

Seamless Content Delivery

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ABSTRACT

Widespread and affordable broadband access opens up opportunities for delivery of new streaming services. However, what is expected to fundamentally change the way that people use the network is the ability to produce, and seamlessly deliver and share their own multimedia content. SEA consortium is confident that in a few years everyone will be multimedia content producer, mediator and consumer, and aims to provide the means to distribute A/V user-centric services, with superior quality and flexibility, in a trusted and personalized way.

Categories and Subject Descriptors

B.4.1 [Input/Output and Data Communications]: Data Communications Devices

C.2.4 [Distributed Systems]: Distributed applications.

General Terms

Design, Measurement, Performance, Experimentation.

Keywords

Scalable Video Coding, Multi-View Coding, P2P, Multi-Description Coding, Cross Layer Adaptation.

1. INTRODUCTION

Widespread and affordable broadband access opens up opportunities for delivery of new streaming services, making ICT crucial to European growth and quality of life. The networked future however, is not envisaged to be simply a faster way to go online. What is expected to fundamentally change the way that people use the network is the ability to produce, and seamlessly deliver and share their own multimedia content. SEA consortium is confident that in a few years everyone will be multimedia content

producer (by publishing digital pictures, video recordings, remote e-health services, home surveillance, etc.), multimedia content mediator (by storing/forwarding streaming content) and multimedia content consumer (digital television, video on demand, mobile broadcasting and alike).

Towards this forthcoming age, SEA (SEAMless Content Delivery) [1] aims to offer a new experience of seamless video delivery, maintaining the integrity and wherever applicable, adapting and enriching the quality of the media across the whole distribution chain.

We believe that the user should be placed at the centre of a multimedia streaming, content aware network architecture, acting as content consumer, content mediator and content producer. The content aware network may consist of four types of content delivery networks:

- a) Broadcasting networks e.g. terrestrial (DVB-T), satellite (DVB-S/S2), cable (DVB-C),
- b) Interactive/on demand Bidirectional networks e.g. xDSL, WiMAX,
- c) Mobile networks e.g. 3G/4G, GERAN, UTRAN, DVB-H
- d) Mesh P2P logical overlay topologies.

In more details, SEA aims to introduce novel services and new business models by innovating over three key-content delivery pillars:

- A) **Multi-layered/Multi-viewed content coding.** SEA considers the evolving H.264 SVC (Scalable Video Coding), H.264 MVC (Multi View Coding) and their emerging standards, as the major foreseen content delivery technologies over heterogeneous networks, multiple terminals and large audiences. SVC will offer layered temporal/spatial/quality content scalability, while MVC will introduce a truly personalised video delivery experience by allowing the user to select among the different views embedded in a single video stream. Future truly free-view point applications will become available by adding depth information to MVC coded sequences.
- B) **Multi-source/multi-network streaming & adaptation.** SEA will offer on-the fly content adaptation, inherited resiliency and enriched PQoS by dynamically combining different content layers,

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views and representations of the same resource (video stream) transmitted from multiple sources (different servers or peers in case of P2P streaming) and/or received over multiple diverse paths or networks. Reconstruction of the content segments may take place either within the network (offering transparent streaming to low-end terminals) or at the end-user terminal in case multi-network connectivity is available. Cross-network adaptation and cross-layer optimization especially in P2P overlay topologies, will offer traffic adaptation (load balancing to avoid network flooding) and optimal use the available resources (bandwidth).

- C) **Content Protection and lightweight asset management.** New business models for large scale content distribution will be facilitated side-by-side to a proper content protection and asset management mechanism. Within SEA, personalised content protection will be offered in the extended delivery environment. The work will advance in the adaptation of the content protection and rights management solutions for new media in P2P networks.

SEA will test and validate the developed technologies over real testbeds and real-time emulators of various networks (3G/4G, WiMAX, ADSL and WLAN IEEE 802.11b/g/a) along with a large state-of-the art P2P testbed and a real 3G/4G network. Over this heterogeneous architecture, an innovative P2P IPTV-like application will efficiently combine and utilise all SEA networking and multimedia technological advances, validate the SEA concept and optimise the SEA platform behaviour.

In this paper, we present the main issues that SEA will tackle and the expected technological innovations and results.

2. LOGICAL NETWORK ARCHITECTURE

The SEA concept and network architecture is elaborated in Figure 1. We assume an integrated service/ content provider's oriented business model, reflected to the network architecture. The service/content provider is located at the core network and using a client/server's paradigm-based distribution chain, offers streaming A/V services over broadcasting, interactive/on demand networks (including the Internet), and 2G+/3G/4G mobile networks. Individuals may also operate as content creators and service providers by distributing their personal content, including but not limited to video streams. Moreover, novel "follow me" like services may be introduced, where the home-based equipment may operate as service mediator and content forwarder and a subscriber may consume personalised streaming services, properly adapted to network characteristics/conditions and his mobile phone/PDA capabilities, while on the move.

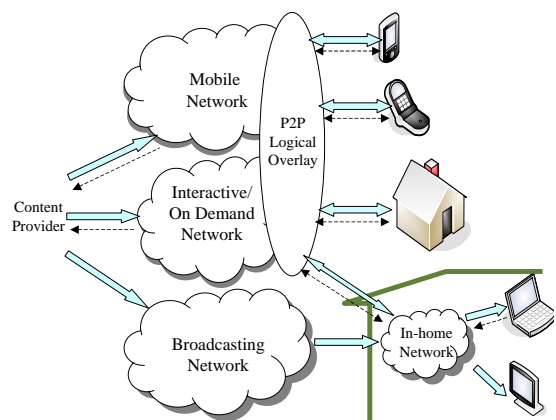


Figure 1: SEA Logical Network Architecture

The SEA network architecture also considers trusted Peer-to-Peer (P2P) overlay topologies in a broadband, heterogeneous architecture. This is also compatible with the increasing and expanding WiFi community networks architectures. In this case, services may be offered not only by centrally located media streaming servers, but by groups of end-user devices, acting as distributed content repositories. Given content protection and management is in place, network operators and service providers may offer value-added streaming services with remarkable PQoS, while avoiding the nightmare of network scaling and the expenses in network infrastructure upgrades, as the content (at least the most popular one) and the network resources (traffic load) may be distributed and thus balanced to a large number of peers. Moreover, individuals may produce their own (real-time) content and make it publicly available to a larger audience, without having to rely on a specific, expensive networking infrastructure. In this environment, video streaming scalability, resilience and PQoS may be exponentially increased, as not only multiple-networks, but also multiple-source may stream video segments, enriching the content on-the-fly either at the network and/or at the end-user terminal.

However, in order to realize the above service provisioning scenarios, a number of issues have to be considered and tackled. Advanced scalable and multiview video coding, knowledge of the network conditions, innovative cross layer optimization, real-time service adaptation, on-the fly PQoS enrichment, content protection are some of the issues that SEA aims to solve.

2.1 Advances in Video Coding

The first step in realising seamless content delivery and truly personalised video view is to add innovative scalability and multi-view features to the encoding stream, making minimal compromises to the required bandwidth.



Figure 2: Examples of multi-view coded video from a set of linear camera settings

2.2 Advances in scalability

Scalable video coding is a highly attractive solution to the problems posed by the characteristics of multi-networks, multi-sources, multimodal video transmission systems.

The **Scalable Video Coding (SVC)** activity group of the Moving Picture Expert Group (MPEG) of ISO/IEC and the Video Coding Expert Group (VCEG) of ITU-T have recently finished their joint standard as H.264 Annex G and MPEG-4 Part 10 Advanced Video Coding Amendment 3. This standard is expected to outperform all existing scalable video coding solutions in terms of coding efficiency and required computational power, ensured by a complete single-loop decoding process.

Members of the SEA consortium (Fraunhofer HHI, STM, Thomson) have played a key role in the standardization activity, both coding, storage and signalling/transport. Moreover a real-time SVC encoder is already available to the SEA project. SEA will further optimize SVC decoder for platforms like PDAs and further utilise and step over this encoder for offering scalable, multi-layered content. The different video layers will be stored in central streaming servers and/or cached in distributed peers in the network.

2.3 Advances in flexibility/personalisation

The next vision in video encoding, **Multi-view Video Coding (MVC)** addresses efficient integration of data and will provide for personalised views and extended 3D rendering video functionalities. MVC will enable new real time services allowing the end user to interactively choose from different views embedded in one video stream, with much better data rate performance than simulcasting different views of the video. As an extension of H.264/AVC, MVC standardization is scheduled for 2008; thus real time capable implementations are not available. Specific MVC algorithms give significantly better results compared to methods proposed before or based on plain H.264/MPEG4-AVC simulcast. Within SEA a real-time encoder and a decoder library for MVC will be

implemented and optimized on PC platforms. The libraries are to be integrated into client-server applications.

Figure 2 illustrates multi-view video, i.e. multiple (N) synchronized video streams showing the same 3D scenery from different viewpoints. MVC is under development for efficient compression of such data. This format is directly suitable for 3D displays with up to N simultaneous views. Based on statistical analysis of interview/temporal prediction, the MVC scheme uses the prediction structure of hierarchical B pictures for temporal and different view coding [2]. Hierarchical B pictures provide significantly improved RD performance when the quantization parameters for the various pictures are assigned appropriately. Additionally, full inter-view prediction is used for enhancing coding performance.

Apart from MVC encoder/decoder, within SEA signalling and transport framework for MVC will be developed and integrated, which will be used to efficiently distribute different views to the requesting users only, while allowing a minimum usage of bandwidth.

2.4 Advances in Resilience

The SEA architecture combines a multi-Radio Access Technology (RAT) network with a number of access networks and P2P overlays; thus packet loss rate is expected to be significant. On the other hand, the probability of having more than one paths between the server(s) and the terminal is also quite high. In this particular case, **Multiple Description Coding (MDC)** turns out to be very efficient.

Most MDC approaches are based on spatial and temporal sub-sampling. As an example, two low resolution videos can be generated from the original high definition signal, thus yielding two alternative descriptions that can refine each other; in such a case, the added redundancy is contained on the amount of correlation of the signal and cannot be easily tuned according to user/network needs. Recently, *rate distortion optimization* approaches have proven to be very effective in the analysis and the design of

MDC techniques [3]. In fact, standard rate control and optimization algorithms can be designed so as to take into account the possibility to insert a certain amount of redundancy for error resilience purpose.

This approach can be exploited to allocate the MDC extra rate according to a given optimization criterion, e.g. depending on the network status. In parallel, H.264 coding standard encompasses the possibility to create redundant picture representations, which can be used to form H.264 compatible descriptions of the video sequence. In conclusion, rate control and the redundant representation option can be jointly used to design a H.264 compatible MDC codec. H.264 compatibility guarantees that such MDC solutions can be extended to SVC and MVC, thus allowing novel and not yet studied approaches.

3. ARCHITECTURE INNOVATIONS

The advanced coding schemes will facilitate video distribution with enriched QoS, especially in case of high-end multi-modal terminals able to receive and reconstruct multiple video streams segments (i.e. layers, views, descriptions). However, home terminals or low-cost mobile terminals may be only capable for decoding at a particular bit-rate or may be only feasible to correctly display up to a particular image resolution. Thus, in order to meet all SEA innovative features, the media delivery service architecture should be content aware and have knowledge of the access technologies as well as to the utilised end-user device capabilities and characteristics. The network has to provide the relative adaptation functionalities, to seamlessly support the majority of terminals. On the other hand, particular access technologies (e.g. 3G networks) can support services up to a particular bit-rate and with certain QoS, while in P2P networks the end-to-end path may be unknown or time variant.

SEA should also be able to support terminal mobility, including service continuity, between different (radio) access technologies, or maintaining and supporting the same capabilities of access control (authentication, authorization), privacy and charging when moving between different (radio) access technologies. IP service continuity should be maintained, i.e. SEA should hide the impact of mobility events to the end user and the IP application(s), i.e. the service can continue without user intervention or special application support to mask the effects of a mobility event.

In case of building a service architecture upon the described variety of access networks, it is desirable to have as much information and adaptation at the lower layers (up to the network layer) as possible, along with scalability functionality coming with the media codec. Certain functions such as content caching in the network, content adaptation and cross-layer optimization would certainly need knowledge of the network conditions/characteristics. In order to overcome this problem, wherever applicable in the SEA architecture, we introduce intelligent media/network aware nodes. A Media Aware Network Element (MANE) is defined as a network element, such as an application layer gateway that is capable of parsing certain aspects of the RTP payload headers or the RTP payload and reacting to the contents and modify session signalling. In SEA two MANE types will be introduced (Figure 3):

- seamless Home Media Gateway (sHMG), located at the edge of the extended home environment and
- seamless Network Media Gateway (sNMG) at the edge of the 3GPP Service Architecture Evolution (SAE).

The SEA MANE nodes (sHMG and sNMG) will be network-based components for SEA architecture and will support the intelligent, seamless content distribution. They will offer functions like network and terminal awareness,

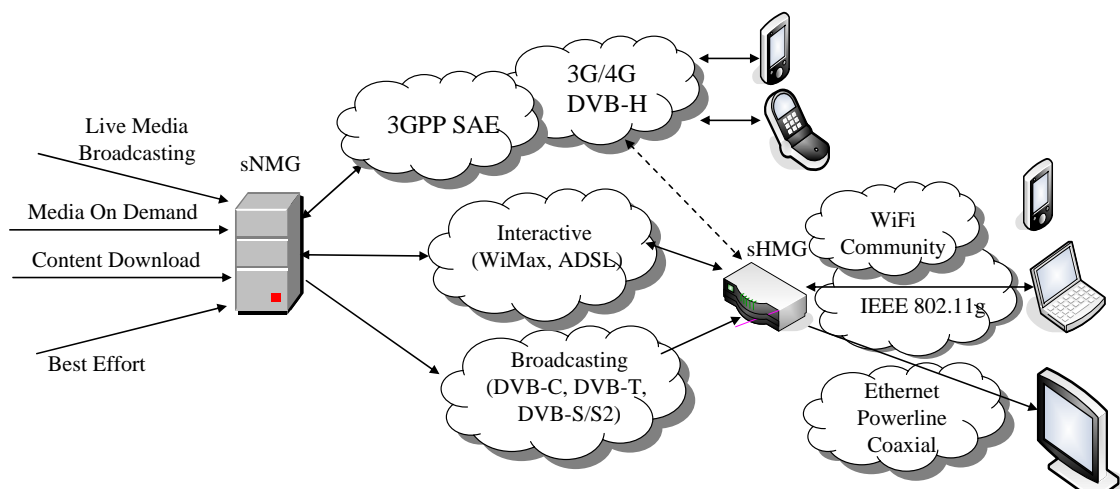


Figure 3: SEA Network Architecture

content enrichment and content protection. In the longer term, they may be integrated on Internet Multimedia Systems (IMS) as defined by ETSI TISPAN. They will offer multimedia storage, dynamic content adaptation and enriched PQoS by dynamically combining multiple multimedia content layers from various sources. Moreover, as they will have knowledge of the underlined networks, they will provide information on the network conditions/characteristics, which will be utilised by the Cross Layer Control (CLC) mechanism and adapt the multimedia streams to the next network in the delivery path. This will be extremely important in case of a low bandwidth, but guaranteed QoS mobile networks and in the broadband, but best effort P2P topologies.

Another innovation, also related with the foreseen business model and the SEA approach to provide on-the-fly enriched PQoS, is that sHMG will be able to offer multimedia content adaptation and caching/storage functions to the service provider and the community. The storage capabilities of the sHMG will be divided in two partitions. One partition will be allocated to the user, where personal/private content will be located. This content will be distributed on user demand and under user permissions, assent and will support P2P communications. Another partition will be allocated to the service provider and/or the community network, and will be utilised as temporal cache. A/V content files, layers or segments will be stored and indexed there, adapted and retrieved/relayed on remote (guest) users or subscribers' request. In this way, not only a "follow me" service will be available, where the user will be able to receive services and retrieve content remotely, adapted to the network and the terminal that he/she is currently located, but P2P (super)distribution and load balancing will also be feasible. Of course, as the uplink (e.g. ADSL) connection may be flimsy, the owner of the sHMG will have priority over other users.

4. SEA PLATFORM VALIDATION

Due to the complexity of the SEA platform, the great heterogeneity of the target access network technologies and topologies (P2P), validation and testing will not be a trivial task. A number of network and network components have to be initiated and integrated before SEA functionality can be validated.

Figure 4 shows the SEA testbed reference architecture. It consists of three islands:

- a) a *SAE emulated testbed*, located in Germany,
- b) a large *P2P testbed*, hosted by UCLA and STM, and
- c) a *3G/4G infrastructure testbed* hosted by Vodafone.

The testbeds will be interconnected via high-speed Internet links, thus functionality from one testbed can be tested, validated and demonstrated from another. In more details:

The SEA emulated testbed is a multi-RAT environment, which incorporates a number of SAE components and access networks based on RAT real-time emulators. In this way, it will enable the SEA project to operate with dedicated cell and channel conditions, without being annoyed by any interference and side effects.

5. SEA P2P TESTBED

The P2P testbed will be hosted in the UCLA Network Research Lab (NRL). Via NRL UCLA, SEA will get access to the PlanetLab, one of the largest and most advanced P2P networks worldwide. PlanetLab is a world-wide distributed network testbed that enables the development and performance evaluation of large scale distributed systems such as P2P platforms. PlanetLab currently consists of 776 nodes at 378 sites. Nodes are deployed on university campuses and industrial networks, geographically spread around the world. Initially, nodes are populated with a minimal Fedora Core 2 Linux installation. Each user is assigned a slice, a set of allocated resources distributed

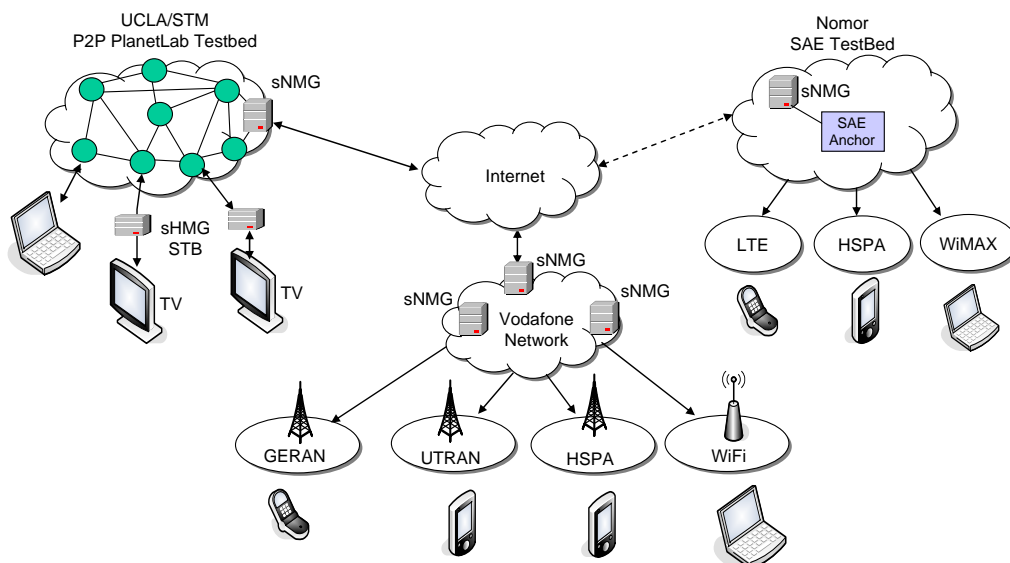


Figure 4: SEA testbed architecture

across PlanetLab. After nodes have been assigned to a slice, virtual servers for that slice are created on each of the assigned nodes.

NRL UCLA testbed implements an overlay network on PlanetLab, which aims at testing P2P streaming strategies in a real, but controlled deployment. Presently, the testbed evaluates a P2P network which comprises 250 nodes and a single video source. The testbed design enables to measure the playback delay, buffer and continuity index at each single node. By planning the lifetime of each single node in the network, it is possible to emulate user behaviour and measure its impact on performance. Moreover, any video codec can be easily integrated in such setting. In particular, PlanetLab will allow SEA to evaluate our peer selection algorithm and multi-description codes strategies in realistic yet controlled environment. We will be able to evaluate the reliability of the proposed architecture under different level of churns and within a network that presents a wide range of round trip times thus evaluating the feasibility of a large scale IPTV system based on P2P or hybrid architectures. On the top of this testbed, the sHMG functionality will be ported on an experimental STB to be integrated and validated in the PlanetLab testbed.

6. SEA 3G/4G TESTBED

Vodafone's commercial network will be used for the evaluation of the SEA concepts and prototype. SEA will get access in one segment of the network, integrate a small number of sHMG and sNMG, while it will also be able to utilize the real 2G+/3G (3GPP release 5) /WiFi commercial access networks. In this testbed, SEA will validate the emulated results and provide for interoperability tests with actual 3G/4G equipment.

Moreover, interconnection especially between this testbed and the P2P testbed will enable long distance tests. For examples, two sNMG will be installed as testbed's anchors (Figure 4). The video quality will be tested at:

- a) the P2P testbed anchor, to validate the behaviour as compared to the P2P delays,
- b) the edge of the 3G/4G testbed to test the network delay (with and without sNMG optimization and content enrichment) and
- c) the user mobile phone, to validate various access technologies along with multi-network streaming.

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