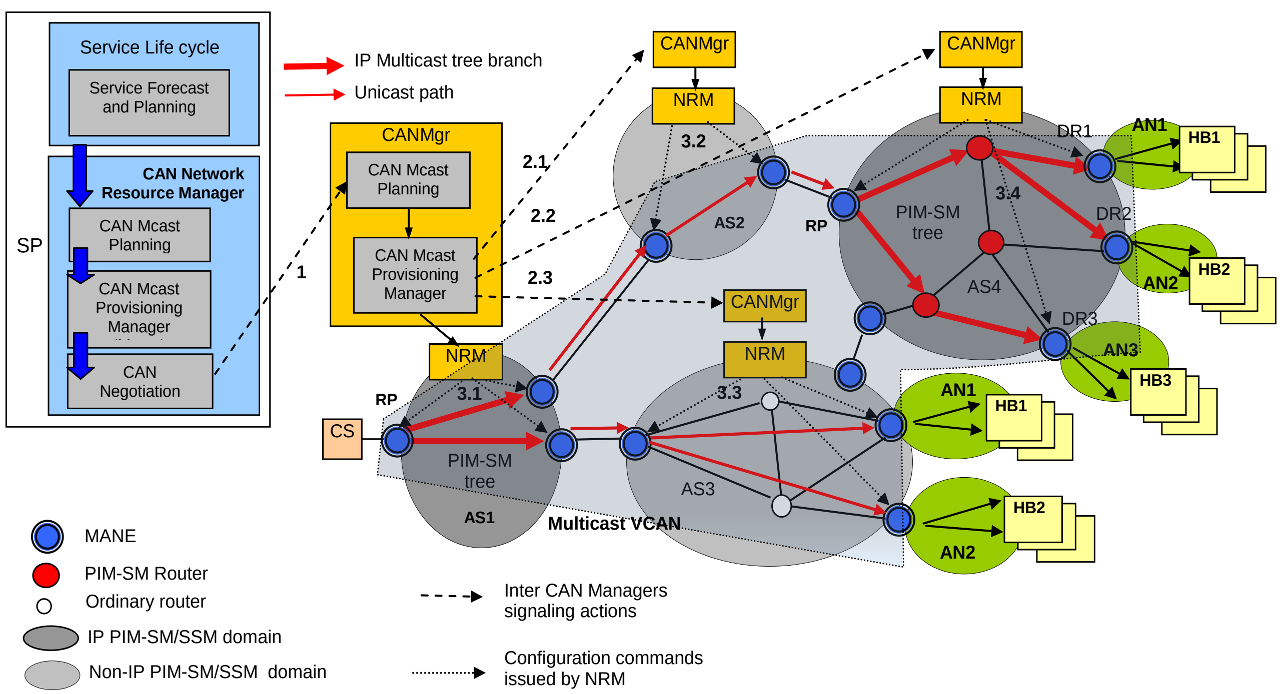

Figure 2 Hybrid multicast tree and management actions
AS – Autonomous System; CANMgr- CAN Manager; NRM – Intra-domain Network Resource Manager; DR – Designated Router; RP – Rendez-Vous Point (PIM-SM); HB- Home Box

V. HYBRID MULTICAST MANAGEMENT

In this section, the hybrid multicast management framework is described. We focus first on defining the management entities involved, then the process of multicast VCAN construction, and finally QoS aspects of multicast trees.

A. *Management Entities*

This section outlines the management framework for H-Mcast in ALICANTE. The decision to construct multicast enabled VCANs belongs to the Service Manager (SM@SP) of the Service Provider (Figure 2). More complete description of the SM@SP is given in [19]. Here we only emphasize those ones involved in multicast management.

The *CAN Network Resources Manager* (*CAN_RMgr*) is a SM@SP functional block performing all actions to assure the VCAN (unicast, multicast) support to the SP. It negotiates actions like *VCAN planning*, *provisioning and operation*. An SLA between SP and CANP establishes the provisioning and operation clauses for the future VCAN.

The CAN_RMgr@SM of the SP interacts with other modules of the SM@SP: *Service Forecast and Planning* - an *offline process* performing service predictions and their associated plans of deployment, considering the business needs as input; *Service Deployment Policy* (not shown in Figure 2) - containing predefined rules for service planning and deployment. This information is derived from the high-level SP business interests. The detailed functionality of these are out of scope for this paper.

The CAN_RMgr@SM contains: *CAN Mcast Planning*, *CAN Mcast Provisioning and CAN Negotiation* modules as a main tuple to provision VCANS. Not shown in Figure 2, are: *CAN Operation and Maintenance* intervening during VCAN exploitation; *VCAN Repository* data base to keep all data related to VCAN provisioning, installation and current status; *CAN Deployment and Operation Policies* to guide the other blocks of the CAN_RMgr@SM. The interface implementation for communications between external

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modules will be based on SOAP/Web Services interfaces, used for SOAP requests and responses.

At CAN layer, the *CNMgr@CANP* has a Multicast Manager (*McastMgr@CANP*) to perform actions to execute the SP multicast service requests, i.e., related to multicast VCAN provisioning and operation. In Figure 2, two modules called *CAN Multicast Planning and CAN Multicast Provisioning Manager* are suppose to perform the actual planning of the multicast VCAN in terms of all tree elements and domains to be spanned.

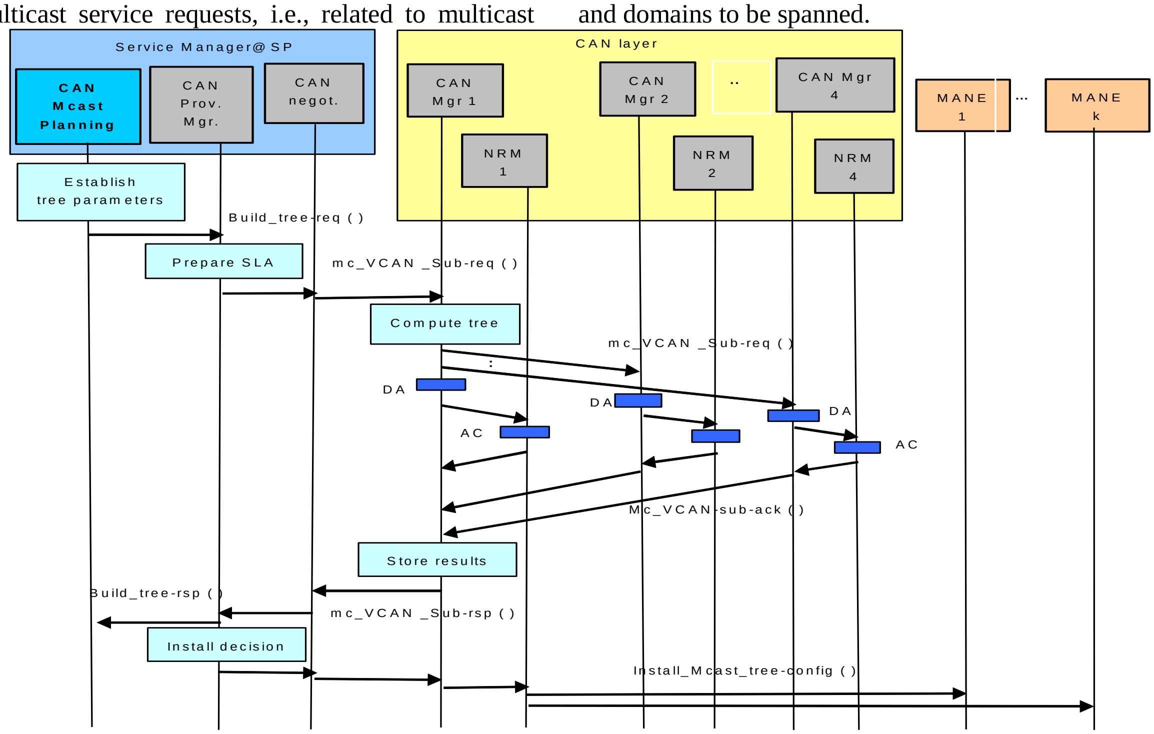

Figure 3. Message Sequence Chart example of communication between management entities to build a H-Mcast tree

B. *Multicast VCAN Construction*

To following SALs negotiation protocols/interfaces are currently specified and implemented in ALICANTE to support the multicast VCAN framework:

- *CAN Mcast Provisioning@SP – CAN Mcast Planning@CANP* (Figure 2, action 1)
- *CAN Mcast Provisioning@CANPk - CAN Mcast Provisioning@CANPm* (Figure 2, action 2.1,2.2, 2.3)
- *CAN Mcast Provisioning@CANPk- Intra-domain NRMk* (Figure 2, action 3.1, ..3.4))

Figure 2 shows the sequence of actions to construct the multicast VCAN. Figure 3 shows the Message Sequence Chart presenting the required signaling between management entities. The sequence of action is:

1.CAN Multicast Planning at SP, establishes (after cooperation with Service Forecast and Planning) the tree characteristics, from the service point of view, i.e., the root and leaves IDs (where servers and current or future users are located) QoS classes of services characteristics, bandwidth necessary, static/ dynamic characteristics, etc. We recall that the SP does not have to know the inter-domain topology but only the root and the network nodes that are leaves of the tree. How the VCAN Planning at SP is performed is out of scope of this paper.

2. After this planning the *CAN Mcast Provisioning Manager* at SP, via its *CAN Negotiation* module, asks to CANP and negotiate with it the VCAN construction (Figure 2, action 1). Let it be *CANP1* at AS1.

3. The *CAN Mcast Planning@CANP1* computes details of the multicast tree. Initially, the other NP (let them be *n, m, p,..*) domains involved are determined. Then a mesh of possible ingress/egress MANE nodes is determined. Using an appropriate metric, a tree (containing not only number of "hops" but bandwidth constraints, etc.) is computed by using a modified constrained routing Dijkstra shortest path algorithm (SPF) algorithm. The details of this algorithm will be presented in a future work.

4. The *CAN Mcast Provisioning@CANP1 will contact the CNAP2, 3, 4* to negotiate with them the multicast VCAN (Figure 2, action 2.1, 2.2, 2.3). Details of such negotiations and cases of success failures wil be a future work.

5. Each CAN Manager will negotiate with its Intra-domain NRM the possibilities to realize the VCAN tree part in the corresponding domain. (Figure 2, action 3.1, ..3.4).

6. Supposing success scenario, acknowledgments are returned to the *CAN Mcast Provisioning@CANP1*, and from this to SP concerning this multicast VCAN subscription.

7. Immediately or later the SP can ask the tree installation in the network. To this set of actions the Provisioning managers will contribute at SP and CANP and also the involved IntraNRMs and associated MANEs.

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C. QoS assurance and Resource Management

The approach adopted is that one CAN is associated to a given *QoS class*. The QoS classes in ALICANTE have reused the framework defined in [20],[21], but adapted to VCAN context. One may have several levels of granularity when defining CANs, while the main common idea is preserved: that CAN layer offers to the SP, *Parallel Internets* specialized for different types of applications content. In ALICANTE the VCANs are constructed after successfully accomplishing Admission Control (AC) in each NP domain. This is the basis of capability to guarantee the QoS. In multicast case also AC is applied. This check can be applied statically, at VCAN subscription time, or dynamically at VCAN invocation time.

VI. CONCLUSIONS

The paper proposed an architectural solution for management of hybrid multicast (H-MCast) capable to construct virtual Content Aware Networks, QoS capable in a multi-domain network context. The overall system architecture is introduced and then the multicast-related management entities roles are defined. The necessary interfaces/protocols between the management entities are defined. A multi-domain peering solution is proposed and multicast scenarios are presented in order to emphasize the signalling phases required. Further work is going on to develop the above mentioned protocols and also the resource management framework in order to add QoS capabilities of the VCANs.

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