Quality of Services Assurance for Multimedia Flows based on Content-Aware Networking

Eugen Borcoci, Mihai Stanciu, Dragoş S. Niculescu
Telecommunications Dept.
University POLITEHNICA of Bucharest
Bucharest, Romania
e-mails: {eugenbo, ms, dniculescu}@elcom.pub.ro

George Xilouris
NCSR Demokritos
Institute of Informatics and Telecommunications
Athens, Greece
e-mail: xilouris@iit.demokritos.gr

Abstract—**This paper proposes a new architectural solution to support Quality of Services (QoS) for real time media flows in a multi-domain system based on new concepts as Content-Aware Networks (CAN) and Network Aware Application (NAA). The system described, based on coupling between network and applications is focused, but not limited to, on multimedia services, with content aware processing in the network, including QoS assurance. The architecture actually parallelizes the Internet in virtual CAN networks, spanning multiple domains and assigning specific quality of services classes to different CANs. This work is a part of the starting effort inside of a new European FP7 ICT research project, ALICANTE.**

Keywords— Quality of Service; Content-Aware Networking; Network Aware Applications; Multimedia distribution; Future Internet

I. INTRODUCTION

A new trend in the Future Internet (FI) [1-6] is to increase the coupling between the transport architectural stratum and application layer, the result being that one has content awareness at the network layer and network aware applications at the higher layer. The new concepts are called *Content-Aware Networks* (CAN) and *Network-Aware Applications* (NAA). This approach is supposed to support richer processing of media flow at the network level. The solution is investigated by many groups, given the general accepted vision, stating that [10][11] the FI will be strongly service-content oriented and media oriented. The CANs can be constructed as overlays, on top of traditional IP networks using network virtualization (note that this is seen as a main way to make the Internet more flexible [8][9][12]). CAN routers are optimized for additional tasks (with respect to the traditional ones) such as content/context-based filtering, QoS processing, routing/forwarding, adapting and transforming the packet flows.

This work is a starting activity, performed in the framework of a new European FP7 ICT research project, "Media Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", ALICANTE, [15] [16][17]. Inter-working environments are defined, to which different cooperating business actors belong: *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. The "*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 (sub)layers. By *Service*, if not specified differently, we understand here *high level services*, as seen at the application/service layer. The above environments are actually present in current deployments, but there is insufficient collaboration between them. The neutral network service, considered many years as a basic and good principle (despite that there are large discussions to preserve it or not in FI), proves nowadays to be a weak solution, especially if one considers the new multimedia communications and their increasing importance in the FI.

This paper proposes an enhanced solution for guaranteed QoS assurance in a multi-domain CAN network context. It is organized as follows. Section 2 presents samples of related work. Section 3 summarizes the overall ALICANTE architecture. Section 4 is focused on the CAN solutions for QoS assurance. Section 5 contains some conclusions.

II. RELATED WORK

Nowadays a higher coupling between the Application and Network layers is investigated, targeting to better performance (for multimedia) but without loosing modularity of the architecture. The CAN (i.e., adjusting network layer processing based on limited examination of the nature of the content) and NAA (i.e., processing the content based on limited understanding of the network condition) are studied in the framework of re-thinking the architecture of the FI.

The work [13] considers that CAN/ NAA can offer a way of evolution of networks beyond IP. The capability of content-adaptive network awareness is exploited in [1] for joint optimization of video transmission. The CAN/NAA approach can naturally lead to a user-centric FI and telecommunication services as described in [3][8][9]. The work in [9] discusses the content adaptation issues in the FI

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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, [4][6]. The architecture can be still richer if we add context awareness to content awareness [7]. The CAN approach, on the other side, 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. The CAN/NAA approach can also help to solve the current networking problems related to the P2P traffic overload of the global Internet [14]. The application layer traffic optimization (ALTO) problem studied by IETF can be solved by the cooperation between the CAN layer and the upper layer.

III. ALICANTE SYSTEM ARCHITECTURE

The ALICANTE architecture includes network-awareness at the service/application level and content-awareness at the network level. In [15][16][17] the main concepts of ALICANTE are fully introduced.

A flexible business model is defined, composed of traditional SP, CP, NP - Providers and End-Users (EU). A new actor is the CAN Provider (CANP) which is the virtual layer connectivity SP, offering content-aware network services. A new entity is also defined: Home-Box (HB)- which can be partially managed by the SP, the NP, and the end-user. The HB is a physical and logical entity located at end-user's premises and gathering content/context-aware and network-aware information. The HB can be also seen 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).

The architecture is composed of four layers/environments: User Environment, Service Environment plus HB layer, CAN layer and traditional network layer. Two novel virtual layers exist [16][17], (CAN layer for network level packet processing and HB layer for the actual content delivery, in the user proximity) working on top of IP. The virtual *CAN routers* (CANR) perform the CAN processing. They are also called *Media-Aware Network Elements (MANE)* to emphasize their additional capabilities: content and context - awareness, controlled QoS/QoE, security and monitoring features, etc., in cooperation with the other elements of the system.

The SE [17] uses information from the CAN layer to enforce NAA procedures, in addition to user context-aware ones. Per flow adaptation can be deployed at both HB and CAN layers, as additional means for QoS, by making use of scalable media resources.

In the Data Plane, CAN concepts are applied in order to perform network/transport intelligent content-aware processing (QoS, based on provisioning and dynamic adaptation, routing/forwarding, security, etc.). 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 I/F between CAN and the upper layer allows cross layer optimizations interactions, e.g., including offering distance information to HBs to help working in P2P style. At all levels, monitoring is performed in several points of the service distribution chain and regulates a two fold adaptation action, at the virtual HB Layer and at the virtual CAN Layer.

Figure 1 presents the overall architecture and emphasizes the CAN layer and physical perspective of the system. The UMgr, SMgr, CANMgr, NRMgr – are respective managers at user, service, CAN and network levels.

The network infrastructure contains several NP domains (e.g., autonomous systems - AS) and access networks (AN). Each domain has an Intra-domain Network Resource Manager (Intra-NRMgr), as the ultimate authority configuring the network nodes. The CAN layer cooperates with HB and SE layers, seen as users of the CAN services and using network-aware information delivered by the CAN layer. 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 offered also in a distributed way based on processing individual flows, content-related metadata, and verification of content-related predicates.

The upper layers HB, UE, SE elaborate together network -aware and context-aware applications. The HB layer hosts the service adaptation, service mobility, security, and overall management of services and content. Service Provider(s) may request CAN construction to CANP.

All CAN operations are performed in MANE nodes, installed at the edges of the domains (for scalability). 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 MANEs perform processing according to the content properties (described by metadata or packet headers or derived by on-fly content-type analysis) also depending on network properties and its current status. The MANE basic set of functions are [16][17]: content-aware intelligent routing, flow adaptation, QoS and resource allocation, filtering and specific security functions, data caching. The CAN/MANE approach offers advantages over conventional routing but raises several challenging open research aspects, given more tasks to be performed by MANE in comparison with traditional routers.

The SP can offer (via CAN layer) QoS guaranteed services, realized at CAN level, by constructing appropriate virtual (unicast or multicast) single or multiple-domain pipes in the network, with or without resource reservations, based on Service Level Agreements (SLA) contracts. Then, as a second level of actions, adaptation actions will be performed, e.g., adapting flows proactively if we have Scalable Video Codec sources.

IV. CAN LAYER AND QOS ASSURANCE

This section presents several aspects related to (V)CANs and QoS; the approach adopted is that one CAN is associated to a given QoS class. Actually one may have several levels of granularity when defining CANs. However, irrespective to

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the granularity, the main common idea is preserved: that the CAN layer offers to the SP "Parallel Internets" specialized at different types of applications content. We consider below the definitions related to QoS classes (QC), in order to establish the relationship between CANs and QoS classes. These classes should be combined when a CAN (represented for instance by a "QoS plane") is spanned over multiple domains.

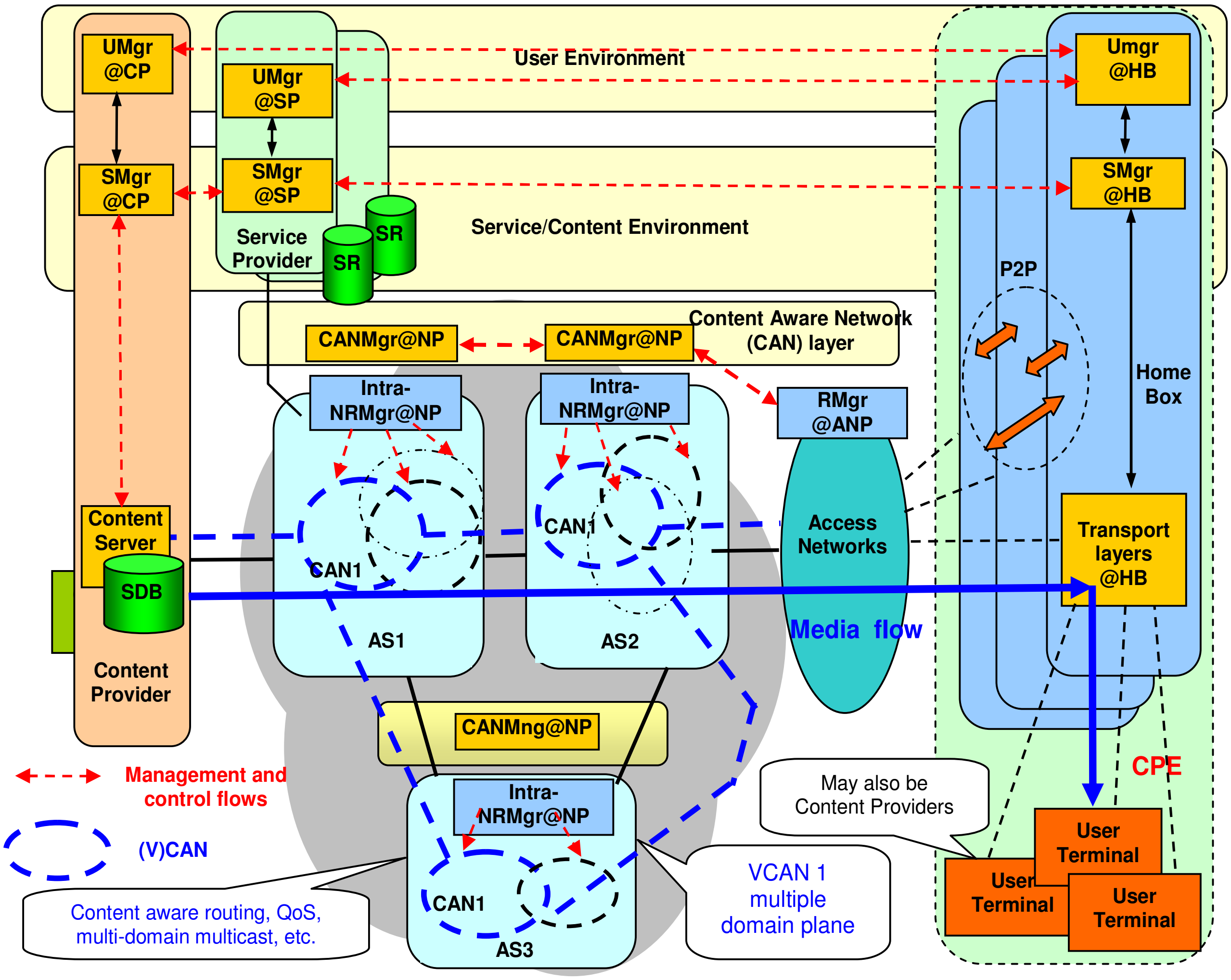

Figure 1. The ALICANTE Overall Architecture

A. *QoS Classes Definitions*

A (well known) QoS class is a QoS transfer capability [18][19] represented by a set of attribute-value pairs, expressing various packet transfer performance parameters such as one-way transit delay, packet loss, jitter. A provider domain's supported QCs can be divided [18][19][22] into *local* QoS classes (l-QCs) and *extended* QoS classes (e-QCs), to allow us to capture the notion of QoS capabilities across domains. From a service offering perspective, QoS classes correspond to the performance (transfer quality) guarantees expressed in contracts as SLSs. From a service provisioning perspective, the QCs classes split the network QoS space into a number of distinct classes, and hence set the traffic-related objectives of traffic engineering functions:

- QoS class (QC): a basic network-wide QoS transfer capability of a single provider's domain. It is defined (in DiffServ but not only) as a set of parameters expressed in terms of {Delay, Jitter, Latency}.
- Local QC (l-QC): a QC that spans a single AS. This is a notion similar to Per Domain Behavior (PDB) – in DiffServ technology.
- Extended QC (e -QC): a QC that spans several ASes. It consists of an ordered set of l-QCs. The topological scope of an e-QC usually extends outside the boundaries of the local domain.

An abstract and flexible definition is the Meta-QoS-Class, MQC [18]. It captures a common set of QoS ranges of

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parameters spanning several domains. It relies on a worldwide common understanding of application QoS needs (e.g., VoD service flows need similar QoS characteristics, whatever the transited AS is). The MQC concept offers the advantage that the existence of "international" well known classes greatly simplifies the inter-domain signaling in the sequence of action to establish domain peering in the multi-domain context.

A Meta-QoS-Class can be defined with the following attributes, such as [18]: a list of services (e.g., VoIP) for which the MQC is particularly suited; boundaries for QoS performance attribute (one-way transit delay, one-way transit variation delay –jitter, loss rate); constraints on the ratio: resource for the class - to traffic for the class.

The attributes could depend on AS diameter (e.g., a longer delay could exist in a large AS, and performance attributes can be weighed in order to prioritize those ones to which the service is more sensitive). A given MQC in an AS followed by the same MQC in the next AS should equal the same MQC (invariance).

There is a flexible relationship between a MQC and l-QC of a domain (i.e., not one-to-one relationship) :

- several MQCs (defined by different values of DiffServ DSCP codes), can be mapped onto the same l-QC,
- vice-versa: one can define several l-QC which belong to the same MQC (this means that any such l-QC could be composed with any l-QC of a neighbor domain if the latter l-QC belongs to the same MQC). If for the same service (e.g., VoD) several qualities are wanted, then a hierarchy of MQCs should be defined.

The MQC concept is useful in practice only if a limited set of Meta-QoS-Classes are defined. Each AS classifies its own l-QCs based on Meta-QoS-Class. An l-QC from an AS can be bound only with a neighbor l-QC that refers to the same Meta-QoS-Class. A Meta-QoS-Class typically bears properties relevant to the crossing of one and only one AS. However, this notion can be extended in a straightforward manner to the crossing of several ASes, as long as we consider the set of ASes as a single super-AS.

B. CANs and Network Planes

In ALICANTE, a concept of Parallel Internets (PI) [20] will be adopted, but modified and enriched 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 (NPl). In ALICANTE, generally a one-to-one mapping between a CAN and NPl will exist.

A CAN Network is an overlay seen as a network plane (NPl) + content awareness. Specialization of CANs may exist in terms of QoS level of guarantees (weaker or stronger), QoS granularity, content adaptation procedures, degree of security, etc.

A given NPl is defined to transport traffic flows from services with common connectivity requirements. The traffic delivered within each NPl receives differentiated treatment both in terms of forwarding and routing, so that service differentiation across NPls is enabled in terms of edge-to-edge QoS, availability and also resilience.

A given NPl/CAN can be realized by the CANP, by combining several processes [17], while being possible to choose different solutions concerning some "dimensions":

- Routing: different paths can be implemented for individual CANs/NPls in order to support heterogeneous service requirements. Routing differentiation can be realized at several levels, e.g., one can define dedicated topologies to get several routing adjacencies towards the destination; dedicated paths selection to achieve multiple path (based on different routing metrics in different NPls).
- Data plane forwarding and packet processing: different classification, metering and drop policies, different packet scheduling behavior by configuring different policies in a common scheduler, assigning dedicated scheduling resources, etc.
- Resource management: Data packets can be treated differentially in terms of policing, shaping, degree of multiplexing, over-provisioning factor, queuing, etc.

The CAN granularities from the QoS point of view can be as follows (classified from a lower degree to higher degree):

C. Multi-domain CANs based on Meta-QoS-classes

This is the simplest implementation of CANs. Each (V)CAN, spanning one or more domains, has associated a given MQC. The resulting Internet appears as a set of PIs or equivalently CANs, or MQC planes. Each Internet consists in all the l-QCs bound in the name of the same MQC. If an l-QC maps several Meta-QoS-Classes, then it belongs to several Internets. The SP can define several CANs represented as PIs. The metadata inserted in the data packets allow ingress MANE to select the VCAN that is the closest to its needs (the "best match" principle is preserved), as long as there is currently a path available for the destination.

In a MQC plane, all paths are considered (to a reasonable extent) as equal. Therefore, the problem of path selection amounts to find one best path, for the selected MQC plane. This principle is similar to the traditional IP routing approach. So, for the inter-domain part, one can rely on a BGP-like protocol doing the path inter-domain selection process.

The DiffServ concept of Per-Domain Behavior (PDB) is not identical with the MQC concept. The two concepts both specify some QoS performance values, but they differ in their purposes. The PDB objective is to help implement QoS capabilities within a network, while the MQC definition objective is to help agreement negotiation between CANPs/SPs. Actually, a PDB is closer to an l-QC than to a MQC. The main advantage of the MQC concept is that it simplifies the horizontal negotiations between CAN Managers to chain the single-domain CANs into multi-domain CANs.

Examples of CANs associated each to one of the four MQCs can be: *Premium MQC*; *Gold MQC* for TCP-friendly (elastic) traffic; *Gold MQC* for non TCP-friendly (non-

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elastic) traffic; *Best effort MQC*. Examples of basic groupings can be: the overall network organized as an Internet with four Meta-QoS-Classes and an Internet with only the last three Meta-QoS-Classes.

For each MQC one should define parameters. An example for a Premium MQC could be: *Usage:* real time flows, needing constant bandwidth guarantees; *Performance:* Delay, Jitter, Loss – very low (qualitative); *Constraints:* admission control will be applied and possibly shaping to enforce the resource requirement; *Resources:* on each output interface, the traffic for the class is always much smaller than the bandwidth reserved for the class (EF based). The resources must always absorb the traffic with no loss, even with burst aggregates.

Mapping of high level services on such CANs has a low granularity. For instance, if one adopts the TISPAN taxonomy [21], the TS 23.107 document identifies four QoS classes: conversational class, streaming class, interactive class, and background best effort. In such a case VOIP and Video conference will be included in the first class, given their interactivity.

The ALICANTE mapping of service flows on CANs based on MQC approach could be done by defining four type of CANs each one having its well-known MQC. Therefore the four CANs expose decreasing QoS capabilities irrespective to what the type of the service is (video, audio, data). The content awareness of the system means to classify the flows according to their QoE class (gold, silver, etc.) and assign them to be transported over the appropriate CAN/MQC-plane.

D. Multi-domain CANs based on local QC composition

This case is more complex than the previous one. Each domain may have its local QoS classes. Several Local QCs (l-QC) can be combined to form an Extended QC (e-QC). Composition rules for QoS classes should be defined. The granularity is greater than in the MCQ approach, in the sense that a greater number of parallel CANs can be defined. Still, a CAN plane offers a single resultant QoS class.

E. Multi-domain hierarchical CANs based on local QC composition

This case is the most efficient but also the most complex. Each domain may have its local QoS classes. Several Local QCs (l-QC) can be combined to form an Extended QC (e-QC). The difference from the previous solution is that inside each CAN several QOS classes 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. – if SP wants to do it. Additionally to the required QC, a priority indicator can be considered (this is a figure established by the SP), indicating the current priority seen from the business point of view by the SP; e.g., for an emergency situation, a video service flow may have a greater priority than for a high definition entertainment video flow. The granularity is greater than in the MCQ approach, in the sense that a greater number of parallel CANs can be defined. Still, a CAN plane offers a single resultant QoS class.

F. CAN provisioning and content aware processing of service flows

Figure 2 shows an example of two provisioned multi-domain CANs, spanning respectively: CAN1: AS1, AS2; CAN2: AS1, AS2, AS3; based on the implementation in AS1, 2, 3 of the MQC1, 2 as shown.

It was supposed that a functional block CAN-NRMgr exists at SP to initiate the CAN construction conforming to the needs of SP (e.g., based on forecast traffic data). It is shown in a simplified way how the CANs are realized and how the QoS based on content classification is realized in the first MANE of AS1. The following actions are performed:

- CAN 1,2, have been requested (negotiation) by CAN NRMgr@SP, to CANMgr@AS1. The topological data and QoS needs are delivered by the CAN NRMgr@SP (action 1 in Figure 2).
- CANMgr@AS1 negotiates resources with IntraNRM@AS1 (action 2).
- Multiple domain CANs are needed, so CANMgr@AS1 negotiates SLAs (actions 3.1, 3.2) with CANMgr@AS2, CANMgr@AS3 (hub inter-domain peering model is supposed here). The inter-CANMgr negotiations are not visible at SP level.
- CAN1, 2 are installed in the network at SM@SP request (actions 4, 4.1 and 4.2)
- MANE1 is instructed how to classify the data packets, based on information as: VCAN_Ids, Content description metadata, headers to analyze, QoS class information, policies, PHB – behavior rules, etc. obtained from CAN NRMgr@SP via CANMgr@AS1 and IntraNRM@AS1. Also, the output part of the MANE1 is configured for queuing and scheduling as to realize the QoS classes.
- Service Management at SP instructs the SP/CP server how to mark the data packets. The information to be used in content aware classification can be composed of high level headers (e.g., RTP); content description metadata (including optionally an explicit VCAN_Id to simplify the MANE analysis task

The implementation of the QoS classes in the network can be done based on known QoS technologies like MPLS + DiffServ. The mapping of the (V)CAN onto actual paths is performed by the Intra NRMgr. Applying the above procedures, the data flows are classified by the MANE, assigned to the appropriate CAN and processed according to the QoS class associated to that CAN.

A data packet is analyzed by the classifier and assigned to one of the CANs, depending on: MANE classification information and policies; data packet high-level protocol headers and/or metadata and/or VCAN_Id contained in the packet. Consequently, the packet is forwarded to the appropriate logical CAN for further processing.

V. CONCLUSIONS AND FUTURE WORK

The paper proposed an architectural solution supporting QoS in a virtualized network environment, based on content awareness at network level, in the framework of a complex system for media distribution. 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 fully validate the concept and then to design and implement the system in the framework of the FP7 research project ALICANTE.

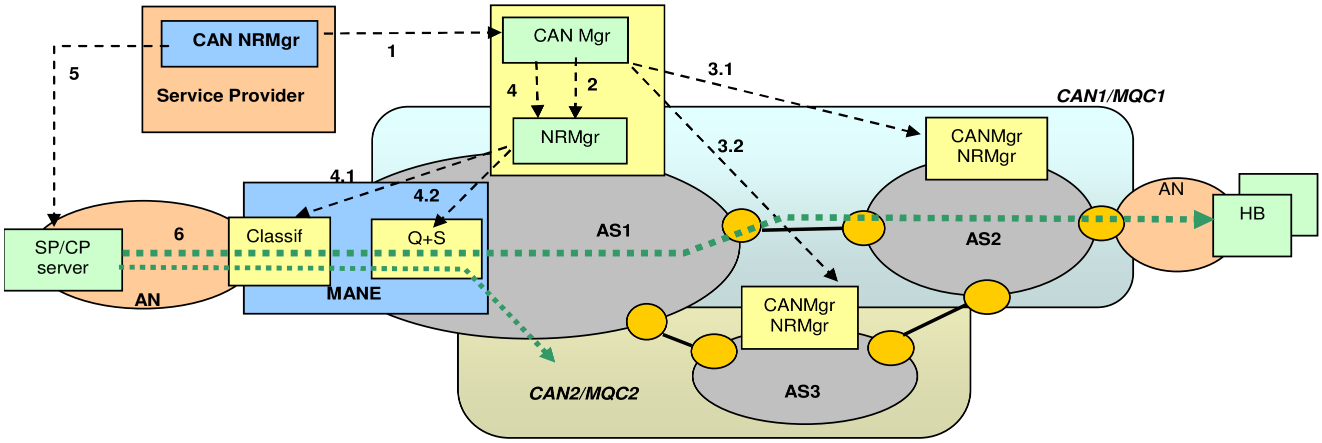

Figure 2. Example of multi-domain CANs based on MQCs

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