Control Plane Design for a Content Streaming System with Dual Adaptation

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Abstract — **Content streaming delivery has been recently considered as an attractive solution for media distribution, based on light architectures, working on top of the current Internet Protocol (IP) technologies. Such a system is considered here, integrating functionalities such as content server initial selection based on multi-criteria algorithm and then media adaptation (using dynamic adaptive streaming) and/or server switching - during the media session. This work-in-progress contributes to identify the main design concepts for the Control Plane of the architecture and in particular for the monitoring of Quality of Services (QoS) and Quality and Experience (QoE), aiming to support both the server selection and in–session adaptation actions.**

Keywords — Content delivery, Dynamic Adaptive Streaming over HTTP, Monitoring, Server and Path selection.

I. INTRODUCTION

Recently, over-the-top (OTT) solutions are proposed and developed, for media/content delivery, where the services are delivered over the current Internet by an entity called Service Provider (SP) that is not directly responsible for the quality of the flows transmission to the end-user; users access is done via the "public Internet". The OTT SP could exist as a separate entity from traditional Internet Service Provider (ISP). Also, combined solutions exist, with OTT Service Providers using the Content Delivery Network (CDN) Providers' infrastructure to improve the quality of delivery.

A *light (OTT-like) novel architecture* for content streaming systems over the current Internet is proposed by the European *DISEDAN* Chist-Era project [3], (*service and user-based* ***DI****stributed* ***SE****lection of content streaming source and* ***D****ual* ***A****daptatio****N*****,** 2014-2015). The business actors involved are: *Service Provider (SP)* - an entity/actor which delivers the content services to the users and possibly owns and manages the transportation network); *End Users (EU)* consumes the content; a *Content Provider (CP)* could exist, owning some *Content Servers (CS)*. However, DISEDAN does not deal with contractual CP-SP relationships; therefore one may assume that CSs are also owned by the SP. A solution is proposed for the (multi-criteria-hard) problem of best content source (server) selection, considering user context, servers' availability and requested content. The solution novelty consists in: (1) *two-step server selection mechanism* (at SP and at EU) using algorithms that consider context- and content-awareness and (2) *dual adaptation mechanism* consisting of *media adaptation* (also called *media flow adaptation*) and *content source adaptation* (by *streaming server switching*) when the quality observed by the user suffers degradation during the media session. The solution could be rapidly deployed in the market since it does not require complex architecture like Content Oriented Networking or CDNs [1] [2].

The *Dynamic Adaptive Streaming over Hypertext Transfer Protocol- HTTP (DASH)* technology has been selected for in-session media adaptation. The DASH was recently adopted as multimedia streaming standard, to deliver high quality multimedia content over the Internet, by using conventional HTTP Web servers [4] - [8]. It uses the HTTP protocol, minimizes server processing power and is video codec agnostic. Its basic concept is to enable automatic switching of quality levels according to network conditions, user requirements, and expectations. A DASH client continuously selects the highest possible video representation quality that ensures smooth play-out, in the current downloading conditions. This selection is performed on-the-fly, during video play-out, from a pre-defined discrete set of available video rates and with a pre-defined granularity (according to video segmentation). The DASH offers important advantages (over traditional push-based streaming), like: significant market adoption of HTTP and TCP/IP protocols to support the majority of the today Internet services; HTTP-based delivery avoids NAT and firewall-related issues; the HTTP-based (non-adaptive) deployment of progressive download existing today, can be conveniently be upgraded to support DASH; the ability to use standard/existing HTTP servers and caches instead of specialized streaming servers allows reuse of the existing infrastructure.

This work-in-progress is dedicated to take design decisions for a light Control Plane (CPl) and especially for its Monitoring subsystem (MON). The MON components are developed at SP, CS and optionally at EU Terminal (EUT). The MON is an essential DISEDAN component, contributing to the evaluation of the QoS and QoE. It is able to support both the initial server selection and then in-session actions.

Note that our main purpose here is not to essentially innovate in monitoring tools (a lot of implementations are available), but to integrate different components, aiming to develop a monitoring subsystem appropriate for DISEDAN light architecture.

Section II is a short overview of related work. Section III outlines the overall architecture and problem description. Section IV contains the paper main contributions, focused on defining CPl (Monitoring included) design decisions and implementation-related implications. Section V contains conclusions and future work outline.

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II. RELATED WORK

The real-time adaptation in content streaming is a powerful and dynamic technique, adopted to solve the fluctuations in QoE/QoS. One can classify adaptation as acting on Media (flow) and/or on CS. The *Media adaptation* is a significant technique and main research innovation area in media streaming applications [6][7][13]. *CS adaptation* means a new content server selection (during the media session) and switching (handover), depending on the consumer device capabilities, consumer location, content servers state and/or network state [9][10].

A so-called "dual adaptation" is a process that integrates the above adaptation methods. The DISEDAN novel architecture [3] combines the initial server selection (result of cooperation between SP and EU) with session-time dual adaptation, in a single solution.

The initial server selection is based on optimization algorithms like *Multi-Criteria Decision Algorithms (MCDA)* [9][10], or *Evolutionary Multi-objective Optimization algorithm* (EMO) [11], modified to be applied to DISEDAN context. In these works several scenarios are proposed, analyzed and evaluated. In particular, the availability of different static and/or dynamic input parameters for optimization algorithms is considered. The result of this variability is that several CPl designs are possible, different in terms of performance and complexity. The dynamic capabilities for the initial CS selection and then for adaptation decisions depends essentially on the power of the DISEDAN monitoring system. It is the objective of this paper to analyze these variants, and define the monitoring subsystem.

The challenge in DISEDAN is to combine the DASH-related functionalities with additional monitoring in order to finally realize the dual adaptation.

The standard ISO/IEC 23009-1, "Information technology -- Dynamic adaptive streaming over HTTP (DASH)" [6], defines the DASH-Metrics client reference model, composed of *DASH access client (DAC)*, followed by the *DASH-enabled application (DAE)* and *Media Output* (MO) module. The DAC issues HTTP requests (for DASH data structures), and receives HTTP request responses. Consequently three observation points (interfaces – I/F) can be identified:

- O1 *at network-DAC I/F*: a set of TCP connections, each defined by its destination IP address, initiation, connect and close times; a sequence of transmitted HTTP requests, each defined by its transmission time, contents, and the TCP connection on which it is sent; and for each HTTP response, the reception time and contents of the response header and the reception time of each byte of the response body.

- *O2 at DAC-DAE I/F*: consists of encoded media samples. Each encoded media sample is defined as: media type; decoding time; presentation time; the @*id* of the Representation from which the sample is taken; the delivery time.

- *O3 at DAE-MO I/F*: consists of decoded media samples. Each decoded media sample is defined as: the media type; the presentation timestamp of the sample (media time); the actual presentation time of the sample (real time); the @id of the Representation from which the sample is taken (the highest dependency level if the sample was constructed from multiple Representations).

A summary of the metrics semantic defined in ISO/IEC 23009-1 [6], is: *Transmission Control Protocol (TCP) connections, HTTP request/response transactions, Representation switch events, Buffer level, Play list.* A similar list of QoE metrics standardized by 3GPP defined in 3GPP in 26.247, applicable for DASH, [8][13], contains: *HTTP request/ response transactions; Representation switch events; Average throughput; Initial play-out delay; Buffer level; Play list; MD information*.

III. DISEDAN SYSTEM ARCHITECTURE

A. General framework and assumptions

The definition and some details of the system architecture are already given in [3][9][10][12]. In this section, a summary only will be presented to support understanding of the CPl design decisions.

The main business entities/ actors are those mentioned in Section I: SP, EU, CS. The SP and CP entities are not seen as distinct in DISEDAN system. Also, a full CS management is out of scope of this system. The connectivity between CSs and EU Terminals (EUT) is assured by traditional *Internet Services Providers (ISP) / Network Providers (NP*) - operators. The ISP/NPs do not enter explicitly in the business relationships set considered by DISEDAN, neither in the management architecture (DISEDAN works in OTT style).

However, the DISEDAN solution can be also applied in more complex business models, e.g., involving Cloud Providers, CDN providers, etc. The relationships between SP and such entities could exist, but their realization is out of scope of this study. While Service Level Agreements (SLAs) might be agreed between SP and ISPs/NPs, related to connectivity services offered by the latter to SP, such SLAs are not directly visible at DISEDAN system level.

The system can work over the traditional TCP/IP mono and/or multi-domain network environment. The EUTs might not have explicit knowledge about the managed/non-managed characteristics of the connectivity services. No reservation for connectivity resources, neither connectivity services differentiation at network level are explicitly supposed (but they are not forbidden). This proves the system flexibility: it can work both in OTT style, or over a managed connectivity service offered by the network. Therefore, the SP does not commit to offer strong QoS guarantees for the streaming services provided to EUs. Consequently, DISEDAN does not suppose, but does not exclude, establishment of a SLA relationships between EUs and SPs management entities. However, it is assumed that a Media Description Server exists, managed by SP, to which EUT will directly interact.

The media streaming actions are independent on the transport networking technology. The EUT part (client side) works as a standalone client application, without any mandatory modifications applied to the SP; however, SP should provide some basic information to EUT, to help it in making initial server selection (and optionally to help in-session CS switching). The decision about dual adaptation (media flow adaptation and/or CS switching will be taken mainly locally at EUT, thus assuring User independency and avoiding complex signaling between user and SP during the session.

Several CSs exist, known by SP (geographical location, server availability level, access conditions for users), among which the SP and/or EUs can operate servers selection and/or switching. The proposed architecture does not treat how to solve failures inside the networks, except attempts to do media flow DASH adaptation or CS switching.

The proposed system does not explicitly treat or innovate in the domain of content protection, Digital Rights Management (DRM), etc., but might use currently available solutions. Billing, financial aspects and other business related management of the DISEDAN high level services are out of the project scope.

The work [12], elaborated also in DISEDAN framework, has defined all requirements coming for EU, SP and out of them derived the general and specific System requirements, together with some assumptions and constrains imposed to such a system. The resulting high level architecture has been determined by such requirements. This work is based on the assumption of fulfillment of those requirements.

B. General Architecture

Figure 1 shows a simplified high level view of the general architecture.

The SP includes in its Control Plane:

- *MPD File generator* – dynamically generates Media Presentation Description (MPD) XML file, containing media segments information (video resolution, bit rates, etc.), ranked list of recommended CSs and, optionally - current CSs state information and network state (if applicable).
- *Selection algorithm* –runs Step 1 of server selection process. It exploits *MCDA* [9][10], modified to be applied to DISEDAN context, or *EMO* [11], etc., to rank recommended CSs and media representations, aiming to optimize servers load as well as to maximize system utilization.
- *Monitoring module* – collects monitoring information from CSs and performs the processing required to estimate the current state of each CS. Note that if some EU information should go to SP, then this information is transited (and aggregated) from EUT via CS towards SP.

The End User Terminal entity includes the modules:

- *Data Plane: DASH (access and application)* – parses the MD file received from SP and handles the download of media segments from CS; *Media Player* – playbacks the downloaded media segments.
- *Control Plane: Content Source Selection and Adaptation engine* –implements the dual adaptation mechanism; *Selection algorithm* –performs the Step 2 of server selection process. It can also exploit MCDA, EMO, or other algorithms to select the best CS from the set of candidates recommended by SP; *Monitoring module* – monitors changing (local) network and server conditions.

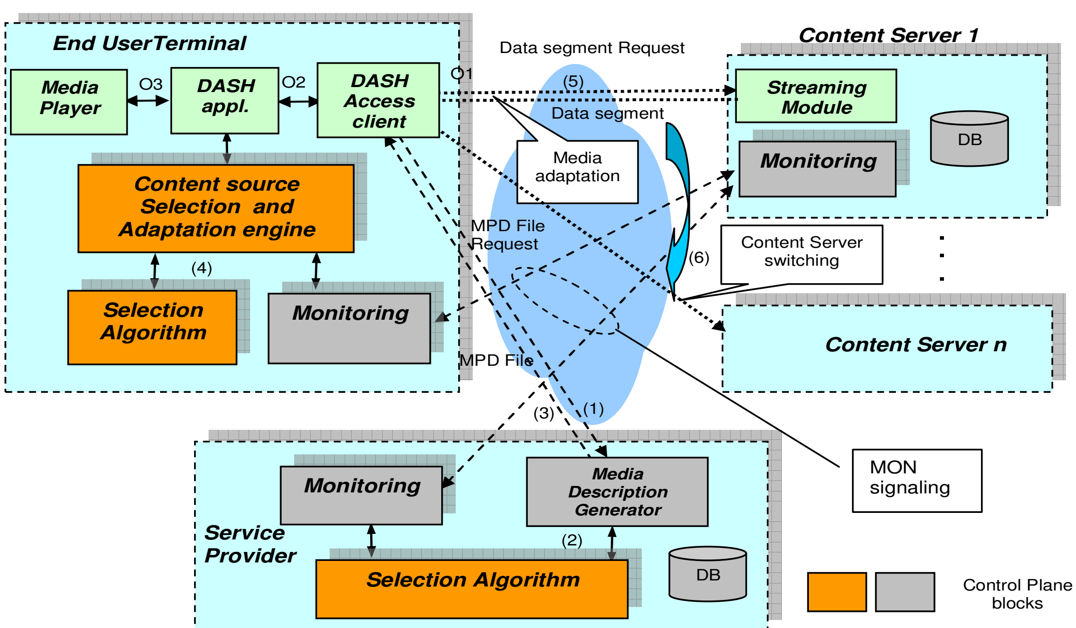

Figure 1. DISEDAN general architecture; DASH - Dynamic Adaptive Streaming over HTTP; MD – Media Description; DB – Data Base ; O1, O2, O3 – DASH Observation Points [ISO/IEC 23009-1]

The CS entity includes the modules:

- *Data Plane: Streaming module* – sends media segments requested by End Users; *Monitoring module* – monitors CS performance metrics (CPU utilization, network interfaces utilization, etc.). In a complex implementation of the CS, the monitoring can evolve from a simple probe to an advanced monitoring module, capable to supervise not only the active sessions but also some connectivity characteristics from this CS to different groups of users.

The following functional steps are performed (simplified description): (1) EUT issues to SP a media file request. (2) SP analyzes the status of the CSs and runs the selection algorithm (optionally the SP could make first, a current probing of the CSs); for each user request the SP could consider also the user profile, the policies of the SP for this user's class and other information at the SP side (e.g., state of the servers and possibly network-related information). (3) SP returns to EUT a ordered list of candidates CS (SP proposal) embedded in a MD- xml) file. (4) The EUT performs the final CS selection, by running its own selection algorithm and (5) starts asking segments from the selected CS. During media session the EUT makes quality and context measurements. Continuous media flow adaptation is applied using DASH technology, if necessary, or (6) CS switching is decided. From the EU point of view, the steps 1-2-3 composed the so-called Phase1 and steps 4-5-6 the Phase 2.

During the receipt of consecutive chunks, the user's application can automatically change the rate of the content stream (internal DASH actions- which are out of scope in this paper) and/or also can switch to another CS. When EU receives requested segments, it performs measurements to monitor parameters of download process. Note that the system is flexible in terms of monitoring procedures to follow. For instance if EU detects deterioration of downloading rate, it can use SP information about alternate CSs and/or it can start probing CSs. When the probing process finished, EU starts dual adaptation process to decide : media or server adaptation. If the first is selected, then EU downloads (via DASH) next segments with reduce rate, otherwise switches to another CS.

IV. MONITORING SUBSYSTEM

The architecture of the DISEDAN CPl is flexible. Several variants/versions of designs can be considered, i.e., a basic one or more complex, essentially depending on the roles of the business entities and their capabilities, interactions and also on SP and EU policies. The selection algorithms MCDA/EMO might work with different sets of static and/or dynamic input parameters. An important component of the CPl is the Monitoring *(MON@DISEDAN*).

A. Monitoring Architecture

Three MON modules have been identified in Figure 1: MON@SP, MON@CS, MON@EUT. However, not all these entities must participate to all phases of functioning. The variety of solutions determine the system overall performance but with additional cost for the more complex solutions. The monitored data are used to accomplish the following macro objectives :

- guide the initial server selection at SP and (optionally) at EU,
- guide the media adaptation and/or CS switching.

From the EUT point of view, two phases are distinguished: *Phase1* in which the EUT is not connected to any CS, but it just tries to do this, by contacting the SP; *Phase2* in which the EUT is currently served by a CS (media session time). The monitored data at EU level are different in Phase 1 w.r.t. Phase 2.

Note also that during media session, the DASH subsystem performs its own evaluation of the QoE and based on this, decides upon requested rate of the next video segment. The implementation of this type of monitoring is out of MON scope. However, the data collected from such on-line monitoring can be combined with other values delivered by MON@EU and delivered to other entities in the hierarchy (CS, SP). Actually, we adopted the approach described in [13] where it is recalled that in the 3GPP DASH specification TS 26.247 [7-8], QoE measurement and reporting capability is defined as an optional feature for client devices. If the EUT supports the QoE reporting feature, the DASH standard also mandates the reporting of all of the requested metrics at any given time; that is, the client should be capable of measuring and reporting all of the QoE metrics specified in the standard.

The standard TS 26.247 also specifies two options for the activation or triggering of QoE reporting: a. via the Quality Metrics element in the MPD; b. via the OMA Device Management (DM) QoE Management Object. In both cases a and b, the trigger message from the CS would include reporting configuration information such as the set of QoE metrics to be reported, the URIs for the server(s) to which the QoE reports should be sent, the format of the QoE reports, information on QoE reporting frequency and measurement interval, percentage of sessions for which QoE metrics will be reported, and access point names to be used for establishing the packet data protocol (PDP) context to be used for sending the QoE reports.

The selection algorithms MCDA/EMO might work with different sets of static and/or dynamic input parameters.

To achieve scalability of the monitoring system an important design decision is to avoid direct signaling between EUT and SP, except the initial request issued by EUT towards SP, in order to get the MPD xml file. Apart this phase, any monitored information obtained in EUT premises will be sent to the current CS serving that EUT.

We define three control bi-directional channels (see Figure 1) :

EUT-SP to generate the EU request to SP and to get the MD file from SP. This is performed in Phase 1 of the DISEDAN functional cycle, i.e., at CS selection time.

EUT–CS triggered by the serving CS, to report, the monitored data about current EU status and media session data. This signaling is performed during Phase 2 time life for this EUT (i.e., media session).

CS-SP- to report: CS status data (capacity occupied, number of connections currently served, etc.); status data received from EUT (such data can be related to some individual users or aggregated at the CS level. The communication on this channel is triggered by the SP.

B. Typical Scenarios

Figure 2 presents a simplified *Message Sequence Chart (MSC)* illustrating the activities, communication in Data Plane (DASH) and the associated signaling executed in the Control Plane. One can see the Phase 1 and Phase 2 sets of actions, performed by EUT1.

Several types of monitoring activities are performed, described below.

Proactive monitoring: executed in some continuous mode (at SP level and possibly at EUT level- see the “loop” notations in Figure 2); such information is input for the CS selection algorithm (Phase 1), when some new content requests arrive from a given EU to SP. At SP, this means supervision of different servers, maybe networks, and user communities, depending on its policies. SP/CS cooperation on this purpose is envisaged. Such data can be also used to construct a history and updated status of the environment envisaged by the SP. The CSs could be involved in proactive monitoring, provided they are capable to probe the connectivity characteristics towards different groups of users (indicated by the SP).

At EU side, proactive monitoring might be performed, depending on capabilities of the EUT and its SW. In some more complex scenarios the EU can construct history, dedicated to its usual content connections (if they are estimated to be repeated in the future). The terminal context can be evaluated by such measurements, including its access network status.

In-session monitoring: monitoring is performed on a flow and data are collected in real time, to assess the level of QoS/QoE observed at EU side. These actions are basically performed by the EUT. Note that two kind of information are produced:

- collected by the DASH mechanisms, to serve internally as real time inputs to adaptation decision engine at EU,
- collected by the MON@EUT, which can be consolidated with those produced by the DASH, thus offering a more complete view not only about the reception of he media flow but also on general status and environment of the EUT.

In more complex DISEDAN variants, the SP and/or CS can be involved in such monitoring, at least in being aware of results (note that no SLA concerning mutual obligations of SP/EUs, related to QoE are established in DISEDAN system): for all active users or subsets; for all monitored data or summaries; full or summary monitored values.

Opportunity related monitoring: measurements essentially performed by the EUT to test the opportunity of switching the CS that delivers the content to EU. An example of such category is the Probing of some CS candidates if a CS switching action is prepared.

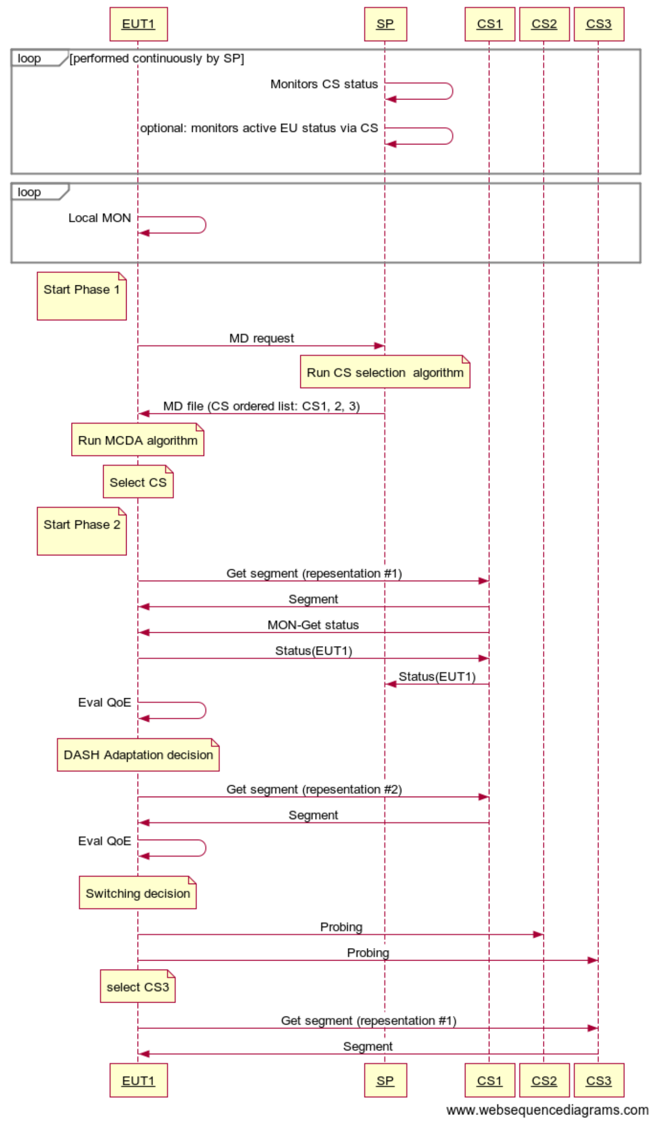

Figure 2. Typical activity and signaling diagram

C. Metrics and MON versions

Apart from DASH defined metrics (in-session observed), the MON subsystem may collect information on:

MON@EUT: CS accessibility (probing); EUT local dynamic context; historical and prediction data on servers and paths utilization.

*MON@SP:*CS status (collected from CS); active Users status; current load on some paths (here the network monitoring of the NP should cooperate); other dynamic, characteristics of some paths (e.g., loss, jitter); historical and prediction data on servers and paths utilization.

*MON@CS:*CS status (load); CS environment data (network paths, connectivity paths dynamic characteristics - evaluated at overlay level - from CS to different groups of users; EUTs data, active user groups data.

Therefore the overall MON system design is flexible, since it can combine different features of the above components.

D. Implementation aspects

SP and CS will have an internal database that will contain monitored and/or post-processed data. Also these two entities will be capable to send and receive JSON messages embedded in simple HTTP calls. EU might not have any internal database; it will just have the basic capability to send only simple HTTP calls to either SP or CS.

For Database is proposed to use *PostgreSQL*, technology [16]. The *PostgreSQL* is a powerful, open source object-relational database system. It runs on all major operating systems, including Linux, UNIX, and Windows.

SP and CS must be able to receive and send simple HTTP messages to each other. For this reason it is needed need a web server and a programming language to implement these features. Web server of choice is Node.js [17].

The *Node.js* [17] is an open source, cross-platform runtime environment for server-side and networking applications. The *Node.js* applications are written in JavaScript, and can be run within the *Node.js* runtime on OS X, Microsoft Windows, Linux and FreeBSD.

Currently the system is under implementation phase, performed by the DISEDAN consortium. A pilot system has been constructed having a core network (three IP network domains, independently managed, a SP entity and several CSs and EUTs distributed onto the local area networks linked to the core. Preliminary tests showed that MCDA applied at server level [10][12], produces the best trade-off selection of the server-path pair offering a good QoE to the EU in rather loaded network conditions.

V. Conclusions and Future Work

This paper presented the design concepts and decisions for the CPl of a *media delivery system having a light-architecture and working on top of the current Internet connectivity.*

The work focus is on the Monitoring subsystem, seen as a main component to provide dynamic information, to support the two major functional phases: initial CS selection and then in-session actions for media adaptation and/or CS switching. The architectural specification and then the design of the monitoring system have been proposed, combining the DASH - embedded monitoring features (to evaluate QoS/QOE) with external-to -DASH monitoring functions, thus completing the updated image of the DISEDAN environment (End User, Content Servers, network).

Future experimental results of the implementation will be reported in another paper.

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