

Content Adaptation Issues in the Future Internet

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Abstract: Future Media Internet is envisaged to provide the means to share and distribute (advanced) multimedia content and services with superior quality and striking flexibility, in a trusted and personalized way, improving citizens' quality of life, working conditions, edutainment and safety. Based on work that has taken place in projects ICT SEA and ICT OPTIMIX, and the Media Delivery Platforms Cluster of projects, we try to provide the challenges and the way ahead in the area of content adaptation.

Keywords—Future Media Internet, Adaptation, Scalable Video Coding

1. Introduction

The Internet has evolved and changed the way we work and live. End users of the Internet have been confronted with a bewildering range of media, services and applications and with technological innovations concerning media formats, wireless networks, terminal types and capabilities. In the near future these numbers are expected to rise exponentially. Moreover, it is envisaged that the Future Media Internet will provide the means to share and distribute (advanced) multimedia content and services with superior quality and striking flexibility, in a trusted and personalized way, improving citizens' quality of life, working conditions, edutainment and safety.

In this evolving environment, new transport protocols, new multimedia encoding schemes, cross-layer and in-network adaptation, machine-to-machine communication, rich 3D content as well as community networks and the use of peer-to-peer (P2P) overlays are expected to generate new models of interaction and cooperation. Furthermore, this will enable the support of enhanced Perceived Quality of Service (PQoS) and innovative applications “on the move”, like virtual collaboration environments, personalized services/media, virtual sport groups, on-line gaming, and edutainment. In this context, the interaction with content combined with

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interactive/multimedia search capabilities across distributed repositories, opportunistic P2P networks and the dynamic adaptation to the characteristics of diverse mobile terminals are expected to contribute towards such a vision.

Based on work that has taken place in the projects ICT SEA[†] and ICT OPTIMIX[‡] and the Networked Media Unit: Media Delivery Platforms (MDP)[§] cluster of projects, we try to provide in the following an overview of the challenges and the way ahead in the area of content adaptation. The remainder of this paper is organized as follows. Section 2 introduces a content-aware (access) network architecture. The means for cross-layer adaptation for enriched PQoS is described in Section 3. The main challenges we established for cross-layer adaptation are highlighted in Section 4 and Section 5 concludes the paper.

2. Content-aware Access Network Architecture

Even in the near future, the access network (even the evolved one) will remain the weaker part of the network. Moreover, in Peer-to-Peer (P2P) networks the end-to-end path may be unknown or time variant. Thus, 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 codecs. Certain functions such as content caching in the network, content adaptation and cross-layer optimization would certainly need knowledge of the network conditions and characteristics.

In order to overcome this problem, wherever applicable in the network architecture, we introduce intelligent media/network-aware nodes. Within SEA we have introduced two types of content-aware edge devices/Media Aware Network Element (MANE):

- a) Home Media Gateway (HMG), located at the edge of the home environment and
- b) Network Media Gateway (sNMG) at the edge of the access networks, e.g., the 3GPP Service Architecture Evolution (SAE)

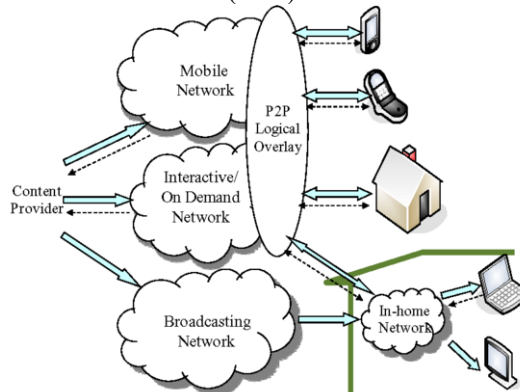


Figure 1: The concept of P2P overlay architecture

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In general content-aware MANEs can offer multimedia storage, dynamic content adaptation and enriched PQoS by dynamically combining multiple multimedia content layers from various sources. Moreover, as they have knowledge of the underlying networks, this information on the network conditions/characteristics can be provided to and utilized by cross-layer control mechanisms and adapt the multimedia streams to the next network in the delivery path. This is an extremely important point for low bandwidth but with guaranteed QoS mobile networks as well as for the broadband but best effort P2P topologies. Introducing the content-aware nodes at the edges of the networks also enables us to realize a Peer-to-Peer (P2P) overlay topology as shown in Figure 1. Given content protection and management is in place, network operators and service providers may offer value-added streaming services with remarkable PQoS. 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 increased, as multiple sources may stream video segments, enriching the content on the fly, either at the network and/or at the end-user terminal.

The sHMG and the sNMG are key components in the SEA network architecture and play an important role in the cross-layer control and adaptation. However, this is not the only approach including an adaptation engine: the OPTIMIX project is working on a similar architecture including adaptation modules, whose role is to adapt the transmitted stream based on the current available QoS information (*quality feedbacks* which can include channel state information, packet error rate at various layers, retransmission rates, video quality, etc.) from the upcoming link. More precisely, the adaptation module will allow to transcode the stream based on requirements produced by the control algorithms (enforced by the controllers at application and base station levels). For scalable streams such as SVC ones, it will read and parse the stream to extract interesting portions of it, and for non-(sufficiently) scalable streams, it will introduce real transcoding of the stream, and not only parsing and cutting of it. Depending on the stream features, the adaptation module will be able to change the spatial, temporal resolutions or the data rate in an efficient manner. Typically, a temporally hierarchical stream [9] will allow temporal downgrade without error propagation, while a normal stream may result in prediction errors when downgrading is performed. Finally, another foreseen option of the adaptation module is the introduction of extension features, such as ciphering capability.

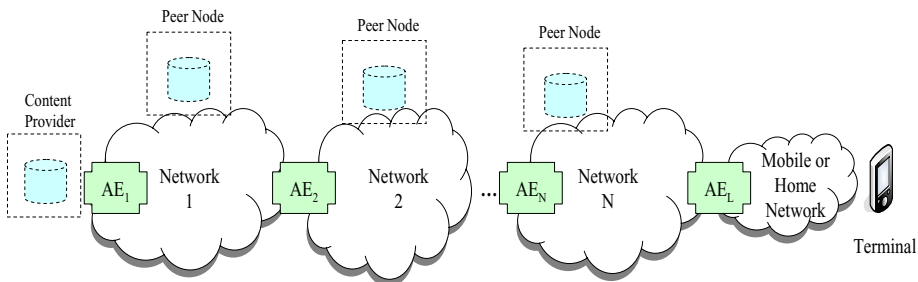


Figure 2: SEA adaptation network architecture

Envisioning such adaptation features in the communication chain nodes (MANEs), we may foresee a number of adaptation scenarios taking into account the final terminal capabilities (ranging from laptops to mobile phones). In order to optimize adaptation and increase the number of available scenarios, we extend the previously introduced

SEA and OPTIMIX adaptation network architecture in a more general format as shown in Figure 2. In this view, we assume that in the path from the Content Provider to the terminal, we may have $N+1$ Adaptation Engines (AE) with N as the number of core networks. Each engine is responsible for adapting the video stream to the next network in the path, i.e., AE_i adapts the video stream to the characteristics/capabilities of Network i , always taking into account the final terminal capabilities and user requirements.

3. Cross-layer Adaptation for enriched PQoS

One of the main challenges in Future Internet audio/visual communication will be the ability to provide a sustainable end-to-end quality as indicated by the user (PQoS), throughout the entire duration of the service delivery. Offering QoS-based services involves interactions, not only among a number of entities along the service delivery chain, but also across different layers. To coordinate effective adaptation and mapping of QoS parameters at service, application and network layers, cross-layer interactions are required. The objective of this adaptation and interaction is to find a satisfactory QoS trade-off, so that each end-user's service can be supported with available network resources. In this chapter, we highlight a very important issue in streaming multimedia: the cross-layer adaptation issues in order to achieve an enriched PQoS.

3.1. Cross-Layer Control/Optimization/Adaptation

During the last couple of years, it has been shown that adaptation techniques limited to adaptation within a single layer are deficient in providing global optimal settings for the system. In contrast, cross-layer approaches have been extensively discussed in recent research literature for its viability for providing better performance than traditional layered architecture. Cross-layer approaches increase interaction among different layers to exploit the inherent characteristics of underlying network to maximize the utility (e.g., QoS) and reduce the cost (e.g., battery life, bandwidth). The involvement of multiple layers in cross-layer adaptation is important otherwise various mechanisms available at different layer are likely to counteract each other's effect. Although cross-layer designs emerged as a by-product of recent proliferation of wireless networks having totally different properties from wired networks, it offers various opportunities for heterogeneous environment, where a variety of application types, network technologies and terminal capabilities are utilized. Initial motivation to work on cross-layer issues was primarily derived from following reasons:

- Wireless networks are characterized by high bit error rate due to fast fading, co-channel interference and shadowing. To overcome these issues, different layers can cooperate to make transmission more resilient to noise.
- Effective network condition estimation requires parameters from multiple layers, e.g., packet loss ratio, BER, SNR etc. Network condition estimation is necessary to increase utilization and reduce cost
- Low efficiency of transport protocols over wireless networks due to their inherent characteristics is also a reason for the consideration of cross-layer design.
- Heterogeneity of applications, terminals and networks require more rigorous adaptation mechanisms. Especially, in the context of multimedia services, content adaptation is absolutely necessary due to enormous dependencies arising from

heterogeneity. Cross-layer adaptation can play a key role in handling such multiplicity of dependencies.

- Cross-layer adaptation can assist smooth transition from best effort to QoS.

3.2. Adaptation Control

In the proposed adaptation architecture, multiple adaptation engines can use information gathered from various layers. Thus, the AEs (see Figure 2) need to coordinate their adaptation information and decisions by proper signalling. The following sections describe how advanced media attributes can be signalled using format specific extensions to SDP and how MPEG-21 elements can be used for media adaptation.

3.2.1. Signaling advanced content attributes over the Internet

Today's Internet streaming systems utilize the Session Description Protocol (SDP) for session declaration or negotiation in the context of other IETF protocols such as the Real Time Streaming Protocol (RTSP) for controlling point-to-point multimedia streaming sessions, the Session Announcement Protocol (SAP) for indicating multicast multimedia streaming sessions, or the Session Initiation Protocol (SIP) for negotiation of multi-directional conversational multimedia sessions. A session description consists of both session wide information and media description sections. For the purpose of adaptation, the media description provides crucial information which can be evaluated by different network elements. Transport of layered media offers opportunities for adaptation by selective manipulation of the different layers, if the attributes of each layer are described in the SDP.

In the following we show an example for specific media signalling for SCV. **Table 1** shows an example where a server offers a multi-session transmission with up to three potential media sessions. Lines 1 to 7 describe the session. The attribute specified in line 7 declares a group having decoding dependencies which contains the media sessions "1", "2" & "3" identified by the "mid" attributes assigned in lines 15, 21 and 26, respectively, to the media description blocks shaded with different colours in **Table 1**. Additionally, each media description is associated with one or more payload type (PT) numbers in lines 8, 16 and 22. Dependencies are given per payload type for all layers except the base layer of an SVC stream or the base view of an MVC stream by an "a=depend:" attribute line [7]. A detailed description for each media session is given by the format specific attributes in lines starting with "a=fmtp:", followed by the PT number to which the line applies. The parameters used in the example are all optional and apply specifically to media of MIME types "H264-SVC" or "H264":

Table 1: SDP example describing Scalable Video Coding content

| Line # | SDP text |
|--------|---|
| 1 | v=0 |
| 2 | o=alice 2890844526 2890844526 IN IP4 192.0.2.12 |
| 3 | s=SVC Scalable Video Coding session |
| 4 | i=SDP is a multi-session offer |
| 5 | c= IN IP4 192.0.2.12 |
| 6 | t=0 0 |
| 7 | a=group:DDP 1 2 3 |

| Line # | SDP text |
|--------|---|
| 8 | m=video 20000 RTP/AVP 96 97 98 |
| 9 | a=rtpmap:96 H264/90000 |
| 10 | a=fmtp:96 profile-level-id=4d400a; packetization-mode=0; mst-mode=NI-T; sprop-parameter-sets=Z01ACprLFig,aP4Eag==; |
| 11 | a=rtpmap:97 H264/90000 |
| 12 | a=fmtp:97 packetization-mode=1; mst-mode=NI-TC; sprop-operation-point-info=<1,2,0,1,4d400a,C80,B0,90,80,100> sprop-parameter-sets=Z01ACprLFig,aP4Eag==; |
| 13 | a=rtpmap:98 H264/90000 |
| 14 | a=fmtp:98 packetization-mode=2; mst-mode=I-C; init-buf-time=156320; sprop-operation-point-info=<1,2,0,1,4d400a,C80,B0,90,80,100> sprop-parameter-sets=Z01ACprLFig,aP4Eag==; |
| 15 | a=mid:1 |
| 16 | m=video 20002 RTP/AVP 99 100 |
| 17 | a=rtpmap:99 H264-SVC/90000 |
| 18 | a=fmtp:99 packetization-mode=1; mst-mode=NI-TC; sprop-operation-point-info= <2,3,1,0,53000c,1900,160,120,C0,200> sprop-parameter-sets=Z01ACprLFig, Z1MADEsA1NZYWCWQ,aP4Eag==,aEvgRqA=,aGvgRiA=; |
| 19 | a=rtpmap:100 H264-SVC/90000 |
| 20 | a=fmtp:100 packetization-mode=2; mst-mode=I-C; sprop-operation-point-info= <2,3,1,0,53000c,1900,160,120,C0,200> sprop-parameter-sets=Z01ACprLFig, Z1MADEsA1NZYWCWQ,aP4Eag==,aEvgRqA=,aGvgRiA=; |
| 21 | a=mid:2 |
| 22 | a=depend:99 lay 1:96,97; 100 lay 1:98 |
| 23 | m=video 20004 RTP/AVP 101 |
| 24 | a=rtpmap:101 H264-SVC/90000 |
| 25 | a=fmtp:101 packetization-mode=1; mst-mode=NI-T; sprop-operation-point-info= <3,3,1,1,53000c,1900,160,120,100,400> sprop-parameter-sets=Z01ACprLFig, Z1MADEsA1NZYWCWQ,aP4Eag==,aEvgRqA=,aGvgRiA=; |
| 26 | a=mid:3 |
| 27 | a=depend:101 lay 1:96,97 2:99 |

- *profile-level-id*: profile and level of the contained AVC, MVC or SVC bitstream;
- *packetization-mode*: specifies whether NAL units are sent one per RTP packet, or whether NAL units may be aggregated either in a non-interleaved or interleaved manner;
- *mst-mode*: specifies for multi-session transport (MST) the way bitstream re-assembly is supported, e.g., relying on RTP timestamps or using cross-session decoding order numbers (CS-DON)
- *sprop-operation-point-info*: one or more vectors of 10 values describing the operation point(s) included in that media session. If present, the hexadecimal values specify: *layer-ID*, *temporal-ID*, *dependency-ID*, *quality-ID*, *profile-level-*

ID, *avg-framerate*, *x-resolution*, *y-resolution*, *avg-bitrate*, *max-bitrate*. A valid vector contains at least the triplet *temporal-ID*, *dependency-ID*, *quality-ID*;

- *sprop-parameter-sets*: Sequence and Picture Parameter Sets of the H.264, MVC or SVC stream.

As can be seen from the example above, the client can choose to request either one, two or three layers of an SVC stream, depending on its capabilities or user preferences, the choice being based either on the profile and level it supports or on more specific values included in the *sprop-operation-point-info* parameter, e.g., frame rate, resolution or bit rate. For media sessions 1 and 2, it can also choose different payload format numbers according to the packetization modes it supports.

Using SDP for the media signalling and adaptation control is by nature a media specific solution. In order to use a wider range of future media codecs within an adaptation context, the next section presents the generic approach of MPEG-21 Multimedia Framework.

3.2.2. MPEG-21 Multimedia Framework

A comprehensive framework that deals with all these issues is MPEG-21 [3]. All parts of MPEG-21 address a distinctive set of requirements, which allow implementers of the standard to design and implement a system or application that goes beyond simple multimedia content delivery in an interoperable way. The MPEG-21 standard provides the transaction of Digital Items among Users. A **Digital Item** is a structured digital object with a standard representation and metadata. A **User** is defined as any entity that interacts within this framework or makes use of Digital Items. A Digital Item can be thought as a virtual structured digital container of media resources and metadata. It can include resources of any media type: audio, video, text, images, and so on. Metadata is the related information for the entire DI or part of a DI which provides semantic support.

Besides the interoperability, digital content needs to be adapted to various transmission channels and terminal devices for delivery. Digital Item Adaptation (DIA) can be achieved by applying various approaches such as adaptation at the server side, at the intermediate proxy or at the terminal. We list here all the relevant requirements exposed to the terminal side from these adaptations:

- 1) **Device independence adaptation:** From a terminal's perspective, terminal-independence adaptation is usually employed. *User Environment Description (UED)* is the key of this approach. It includes descriptive information related to user characteristics, (e.g., user information and user preferences), terminal capabilities (e.g., codec capabilities and display capabilities), network characteristics (e.g., available bandwidth, delay, and error), and natural environment characteristics (e.g., location and time).
- 2) **Content dependence adaptation:** such approach relies on the coding scheme which provides scalability. Particularly, in the case of SVC, it has achieved temporal, spatial and quality scalabilities co-existing in a single bit stream. This allows video adaptation at bit stream level. Such benefit outperforms other coding schemes as it increases the adaptation flexibility. For example, if a terminal is limited by certain constraints, e.g., computing memory or power, and its decoder can support SVC, there is no need of intermediate adaptation, since the receiver can perform the adaptation itself by discarding the relevant Network Abstraction Layer

(NAL) Units that convey enhancing layers. However, in this case the enhancement layers that are dropped at the decoder are delivered to the terminal for nothing and, thus, bandwidth is wasted.

- 3) **Adaptation by quality constraints:** to achieve optimal parameter settings under certain constraints imposed by terminals and/or networks for QoS management, Adaptation QoS (AQoS) is provided to assist the adaptation engine for decisions. AQoS specifies the relationship among various constraints, feasible adaptation operations satisfying these constraints, and associated qualities. AQoS can be used together with *User Constraints Description (UCD)* to acknowledge the adaptation.

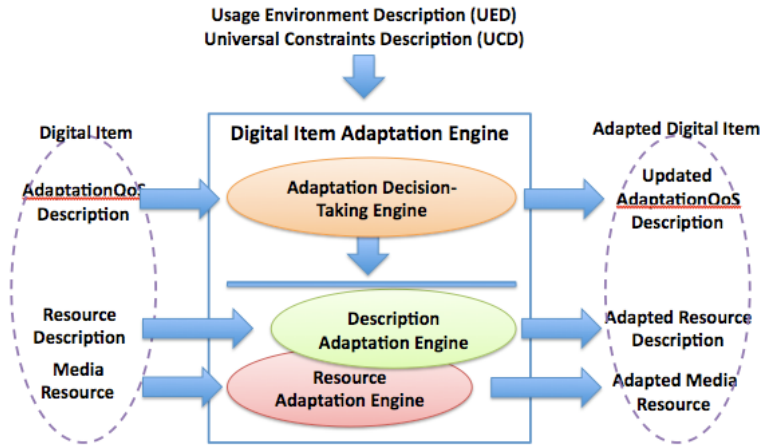


Figure 3: Digital Item Adaptation.

Figure 3 shows a DIA engine incorporating the above-mentioned features but it should be noted that the actual implementation of adaptation engine is outside the scope of the standard. DIA specifies syntax and semantics of the description formats that steer the adaptation. The adaptation put forward several requirements (and possible approaches for solutions at the same time) for a terminal: 1) UED/UCD functional modules needs to be integrated in terminals; 2) a media decoder with support for the media resources' codec (e.g., SVC); 3) terminal and network QoS management for AdaptationQoS need to be provided.

The concept of MPEG-21-enabled cross-layer adaptation can be described [5]:

1. **Cross-Layer Model (XLM):** provides means for describing the relationship between QoS metrics at different levels – i.e., PQoS, ApQoS, and NQoS – and layers – i.e., according to the well-known ISO/OSI reference model.
2. **Instantiation of the XLM** by utilizing *MPEG-21 metadata*: Description formats (i.e., tools) as specified within MPEG-21 Digital Item Adaptation are used to instantiate the XLM for a specific use case scenario, e.g., Video-on-Demand. In particular, the *Adaptation QoS (AQoS)* description tool is used as the main component to describe the relationship between constraints, feasible adaptation operations satisfying these constraints, and associated utilities (qualities).
3. **Cross-Layer Adaptation Decision-Taking Engine (XL-ADTE):** The XL-ADTE is the actual subsystem which provides the optimal parameter settings for media

resource engines according to the XLM by processing the metadata compliant to MPEG-21 DIA.

Within the end-to-end multimedia *delivery chain*, the network QoS may be measured on an aggregated level and mapped to PQoS of individual streams [6].

4. Challenges in Cross-layer Adaptation

The concept of cross-layer design sounds persuasively appealing. However, the successful experience of layered architecture burdens the adoption of a cross-layer approach. Currently, the research community is endeavouring the following challenges:

1. Cross-layer adaptation of the complete network infrastructure is very intricate due to handling enormous dependencies possibly in real time. A flexible architecture with proper interfacing between the layers is inevitable.
2. Cross-layer design breaks the layers and hence a clean isolated implementation of different protocols is no longer possible. Each cross-layer approach affects a complete system. An analysis of these effects becomes difficult.
3. The effects of coexistence of different cross-layer interactions are to be observed in terms of system performance, maintenance and scalability. Analysis is further perplexed if different types of cross-layer optimizations are deployed across an end-to-end delivery chain.
4. Global metrics are required that maximize the utility (e.g., QoS) and minimize the cost (e.g., battery life) under various constraints by efficiently prioritizing layers' local optimization criteria.
5. Optimization of cross-layer parameters is a complex multivariate problem with various constraints derived from QoS guarantees, available bandwidth, power consumption, etc. Apart from the essential requirement of computational efficiency, the highly dynamic nature of wireless networks demands a rapid convergence of the solutions.
6. It has to be evaluated where the actual control of a cross-layer adaptation should be located. Without a central control, different cross-layer adaptations might counteract each other. Different candidates include a separate coordinator or a particular OSI layer.
7. Cross-layer adaptation simulations are generally more complex than traditional network simulations. Hybrid approaches combining network simulation tools, hardware support and analytical approaches are usually required.
8. Not even a single cross-layer proposal has been tested comprehensively under real world traffic scenarios and hence QoS, power consumption and scalability of these approaches are yet to be gauged deterministically.
9. The assurance of fairness is yet an un-promised reality by cross-layer design.
10. As cross-layer designs break the well-established layers of the ISO/OSI model, interoperability issues arise also which are not considered as major at the moment but will emerge once these designs will find their ways into products.

5. Conclusions

In the Future Internet, new formats for multimedia content will evolve and emerge. From today's AVC, AAC, MP3, and early instantiations of SVC, the media delivery

platforms will accommodate the carriage of a wide range of the above formats as well as SVC, MVC, a multitude of audio and gaming-friendly formats, H.265, MPEG/Laser and other surprising industry standards and ad-hoc media formats. All this while striving to be on the one hand content-agnostic, yet applying network intelligence, achieved through intimate content awareness, for the purposes of traffic shaping, PQoS, security, reliability and more, a tough challenge. Furthermore, the prevalence of virtual and parallel personalized worlds, coupled with progressively changing virtual characters, adds a dimension of complexity tricky to contain and to scale up.

Finally, existing networks' Cross Layer Control (CLC) and adaptation provides significant improvements in the PQoS under specific networking and transmission conditions. However, further research is required especially in the case of P2P topologies, where the physical infrastructure may be an arbitrary, timely varying combination of links belonging to different networks. Moreover, CLC schemes are required to face the network and terminal heterogeneity and take advantage of new (3D) advanced coding and delivery schemes by proposing network abstraction mechanisms, able to model the underlined end-to-end paths, describe the functional dependencies and determine the optimum adaptation of the multimedia resources.

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