Media Ecosystem Deployment in a Content-Aware Future Internet Architecture

Georgios Gardikis, George Xilouris, Anastasios Kourtis
Institute of Informatics and Telecommunications
NCSR "Demokritos"
Aghia Paraskevi, Athens, Greece
e-mail: {gardikis;xilouris;kourtis}@iit.demokritos.gr

Evangelos Pallis
Dept. of Applied Informatics and Multimedia
TEI of Crete
Estavromenos, Crete, Greece
e-mail: pallis@pasiphae.teiher.gr

Daniel Negru, Yiping Chen, Petros Anapliotis
CNRS, LaBRI Lab.
University of Bordeaux I
Talence, France
email: {daniel.negru;yiping.chen}@labri.fr

Abstract— **Creation and efficient distribution of new rich media services is foreseen to play a key role in the Future Internet. Emerging FI architectures should be able to fully support and facilitate all kinds of current and future media-oriented applications. The architecture illustrated in this paper facilitates the deployment of an integrated Media Ecosystem, where all users can efficiently not only have access to, but also compose and share rich media services. This is achieved via a mesh of intelligent, media-centric home gateways ("HomeBoxes"), which utilize novel Content-Aware network overlays, developed on top of the existing transport infrastructures. This concept has been designed and is being implemented as an international pilot demonstrator in the frame of the EU-funded ICT project ALICANTE.**

Keywords- Networked Media Ecosystem, Future Internet, Content- aware Networks, Network-aware Services

I. INTRODUCTION

Thanks to its rapid advance and exponential growth during the last year, the Internet is now playing a key role in everyday life, not only in information exchange, business collaboration and education, but also in entertainment. Audiovisual services, whose provision was initially restricted to broadcasting platforms and later to local consumption in multimedia-enabled PCs, are now dominating the global Internet traffic – at a percentage predicted to reach 90% by 2013. Citizens are increasingly using the Net for accessing sharing multimedia content, a trend leveraged by the increase in access bandwidth and advances in service technologies.

In this context, it is admitted that the current Internet architecture and technologies present significant weaknesses when it comes to the provision of multimedia services. The Net, initially designed for resilient, opportunistic transport of non-real-time data, does not provide adequate mechanisms for the differentiation, appropriate handling and monitoring of multimedia traffic. As a consequence, business opportunities related to Internet-based media provision are seriously hampered. A characteristic example is pay-per-view VoD services, which are rarely offered over the Internet due to the lack of QoS mechanisms. Instead, they are mostly restricted in "fenced", managed networks with centralized resource management. It is thus self-evident that approaches towards the Future Internet (FI), in order to be viable and coherent to current trends, should include technologies and architectures which enable efficient distribution of media content.

It is also anticipated that the media service provision chain in the Future Internet will involve a large number of participants/actors, including commercial providers offering enhanced content and services, end-users acting as both content consumers and creators behind multiple terminals of different capabilities, and network operators maintaining reliable and efficient architecture. Similar to the notion of "Ecosystem" in ecology and business, the concept of "Media Ecosystem" corresponds to a novel collaborative paradigm for sharing and consuming media services, dynamically exploiting content and resources from the actors involved. Vital features of such an Ecosystem should be seamless integration with the Future Internet, QoS/QoE provision, tight synergy between the service and network planes, maximum flexibility to support a variety of business models, expandability and also scalability.

In this context, this paper presents a novel architecture which enables the creation of such "Media Ecosystems" within the Future Internet, fulfilling the aforementioned requirements. The Media Ecosystem aims to constitute an integrated environment where end users and service providers share and distribute both legacy and novel multimedia-based services. The proposed innovative architecture relies on two main pillars: an innovative Service Environment, involving an overlay of interconnected media-centric Home Gateways ("HomeBoxes") and a radically enhanced Network Environment, featuring inherent Content

Awareness, enabling the creation of virtual overlays dedicated to media transport. At the same time the Network Environment provides Network Awareness to the Service Environment through a novel cross-layer monitoring system. On top of the Service Environment, a flexible User Environment can be established to provide ubiquitous service access in various usage scenarios using different wired and wireless terminals featuring a global, unified graphical interface and realtime Quality-of-Experience (QoE) monitoring.

The aforementioned Environments are not independent of each other. Under the concept presented, exchange of content- and network-based information between the Network and Service Environment takes place, introducing novel Content-Aware Networks and Network-Aware services.

This integrated architecture, as presented in the paper, is currently being developed in the frame of the EU-funded FP7 project ALICANTE ("Media Ecosystem Deployment through Ubiquitous Content-Aware Network Environment"). ALICANTE was among the highest-ranked research initiatives in the "Networked Media" objective and aims indeed at a very ambitious goal: to transform the Future Internet to a friendly environment for the mutual exchange of broadband media services.

II. HIGH LEVEL ARCHITECTURE

A. *Concept and Architecture*

Figure 1 depicts the generic concept and architecture of the "Media Ecosystem", which, as aforementioned, is composed of three interworking environments: the Network Environment (corresponding to Network Operator resources), Service Environment (representing content and service provider functions) and User Environment (including end-users and their terminals). Principal innovations within the proposed "Media Ecosystem" are: 1) the introduction of Content Awareness to the Network Environment, 2) the inclusion of Network and User context-awareness to the Service Environment; 3) real-time, on-the-fly service and content adaptation in both service and network environments, to offer the best possible quality to end-users. As previously mentioned, an essential component of the architecture is the "HomeBox", an enhanced, media-aware home gateway which stands at the edge of the ALICANTE Media Ecosystem and acts as a proxy/mediator to the end user terminal, which actually presents the service to the user.

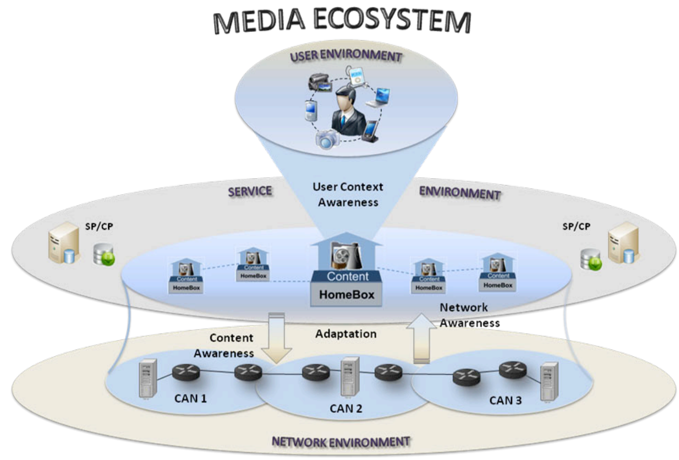

Figure 1. Layered Architecture of the ALICANTE "Media Ecosystem".

As seen in Fig.1, two separately managed architectural layers on top of the traditional network infrastructure are introduced: a Content-Aware Network (CAN) layer in the Network Environment and a HomeBox (HB) layer in the Service Environment.

The CAN layer is used to realise of virtual content-aware network overlays (VCANs) on top of the physical network. The latter are instantiated by existing network elements which, in ALICANTE, are updated/enhanced to Media Aware Network Elements (MANEs). The VCANs offer Content Awareness i.e. intelligent packet processing identifying the type of content actually transported by the packets. Different processing strategies (queuing, routing, adaptation) can be defined for different types of content, to meet transport constraints such as loss, delay and jitter.

The HomeBox layer is composed by the logical mesh of interconnected HomeBoxes, each one running dedicated processes for server selection, service monitoring and media delivery.

Within these architectural layers, appropriate mechanisms are defined in order to adapt the content at different critical steps during its transport. The adaptation of content facilitates its delivery on the network and its consumption on multiple heterogeneous user-devices. The integration of the HomeBox and CAN layers enables several new features inside the Network/Service/User Environments, which are detailed in the following sections.

A. *Service Environment*

Enriched networked media services and content are delivered to end-users through the Service Environment, which, apart from the HomeBox layer, also includes the functions of the Service and Content Providers (SP/CP) and the HomeBox layer. In specific:

- A new essential element -"HomeBox"- is defined in the service distribution chain. The HomeBox (HB) is capable of advanced functionalities, such as handling service management and adaptation, user mobility, security. The logical overlay of interconnected HBs forms the HomeBox layer.

- An open and flexible SP/CP framework is defined, allowing providers to offer enhanced types of services and content. The SP/CP framework basically includes a set of traditional servers offering the content and services accompanied by a Service Registry containing detailed information on all available services.
- The Service Environment receives user context information from the User Environment and network information from the CAN Network Environment in order to harmonize the provision of service both with the user/terminal context and the terminal network conditions.

B. *Network Environment*

The enhanced Network Environment realizes and offers to the Service Environment a rich and virtualized networked space, through an all-IP environment prototype, which can be customized and exploited for delivering networked media content. Key additional features in the Network Environment are:

- A new virtual CAN layer built on top of traditional network/transport layer. It is supported by Media Aware Network Elements (MANEs) and instantiates VCANs i.e. virtual network overlays with Content-Aware functionalities
- Distributed Management and Control function. VCANs can be customized to respond to the upper layer needs, including 1-1, 1-n and n-m communications. This distributed function ensures the management and control on both intra-domain and inter-domain level, to achieve efficient network resource exploitation at network provider level.
- Cross layer optimizations between the Network and Service environments. The virtual CAN layer exports network monitoring data to Service Environment components, thus making them Network-Aware and increasing their efficiency and adaptability[1][2]. The CAN layer also receives content-related information from upper layers to perform content-aware functionalities.

C. *User Environment*

The enhanced User Environment concentrates Use terminal interfaces and functions and allows end-users to consume and/or generate content and exploit different services delivered by components of the Service Environment:

- New dimensions are added to the user by giving him the possibility to have several roles, such as Content and Service Consumer, Content and Service Provider and Content and Service Manager.
- A User Profile is elaborated for characterizing the static and dynamic parameters of the user and his/her context, in order to be exploited by Service Environment elements for the delivery of adapted services (Context-Awareness).
- Quality of Service (QoS) and Quality of Experience (QoE) is constantly monitored at service consumption, to trigger adaptation decisions and facilitate service monitoring from the SP/CP side.

The following sections present more details on the Service and Network environments.

III. SERVICE ENVIRONMENT

This section presents the Service Environment, which is the central part of the "Media Ecosystem" architecture. Media content and services can be provided i) by a Service Provider or ii) by any end-user through his/her HomeBox (User Generated Content). Therefore, the service environment can be divided into two parts (cf. Figure 2): The Content/Service Provider (CP/SP) part, centralized at the provider side and the HomeBox part, distributed to each end-user.

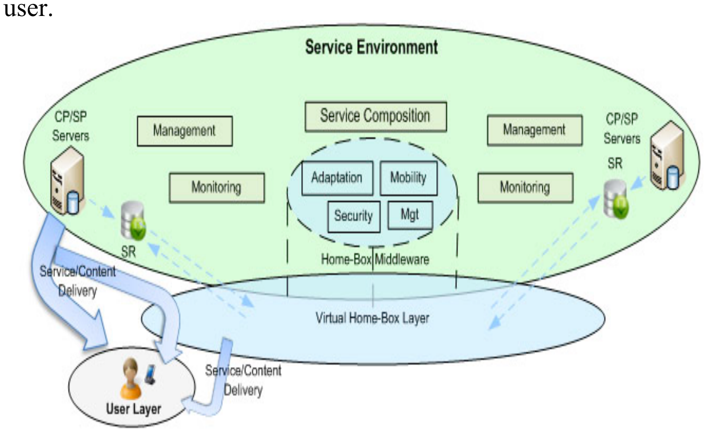

Figure 2. Media Service Environment

A. *Service Creation and Provision*

From an architectural viewpoint, the service environment at the provider side is composed of SP/CP provisioning servers and the Service Registry (SR). The provisioning servers aggregate content and services from the CP and other SPs, and provide a broad spectrum of real-time and non-real-time media services (IPTV, VoD, video/audio telephony/conferencing, media messaging etc). The Service Registry manages the descriptions of available services, including their content, location or access method. The Service Registry allows CPs, SPs and End-Users to publish new services and discover existing services.

From a functional viewpoint, different modules are implemented in the service environment to offer flexible control and management to the Service Provider. The Service Delivery module ensures the actual data transfer from the CP/SP servers to user's terminals; the Service Management module offers the management and control interface for the Service Provider; the Service Composition module offers simple and adapted tools for both Service Provider and End User to compose and publish new services; the Service Monitoring module receives measurement results from some specific tools and monitors the overall service quality.

It must be noted that all multimedia flows traverse the network in a consistent stream format i.e. Scalable Video Coding (SVC). This allows easy and rapid adaptation of the service in the Network Environment by dropping or re-including SVC layers to adapt to network capacity in the approach described in [3]. The process of transcoding from the initial media format to SVC is undertaken by the Server (or the serving HomeBox, for user-generated services).

B. *Collaborative Overlay based on HomeBoxes*

Different access modules deployed at the edge of network (e.g. home gateways, set-top-boxes) have generally large storage capacity and stable online presence. The concept of leveraging these access modules in order to build a collaborative overlay for content distribution has emerged recently [4]. In the "Media Ecosystem", the HomeBox is present in each user's home. While the HomeBox architectural layer is a part of the Service Environment, the HB itself concentrates functions from all three environments (User, Service and Network). In this context the HomeBox enables the communication among environments (cf. Figure 3):

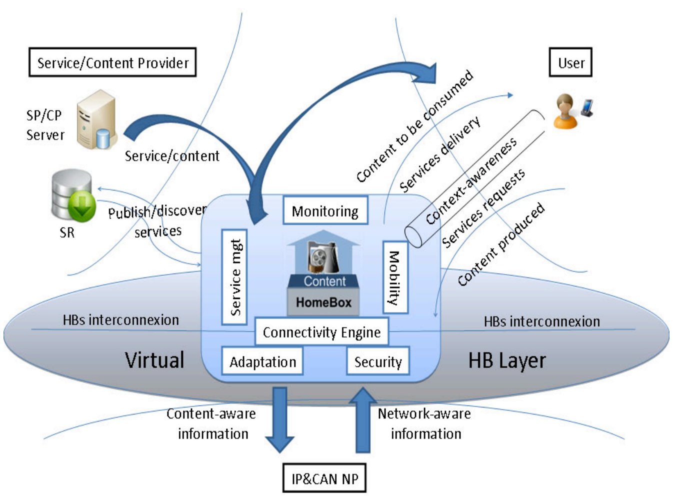

Figure 3. Virtual HomeBox Layer

Service environment functions implemented in the HB enable every participating HB to simultaneously be Content Consumer and Content Provider. Depending on the type of service, the Service Provider selects the mode of connection. P2P mode is generally used for the multicast service for popular content.

The HomeBox is also a central point of the user's Home Network, acting as local server to deliver the content to all devices in the home environment with different capabilities, as well as to some "remote" devices, allowing the user to ubiquitously access his/her content and service. The HomeBox is also in charge of collecting the information on the user context. User's devices are usually directly connected to the HomeBox, so that the user-related information can be easily centralized in the HomeBox. Then this information is reported to the Service Environment to activate the feature of User Context-awareness.

Finally, the HomeBox is directly and physically connected to the Network Environment via an access network (e.g. xDSL, FTTx, WMAN etc.). It serves as a gateway between the user's home network, and the virtual CAN.

IV. Network Environment and Content-Aware Networking

The corresponding lack of interoperability and integration functions, the lack of frameworks for adapting content to application environments, and the content protection mechanisms which tie content to particular formats or platforms, prevent end users not only from effectively transferring content and services between technology platforms but also from creating applications which are ubiquitous in their experience. These constraints limit the value of services to users, and their freedom to create and distribute their own forms of content [5].

Towards the solution of the above issues, the ALICANTE Network Environment (Fig. 4), offers the realisation of virtual Content Aware Network overlays on top of the physical infrastructure. The established VCANs provide not only content-awareness to the network but also network-awareness to the service/user environment. Such an approach is seen to improve data delivery as traffic differentiation is not performed solely on network-level information (e.g. source/destination IP address/port or class-of-service tagging) but also by procedures which try to discover the nature of the transferred service either by applying statistical methods for classification [6], [7] or/and packet payload inspection [8].

To achieve this, traditional routers are upgraded with novel functions to Media-Aware Network Elements (MANEs). A per-domain CAN Manager (module which manages the CAN overlay) is also introduced. MANEs result from the enhancement/upgrade of current network routers, especially at network edges, in order to provide the overlaying and content awareness features.

Content-aware processing and traffic type identification in MANEs is based on intelligent algorithms able to apply deep IP packet payload inspection and/or statistical methods in order to identify the transferred content. The critical information for the accurate identification can be either the metadata information transferred with the content or packet field analysis of the content flow. The heavy processing that could occur in these network elements raises some scalability issues. In order to deal with these issues, the processing in each network node is done in a stateful manner. Each packet flow is at first separated [9] and then the content is identified. After this procedure the incoming packets that belong to the same flow are automatically identified. Furthermore, the identification is only taking place at the network edges, since, after the identification of the content, the corresponding flow's packets are marked according to the supported network management technology; core routers may forward/route the flows as marked without inspection.

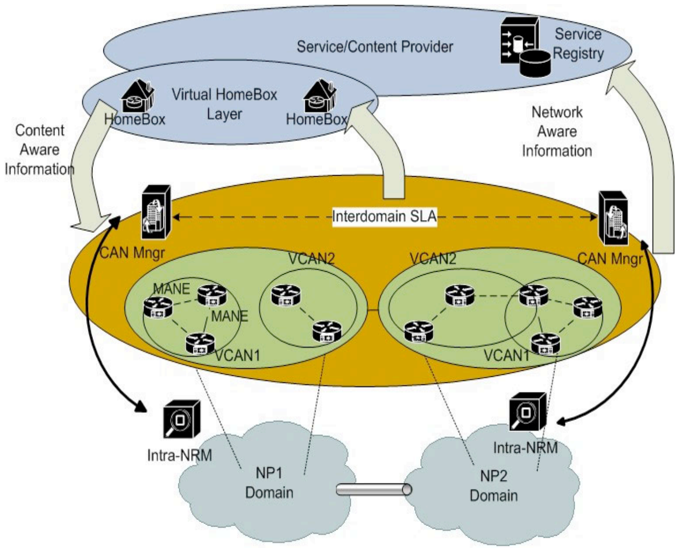

Figure 4. ALICANTE innovative Network Environment

The management entities of the CAN overlay (CAN managers) constitute an innovative management and control system. They are responsible for defining /creating the virtual CANs and all related actions to:

- configure, maintain and update CANs
- advertise and negotiate CAN usage with upper layers, using SLA/SLS contracts
- communicate with other CAN managers in order to establish multi-domain chains, using SLA/SLS contracts
- communicate with the intra-domain network resource managers (Intra-NRM), which have the ultimate authority upon the network provider resources, thus conserving each domain's independency.

V. DESCRIPTION OF A SERVICE LIFECYCLE

This section describes the actions taken during the provision of a service within the ALICANTE architecture. The aim of this description is the more comprehensive illustration and demonstration of the functioning of the different network and service components –which were described in the previous sections - as well as the interactions among them.

Media services provided and consumed within the ALICANTE ecosystem could be discriminated into three categories:

- Consumer services: IPTV, voice/video calls, on-line gaming, remote home monitoring, SOHO communications
- Enterprise services: Voice/video calls, multimedia conferences, inter-site SD and HD webcasts
- PEG (Public, Education and Government) services: E-health with 1- or 2-way video, multi-site SD and HD classroom webcasts, 2-way audio and video feeds to Police/Fire/Ambulance, local community video streaming

The initiation/creation of a new service instance, either push or on-demand, unicast or multicast, is performed by the Service/Content Provider or the End User (for user-to-user services). The Service Composition module is used for the creation and publication of a new service. The creation of the service is declared to the Service Registry, which contains a set of metadata describing the service and the content, and also the servers and/or HomeBoxes which offer it.

The end user (content consumer) accesses the ALICANTE Ecosystem via his/her User Terminal, which can be any fixed or portable device associated with the user's HomeBox. All connections and service requests are routed via the HomeBox. Via a friendly GUI residing in the Terminal, the user browses the Service Registry and selects the desired service. Upon selection, the Service Registry analyses the User Profile, which also contains information about the presenting terminal (e.g. terminal type, mobility, access network type and capacity, screen resolution, processing power etc.) and responds with a set of "peers" (Servers and/or HomeBoxes) which can offer the service under the specific terminal requirements.

Having this list, the user's HomeBox can query the CAN Manager to ask for the "network distance" to each of the serving peers. This distance is actually a set of network-level measurements (bandwidth, loss, jitter etc.) corresponding to the path between the server and the consumer. Based on these measurements, the user's HomeBox can select the "best" peer to which the request will eventually been sent.

Upon selection, the HB sends to the serving peer the request for the service along with the User Profile. The service flow is initiated in Scalable Video Coding (SVC) format and conveyed to the consumer's HomeBox over a virtual CAN overlay. The VCAN to actually transport the service has a priori been negotiated between the Service and CAN management entities. The Media-Aware Network Elements (MANEs), which implement the VCAN, inherently featuring Content Awareness, recognize the nature of the service, as the latter traverses through them, and treat it accordingly.

In case of network congestion, the MANEs can perform in real time media flow adaptation, i.e. selectively drop layers from the scalable SVC flow in order to ensure the delivery of the service, even at reduced perceptual quality. At the User Terminal, a dedicated module, namely the QoE (Quality of Experience) Monitoring Tool, performs real-time analysis of the receiving flow and feeds the Service Manager with periodic reports regarding the QoS and QoE of the flow received, including cross-layer monitoring data[10].

The ALICANTE service provision mechanism, as it was briefly described, achieves a threefold goal:

- The efficient creation, discovery and distribution of the service among various Service/Content Providers and Consumers within the same network-ecosystem
- The optimized delivery of the service via enhanced network overlays (VCANs) enhanced with content awareness, traffic differentiation and dynamic on-the-fly adaptation mechanisms, resulting in a dramatic increase of the offered QoS/QoE
- The continuous cross-layer monitoring of the offered service, allowing the Service/Content Provider to control and adapt it in real time.

VI. CONCLUSION

This paper described a novel architecture for deployment of Media Ecosystems within the context of the Future Internet. This architecture, which realizes Content-Aware networking and accommodates for Network-Aware applications, can be applied in any existing provider network in order to enhance it while keeping it backwards compatible (i.e. still able to convey legacy, non-registered services). It is being implemented within the frame of the EU-funded ALICANTE project, which started March 2010 and is planned to run for three years. Currently (February 2011), system definition has been completed and early versions of most modules have been implemented.

The viability and efficiency of the proposed architecture will be investigated in an international demonstrator, including autonomous but cooperating systems/pilots in Aveiro (Portugal), Bucharest (Romania), Bordeaux (France) and Beijing (China), in which both intra-network and inter-network use cases will be investigated and validated. The goal will be to demonstrate the features and added value of the proposed architecture which extends beyond plain technical superiority; it also introduces new aspects in the business sector by including multiple actors under a single platform and by creating in this way new business opportunities which current infrastructures cannot provide.

ACKNOWLEDGMENT

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