Design of a Flexible Over the Top Content Streaming System with Dual Adaptation

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Abstract — **Real-time content delivery services have recently achieved high popularity in Internet, both for professional communities and also for entertainment. In contrast with some complex architectures like Content Delivery Networks, or Content Oriented Networks, this paper considers a light architecture, working on top of the current networking IP multi-domain infrastructures. It enhances the real-time (video) content delivery, by exploiting the cases where the content object exists on several servers. The system performs an initial content server selection (based on multi-criteria) considering the servers' load status and network conditions. Then it performs in-session media dynamic flow rate adaptation. Additionally, if necessary, a server handover is triggered. All above functionalities are assembled in a unified solution. This paper is a preliminary work, to identify the main requirements and then to develop the design for a family of implementations. Different design decisions variants are analyzed and explored, proving the solution flexibility. Currently the proposed system is under implementation in the framework of a European project.**

Keywords — content delivery; multi-criteria decision algorithms; server and path selection; media adaptation, monitoring, Future Internet; content-aware networking.

I. INTRODUCTION

The content-related real-time services are more and more present in the current and Future Internet, leading to recent significant developments [1][2]. Dedicated infrastructure like Content Delivery Networks (CDNs) improve the services quality [3], by distributing the content replica to caching servers, located close to groups of users; they are largely used in the real world. Content/Information Oriented/Centric Networking (CON/ICN/CCN) approaches [4][5], decouple names from location and introduce novel paradigms such as content-based routing, in-network (in routers) caching, etc.

However, all the above solutions involve highly complex architectures, high CAPEX and significant modifications in Service/Content Providers and Network Providers/Operators systems.

As an alternative, Service Providers (SP) might deliver services in *over-the-top* (OTT) style, over the current best effort Internet as a significantly cheaper solution. An OTT Service Provider (SP) could act as a separate entity from the traditional Internet Service Provider (ISP). Also, combined solutions could exist, with OTT-like SPs using the CDN Providers infrastructure to improve the quality of delivery. When transport problems appear in the network, the OTT approach to preserve or even improve the quality, are frequently based on adaptive solutions for media streams or servers. The overall goal is to maintain a good or at least an acceptable degree of the quality of experience (QoE) perceived at receiver side.

A light architecture (OTT-like), for content streaming systems is proposed by the European *DISEDAN* Chist-Era project [1][6], (*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 (*an entity/actor which deliver content services and might own or not a transportation network); *End Users (EU)* which consumes the content; a *Content Provider (CP)* could exist, owning *Content Servers (CS)*. DISEDAN does not deal with CP/SP contractual relationships; we may assume that the content servers are owned by the SP.

This paper is an extension of a previous one [1] presented at CONNET 2015 Conference, dedicated to develop the design of a flexible system in the framework of DISEDAN project.

An initial assumption is that a given content object is present on at least one, or several content servers, geographically distributed over one or several network domains. In such conditions, a *novel concept* is introduced by DISEDAN, based on:

(1) *two-step server selection mechanism* (initial at SP and then at EU sides) using algorithms that consider context- and content-awareness and

(2) *dual in-session adaptation mechanism,* consisting in *media flow adaptation* (based on Dynamic Adapative Streaming over HTTP – DASH recent technology [7][8][9]) and/or content source adaptation (by *streaming server switching*) if quality degradation is observed at the EU Terminal (EUT) during the media session.

An effective solution is constructed in DISEDAN for the multi-criteria selection (hard problem) of the best *content source (server)*, while considering user context, server availability and requested content. The DISEDAN OTT-like architecture is attractive since it avoids the complexity of CON/ICN or CDN.

This work is mainly dedicated to identify the requirements, specify the architecture and then analyze several design decisions variants. Details on server/path selection, optimization algorithms and adaptation process combined with server switching are treated in other works [15][16][18].

Also it should be mentioned that this paper does not have as objective to detail the internal procedures of the functional blocks. These elements (i.e., algorithms, active or passive monitoring procedures, QoS/QoE evaluation, DASH details, design details and low level description of interfaces, SP or EU policies, etc.) are (or will be) the targets of other works, during the project development.

The DISEDAN system can be flexibly implemented in several variants, depending on the complexity/constraints envisaged and the EUs and SPs requirements. We explore different design decisions and trade-offs, versus the cost and implementation complexity. This work is preliminary; currently, the system is under its implementation.

Section II is a short overview of related work. Section III outlines the overall architecture, based on different sets of requirements. Section IV analyzes various design decisions and implementation-related implications. *Section V is a new contribution of the extended paper; it considers the previous design decisions and develops the functional architectures of the three main entities: Service Provider, End User Terminal and Content Server.* Section VI contains conclusions and future work outline.

II. Related Work

Adaptation techniques enhance the quality of streaming media at the consumer side when the transfer conditions deteriorate. They also support efficient network resource utilization, device-independent universal media access and optimized Quality of Experience (QoE). Many Service Providers apply adaptation, to solve the network variations [7]. Adaptation may act on media flow [7][8][9], and/or on Content server. The latter means in-session new server selection and switching (handover), depending on the consumer device capabilities, consumer location and/or network state [10][11].

Recent solutions for media adaptation use the HTTP protocol, while minimizing server processing power and being video codec agnostic [12]. Relevant examples are: Adobe Dynamic Streaming, Apple's HTTP Adaptive Live Streaming and Microsoft's IIS Smooth Streaming and open HTTP-based protocols like Dynamic Adaptive Streaming over HTTP (DASH) [9]. The DASH continuously selects, on-the-fly, the highest possible video representation quality that ensures smooth play-out in the current downloading conditions. The DISEDAN novelty [6] consists in "dual adaptation" by combining in a single solution the initial server selection (result of the initial cooperation between SP and EU) and in-session dual adaptation.

The initial server selection is based on optimization algorithms like *Multi-Criteria Decision Algorithms (MCDA)* [13][14], modified to be applied to DISEDAN context [15]16], or *Evolutionary Multi-objective Optimization algorithm (EMO)* [17]. The decision variables considered for selections are related to servers' load, network paths characteristics, SP and EUT policy related parameters.

In [15][16] several scenarios are proposed, analyzed and evaluated. The initial content selection problem is a multi-criteria one, given the different degree of availability of parameters of interest at SP, CS and respectively EUT levels. In particular, the availability of different static and/or dynamic input parameters for optimization algorithms is considered. Therefore, several designs are possible, different in terms of performance and complexity. It is the objective of this paper to analyze these variants, seen as design/ implementation decisions.

The main advantages of the DISEDAN approach versus others solutions are: simple architecture, working in OTT style and avoiding complex (as needed in ICN, CDN) management and control; multi-domain capabilities; embedding in a single solution the initial server selection, in-session dynamic media flow adaptation and/or server switching; backward compatibility versus current content streaming systems; low cost for implementation.

The principal limitation of the DISEDAN solution consists in its OTT-style of working; no strong QoS guarantees are offered to the end users.

III. DISEDAN System Architecture and design guidelines

While considering the above general concepts, assumptions and requirements should be identified, to provide inputs for the system design.

A. *General framework and assumptions*

The main business entities / actors have been mentioned above: SP, EU, CS. The connectivity between CSs and EU Terminals (EUT) are assured by traditional Internet Services Providers (ISP) / Network Providers (NP) - operators. Due to its OTT-style, DISEDAN does not consider, in its management architecture the connectivity – related relationships between SP and ISP/NPs. Note that some Service Level Agreements (SLAs) might exist, related to connectivity services, but they are not directly visible at our system level. The DISEDAN solution is also applicable to other business models, e.g., involving CPs, CDN providers, etc. The relationships between SP and such entities could exist, but their realization is out of scope of this study. The system works on top of the current 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. Network level resources reservation, or in-network connectivity services differentiation might exist, but they are not mandatory supposed. This approach shows the system flexibility: it can work in OTT low cost style, with no direct control of the connectivity services (from QoS point of view) or, in a more complex deployment, over a network having managed connectivity services. Therefore, in principle, the

SP envisaged in DISEDAN cannot offer strong QoS guarantees to EUs. Consequently, DISEDAN does not manage (but it does not exclude) possible EUs/SPs SLA contracts/relationships. However, it is assumed that a Media Description Server exists, managed by SP, to which EUT will directly interact.

The media streaming operations are independent from networking technology. The client-side streaming system, acts as a standalone application, (no mandatory modifications for SP are required); however, DISEDAN assumes that SP should provide some basic information to EUT, in order to help the initial server selection by the EUT. Then, the in-session decisions about dual adaptation are taken mainly locally at EUT, based on the real time delivery evaluation of the quality seen by the receiver. Based on the above approach, a complex EUT-SP signaling is avoided.

In a general case, several CSs exist (containing replicas of media objects), known by SP (geo-location, availability, access conditions for users), among which the SP and/or EUTs can operate server selection and/or switching. No restriction is imposed either on the geo-localization of EUTs or of CSs. Note that the proposed system does not consider how to solve network failures, except attempts to perform media flow DASH adaptation or CS switching. The terminal devices are supposed to have all the required subsystems and peripherals for video/ audio display and device control.

Note that several assumptions and requirements are general ones – needed in a content delivery system and they are not specific to only DISEDAN system.

B. End User Requirements

These requirements are expressed as End User needs, and are derived from *user scenarios* - when selecting and consuming media content - related services. The EUT (basically) but also the rest of the system should be designed as to fulfill the requirements coming from EU.

- The system must admit the usual user profiles. EU should be able to identify itself and login into the system through a controlled environment.
- The EU must be able to select among several SPs and among content items, servers and classes of quality – in the limits offered by the selected SP.
- The DISEDAN system must allow to EU: initial (optionally automatic or manual) server selection; in-session dual adaptation will be automatically enforced, to maximize the Quality of Experience (QoE).
- The EU should receive information from SP (on servers and possibly on network paths) to help him in selection. The EU should also have the possibility to finally decide on server selection/switching or amount of adaptation actions initiated and/or performed.
- The EUT must be still able to work by using only minimal information on server and network (e.g., server capacity or download bandwidth from the server) delivered by the SP. The final content server selection decision is basically locally taken, while avoiding complex signaling between user and SP.
- The EU should have the possibility to be informed about of QoE level delivered by the system.
- The client SW installed on the EUT should have maximum independence from the operating system running on the terminal.

C. Service Provider Requirements

These requirements are expressed as SP business and technical needs. The DISEDAN system:

- Should allow SP to develop multimedia content-based services, e.g., live - streamed IPTV services, Video on Demand (VoD) and its derivatives (e.g., streamed VoD, downloaded / pushed content).
- Must allow SP to filter the control information delivered to the EUs, but should not impose major architectural modification in the common SP Management and Control (M&C) architecture.
- May allow SP to apply different policies in its server selection (e.g., to maximize CS utilization and/or improve QoE)).
- Should be able to use in a flexible way the SP static/dynamic (monitored) information on servers and (possibly) on network paths status and availability, in mono or multi-domain contexts.
- Must not restrict the networking technologies (QoS capable or not) used by SP.
- Must support the SP-EU cooperation for dual adaptation purposes.
- Should offer to the SP the minimal capabilities to manage the Content Severs (if no distinct Content Provider business entity exists).

D. General System Requirements

These requirements are derived from the previous requirements for End User and Service Provider. They are related to the overall DISEDAN system, which:

- Must work in the traditional TCP/IP mono and multi-domain, in OTT style, on top of arbitrary network technology; the EUTs or CSs can be placed everywhere.
- Should provide a simple management with minimal architectural modifications at SP side or at EUT side.
- Must optimize multi-criteria content source selection, and then dynamic dual adaptation, considering user context, servers' availability, network conditions and content distribution mode. It will apply: a. *two-step server selection* (at SP and then at EUT) based on context/content - aware algorithms; b. *dual adaptation*, (media adaptation and/or server switching).
- At EU side, a standalone client application must exist. No mandatory modifications at SP M&C side are required; however, SP M&C should provide information to EUT, to help it in initial server selection.
- Should provide flexible possibilities to assign/balance the decision power between SP/EU, regarding sever selection/switching and dynamic adaptation.

Other, more specific EUT, SP and CS system requirements have been derived from the general ones but they are not detailed here.

E. General Architecture

Fig. 1 shows the high level – described, general architecture. The Service Provider entity includes the following functional modules:

- *Media Description generator* – dynamically generates Media Description (MD) XML file, containing media segments information (video resolution, bit rates etc.), ranked list of recommended CSs (for a given EU request) and possibly - CSs current state information and even information on network state (if applicable).
- *CS Selection (step 1) algorithm* **-** exploits MCDA or EMO, to rank the CSs and media representations, aiming to optimize servers' load and to maximize the system utilization.
- *Monitoring module* – collects information from Content Servers and estimates their current states.

The End User Terminal entity includes the modules:

- *DASH* – parses the MD file received from SP and handles the download of media segments from Content Servers.
- *Content Source Selection and Adaptation engine* – implements the dual adaptation mechanism.
- *Selection (*step 2) *algorithm.* - exploit MCDA, EMO, or other algorithms to select the best CS from the list recommended by SP.
- *Monitoring module* – monitors the local network conditions and – possibly **-** the server conditions.
- *Media Player* – playbacks the media segments.

The Content Server entity includes the modules:

- *Streaming module* – sends media segments requested by End Users.
- *Monitoring probe* – monitors CS performance (CPU utilization, network interfaces utilization, etc.). In a complex implementation of the CS, the monitoring probe could be replaced by a more capable monitoring module, to supervise both the active sessions and some connectivity characteristics from this CS to different groups of users.

The following (macro) procedural steps are:
1. The EUT issues a media file request to SP.
2. The SP analyzes the status of the CSs (involved in the request parameters) and runs the selection algorithm (optionally the SP could make first, a current probing of the CSs). Some SP policies could be enforced in this phase.
3. The SP returns a candidate CS list to EUT.
4. The EUT performs the final CS selection (by considering additional local information) and starts asking media segments from the selected CS.
5. During media session, the EUT measures the quality and evaluates the context. It applies DASH adaptation or if necessary, CS switching is decided.

When the user requests a Multimedia content, the SP sends an *xml* file containing Media Description (MD). This file is updated (from the static *xml* file) for each user request by considering the user profile, the SP policies for this user's class and other information at the SP side (e.g., state of the servers and possibly network-related information). The list of candidate CSs and other information are written inside the *xml* file. Also caching server *url* addresses can be added. The list may be ordered, following some desired metrics.

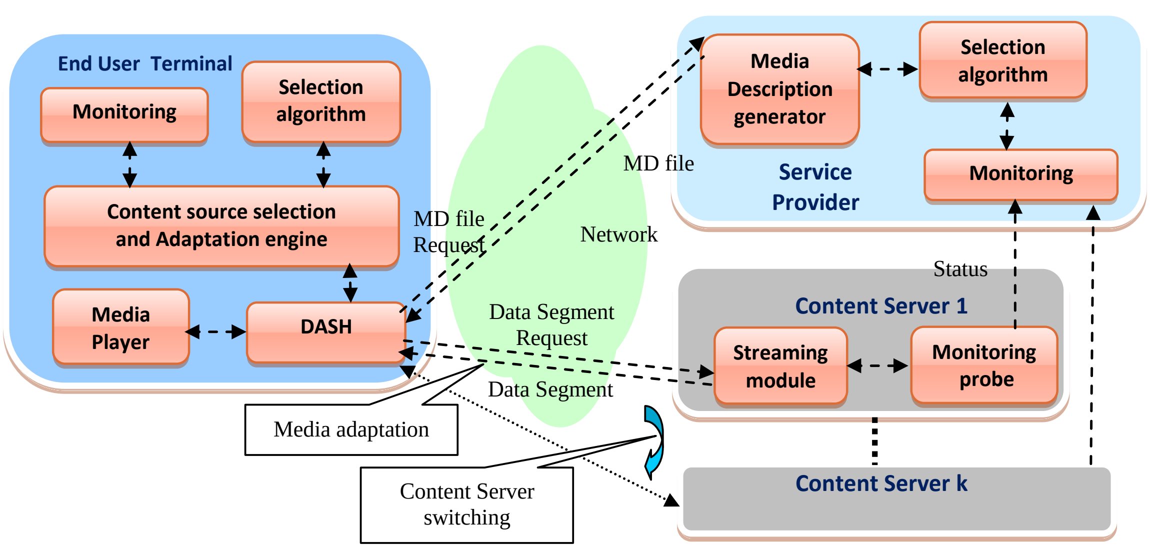

Figure 1. DISEDAN general architecture; DASH - Dynamic Adaptive Streaming over HTTP

When the user's application receives the MD file, it performs the final CS selection and possibly the network path choice (note that this last choice is not always possible in the current Internet with regular routing and forwarding). This decision can be based on user context, i.e., a MCDA can be run or, the EUT can simply select the first CS in the ordered list returned by the SP. Generally the CS selection achieves the final step of multi-objective optimization.

After final CS selection, the EUT starts to ask segments from the selected CS. During the receipt of consecutive chunks, the user's application can automatically change the rate of the content stream (DASH actions) or, if still problems exist, it can switch the CS.

The EUT performs measurements of the parameters of download process. If EUT detects deterioration of downloading rate, it can use SP information about alternate CSs and/or it can start probing CSs. After probing, the EUT decides on media or server adaptation.

IV. Design Decision Variants

The DISEDAN architecture is intended to be flexible. Several variants/versions of designs can be considered, i.e., basic ones or more complex, essentially depending on the roles of the business entities and their capabilities, interactions and also on SP and EU policies.

A. Monitoring procedures

The types and amount of static and dynamic monitoring data collected by various entities have a significant impact on the solutions. Consequently, the MCDA/EMO algorithms will have different sets of input parameters. Apart from static information available at SP, three types of monitoring contexts and possible policies can be identified.

An important component of the Control Plane is the Monitoring subsystem *(MON@DISEDAN*), whose components are distributed at SP, CS and EUT sides.

Apart from DASH defined metrics (in-session observed), the MON subsystem may collect information though its respective components, at each DISEDAN entity, as described below:

- *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 (i.e., those who are in-session) 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, dynamic characteristics of connectivity paths from CS to different groups of users - evaluated at overlay level; EUTs data, active user groups data.

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

Several types of monitoring activities can be performed.

- *Proactive monitoring:* executed in continuous mode; the monitoring information becomes 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 their 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 software. 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, in two ways:
  - 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.

B. Possible Roles of the Business Actors

The DISEDAN project outlines a set of optional Provider side modifications (w.r.t. useful information and metrics provided by SP to the client) that can further optimize server selection. The design can be backwards-compatible, ensuring that each modified client or SP can cooperate with the other side, if the latter is using existing common content distribution solutions. Consequently, a range of solutions are proposed in this paper for SP, CS and EUT roles, i.e., several variants (named "use cases"), that are listed below.

Tables I, II and III illustrate different design choices, listed in increasing order of complexity and, consequently, in increasing order of performances and costs, for SP, CS and EUT. Note that, although the Monitoring subsystems could be included generally in the architectural Management Plane, the *Mon@SP*, *Mon@CS* or *Mon@EUT* are specified in the tables in a distinct way, in order to emphasize the dynamic character of the data collected. Depending on the specific requirements and constraints, different variants can be selected as design/implementation choices of the DISEDAN system.

Note also that the tables do not detail the monitoring capabilities embedded in the DASH adaptation subsystem.

TABLE I. SERVICE PROVIDER - DESIGN VERSIONS

	Information known (by SP) about:	**Obtained from**	**Type of information**	**Is Monitoring system involved?** (in collecting the Column 2 information)	**Remarks on SP role**
SP-V1	CS list and their locations	Mgmt@SP	Quasi-static	No	SP solves the user requests. SP is involved in initial server selection, or during media session (to help switching decision at EUT), based only on ordered list of servers and depending on their load. (*minimum complexity*)
	Content files (objects) mapping on different servers	Mgmt@SP	Quasi-Static or dynamic	No	
	CS status (current load)	CSs	Dynamic	Yes	
	User groups	Mgmt@SP	Quasi-static	No	
	Active (in-session) users (information is based on EUT request accounting only)	EUs	Dynamic	No	
SP-V2	**Idem as SP-V1, plus below items**				Idem as in SP-V1 but more qualified assistance in selection of the initial (server-path) pair. Problem: how can a given user invoke usage of a selected path if multiple paths are available? Usually the choice can address only the inter-domain paths.
	Potential user groups	Mgmt@SP	Quasi-static	No	
	Basic connectivity paths (from different CSs to different groups of users) static characteristics - obtained at overlay level	Mgmt@SP/ CSs	Quasi-static	No	
SP-V3	**Idem as SP-V2, plus below items**				Idem as in SP-V2 but more assistance in selection of the initial (server-path) pair, given the paths current load information. This is a powerful but expensive solution involving strong CS-SP interactions.
	Current loads of the paths (bandwidth availability)	CSs	Dynamic	Yes	
SP-V4	**Idem as SP-V3, plus below items**				Idem as in SP-V3 but more assistance is available in the selection process of the initial (server-path) pair.
	Other dynamic paths characteristics (delay, loss, jitter, etc.)	CSs	Dynamic	Yes	
SP-V5	**Idem as SP-V4, plus below items**				Idem as in SP-V4, but more flexibility from business point of view. The SP offered services can be better customized.
	SP Policy Information	Mgmt@SP	Static	No	
SP-V6	**Idem as SP-V5, plus below items**				Idem as in SP-V5, plus more powerful set of knowledge on system history. (*maximum complexity*)
	Historical and prediction data on servers and paths utilization	Mgmt@SP + Mon@SP	Dynamic	Yes	

TABLE II. CONTENT SERVER –DESIGN VERSIONS

	Information known (by CS) about:	**Obtained from**	**Type of information**	**Is Mon@CS involved?** (in collecting the Column 2 nformation)	**Remarks on CS role**
CS-V1	EU authorization data	Mgmt@SP	Quasi-static	No	The selected (by the EUT) CS solves the user content requests. CS status info is delivered to SP. CS info on active users can be also delivered to SP.
	EU requests	EUTs	Dynamic	Yes	
	CS status (current load)	Mgmt@CS	Dynamic	Yes	
	Active (in session) users	EUs	Dynamic	Yes	
CS-V2	**Idem as CS-V1, plus below items**				Idem as in CS-V1 but more assistance in offering (via SP) additional information for selection of the initial (server-path) pair.
	Potential user groups	SP	Quasi-static	No	
	Static characteristics of	Mon@CSs	Quasi-static	Yes	

	connectivity paths (evaluated at overlay level) from different CSs to different groups of users				
CS-V3	**Idem as CS-V2, plus below items**				These data can be be sent to SP to help for more efficient management of EU connections. If multiple paths are available, the CSs should have some source routing capabilities in order to force the stream to follow a given path.
	Active User groups	Mgmt@CS	Dynamic	Yes	
	Connectivity paths dynamic characteristics (evaluated at overlay level) from different CSs to different groups of users	Mon@CS	Dynamic	Yes	

TABLE III. END USER TERMINAL – DESIGN VERSIONS

	Information known about:	**Obtained from**	**Type of information**	**Is Mon@EUT involved?** (in collecting the Column 2 nformation)	**Remarks on EUT role**
EUT-V1	EUT local static context	Mgmt@EUT	Quasi-static	**No**	EUT issues content requests to SP. For server selection it uses the MD file sent by SP and its local static context information. For dual adaptation it uses the monitored data (including the DASH embedded one) and basic probing information.
	MD file	SP	Dynamic	No	
	QoE quality during session	Mon@EUT	Dynamic	Yes	
	CS accessibility (basic probing)	Mon@EUT	Dynamic	Yes	
EUT-V2	**Idem as EUT-V1, plus items below**				EUT issues content requests to SP. For server selection it uses the MD file sent by SP and its static context information. For dual adaptation it uses the monitored data and probing information.
	EUT local dynamic context	Mon@EUT	Dynamic	Yes	
	CS accessibility (advanced probing)	Mon@EUT	Dynamic	Yes	
EUT-V3	**Idem as EUT-V2, plus items below**				
	Local Policy information	Mgmt@EUT	Static	No	Possible local policy data are used in server selection and dual adaptation.
EUT-V4	**Idem as EUT-V3, plus items below**				
	Historical and prediction data on servers and paths utilization	Mgmt@EUT Mon@EUT	Dynamic	Yes	Possible history and prediction data are used in server selection and dual adaptation.

V. DESIGN DECISIONS DETAILS

This section will refine the functional blocks introduced in the previous one, in order to prepare the software functionalities specifications. We recall that objective of this section is limited to refine the architecture and proceed to design of the functional blocks, in such a way as to respond to the flexibility features proposed initially. The validation and performances of the system will be treated in other complementary works during the project.

The functional blocks inside each DISEDAN actor are presented in high level view, in the following subsections. Figures 2, 3 and 4 show the complete architecture (functional blocks and the relationship between them). However, in the basic version of the DISEDAN system, only the most important ones are actually implemented – i.e., those needed to prove the innovative concepts.

Figures 2, 3 and 4, use three marking types for functional blocks:

- the functions mandatory implemented in the basic DISEDAN version are depicted in *dark gray color* boxes;
- the *light gray colour* boxes can be implemented as static versions in the basic DISEDAN system and extended with dynamic capabilities for advanced SP versions;
- the *white color boxes* represent functionalities which could exist in advanced versions of SP (i.e., complete real life system implementation, with advanced functionality, in order to provide the best possible QoE).

A. Service Provider Functional Blocks

Figure 2 shows the SP functional blocks.

The (lightweight) SP functional blocks implemented for DISEDAN basic version are:

- *Comm Agent* –used for communication with external entities (in particular EUT and CS). It can also be used by the monitoring system. The *Comm Agent* will serve only the Management and Control

Plane communications between SP and EUTs and CSs.

- *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).
- *MCDA* - performs the selection algorithm – i.e., runs Step 1 of the server selection process.
- *Monitoring module* – basically it collects monitoring information from CSs and performs the processing required to estimate the current state of each CS. If some EU-related information should go to SP, then this information are collected by the CS from EUT, and then aggregated and transited towards SP.
- *Data Base* - contains the static and dynamic information about CSs, EUT communities and profiles, etc. In the basic version these static information are filled offline into DB. In advanced SP implementations, the DB can be split in two modules Run-time DB and Quasi-static DB, containing respectively fast volatile data and respectively mid-long term data.
- *CS Discovery* - it has the role to discover the CSs locations, their main characteristics and content items available (mapping of the content objects - to - CS). In the basic version of SP these data can be statically introduced by the administrator.
- *EUT Discovery*- it has the role to discover the EUT groups locations and their main profiles. In the basic version of SP these data can be statically introduced by the administrator.

In advanced versions of SP implementations, other blocks can be added and also some of the existing ones are enhanced to have dynamic capabilities:

- *CS Dynamic Discovery* - it has the role to dynamically discover the CSs locations, their main characteristics and content items available (mapping of the content objects – to – CS). Periodical updates are necessary. This module should be existent in the SP-V2…SP-V6 versions of SP.
- *EUT Dynamic Discovery*- it has the role to dynamically discover the EUT groups locations and their main profiles. Periodical updates are necessary. This module should be existent in the SP-V2…SP-V6 versions of SP.

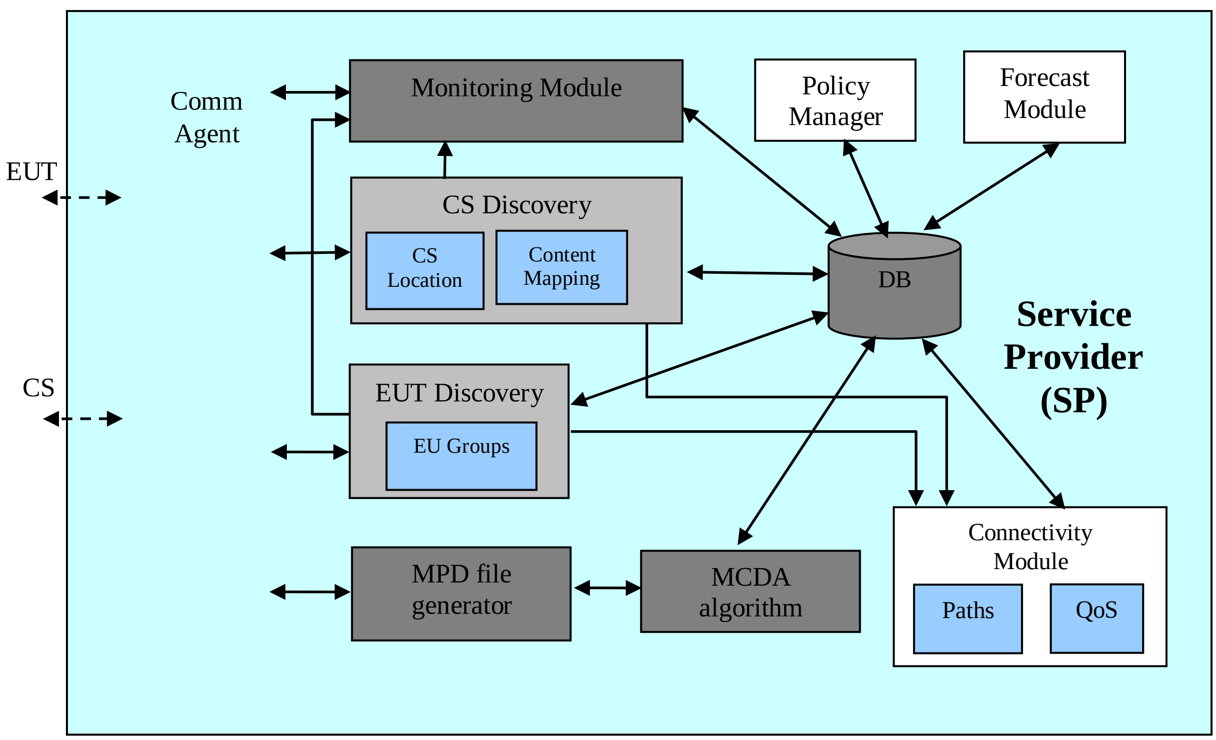

Figure 2. The Service Provider software architecture

- *Connectivity Module* – is an optional functional block, collecting and maintaining updates about connectivity characteristics (paths, QoS parameters) between the CSs of interest (list of them is delivered by the CS discovery module) and different groups of EUTs. If this module exists, then the SP level selection decision of the content server can be more powerful. The reason is that in such case not only CSs are selected but also some lists of "good" pairs {CS, path} could be selected and proposed to the EUT, in response of its request. A scalable solution (given the multi-domain characteristic of DISEDAN) for such a block implementation is to consider only overlay paths crossing one or several network domains. This module should be existent in the SP-V2…SP-V6 versions of SP.
- *Policy Manager* – is a module that can apply various policies at SP level (e.g., related to business and/or technical aspects). The effect will be the modification of the selection produced by MCDA, and, consequently, of the list returned to the EUT. This module should be existent in advanced SP-V5, SP-V6 versions of SP. Such policies can provide inputs to the MCDA process (see [15]), in two ways:
  - by assigning different weights to the existing decision variables – depending on policy considerations,
  - by defining new decision variables (derived from policies) to the MCDA matrix.
- *Forecast Module* – A module that can make educated predictions based on various data like history, communication preferences with other similar modules in places, like SP and CS. This module should be existent in the SP-V5…SP-V6 versions of SP.

B. End User Terminal Functional Blocks

The EUT high level architecture is presented in Fig. 3. The End User Terminal control logic contributes (by cooperating with SP) to the selection of the best available Content Server in order to provide the best possible experience to the user. On the request of the human End User, the EUT will send the request to the SP. The SP response contains an ordered list of preferred (after SP evaluation) Content Servers. The order of the CS in the list represents the preference of the servers from SP point of view.

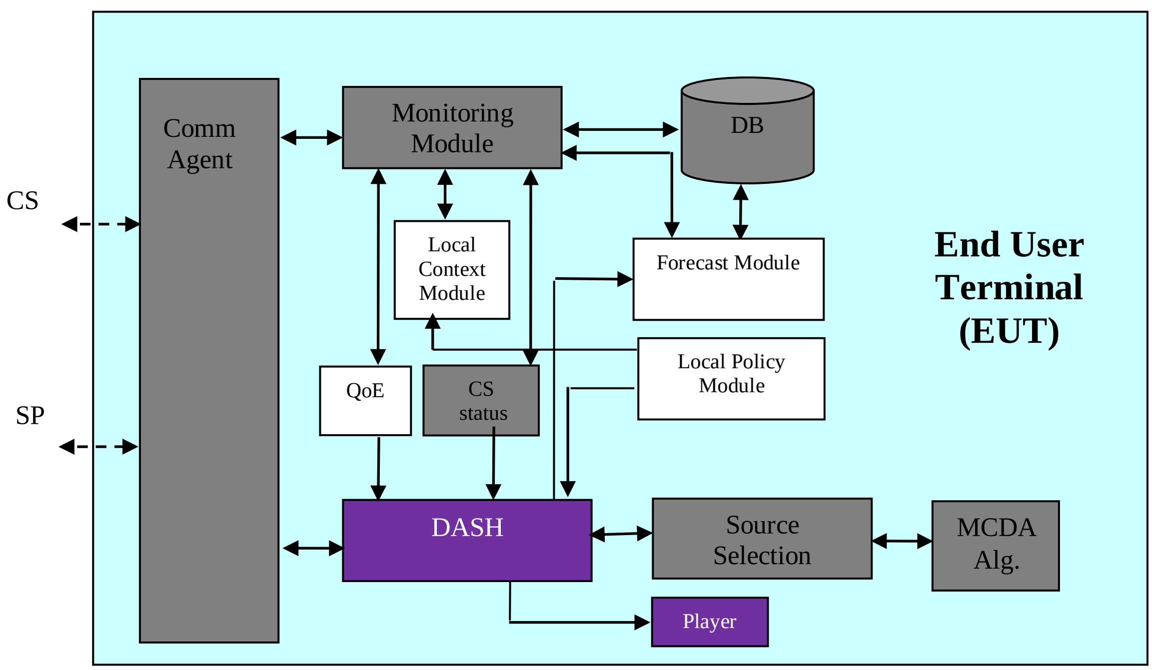

Figure 3. The End User Terminal software architecture

(DASH and Player boxes represent libraries of already existing software)

The functional blocks implemented in the DISEDAN basic version are:

- *Comm Agent* – used for communication with other external entities (in particular, SP and CS). It can also be used by the monitoring system.
- *CS status* – it can be seen as a monitoring system part, but here it is depicted as standalone, to emphasize its role in proof of concepts. This block finds out (considering the path from CSs to EUTs) the Round Trip Time (RTT) and Number_of_Hops towards each CS selected by the SP and reachable by the EUT. This information can be used later in the MCDA algorithm inside EUT (when making the final CS selection).
- *MCDA alg* – it runs the MCDA algorithm. A sub-block not represented in the figure does exist inside MCDA algorithm. This bloc creates the input data for the algorithm, ie., the matrix of values (see [15][16]), constructed from data like RTT, hop count and the priority as set by the SP. The result provided by the MCDA is sent to the *Source Selection* block.
- *Source Selection* – based on the decision of the MCDA algorithm this block creates the URL request for the elected CS and calls the DASH player.
- *Monitoring Module* – it can monitor various local aspects of the network or of the terminal itself. Note that it can be a simple block fed with static information – for the basic implementation; however, it could perform real monitoring in advanced EUT versions.

DB – A data base used to keep EUT staic and volatile data.Special blocks are coming form open source software that DISEDAN uses for the proof of concept:

- *DASH – The Dynamic Adaptive Streaming over HTTP* library. It is the DASH client that gets the movie from the CS where the DASH server is running.
- *Player* – the VLC media player is the ones that finally displays the movie content on the EUT screen.

The following blocks can be implemented in DISEDAN advanced versions, e.g., for some complete commercial implementation:

- *QoE* – Quality of Experience block; it is part of monitoring but is depicted separately in Fig.3, given its importance (recall that the final goal is to contribute to achieve the highest possible QoE). Additionally, the DASH subsystem itself has various internal mechanisms to adapt to environment conditions.
- *Local Module Policy* – it is a module that can apply various policies at the EUT level (e.g., related to business aspects and/or some special policies like for example parental-child control-related policies).
- *Local Context Module* – it is an agent that can gather information about the terminal (by aggregating static EUT information and dynamic monitoring information.

Forecast Module – makes based-on–learning predictions based on various data like history, preferences, communication with other similar modules in places like SP and CS.

C. Content Server Functional Blocks

The CS high level architecture is presented in Fig. 4. The functional blocks implemented for DISEDAN basic version are:

- *Comm Agent* – used for communication with other external entities (in particular SP and EUT). It can also be used by the monitoring system.
- *Data Plane - DASH Streaming module* – sends media segments requested by End Users.
- *Monitoring module* – monitors the basic CS performance metrics (CPU utilization, network interfaces utilization, etc.).
- *Current State module* – contains the main parameters describing this CS status (EU served, number of sessions, load, etc.).
- *Data Base* – contains information produced by the monitoring and also the data about currently EUs served by this CS and maybe some potential ones.

The following blocks can be implemented for advanced DISEDAN versions of the CS:

- *Advanced Monitoring module* - 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.
- *EU Module* – determines data about the EUs (status, groups) by using communication services offered by the communication agent.
- *Connectivity Module* – optional functional block, collecting and maintaining updates about connectivity characteristics (paths, QoS parameters) between the CS and different groups of EUTs. If existent, this module would provide additional information to the Connectivity Module of the SP.
- *AAA Module* – performs conventional Authentication, Authorization and Accounting functions. It is not essential for DISEDAN proof of concepts.
- *Forecast Module* – can make based-on–learning predictions based on various data like history,

preferences, communication with other similar modules in places like SP and CS.

VI. Conclusions and Future Work

This paper presented an analysis of design decisions for implementation variants of a novel and flexible light-architecture content delivery system, working on top of the current Internet networks. The system involves a Service Provider, End Users and Content Servers owned by the SP.

The novelty consists in including in a single solution of initial content server selection, (based on collaboration SP - EU, and multi-criteria optimization algorithms like MCDA, EMO, etc.) and session-time DASH adaptation and/or intelligent server switching (if the quality of the flow is degraded at the End User).

Several versions of designs are proposed, illustrating the architectural approach flexibility and comments are given on the associated complexity.

The main DISEDAN advantage consists in avoiding to develop complex M&C planes and signaling, while still offering sufficient QoE (due to adaptation capabilities) to the end users, in a cheap and fast implementable OTT-style solution. Note that the price paid for this lower cost solution is paid by the fact that DISEDAN cannot provide contracted (via SLA) hard QoS/QoE guarantees for its users.

However, the DISEDAN architecture is flexible, in the sense that it can benefit, if existent, of better managed connectivity services in the network; as well, it can benefit from information related to network static characteristics and dynamic monitoring data, possible to be collected by the Control Plane. In such cases the MCDA-based server selection algorithm can provide better solutions and consequently, higher QoE perceived by the End Users.

Preliminary results assessing the validity of the solution and performance of the algorithms are already reported in [15][16][18].Ongoing work is currently performed, to implement the described system (in the DISEDAN project).

In parallel with design and implementations, simulations have been performed (see extensive results in [18]), including large scale network environment, to prove the capabilities of the proposed architecture.

Details on the implementation of the functional blocks will be reported in future papers.

Complete results and performance evaluation of the implemented system, obtained for different use cases, will be also reported in some future papers. Comparisons with existing systems will be also provided.

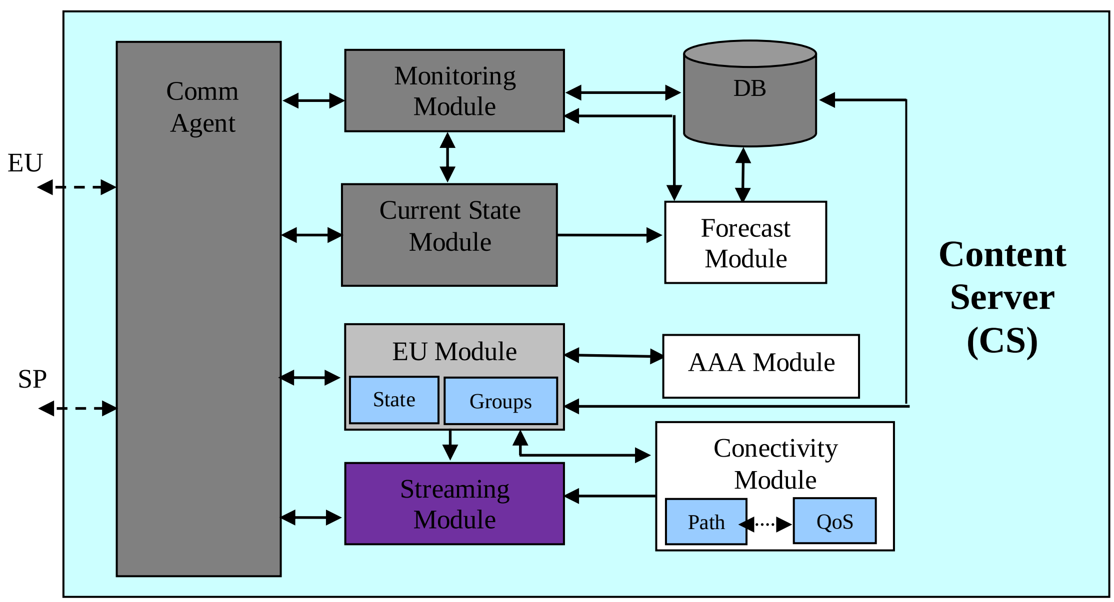

Figure 4. The Content Server software architecture

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