Flexible Design of a Light-Architecture Content Streaming System with Dual Adaptation

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Abstract **—Real time content delivery is a high popularity service in Internet. In contrast with some complex architectures like Content Delivery Networks, Content Oriented Networks, this paper considers a light architecture, working on top of the current networking technologies. It enhances the (video) content delivery via Internet, based on multi-criteria content server initial selection and then in-session media adaptation and/or server handover, all the above in a unified solution. This in-progress work explores different design variants, illustrating the solution flexibility.**

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

I. INTRODUCTION

The content-related services are more and more present in the current and Future Internet, leading to recent significant developments [1]. Dedicated infrastructure like Content Delivery Networks (CDNs) improve the services quality [2], by distributing the content replica to cache servers, located close to groups of users; they are largely used in the real world. Content/Information Oriented/Centric Networking (CON/ICN/CCN) approaches [3][4], decouple names from location, introduce content-based routing, in-network caching, etc. However, all the above need 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 cheaper solution. An OTT SP could be a separate entity from the traditional Internet Service Provider (ISP). Also combined solutions exist, with OTT SPs using the CDN Providers infrastructure to improve the quality of delivery. The OTT solutions approach to improve the quality, when transport problems appear in the network, are frequently based on usage of adaptive solutions for media streams and or servers, in order to maintain acceptable quality at receiver side.

A light architecture (OTT-like), for content streaming systems is proposed by the European *DISEDAN* Chist-Era project [5], (*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 owns 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 assume that servers are owned by the SP. An effective solution is constructed for the multi-criteria hard problem of *best content source (server) selection*, considering user context, servers' availability and requested content. A novel concept is introduced based on: (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 in *media flow adaptation* and/or content source adaptation (by *streaming server switching*) if quality degradation is observed during the media session. Such an OTT-like solution is attractive since it avoids the complexity of CON/ICN or CDN.

This work is mainly dedicated to analyze the design decisions variants. Details on server/path selection, optimization algorithms and adaptation process combined with server switching are treated in other works [13[[14]..

The 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. Section IV contains the paper main contributions, analyzing various design decisions and implementation-related implications. Section V 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. It also support efficient network resource utilization, device-independent universal media access and optimized Quality of Experience (QoE). Many Service providers apply it, to solve the network variations [6]. Adaptation may act on Media (flow) [6][7][8], 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 [9][10].

Recent solutions for media adaptation use the HTTP protocol, minimizing server processing power and being video codec agnostic [11]. 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) [8]. The DASH continuously select, on-the-fly, the highest possible video representation quality that ensures smooth playout in the current downloading conditions. The DISEDAN novelty [5], conists in "dual adaptation" by combining in a single solution the initial server selection (result of 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)* [12] modified to be applied to DISEDAN context [13]14], or *Evolutionary Multi-objective Optimization algorithm* [15]. 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. 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.

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 SP - ISP/NPs relationships in its management architecture. 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 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 are not mandatory supposed (but not forbidden). This shows the system flexibility: it can work in OTT style, or over a managed connectivity services. Therefore, the SP cannot offer strong QoS guarantees to EUs. Consequently, DISEDAN does not manage (but does not exclude) possible EUs/SPs SLA 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 on networking technology. The client-side streaming system, acts as a standalone application, (no mandatory modifications for SP); however, SP should provide some basic information to EUT, to help its initial server selection. The decision about dual adaptation are taken mainly locally at EUT, thus avoiding complex EUT-SP signaling.

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 servers 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.

B. End User Requirements

These requirements are expressed as EU needs, and are related to *user scenarios* - when selecting and consuming media content related services.

- The system should admit the usual user profiles. EU should be able to identify itself and login into the system through a controlled environment.
- The EU should 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 should allow to EU: initial (optionally automatic or manual) server selection; in-session dual adaptation will be automatically applied, to maximize the Quality of Experience (QoE).
- The EU should receive information from SP (on servers and possibly on network) 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 should 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 selection is basically locally taken, thus avoiding the in-session 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 SP Management and Control (M&C) architecture.
- Should allow SP to apply different policies in its server selection (e.g. to maximize CS utilization).
- Should be able to use the SP static/dynamic (monitored) information on servers and 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 are results from the previous requirements for: User and Service Provider. The DISEDAN system:

- 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 and EUT.
- Must optimize multi-criteria content source selection, and then dynamic dual adaptation, considering user context, servers availability, network conditions and distribution mode. It will apply: a. *two-step server selection* (at SP and EU) based on context/content-aware algorithms; b. *dual adaptation,* (media adaptation and/or server switching).
- At EU side, a standalone client application exists. 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 specific EUT, SP and CS system requirements have been derived from the general ones but they are not detailed here.

E. General Architecture

Figure 1 shows the general architecture. The Service Provider entity includes the following functional modules:

- *MD File generator* – dynamically generates Media Description (MD) XML file, containing media segments information (video resolution, bit rates etc.), ranked list of recommended CSs and possibly - CSs current state information and even information on network state (if applicable).
- *CS Selection (step 1) algorithm* - it 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*. It can also 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 condtions.
- *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 to different groups of users.

The following (macro) functional steps are:
1. The EUT issues a media file request to SP.
2.The SP analyzes the status of the CSs and runs the selection algorithm (optionally the SP could make first, a current probing of the CSs).
3. The SP returns a candidate CS list to EUT.
4. The EUT performs the final CS selection and starts asking 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 is written inside the *xml* file. Also caching server *url* addresses can be added. The list may be optionally ordered, following some desired metrics. When the user's application receives the MD file, it performs the final CS selection and possibly the network path. This decision can be based on user context or, one can simply select the first CS in the ordered list. The CS selection achieves multi-objective optimization. After final 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.

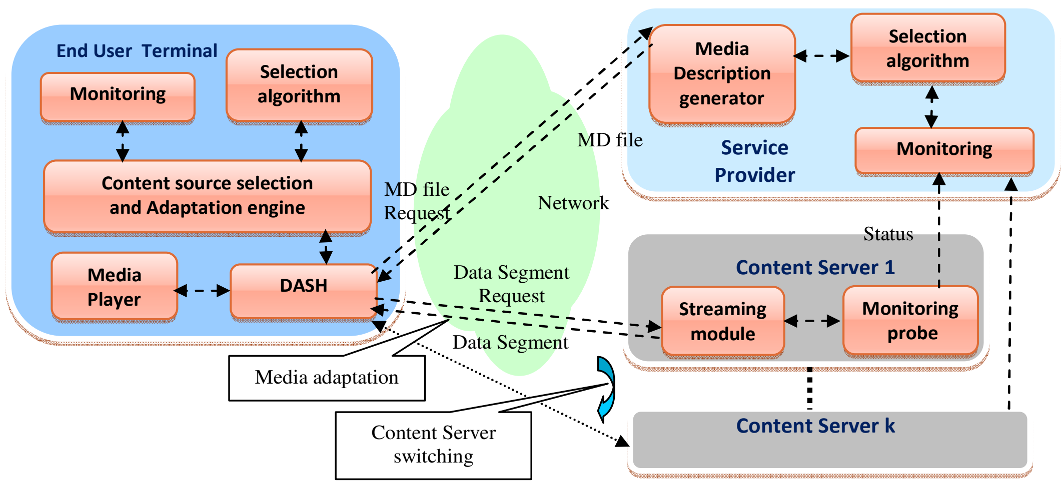

Figure 1. DISEDAN general architecture; DASH - Dynamic Adaptive Streaming over HTTP

The EUT performs measurements on 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 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.

Proactive monitoring: data are continuously collected (at SP level and possibly at EUT level); they guide the initial CS selection, when some new content requests arrive. At SP, this means supervision of different CSs, maybe network paths and user communities, depending on its policies. SP/CS cooperation on this purpose is envisaged. Such data can be 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, in some more complex scenarios, the EUT can construct history, e.g., dedicated to its favorite content connections, or focused on network context.

Session-time (Real-time) monitoring: the data are measured on the media flow, basically at EUT. In more complex DISEDAN variants, the SP and/or some CSs 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 exist) for: all active users or subsets; all monitored data or summaries of them; full or summary monitored values.

Opportunity related monitoring: these are measurements essentially performed by the EUT, to test the opportunity of switching the CS that delivers the content to EU.

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 content distribution solutions. Consequently, we propose a range of solutions regarding the SP, CS, EUT roles, i.e., several variants (named “use cases”) and listed below.

The Tables I, II, III illustrate different design choices, listed in increasing order of complexity and consequently of performances, 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.

V. CONCLUSION 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

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intelligent server switching, if the quality of the flow is degraded at the End User. Several versions of designs, are proposed illustrating the system flexibility and comments are given on the associated complexity.

TABLE I. SP-RELATED DESIGN VERSIONS

	Information known about:	Obtained from	Type	Monitoring system involved	Remarks on SP role
SP-V1	CS list and locations	Mgmt@SP	Quasi-static	No	SP solves the user requests. SP is involved in initial server selection, or during session (to help switching decision at EUT) , based only on ordered list of servers, depending on their load. (*minimum complexity*)
	Content files mapping on servers	Mgmt@SP	Quasi-Static/dynamic	No	
	CS status (current load)	CSs	Dynamic	Yes	
	User groups	Mgmt@SP	Quasi-static	No	
	Active users	EUs	Dynamic	No/yes	
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). Problem: how can a given user invoke usage of a selected path if multiple paths are available.
	Potential user groups	Mgmt@SP	Quasi-static	No	
	Basic connectivity paths static characteristics (at overlay level) from different CSs to different groups of users	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), given the paths current load information.
	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 in selection of the initial (server-path).
	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.
	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 –RELATED DESIGN VERSIONS

	Information known about:	Obtained from	Type	Mon@CS involved	Remarks on CS role
CS-V1	EU authorization data	Mgmt@SP	Quasi-static	No	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 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).
	Potential user groups	SP	Quasi-static	No	
	Basic connectivity paths static characteristics (evaluated at overlay level) from different CSs to different groups of users	Mon@CSs	Quasi-static	Yes	
CS-V3	**Idem as CS-V2, plus below items**				These data can be help SP 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 –RELATED DESIGN VERSIONS

	Information known about:	Obtained from	Type	Mon@EUT involved	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 static context information. For dual adaptation it uses the monitored data 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.

A main DISEDAN adavantage 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.

Simulations have been performed, including large scale network environment, to prove the capabilities of the proposed architecture. Partial results assessing the validity of the solution and performance of the algorithms are already reported in [13][14]. Ongoing work is currently performed, to implement the described system (in the DISEDAN project). Performance of the implemented system, obtained for different use cases, will be reported in some future papers.

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