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A Novel Architecture for Multimedia Distribution based on Content-Aware Networking

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Abstract—**This paper proposes a novel virtual Content-Aware Network (CAN) layer as a part of a full layered architecture, focused, but not limited to, on multimedia distribution with Quality of Services (QoS) assurance. The overall system is based on a flexible cooperation between providers, operators and end-users, enabling users to access the offered multimedia services in various contexts and also to become private content providers. The paper introduces the main concepts and architecture for the main virtual network layer (i.e., CAN), exposing its role and interfaces among overall system layers. This work is a part of the starting effort inside of a new European FP7 ICT research project, ALICANTE.**

Keywords: content-aware nertworking, network aware applications, quality of services, multimedia distribution, Future Internet

I. Introduction

It is widely accepted today that the Future Internet (FI) should solve a lot of issues, not satisfactorily fulfilled by the current one. This affects all architectural layers, being related to new service paradigms, flexibility, scalability, security and trust, user-friendly behavior, flexible business model and roles of entities, coping with heterogeneity of lower layer network technologies, generalized mobility, etc. Revolutionary, evolutionary, or hybrid approaches are proposed [1], [2], [4]. Among them the concept of network virtualization is considered as a main way for Internet evolution to allow diversification of the next architectures in a flexible manner [1], [2], [5].

On the other side, from the end user perspective, the FI is defined by the set of services it provides [3]. The end user sees the FI as a tool providing easy access to various type of information in real and/or non-real time (e.g., general data, voice, video, music, multimedia), search engines, different services (e.g., access, personal communication, business and entertainment services), or social networking platforms.

The "content orientation" is a main FI paradigm. Digital multimedia services and networked media content are playing an increasing role in citizens' economic, social and cultural life, touching all domains as industry, administration, business, education, culture and entertainment. This trend is recognized also by the European commission, which defined the "Objective ICT-2009.1.5: Networked Media and 3D Internet" in the FP7 Call 4 [4], [6]. In this call new targets are defined as *content-aware networks (CAN) and network-aware applications (NAA).* We can see here a new approach in which the neutrality of the network is no more supposed, but intelligence and a higher degree of coupling to the upper layers are embedded in the network nodes. Based on virtualization, the network can offer enhanced transport and adaptation-capable services. It is hoped that in such a way, architectures and technologies for converged and scalable networking and delivery of multimedia content and services can be achieved. Dynamic optimization is desired, with policies taking into account the content and adaptation needs, the user contexts, requirements and social relational network. This should be done for a variety of contents and services including home management and various applications, locations and mobility scenarios. The FI should enable multiple user roles, e.g., as content producer, user, or manager.

The work of this paper is a part of the starting effort inside of a new European FP7 ICT research project, "MediA Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments", ALICANTE, [19]. The project proposes a new *Media Ecosystem*, gathering a mass of existing, but also new potential content creators and media Service Providers (SP), essentially stemming from customers (active users). Such a Media Ecosystem, by analogy with the ecology or business counterparts, can be characterized by inter-working environments to which the actors belong and through which they collaborate, in the networked media domain. These environments are: *User Environment (UE)*, to which the End-Users belong; *Service Environment (SE)*, to which the Service and Content Providers belong; *Network Environment (NE)*, to which the Network Providers belong.

By *Environment*, we understand here a generic and comprehensive name to emphasize a grouping of functions defined around the same functional goal and possibly spanning, vertically, one or more several architectural (sub-) layers. This name is used to characterize its broader scope,

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with respect to the term *layer*. By *Service*, if not specified differently, we understand here *high level services*, as seen at application/service layer.

The above environments are nowadays present in real deployments, but actually there is not sufficient collaboration between them. The User context is not taken into consideration by the Service (or Content) Provider delivering the service (content), which, as a consequence, could not be capable of adapting the service (content) to the capabilities of the user. The current architectures do not include exchange of content-based and network-based information between the network layers and upper layers, implying that CAN and network-aware services/applications have difficulties to emerge. This neutral network service considered many years as a good principle proves nowadays to be a weak solution, especially if one considers the new multimedia communications and their increasing importance in the FI.

The paper is organized as follows: Section II presents samples of related work. The main concepts and overall ALICANTE architecture is defined in Section III. Section IV is the main part of the paper and it is focused on the CAN layer functionality and interfaces. Conclusion, open issues, and future work are briefly outlined in the Section V.

II. Related Work

The content-aware networking (CAN) and network-aware applications (NAA) approach is a new mode to design the layered architecture, breaking the classic TCP/IP and OSI stack concepts. Traditionally, the way in which contents are generated, processed, and distributed is seen as separated from the transport itself. The challenge and question is whether in the context of new requirements of multimedia and combined service flows, one can enable better interactions without losing modularity of the architecture. In such a context, both content-aware networking (i.e., adjusting network resource allocation based on limited examination of the nature of the content) and network-aware content processing (i.e., adjusting the way contents are processed and distributed based on limited understanding of the network condition) are of high interest both for research communities and industry, in the overall framework of re-thinking the architecture of the Future Internet.

In [7], it is considered that CAN and NAA can offer a way for evolution of networks beyond IP. One can benefit from routing based on content and/or context and embed business rules into high-speed low-latency networks. The capability of content-adaptive network awareness to offer joint optimization of video transmission is analyzed in [8]. The CAN/NAA approach can naturally lead to a user-centric FI and telecommunication services as it described in [9]. The work in [10] discusses the content adaptation issues in the FI as a component of CAN/NAA approach. Naturally, the CAN/NAA approach supports better QoE/QoS capabilities of the future networks, [11], [15]. The architecture can be still richer if to content awareness we add context awareness [12], [16]. A new content-aware cooperative multiple access protocol for packetized voice is proposed in [13].

On the other side, the high amount of packet header processing necessary to be embedded in the CAN elements raises serious problems similar to deep packet inspection techniques [14]. Thus, it is needed to find new methods to minimize the processing tasks in high-speed routers.

Another contribution that CAN/NAA approach can bring to solve the current networking problems is related to the P2P traffic overload of the global Internet [17], [18]. The *application layer traffic optimization* (ALTO) problem studied at IETF can be helped by the cooperation between the CAN layer and the upper layer, following in principle the ideas mentioned in [17], [18] but solved via the CAN approach.

However, there is currently no complete and open architecture for multimedia distribution, able to accommodate both – all, current, and future needs of multimedia content oriented services on one side, and flexible, scalable, and efficient usage of network transport resources over heterogeneous networking technologies on the other side. Therefore an open field for research in this domain exists.

III. ALICANTE System Architecture

The ALICANTE architecture promotes advanced concepts such as content-awareness to the network environment, user context-awareness to the service environment, and adapted services/content to the end-user for his/her best service experience while being a consumer and/or producer.

A. *Novel Virtual Layers*

Two novel virtual layers are proposed on top of the traditional network layer, i.e., the CAN layer for network level packet processing and a Home-Box (HB) layer for the actual content delivery. Innovative components, instantiating the CAN are called *Media-Aware Network Elements (MANE*). They are actually CAN-enabled routers and associated managers, offering together content-aware and context-aware Quality of Service/Experience, security, and monitoring features, in cooperation with the other elements of the ecosystem.

The upper layer, i.e., the SE, uses information delivered by the CAN layer and enforces network-aware applications procedures, in addition to user context-aware ones. The novel proposed *Home-Box* (HB) entity is a physical and logical entity located at end-user's premises and gathering *context-aware, content-aware, and network-aware* information essential for realizing the big picture. Associated to the architecture, there exists an open, metadata-driven, interoperable middleware for the adaptation of advanced, distributed media resources to the user's preferences and heterogeneous contexts enabling an increased Quality of Experience. The adaptation will be deployed at both HB and CAN layers making use of scalable media resources. Finally, the validation of the project architecture and results will be done in a large-scale international pilot, in preparation for bringing it to the market.

B. *Business Model*

The architecture defined can support a set of actors, representing a new business model, enough flexible and capable to satisfy the Service/Content/Network Providers' and end-users objectives and needs, together with flexibility in offering new possibilities in terms of their role as consumers, providers, and managers. The main business actors/entities envisaged are the following:

Content Consumer (CC) or *End-User (U)* is an entity (human plus a terminal or a process), which establishes a contract with an SP for service/content delivery. These users are the final target recipients of services. A CC might also be an organization acting on behalf of individual end-users.

Content Provider (CP) gathers/creates, maintains, and distributes digital information. The CP owns/operates network hosts (content sources) but it might not own any networking infrastructure to deliver the content. The content is offered to the CCs or SPs through Service Level Agreements (SLAs). There may be business relationships between CPs and NPs to host or co-locate the content servers that belong to CPs. The CC can also be a private CP.

Service Provider (SP) delivers to CCs high level services and aggregates content obtained from multiple CPs. SPs may not necessarily own a transport infrastructure, but rely on the connectivity services offered by Network Providers (NPs), or CAN Providers (CANP). CCs have interactions with SPs and SPs are ultimately responsible for the service offered to them. SPs may interact with each other in order to expand their service base. SPs use the services of CPs and NPs, or CANPs, through appropriate SLAs.

Network Provider (NP) traditionally offers connectivity providing reachability between network domains/hosts. NPs own and administer IP connectivity infrastructures. They interact with each other for the purpose of expanding the geographical span of the offered connectivity services.

Home-Box (HB) Provider is a new **ALICANTE** business entity, which can be partially managed by the SP, the NP, and the end-user. The HBs can cooperate with SPs in order to distribute multimedia services (e.g., IPTV) in different modes (e.g., P2P);

CAN Provider (CANP) is a new **ALICANTE** business entity, seen as a virtual layer functionality provider. It is actually an enhanced, virtual NP. Note that the additional CAN functions are performed by network nodes and therefore they are executed by the Network Provider. It offers content-aware network services to the upper layer entities.

C. *Hierarchy of Functions*

More specifically, ALICANTE proposes several new features inside the Network/Service/User Environments in order to enable the future generic Media Ecosystem that:

At network level, it realizes and offers to upper layers, a rich and virtualized networked multimedia space, through an all-IP prototype for environment, customizable for delivering networked media content. The architecture is capable of:

— *applying CAN concepts*, to perform network/transport intelligent content-aware processing (routing, dynamic adaptation, security, etc.) for existing and future emerging applications in a scalable, open and optimized way. This is the main role of the new CAN layer;
— *realizing distributed management and control* in order to customize the CANs as to respond to the upper layer needs, including 1:1,1:n, and n:m communications, and also allow efficient network resource exploitation at network provider level;
— *performing cross layer optimizations* between the virtual CAN layer and upper layers, including, but not limited to, peer-to-peer (P2P) approach. This optimization will be possible due to network awareness capabilities of the upper layers; and
— *extending CAN functionalities* for achieving an efficient collaboration with elements in the Service Environment, enabling content-awareness and network-awareness.

At service/content level, it delivers enriched networked media services and content, which can be efficiently exploited by end-users. The architecture new features are:

— *elaborating a new approach for the delivery of services* which includes the HB as a new element in the service distribution chain, capable of advanced functionalities (service management and adaptation, user mobility, security);
— *creating a new virtual HB layer*, composed of virtually interconnected HB (in traditional distributed client/server mode or P2P mode), capable of advanced provisioning of service/content;
— *dissociation of the Service/Content Providers' roles and capabilities* and the *Home-Box layer role and capabilities* in terms of service/content exploitation and delivery, which will lead to the vision of their efficient cooperation;
— *enhanced services*: *delivery* - through the servers or HBs, in various modes; *discovery* - the introduction of a new type of component called *Service Registry (SR);* efficient *management*; *service composition* - realization of a Service Composition Engine supporting streaming media applications; and
— *achieving collaboration* with the User Environment and with the CAN Network Environment.

At user level, it allows the users to consume and/or generate content and exploit services delivered by components of the SE. The new related architecture features are:

— *adding new dimensions* to the user by giving him the possibility to have several roles, such as: Content and Service Consumer; Content and Service Provider; Content and Service Manager;
— *elaborating a User Profile* to characterize the static and dynamic parameters of the user and his context, in order to be exploited by SE elements (HB) for the delivery of adapted services;
— *permitting any user* to access/deliver/manage any service/content on any device from anywhere and at any time, thanks to a specific User/Service interface and QoE monitoring tool at the user's terminal side; and
— *achieving efficient collaboration* with the SE, enabling user context-awareness, for the best end-user experience.

At all levels, monitoring is performed in several points of the service distribution chain and regulates a twofold adaptation action, at the virtual HB Layer and at the virtual CAN Layer.

IV. CONTENT AWARE NETWORK LAYERED ARCHITECTURE

Figure 1 presents the overall architecture showing the environments described in the previous sections and emphasizing the CAN layer and physical perspective of the system. The main interaction between the SE environment and CAN layer are summarized by arrows denoted *content-aware* and *network-aware* respectively. The bottom part of the figure shows a possible network infrastructure composed of access networks (AN) and several autonomous systems (AS).

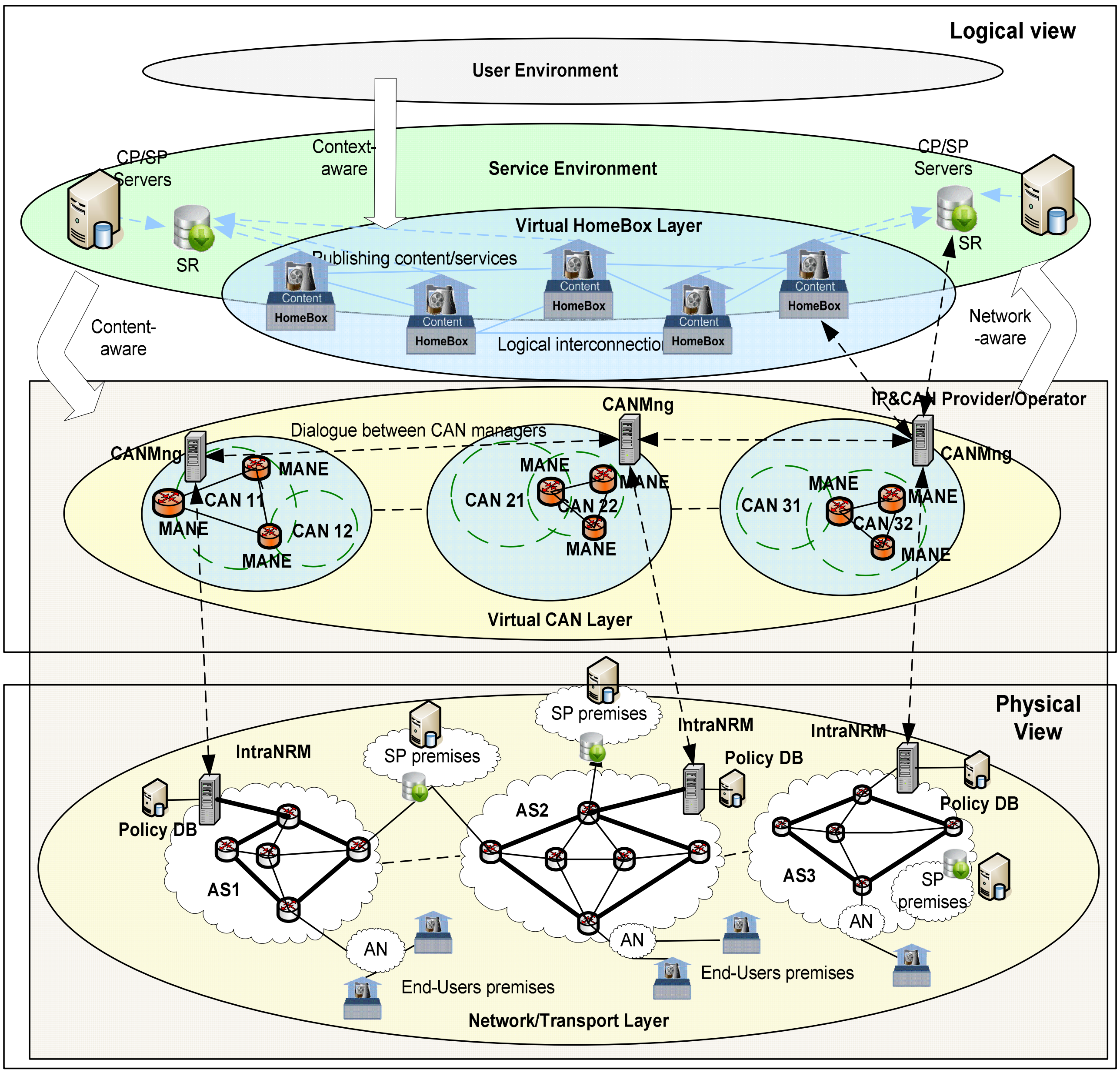

Figure 1 The ALICANTE Architecture: details on Virtual CAN Layer [19].

A. Vertical and Horizontal Layering

Two novel virtual layers are proposed on top of the traditional Network layer, virtualizing the network nodes: one layer for packet processing (CAN layer) and the other for content delivery (Home-Box layer);

- *Virtual Content-Aware Network (VCAN)* layer offers an enhanced support for packet payload inspection, processing and caching in network equipment. It is developed over traditional IP network/transport layer. It will improve data delivery via classifying and controlling messages in terms of content, application and individual subscribers; it improves QoS assurance via content-based routing and increases network security level via content-based monitoring and filtering. In such a way, content- and application-aware networks are created to provide high levels of performance, end-user experience, and to enable application and subscriber-specific data forwarding. The specific components in charge of creating this VCAN are the Media-Aware Network Elements (MANE), i.e., the new CAN routers, and the CAN managers.
- *Virtual Home-Box layer* is an upper layer, using CAN services and taking into account network-aware information delivered upward by the CAN layer. Thanks to this layer, inter-working with the User, Service, and Network Environments, one can elaborate network and context-aware applications and deliver the necessary inputs to create content-aware networks. The adaptation, service mobility, security, and overall management of services and content are being assured at this layer through a new specific middleware proposed by the project, working in conjunction with the other layers.

The interactions between the above mentioned two layers establish together a *powerful cross-layer optimization loop* providing end-users with the best possible service experience and optimizing the resource usage.

Seen from the traditional layered architecture perspective, the system can be divided horizontally into three parallel planes: *Management*, *Control* and *Data Planes* (MPl, CPl, DPl) cooperating with each other. They are not represented explicitly in the picture, which only emphasizes some important interfaces and relationships, as presented below:

Management and Control Interfaces: The main management and control entity in the VCAN layer is the CAN Manager (CANMng). Corresponding to its roles, we distinguish the following interfaces of CAN Manager with the Virtual Home-Box layer: to advertise CANs and negotiate their usage and to help the establishing of connectivity relationships at Virtual HB layer based on, e.g., network related distance information. The CANMng has also interfaces to the lower network layer in order to negotiate CANs and request their installation.

Data Plane Interfaces: The data plane interfaces transport the packets between the VCAN layer and the Virtual Home-Box layer in both directions. The downloaded packets are especially marked by the application layer, so that they can be associated with the correct CAN and to allow their processing in the data plane of the CAN. To make the processing task easier (performed by CAN nodes in the data plane) and increase the overall performance, MANEs – CAN nodes – may be preconfigured to allow them some freedom to lightly decide on the packets themselves.

Each AS has one CAN Manager controlling that one or several CANs are deployed in each domain. The CAN Manager is the entity which plays the following roles: to (re)define the CANs (according to the enhanced connectivity service targeted) and perform all related actions to configure, maintain and update CANs; to advertise and negotiate the CAN usage with upper layers, using Service Level Agreements/Specifications (SLA/SLS) contracts; to communicate with other CAN managers in order to establish multi-domain chains, again, using SLA/SLS contracts; to communicate with its own intra-domain network resource managers (IntraNRM). The IntraNRMs have the ultimate authority upon the network provider resources, thus conserving each domain's independency.

B. The Content-Aware Network Router

The content-aware network router (i.e., MANE) is an intelligent network node. It takes into account the content type in order to perform appropriate processing (filtering, routing, adaptation, security operations, etc.) according to the content properties (described by metadata or extracted by protocol field analysis) and also depending on network properties and its current status. The results of the content related information analysis provide metrics, which allow deciding the best strategy to adopt for the best content repurposing and publishing methods. The MANE basic set of functions are:

Content-aware intelligent routing: the MANE will decouple the routing process (higher level) by the forwarding (lower level) and make intelligent routing, based on results extracted from packet fields' analysis or content description metadata. Examples of content-aware functions can be anycast and routing based on the publisher-subscriber paradigm;

Content-aware QoS and resource allocation: the MANEs will be able to implicitly deduct the QoS requirements of different flows based on the flows content. The CAN layer will monitor the current status of the CANs from the load point of view. The MANE will maintain an aggregated image of flows that they forward. For every recognized flow type, an appropriate instance of CAN will be assigned depending on the level of QoS guarantees and network status. Efficient resource allocation and/or load balancing can be done in the network depending on traffic types and QoS requirements, by taking benefit from content awareness of MANE and based on operator policies, in terms of resource allocation. The CAN level will interact with the domain network resource management in order to perform mapping onto different L2/L3 QoS aware technologies (e.g., MPLS/Diffserv or Carrier Ethernet). Dynamic re-allocation (not frequently, in order to prevent instability) of the network resources between different CANs can be done, to assure the flexibility and efficiency of resource usage. The MANE has also a role in the adaptation. The latter is actually deployed at different points in the delivery chain: at the service creation, during the transport by the CAN routers, and at the Home-Box site;

Specific Security issues: while keeping usage of current and popular IPSec technologies at network level, we will exploit the possibility to include content related information in dedicated fields. Thus, the end-to-end communication remains encrypted and private whilst the content-aware network can operate seamlessly.

Content awareness is a subject of in-depth packet processing that spans across the traditional Layer 2 and Layer 3 approaches, while the inspection can be driven, by pre-defined policies, thus, obtaining gain in speed and also flexibility. Note that the important aspect related to privacy issues is that packet inspection done by the MANE router is not at all applied to the content itself, but only on metadata describing the content type, in order to offer appropriate processing to these flows from several points of view - quality of services, network resource efficient usage, etc.

C. CAN Management Details

The CANMng has the following roles: defining the CANs that may exist on its given IP core infrastructure, based on domain policy information and requests on future needs of customers; configuring, maintaining and updating CANs; advertising and negotiating the CAN services offered to upper layers; negotiating SLAs with other CAN Managers in order to establish multi-domain CAN-enabled chains; cooperating with intra-domain manager to install, modify, or delete various virtual CANs in the network devices; helping the establishment of relationships at HB layer, at requests of HBs, e.g., based on network related distance information between potential peers for P2P mode.

The CAN manager has interfaces with elements into the Service Environment (HB or SP part - respectively CAN-HB I/F and CAN-SP I/F), intra-domain network resource manager and other domains' CAN managers. The horizontal interfaces allow negotiation between domains, based on SLAs and supporting in this way synergic CAN functioning over multiple domains (e.g., QoS-enabled and controlled paths crossing several CANs). Each CAN Manager advertises its CANs possibilities to outside world and then negotiates and concludes some SLAs with other domains.

D. Functional Aspects

While offering significant advantages over conventional routers the CAN/MANE approach poses several open issues and challenging research aspects. We briefly mention part of them.

- *CAN-related metadata processing:* given the task of performing content awareness, the CAN router should use a flexible structured query mechanisms based on pattern matching (pattern matching tools are needed to parse the packet payloads and recognize predefined sets of patterns, associated with algorithms for different pattern matching, data mining, and content inspection subsystems).
- *Protocol classification and description:* CAN subsystems should analyze the application and protocol to classify and recognize traffic types. For this purpose appropriate languages should be used for protocol description and packet classification. They should provide capabilities for customization and should be flexible to be adapted to new applications and protocols. Techniques for application packet analysis have to be selected by comparatively analyzing the approaches, i.e., stateful/stateless, signature based and behavioral. Investigation of solutions is necessary to offer best trade-offs between a high-speed processing requirement but also flexibility and low cost.
- *Content-based routing:* the CAN router will realizes decoupling between routing based on content (identifiers, scope, service profiles, policies) and forwarding, facilitating new communication paradigms such as anycast and publisher-subscriber.
- *Content-based QoS:* the CAN approach can allow to the Network Provider to offer to the upper layers spezialised CANs optimized for different QoS classes with configurable guarantees.
- *Content caching and processing in the network*: CAN concepts may help to better traffic engineering; the current technologies make realizable storage functions for large amount of data in the network nodes. Traffic can be cached (when appropriate) in specially selected nodes aiming to reduce/balance the network load, reduce end-to-end delay, avoid nodes of the network to enter congestion status. The real-time streams distributions can be enhanced.
- *CAN layer monitoring:* the CAN nodes current status should be monitored from load point of view. The CAN Manager receives performance information from the network layer, and aggregates them in order to evaluate path characteristics between CAN nodes (distance).
- *Improved network security by using packet content analysis:* the packet content inspection can enhance the system capabilities to detect intrusions and anomalies which can jeopardize the network. Given that such mechanisms are to be located in the network nodes, high speed methods should be found.
- *CAN Performance aspects:* CAN applies intensive packet processing executed at network level (contrary to the traditional IP network level), involving a significant processing power. Therefore the challenge in evaluating the performance versus complexity and cost will be an important task of the ALICANTE project. Cross-layer optimization capabilities are possible at CAN layer interface with HB layer, as a powerful tool offered by the CAN and network aware applications approach.

E. End-to-end QoS issues

While CAN approach may offer a larger set of features, the end-to-end QoS assurance with different degrees of guarantees seems to be a natural one. SP can offer 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 SLA contracts. Then, as a second level of actions, adaptation actions will be performed as follows: adapting flows proactively if we have, e.g. Scalable Video Codec sources and while knowing that there are not enough resources but still want transmission; or, dynamically in reactive manner, done later if necessary, because of network or terminal conditions variations. The services will be accessible for users in two ways. The first is based on service subscriptions done by the user via its HB (admission control is applied by SP, in cooperation with NP, depending on available resources) and then future invocations – with guaranteed QoS levels based on resource reservations. The second way is completely dynamic, based on invocation only – but without having guaranteed chance of the call admission success if guaranteed QoS is wanted. A new feature of the proposed architecture is that it can offer a solution to better QoS while working in P2P style at service level. An appropriate signaling system should be developed in the management and control plane to support QoS oriented CANs.

V. Conclusions

A novel layered architecture is proposed based on the Content-Aware Networking (CAN) and Network-Aware Applications (NAA) approach, with a focus on the functionalities of the virtual CAN layer. The work is part of the starting effort inside of a new European FP7 ICT research project ALICANTE. While the architecture fulfills the new requirements for multimedia distribution and services via multiple IP domains it is more general and tries to meet the needs of the Future Internet. A flexible business model supported by the architecture is introduced. The role of the CAN layer, its requirements and interfaces with other system layers are briefly described. QoS capabilities of the architecture are summarized. Challenges are mentioned and open research issues especially related to the performance/cost of CAN devices in real network environment. Significant future work will follow inside the ALICANTE project for detailed specification, validation, and finally implementation on a large-scale testbed.

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