Improving http adaptive streaming systems, the latency and content distribution questions

LaTeX

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PhilosophiæDoctor (PhD), DPhil,..

year month

1. Reviewer: Name

2. Reviewer:

Day of the defense:

Signature from head of PhD committee:

Abstract

Put your abstract or summary here, if your university requires it.

To ...

Acknowledgements

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Introduction

1.1 Motivation

According to *Cisco Visual Networking Index* (7) INTERNET video traffic will increase from 63% in 2014 to to 80% by 2019 of all INTERNET traffic. More specifically, one of the most popular technologies is *streaming*, that, according to *Global INTERNET phenomena report* (19) cited by *Venturebeat's* (26) magazine, could be a 71% of INTERNET traffic in some moments of the day. This fact will make video streaming technologies one of the most important ones in the future INTERNET. Because of that, all agents on industry are trying to improve streaming technologies making them better in performance, cheaper and easier to be adopted to final users.

On the upcoming days a technology defined as *HTTP adaptive streaming* has become very popular instead former technologies like *RTSP*[1] or *UDP*[2] streaming based technologies.

HTTP adaptive streaming techniques consists on the encode of the multimedia content in different resolutions and bitrates and it's sent via *HTTP* to final users. This way user's player can choose the most appropriate streaming quality (bitrate and resolution) is to its environmental circumstances like connection bandwidth, latency, kind of device used to to play the content, and other network conditions.

[1]Real Time Streaming Protocol
[2]User Datagram Protocol

The main advantage of this solution is that, since it is based on HTTP, it makes much easier to deploy it and to be consumed by final user. That is because no kind of *NAT* address conversion or firewalling techniques are necessary like in other technologies (*UDP RTSP*). Due to the aforementioned benefits, several industry agents and researchers have moved their attention to *HTTP streaming* based technologies.

On the other side can be seen that this new technology has several handicaps that have not been optimized and need some research to work better.

One of the main handicaps of these kind of technologies is the *end to end* latency produced on live streaming transmissions. This latency is intrinsic to this technology because of it's basis, but exists some possibilities to improve that unwanted behavior.

As commented before, *HTTP adaptive streaming* systems can be deployed in an easy way using some HTTP tools like *CDN servers*[1]. This can make deployment cheaper but it has of some problems in performance. There are opportunities to optimize the use of those kind of servers to improve their performance.

1.2 Hypothesis

Due the research work made in chapter 2.1.9 and it's results, an research topic centered in the improvement of the *CDN* performance has appeared. Our research work and hypothesis will run into that topic:

A streaming server too busy or with a very narrow bandwidth will offer worse results in a *HTTP adaptive streaming* connection than the use of multiple balanced servers with the same content and narrow bandwidth.

If we could build a system that could balance the streaming load between different servers it could take advantage of the added bandwidth of all servers to get better

[1] Content Delivery Network `HTTP://www.webopedia.com/TERM/C/CDN.html`

results in terms of QoS and QoE offering the best available experience for the user.

Our hypothesis is that load times QoS obtained when using a balanced loaded servers should be lower than the load times obtained from an unique streaming server when low bandwidth is available in each one of them. That would mean to better results in terms of QoE perceived by users.

1.3 Objectives

Main objectives for this research work will be the demonstration of hypothesis defined on 1.2.

Secondary objective, that will be a requisite to get the first objective will be the design and implementation of an balanced streaming server based on several streaming servers with different bandwidths.

In summary, these objectives will be oriented to improve two main factors that are measured in streaming solutions:

- QoS Quality of Service (a objective measure)
- QoE Quality of Experience (a subjective measure from the point of view of the user)

1.4 Research methodology

1.4.1 Research strategy

Given the objectives mentioned in section 1.3, the most appropriated research tools and strategies according to *Oates* book (30) to carry out this research seem to be:

- Design and creation
- Tests to check the differences of the QoS of the existing solutions by measuring latency, consumed bandwidth and many other parameters.

- Questionnaires to ask the users about their perception of QoE that they have about the existing solutions and the proposed by this research work.

1.4.2 Data generation techniques

As said in section 1.4.1 there will be some tests to probe the validity of the hypothesis of this research work. Those tests will the main data generation sources to obtain quantitative data that could measured and compared.

There will be some tests that will generate data form our proposed architecture and from previous used architecture. This way quantitative data can be compared to obtain a result about which one of the selected architectures will offer better performance in terms of *QoS*.

On the other side *QoE* will be evaluated using questionnaires, those questionnaires will be oriented to get a punctuation about the *QoE* perceived by the user, so more quantitative data will be obtained in this part of the research work.

1.4.3 Evaluation

As said before we are supposed to obtain quantitative data, so the comparison between obtained data will get us a way to evaluate the performance from our proposed architecture.

1.5 Research plan

To achieve all objectives proposed in section 1.3 a research plan has been designed based in the following items:

- An intensive *State of the art* study during almost all research duration
- Design tests, surveys and questionnaires
  - CDN's performance surveys design
  - QoE survey and questionnaires design

- Measuring existing technologies
  - CDN's performance surveys execution on existing platforms
  - Obtained data analysis
  - Conclusions
  - QoE survey to users
- MPEG-DASH Server design and implementation
- CDN Server prototype design and implementation
- CDN's improved performance experiments execution
- Final data analysis and conclusions
- Writing thesis and presentation

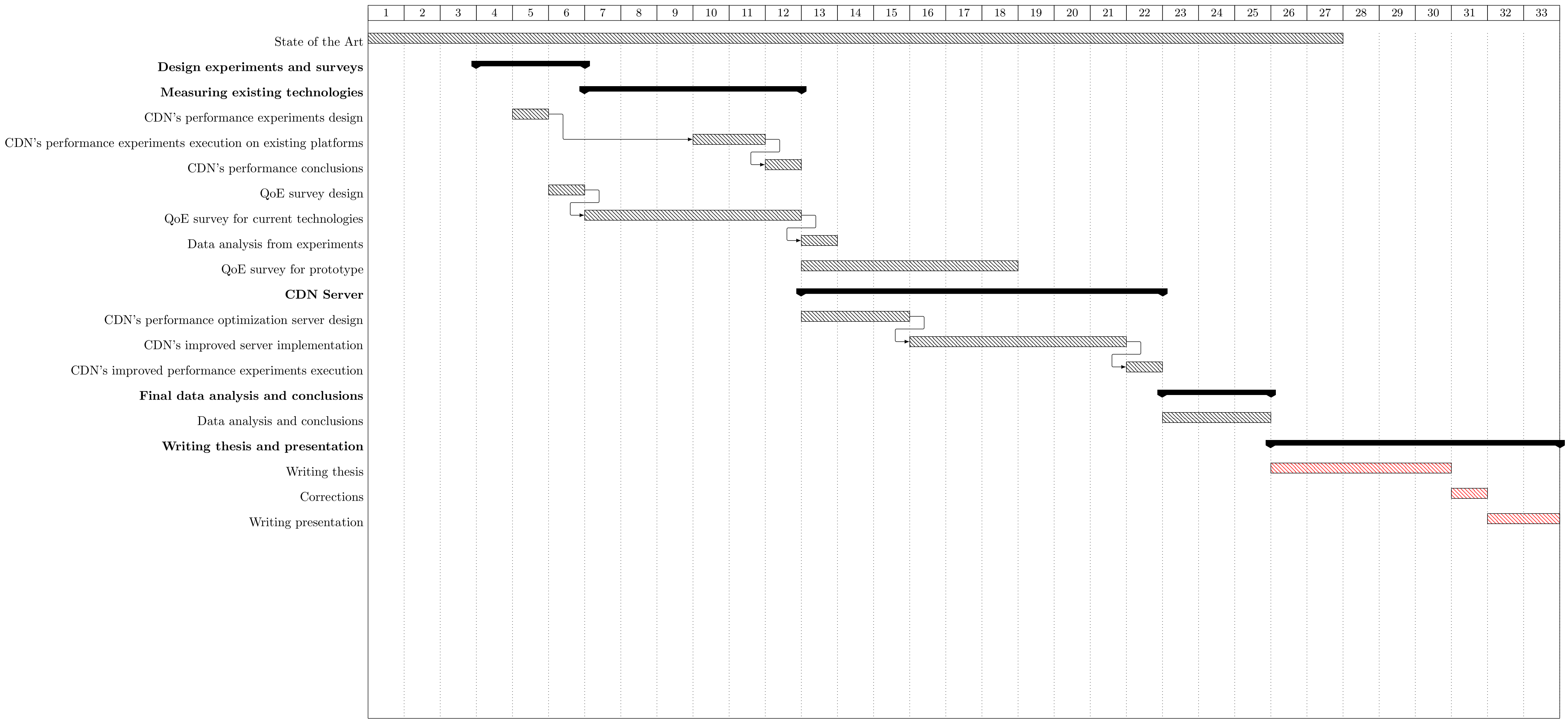
In the *Gantt diagram* attached document can be seen which will be the temporal execution of the proposed items. The estimated duration of this research work is about 33 months. But for this current subject, the research work will only take into account the first steps of the research proposed plan.

Only research planning about *State of the art* and experiments and surveys design will be taken as subject of study.

There are some task that can run in parallel to other task, for example, the *State of the art* study will take almost all research duration but there will be a main study in the first three months to situate the research and the rest of the time, this task will be limited to a vigilance role to check if there are new researches about this kind of technology.

Other task that can run in parallel are the surveys, those surveys are sent to the final users and can run in a parallel way because they wont need a full time research implication, only to be available to answer users questions and save answered surveys.

This *Research plan* will accomplish with all *Research objectives* mentioned on section 1.3 and it's organization will help to complete in a right way this research work.


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
State of the Art
Design experiments and surveys
Measuring existing technologies
CDN's performance experiments design
CDN's performance experiments execution on existing platforms
CDN's performance conclusions
QoE survey design
QoE survey for current technologies
Data analysis from experiments
QoE survey for prototype
CDN Server
CDN's performance optimization server design
CDN's improved server implementation
CDN's improved performance experiments execution
Final data analysis and conclusions
Data analysis and conclusions
Writing thesis and presentation
Writing thesis
Corrections
Writing presentation

2

State of the art

2.1 State of the Art

In this section an initial study of the current *State of the Art* of this research field can be seen. It will help to situate the current knowledge in this research field.

2.1.1 HTTP streaming history

In the beginning was *HTTP progressive download*.
This was the very first streaming technology based on *HTTP*. It consisted on downloading in a progressive way the file that is going to be played from server to client. This file must complain a special characteristic, it must have its codec headers at the beginning of the file, by letting the client downloading it at the beginning of streaming.This will able the client to know the codec content that will be played and this way it could start playing this content without the need to have downloaded the complete file. On contrary side, if the header of codec is present at the end of the file, the player will have to wait to download all content until starting playing it. HTTP progressive download is usually based on *mp4* files. *Mp4* files complain the requisites of content header at the beginning of the file since they can have it's *moov* header at the beginning of the file. This *moov* header contains the data content information about bitrate, resolution and codec of the media contained on the file (see figure 2.1). In (10), researchers show that *HTTP progressive download* when no low-latency is required offers very good results. This fact, joined together to the simplicity and cheapness of streaming server

makes that technology very attractive. This type of streaming let to do seeking on the played file without downloading it completely and is very easy to implement, but lacks of adaptive streaming capabilities, once the client has selected a file to play, it is very difficult to switch to other file with higher or lower quality when network condition requires it.

Other factor for adopting *HTTP streaming* technologies is the fact that now, the client is the element that holds the bigger weight on intelligence and negotiation capabilities, freeing the server of that work. This way the process of selecting the most appropriate streaming quality is much easier and fully relies on client network condition and capabilities.

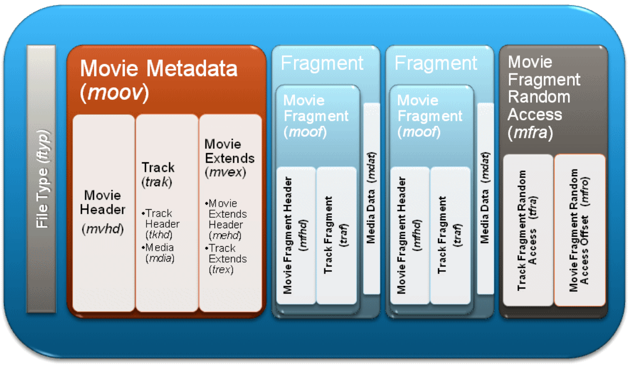


Figure 2.1: moov header scheme

Nowadays video streaming is consumed in so much different ways, at home in a PC or in a smart TV, in mobility with a smartphone or a tablet. Video streaming technologies must adapt the content to consumers device and network capabilities at the moment of the streaming. This need has made that some industry companies had created the concept of *HTTP adaptive streaming* to accomplish those needs.

2.1.2 HTTP adaptive streaming

In *HTTP adaptive streaming* the server divides multimedia content in segments of given duration and codifies them into different qualities and resolutions. This way the player can select which segment can be played depending on the resolution and available bandwidth at the moment. This architecture (Fig 2.2) let the player to switch to lower or higher quality streaming during playing depending on network condition changes.

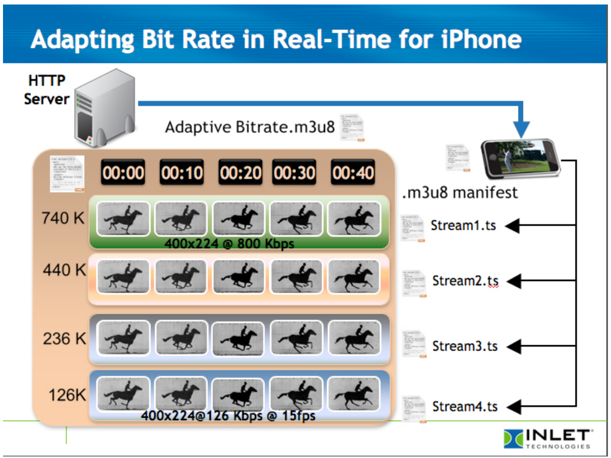


Figure 2.2: adaptive content scheme

First, and most popular, aproximations to *HTTP adaptive streaming* were made several years ago by *Microsoft* creating *Smooth streaming server*, *Netflix* player , *Adobe OSMF Player* and *Apple* with its *HLS* streaming server. In (2) researchers have compared the behavior of some of those *HTTP adaptive streaming technologies* by modifying network conditions and observing what was happening to the streaming. This way they study the way the players are able to manage network issues and how those network issues affect to the *QoE* (quality of experience) perceived by the user. At the same time they suggest a new algorithm to select which content quality should be requested by player at the time that there is a network condition change. This new algorithm will have mooth transitions in network conditions changes and will be more robust to sudden network conditions changed making the *QoE* much better for the final user.

2.1.3 MPEG-DASH

The evolution of those types of *HTTP adaptive streaming technologies* has come from the hand of *MPEG group (17) and 3GPP group (15)*. They have taken all of those previous approximations and have made it's own approximation to *HTTP adaptive* *streaming* architecture, *MPEG-DASH* (16).This architecture is an open standard and can be adopted by anyone. This way there could be multiple implementations of the architecture from multiple companies of any element of the architecture. For example, a company could make a *MPEG-DASH* server application and other one could implement it's own version of the *MPEG-DASH* player and both should be compatible to each other. This architecture is being adopted nowadays as a standard for almost major industry agents in streaming technologies and is studied by researchers to improve its performance.

2.1.3.1 MPEG-DASH main characteristics compared to different streaming technologies

One of the main factors to measure the quality of a streaming technology is the *QoE* perceived by final user, Singh et al. (40) have designed a new algorithm to measure *QoE* in the combined case of adaptive bitrate video and the use of a reliable transport protocol, which is the case of *HTTP adaptive streaming*. The algorithm could be very useful to measure *QoE* in different implementations or improvements of *MPEG-DASH*.

In (32), we can see the most advantages of *MPEG-DASH* architectures against older implementations of *HTTP adaptive streaming technologies* and *HTTP progressive download* architecture. This paper shows in terms of *QoE* the results of that comparison, there can be confirmed that *MPEG-DASH* offers better results than previous technologies.

All logic and intelligence of *MPEG-DASH* architecture is based on client side. The big challenge on the client side is the selection of the best adaptation set to be played depending on the current network conditions and device capabilities. To achieve this goal client can follow different strategies

Research made in (23) uses the expected delivery time of the content consumed from different servers to create a new metric to define how to keep *QoS (quality of service)* on the client side. To achieve the best results for this metric, they have implemented a new algorithm for selecting the quality of the content consumed by player. Then, they study their results based on the quality of the content consumed by the client player.

As described by Thang et al. in (43), the selection of connection throughput to estimate the adaptation set that have to be downloaded could bring some problems to get *smooth* transitions between quality changes in the segments. To solve that potential problems, in (43) researcher propose is using the flexibility of *MPEG-DASH MPD* to indicate to the player a *quality range* in a way that the player can select which adaptation set is the most appropriate for the quality required by the network conditions on the client side. This implementation of new characteristics to *MPEG-DASH* is very useful to get smoother and better streaming quality, but breaks it's compatibility with other implementations of the standard.

2.1.4 New possibilities for MPEG-DASH, extensions etc...

MPEG-DASH is a mature architecture in a lot of ways and some researchers want to improve it in several ways that weren't kept in mind in it's definition;

This section will show the improvements that have been proposed to MPEG-DASH in order to improve the content that is perceived by the user in terms of new content and *QoE* and *QoS*.

Research work (42) shows how *MPEG-DASH* flexibility can be used to provide more quality content through different heterogeneous network in a synchronized way. This can improve the content received by final user. One of the possible applications of this technique could be adding *HDR* capabilities to *MPEG-DASH* architecture in a way that the players that *"understand"* this implementation could have this capability through other networks (internet + broadcast) and clients that don't understand this implementation could read *NON-HDR* streaming quality from broadcast streaming. This implementation could be used too to improve the quality of the streaming by consuming higher bitrate (combined from various sources) by the client.

In a general way all *MPEG-DASH* try to consume the highest quality content in terms of bitrate and resolution that current network bandwidth permits. In (36) Reznik presents a different approach to get the best *QoE*. The proposal is oriented to mobile devices, using its sensors, extra information of environment parameters could be given to the *MPEG-DASH* client. This way the client could select a more appropriate quality content depending on those environment variables and not only based on available bandwidth. This sounds a good idea but the lacking of any implementation or measure of this solution doesn't give us any ideas about the grade of improving of this solution.

In (8) researchers make an experimental study to improve the quality of the content consumed by client player by creating a *P2P* heterogeneous network. This paper proposes that some mobile clients (smartphones) that consume content from 3G mobile network can use WIFI connections between them to create a *P2P* network. The study concludes that this kind of *P2P* networks improve the results of quality consumed similar to the quality given by the addition of all 3G networks.This approximation means a better quality of streaming on client side, but the conditions to get this better results are very restrictive, clients must be very near one to each other to share a *WIFI* connection to get this results, this solution doesn't have any value to clients that are not in the same location.

Other ways to improve the *QoS* of *MPEG-DASH* is to provide more servers where content can be downloaded. In (44), authors present a propose to use multiple servers to get the content by downloading in a simultaneous way the content from different servers.

In a similar way, (31) use different networks where the client device is connected to detect which one of them will offer the better performance in terms of bandwidth and network quality to get the content from the best available network.

Another similar strategy is used in (33), where researchers propose *Openflow* (12) to manage the load over *SDN* [1] in order to select which network will offer the best results in terms of latency and bandwidth.

[1] Software Defined Networks

In (51) researchers propose a strategy based on server and client to get better performance in receiving streaming content. Their propose is a feedback receiver that in client side “asks” the server to generate different duration segments depending on the available buffer in the client.

2.1.5 Future of MPEG-DASH

Nowadays there are a lot of technologies that have some influence in the performance and behavior of *MPEG-DASH*, some of those technologies are expected to change or to evolve. This section will cover the research made over *MPEG-DASH* and how those changes will affect to its performance.

HTTP/2.0 is the expected evolution of current *HTTP/1.0-1.1* protocol, some INTERNET service providers have are using it in experimental way and it is expected to be adopted in the future for almost INTERNET service providers. (27) research shows that there is some overhead in the communications, that drives to a higher bandwidth consumption with the same quality. On the other side *HTTP/2.0* adds some elements that fill the lacks of *HTTP/1.0-1.1* obtaining a better performance on received streaming. Those results have been obtained by disabling the security layer of *HTTP/2.0*, that is a problem because that security layer is mandatory in *HTTP/2.0*.

Although *MPEG-DASH* is a codec-agnostic architecture, that means that no audio or video codec is specified for the architecture, the de-facto standard for video and audio codec are h264 and aac respectively. That means that most implementations of *MPEG-DASH* are based on those video and audio codecs. Nowadays those codecs are used widely in most of video and audio content. MPEG is the organization that has defined those codecs and in the case of video codec, it has created a new version evolved from *h264*, that codec is called *h265*. In (20) researchers have made a study about the implementation of an *MPEG-DASH* server based on *h265* codec and how network conditions and variations of bitrates and different profiles of *h265* influences in the QoE of the streaming.

2.1.6 Latency improvement in MPEG-DASH

The main problem on MPEG-DASH has to be with the technologies on which it is based. The fact that it is based on HTTP protocol makes by design bigger latency than technologies that are based in other technologies like for example UDP based technologies.

Bouzakaria et al. have worked in the improvement of the latency in two aspects of it. In (6) have improved the *bootstrap latency* [1] by applying some techniques: make connections using *HTTP/1.1* or *HTTP/2.0* protocols instead *HTTP/1.0*. As we saw on section 2.1.5 using those kind of protocols can reduce headers in TCP connection, so it will reduce the average data to load reducing the latency of the connection. Other technique that researchers consider to use is encoding the *MPD* file on *base64*, that will reduce the load time too. Their last try to reduce latency consists on adding extra tags to *MPD* file containing the *ISOBMFF* headers, this way the client doesn't need to download the file segment that contains those headers, reducing this way the load and the latency oh the connection. Using the same technique, in (5) they have reduced the by using *HTTP/1.1* connection on server and client side. This way client and server can use HTTP chunk download property, letting the client to download segment chunks even the segment has not been complete deployed on server side.

Shuai et al. (39) research work improves latency on *MPEG-DASH* by designing a minimal buffer on the client side and synchronizing data generation and data consumption to avoid excess data on server side.

2.1.7 CDN content distribution

There are some research works about *CDN distribution content* that tries to improve the performance of *CDN* servers.

According to (24), main problems in *CDN* delivery content consists in choosing which content should be put on each *CDN* server, because all content cannot be dis-

[1] The latency that is produced in the loading of MPD file and ISOBMFF (47) segment headers

tributed in an equal way to all *CDN* servers because problems of cost and performance. In (24) researchers define some new strategies to deliver content through *CDN* and *servers* that depending on the kind of content (live streaming, VoD, etc ...) offers better results than classic delivery strategies.

In (37), researchers propose a *Big data* technology to design an algorithm to learn from previous deployments and customers streaming consumption, which content should be delivered in a priority way to determined *CDN* servers. They predict what cache servers will need some backup support and deploy more if necessary.

Those research works show that some work has been done in the field of reducing the latency on the server side, but not so much work has been done in the field of content distribution using *CDN* servers.

2.1.8 More about CDN

In (34) research work researchers have created an algorithm that used *TCP* multiple connections to download the same *MPEG-DASH* segment from different *CDN* servers and probed that that way offered a much better bandwidth use than using a single *TCP* request.

Jiang et al. made a research about balancing *CDN* request using an algorithm that combined cookies, *CDN* dynamic feedback load balancing algorithm. They compared their algorithm results versus other different algorithms and probed that their algorithm offered better performance.

In (35) researchers use new tools like *SDN*[1] to deploy virtual *CDN* networks that can be deployed and managed in an easy way. Using that technology Rego et al. have proposed a *Load balance* algorithm that deploys and removes streaming servers depending on the demand and elasticity policies.

[1] Software defined networks

In (41) Sinha et al. have faced the problem of selecting the optimal node from an *CDN* network and probed some different strategies to get the best results possible.

In (28) authors refer to a new way to improve *CDN's* by offering users bandwidth to create a high distributed *CDN* network with a *load balance* algorithm to manage all available *CDN's* by surrogating connections to the *home users CDn's* if available bandwidth exists and have shown that its performance is good enough to be compared with commercial *CDN* types in terms of speed.

In (14) researchers look for a good way to selecting the optimal way in terms of network speed when downloading multimedia content from different *CDN* servers.

In (22) Kyryk et al. put their eyes on the delay time, server load an probability of packet loss to create a system to measure *QoS* and describe a load balancing mechanism to get the lowest values and consequently the best *QoS* in the terms mentioned.

2.1.9 Previous research work

In previous research work I have made, I studied different ways to reduce the latency perceived by the user in *MPEG-DASH* streaming in a effort to improve the *QoS* in live streaming situations.

Two different technical approaches have been done in previous research work.

2.1.9.1 HTTP/1.1 vs HTTP/1.0

In this research work the use of web servers based on different version of the *HTTP* protocol will will offer different latencies for the same content. Results obtained shown that *HTTP/1.1* web based servers offered lower latency than *HTTP/1.0* based web servers.

2.1.9.2 Modifying MPEG-DASH manifest

Other option studied was based in the modification of the profile *on-demand* from *MPEG-DASH* in order to improve the load time in live content consumption.

That modification made an improvement of latency perceived by the user and consequently a better *QoS* of the service.

2.2 Summary

In this *state of the art* about *HTTP adaptive streaming* are several parts very well differentiated parts mainly focused into *MPEG-DASH* architecture:

2.2.1 Server side

In the server side, there are several research works that are pushing the limits of the *TCP* and *HTTP* protocols trying to decrease *MPEG-DASH* latency to obtain better *QoS*. Main leaders for this research lines are a group from *ParisTech University*.

2.2.2 Client side

On the client side there is a research effort to offer better algorithms to get the best *QoS* and *QoE* for *HTTP adaptive streaming* depending on the network environment conditions. It doesn't seems to be a common direction of those research work to achieve this objective. A closer look into those papers and trying to review more recent work from authors could help to more knowledge about this research field.

2.2.3 Quality measurement

Measuring *QoS* and *QoE* is a research topic very common in this state of the art, in a general way for any kind of multimedia content or in a particular way focusing into *MPEG-DASH*.

I find this research topic very interesting, especially focusing in the effort to get a relationship between *QoE*, an subjective measure, and *QoS*, an objective measure. This relationship is very important because it will give to the content distributors a direct way to measure *QoE* of their content without the need of a direct answer from their customers, just reading *QoS* metrics that can be done in an automatic and transparent way for customers will lead to a valid *QoE* metric.

2.2.4 Content distribution

Content distribution seems to be the less studied research topic into this state of the art, but a lot of research works mentioned in this document are pointing in the same direction to get results for better content delivery. They are focused into using big data to learn from old data and take actions and systems like *OpenFlow* to execute those actions and deploy, scale and remove new content distribution servers in order to meet the needs for content delivery in certain moments.

Based on all learned from this *State of the art*, the most hopeful research topics both in terms of more research work to be done and future impact are:

- Relationship between *QoS* and *QoE*
- Content distribution

Content distribution will be very important because of *CDN* servers, both virtual ones or real ones and the logic to deploy content on them and their savings for the content providers in terms of bandwidth an storage space. These technology presumably will offer too better *QoE* for customers into the aspect of getting content much earlier if they are deployed into a nearly server.

As evaluated before, a relationship between *QoS* and *QoE* will offer a good way to get *QoE* measures from *QoS* measures made by content providers getting a better experience for the customer.

3

Evaluation

In this chapter the evaluation of the proposed architecture will be discussed.

Main objectives referred on chapter 1.3 of this research work will be the improvement of the *QoS* and *QoE* of an streaming session using an improvement for *MPEG-DASH* architecture.

First step to determine the improvement of any factor is measuring it, because of that measuring *QoS* and *QoE* of received streamings will be the first task to be executed.

To measure those two aspects of an streaming communication will be necessary to know what they mean:

- QoS: is the description or measurement of the overall performance of a service ((49))
- QoE: is a measure of the delight or annoyance of a customer's experiences with a service ((48))

To evaluate those measures it will be necessary to determine which kind of measures are.

On one side *QoS* can be defined in terms of an objective measure, like used bandwidth, resolution of the played streaming, bitrate of the streaming, etc...

On the other side, by definition, *QoE* has been defined for a long time as a subjective aspect perceived and determined by the user who consumes the content, in our case, the streaming.

Given those differences, the way to measure those factors must be different for each one of them.

3.1 QoS

QoS has always been measured as a combination of several objective factors of the played streaming. That makes easy to develop *tests* to measure those factors and to create a good *QoS* equivalent for multiple systems that have to be compared.

In the *state of the art*, section 2.1.3.1, we couldn't find a suitable way to measure *QoS* of the candidates we are going to use to compare against our proposed *system architecture* for streaming, so a new one must be defined to have a common measure to compare between different available architectures and streaming systems.

We will define the description of an streaming on its "physical" characteristics measured at client side:

- Resolution
- Bitrate
- Latency
- Buffer size

3.1.1 Data requirements

First step will be determining which factors are representative for us to measure the *QoS*.

- Streaming resolution
- Streaming bitrate
- Streaming latency
- Streaming Buffer size
- Resolution changes
- Bitrate changes
- Buffer size changes

Those factors are a combination of streaming metrics that can be measured in an objective way. That makes that, according to to Oates ((30)) book, using *surveys* should to be the best approach to measure those metrics.

3.1.1.1 Technologies to be measured

But there is still a question that has not been answered, what is going to be compare?

In several parts from this document has been told that purpose was comparing the performance of different *HTTP adaptive streaming* technologies by comparing its *QoS* and *QoE* measures.

The streaming technologies that are going to be compared are:

- Apple HLS streaming (4)
- MPEG-DASH (16)
- MPEG-DASH improved architecture (our research work)

Those streaming technologies are the most representative ones in terms of *HTTP adaptive streaming* technologies according to (25) .

3.1.2 Data generation method

Wowza Streaming Server (50) will be used to implement and deploy all available streaming platforms except this research work one.

Our *MPEG-DASH* based streaming technology will be deployed manually with its own streaming server.

The objective of this kind of surveys is to measure the behavior of all streaming servers in the same conditions, so the same content must be streamed by all of them and in the same network conditions. So the system will be deployed in a controlled local network and the content will be a color bars video with its timestamp attached to the image.

Figure 3.1: color bar video

3.1.3 Measuring proposed streaming system

A *HTML5* player based on *dash.sj* (11) will be used to reproduce streaming from proposed streaming system. To measure metrics given in 3.1.1 will be necessary to modify this player.

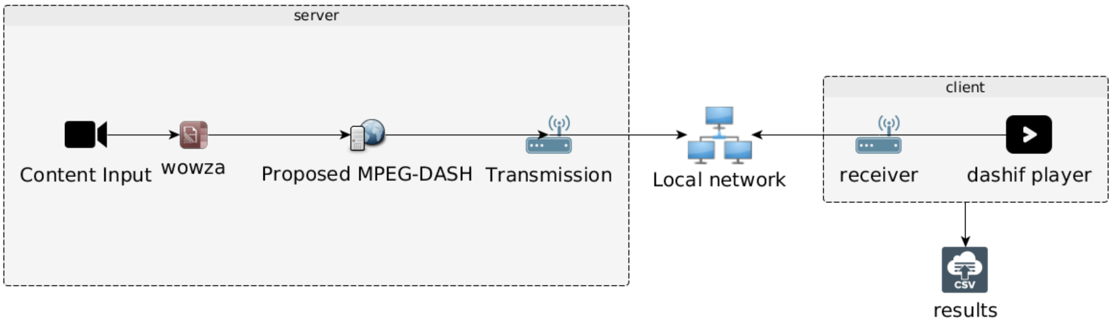


Figure 3.2: survey architecture for proposed system

3.1.4 Measuring others streaming systems

Best way to measure metrics given in 3.1.1 will be similar as previous one, we have three different types of streaming, two *MPEG-DASH* based and one *HLS* based, we will use *dashif* player based to measure the *MPEG-DASH* based streaming and videojs (46) for the *HLS* based streaming.

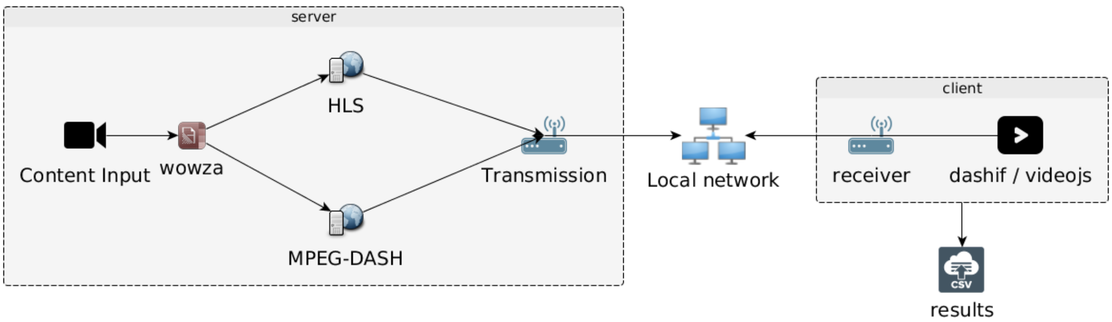


Figure 3.3: survey architecture for streaming

3.2 QoE measuring

According to Zhao et al., *QoE* is being taken into account as the best factor to measure the quality of a video streaming. Keeping in mind that final objective of an Internet video streaming is the transmission and the consumption of the data in the best way for the customers, that premise is very accurate and must be an important metric in any research work that wants to know how good is a streaming system, that fits completely into our research work.

QoE has been defined as *a measure of the delight or annoyance of a customer's experiences with a service* and eventually the only way to get this measure was questioning directly to the customer how was it's experience consuming a streaming.

3.2.1 Purpose

It is known that a questionnaire will only give a subjective perspective of the *QoE* perceived by the users. It wont be the only one tool that we will use to measure the *QoE* but it will give us a valid view of it.

Making an objective measure of the *QoS* of the streaming at the same time than consumer consumes the streamed content we could find a relation between those two factors.

- Which is the best streaming platform of the proposed in terms of *QoE*
- Is our streaming solution good enough in terms of *QoE*

3.2.2 QoE as an objective data measure

There is a trend followed by some researches that try to link *QoS* objective measures to *QoE* measures perceived by consumer.

In (38), Shen et al. have developed a method to measure *QoE* on an objective way that seems very promising in terms of easing the access for broadcasters and service providers to the lecture of *QoE* perceived by users. This research method seems to be to powerful but so much for our research purposes where a questionnaire seems to be more adequate.

Nam et al. in (29) have measured some streaming factors and related those measures directly with the perceived *QoE* from final users, mainly the rebuffering one.

That gives us the idea that QoE could be measured in an objective way, not only using questionnaires.

The streaming factors measured were:

- Start-up latency
- Rebuffering
- Bitrate changes
- Video loaded fraction

Those measured elements can be a good starting way to measure quality of streaming, specially the related ones with bitrate played by clients. With those streaming factor's measures could be used to create a kind of QoS of the streaming to be related in future research work with QoE measures.

In (9), Eckert et al. have developed four different algorithms to get an objective way to measure QoE and have compared their estimation results with real user experiences and their subjective experience while watching different contents and have shown that those kind of algorithms can predict in a good way the QoE perceived by users.

Those algorithms have been developed taking account that the buffer size is directly related with the continuity and the stalling of the streaming. Those two characteristics are generally related with the QoE perceived by the users.

Those research works agree with our point of view to measure at the same time some QoS aspects in order to link those results with QoE.

3.2.3 Objective approach to QoE measure

Our approach to get a quantitative approach to QoE measure will be a mix from techniques used in previous section.

We will extract quantitative data from questionnaire sent to users in order to extract their answers to get a measure of *QoE*.

On the other hand, we will take logs from players used in order to get the quality and continuity of the played content.

This way *QoS* measure from streaming could be established and a direct link between *QoE* and *QoS* from each session could be settled down.

3.2.4 Questionnaire Design

This section will cover the design of the questionnaire to complete our main information goals. In a extended way we are going to define a survey, so we want to get the same kind of data from a large group of people in a standardized way.To achieve a good work in survey designing we will have to follow some directives:

- Data requirements
- Sampling techniques
- Sampling frame
- Sample size
- Response rate and non-responses

3.2.4.1 Data

According to Oates (30) in a survey two different types of data can be obtained:

- Directly topic related
- Indirectly topic related

This questionnaire will get data only from topic related:

We want to know which is user perception about the *QoE* of the streaming (directly topic related data).

3.2.4.2 Sampling frame

In section 3.2.1 our objective will be to know which streaming technology or platform is the best one in terms of *QoE*. So this way we think that the best people to answer this question will be the professionals of this field.

We are going to consider a population of our research and developer colleagues focused on streaming technologies.

3.2.4.3 Sampling techniques

We have defined our sampling frame, so its time to define the sampling techniques to get that sampling frame. There are two kinds of samplings:

- probabilistic
- non-probabilistic

In our case the sampling technique will be a non-probabilistic one;

We are going to ask our colleagues and people we know, they fit the condition of being people related to research and development of related streaming IT but they wont be a representative frame of all population.

To get this data we will use a mix of the following non-probabilistic sampling techniques:

- Convenience Sampling
- Snowball Sampling

3.2.4.4 Convenience Sampling

This technique consists on asking people that will be convenient for this research. By definition, asking working colleagues that have interest and knowledge in this research field fits this type of technique.

3.2.4.5 Snowball Sampling

This technique consists on asking a person who has made the questionnaire to ask other person to answer the questionnaire.

We will ask our colleagues to ask another people to answer this questionnaire to get the biggest sample size possible.

3.2.4.6 Response rate and non-responses

According to Oates (30) a 10% rate of response is not uncommon. We are focusing on a sample-size of about 100 people, we will ask to 70 research colleagues (*convenience sampling*) and we hope at least another 30 people obtained from our *Snowball sampling* techniques.

To avoid lower response rates we will ensure to let know to the people we are asking the importance of this research work in order to determine the best streaming technology in terms of *QoE*. This, united to the fact that the people we are asking are interested on these kind of technologies can assure us at least 40/50 answers.

3.2.4.7 Sample size

The bad news about this kind of Sampling techniques is that the final sample size of answers that could be obtained shouldn't be significant to ensure a 95% of confidence and an 3% of accuracy on our answers.

According to Oates (30) to obtain a 3% certainty and for a total population of 900000 people this questionnaire should be answered for at least 895 people but that is far away from our capabilities.

Our previsions for this questionnaire is that we will get a final sample size of 40/50 answers, what is statistically significant data but can't ensure the error percentages because our target is all world population (we want to be sure that our system is better (or not) than other ones)

3.2.5 Infrastructure

To build this questionnaire will be necessary some infrastructure. Main objective will be to compare different streaming platforms and architecture, so it will be necessary to deploy that infrastructure and make it available to use to the people who answers this questionnaire.

The necessary items to carry out this task will be:

- Streaming servers for all available platforms
- Same content for each platform (content and quality)
- Clients for all available platforms
- Instructions to users about how to deploy/install clients when necessary

3.2.5.1 How to do it

The best way to perform this survey will be using Internet, our sample population will be people that are common and comfortable with IT technologies and answering by Internet won't be a problem for them. Another advantage of making questionnaires on the Internet is that it will be cheaper than other methods and asynchronous for those who respond the questionnaire.

We are going to use Google forms (13) as platform to create our on-line questionnaire.

But it won't be enough to complete all elements of our infrastructure mentioned on 3.2.5. We will need some other tools to deploy all available streaming technologies.

To deploy all streaming platforms and technologies we will opt to deploy them on *Amazon web services* (3).

3.2.5.2 Streaming technologies

The streaming technologies we want to compare on terms of *QoE* will be:

- Apple HLS streaming (4)
- MPEG-DASH (16)
- MPEG-DASH improved architecture (our research work)

As mentioned on 3.2.5, the best way to deploy those streaming technologies will be using *Amazon web service* (3) in combination with *Wowza Streaming Server* (50) mentioned in section 3.1.2 to get *QoS* measures.

3.2.6 Questions

Same questions will be asked for all streaming services to all users in order to compare their answers and answer our main question: which streaming server is the best one in terms of *QoE*?.

Final purpose will be linking *QoS* with *OoE*, so basing in the metrics from section we are going to build a questionnaire that involves *QoS* available metrics to relation them with *QoE*.

Question will be divided by themes, each group of questions will be used to answer some high level related questions.

These question group will be directly related to the subject of the survey, we will use these questions to ask about the *QoE* perceived from each streaming server.

3.2.6.1 Quality

Those questions will give a measure about the quality perceived by the user.

- Has this streaming good resolution?
- Have you noticed any pixelated images in any moment?

3.2.6.2 Buffer performance

Those questions will give an idea of buffer performance of each streaming platform.

- Have you noticed any cuts during playing?
- Have you noticed any discontinuity?
- Have you noticed any yerk during video playback?

3.2.6.3 System Performance

Those questions will offer an idea about the load and the general performance of the player on the user side.

- Was your computer slow when playing streaming?
- Did you notice any abrupt transition between resolution changes?
- if yes, when?
  - up– >down?
  - down– >up?

3.2.6.4 Scoring

As said in section 3.2.3, there is a need to get quantitative data from this questionnaires answers, so “numeric” answers must be given.

To achieve this goal, best way would be scoring answers as follows:

1. Very bad
2. Bad
3. Normal
4. Good
5. Very good

3.2.7 Quantitative data analysis

All results obtained from these surveys, experiments and questionnaires will generate quantitative data and those data must be analyzed in order to obtain some adequate conclusions.

According to (30, Chapter 17) there are different types of quantitative data:

- Nominal data $->$ categories without numerical value
- Ordinal data $->$ numbers are allocated to a quantitative scale
- Interval data $->$ ordinal data measured against quantitative scale
- Ratio data $->$ interval data with zero value in the measurement scale

We will get two types measures, nominal data from questionnaires that will be coded in order to get quantitative data from their results and ordinal data from surveys from *QoS*.

3.2.8 Quantitative conclusions

Best way to get conclusions about questionnaires will be the elaboration of a mean of answers from questionnaires. This will give quantitative data that can be compared between the different available platforms.

3.3 Final evaluation

According with the previous papers mentioned on 3.1 and 3.2 sections, there is a trend from researchers to consider *QoE* a much better way to measure the quality of a video streaming instead of *QoS*. That is because the need to focus streaming measures fully into client's experience.

Video streaming must also pay attention too service providers interests. Service providers want to get the best results by the less money possible. That means that they want the best *QoE* possible on the client side with the less *QoS* possible. This way they will decrease their expenses in bandwidth and equipment but getting a good *QoE* into client side.

Research work will have to mix those two factors in order to get a response for a simple question, will our proposed system architecture will offer the best *QoE* possible for the "worst" *QoS* in a better way than other available systems from market?

3.4 Implementing questionnaire

This section will cover the implementation of questionnaire defined in section 3.2.4.

The execution of this survey can be divided in two different parts, server side and client side.

3.4.1 Server Side

As mentioned in section 3.1.2, we have used a *Wowza streaming server* to implement the required adaptive streaming systems.

First step will be the generation of the necessary video sources to build the adaptive streaming servers that are going to be studied. For these purposes a series of videos based on color bar video as told in Figure 3.1 with the following resolutions have been created using *gstreamer* (18) framework.

- 4K (3840x2160)
- FullHD (1920x1080)
- HD (1280x720)
- 480p (854x480)
- 240p (320x240)

Using those generated videos we have set up two different streaming servers using *Wowza streaming server*, those streaming are based on *MPEG-DASH* and *HLS*.

This way two different *HTTP adaptive streaming* services have been created to be evaluated by the users who will answer to our questionnaire.

3.4.2 Client side

In the client side, web player has been selected in order avoid any operative system dependency. This way streaming can be played in any modern and current web browser.

In order to run proposed web players for each streaming platforms, the most appropriate Javascript libraries must be chosen. Based in the fact that there are two different streaming platforms, two different *Javascript* libraries must be chosen to be used as base for web players. In section 3.1.4 was mentioned that we were going to use:

- dashjs for MPEG-DASH streaming
- videojs for HLS streaming

But after doing some testing with those libraries, different Javascript library was chosen for playing *HLS* streaming content. That was because *videojs* library wasn't fully compatible with *Wowza streaming server HLS* service provided.

Library finally chosen for *HLS* streaming was *videodev* (45).

3.4.3 Bandwidth control

Some previous testing showed that mean Internet speed mentioned by *Akamai report* (1), that is 12Mbps, will be always enough bandwidth to play *4K* resolution streaming content in both streaming platforms studied.

Because of that, we decided to do our tests in a LAN network environment in order to introduce some bandwidth reduction to get some differences in the streaming qualities to be provided for the users.

3.4.3.1 Seed data

First step will be the determination of the bandwidth margins to be studied and asked in the questionnaires. So a preliminary test with both streaming technologies that were to be studied was made.

This test gave us some answers about streaming behavior in different platforms and for different bandwidths bandwidth settings into local area network in terms of usability and quality. Those data can be found in table 3.1.

That previous research will lead us to choose the best qualities and bandwidth restrictions to be offered to the users who will make the survey.

For our survey we have chosen bandwidth values that offer reasonable values of *QoE* in terms of view to no discourage users from viewing the content and evaluating which one of them is better in terms of *QoE*.

Table 3.1: Bandwidth HLS / MPEG-DASH response

Bandwidth (kbps)	HLS	MPEG-DASH
50	No video	Lot of cuts
100	Lot of cuts	Lot of cuts
150	Some cuts low resolution	4K with cuts
200	Low resolution with small cuts	4K with cuts
250	Low resolution with continuity	4K with small cuts
300	4K continuous	4K continuous
400	FHD continuous	FHD continuous

Table 3.2: Bandwidth to be evaluated

Bandwidth (kbps)
150
200
250
300

3.4.4 Answers to the questionnaire

We pretended to get around 100 answers for our survey, but taking into account that we had to modify our tests to add the bandwidth issues we had to take control of the network connection that was going to be used to play the streams. That only was possible to me made using a local area network connection, so the subjects that were going to answer the questionnaire must be in that local network. That limited the quantity of people that could answer the questionnaire to 10.

Despite that short quantity of answers we can elaborate a study of the *QoE* of the offered streaming services and our conclusions:

During the execution of the survey, the missing of an important question in the survey has been noticed. That question will correspond to the general evaluation of the quality of the streaming and could be the direct answer to our research question, “which streaming has better *QoE*?”. That question could have also offered a way to measure the weight of the other questioned elements from survey into the generation of the *QoE* evaluation response.

This way, the importance of the different fields measured in this survey, resolution of the streaming, continuity, etc... could be measured in order to create a general weight of each of them in the evaluation of the *QoE*.

Our propose is to add this question to the next questionnaire in this research field.

Given the low amount of answers evaluated, this research work can only be used to obtain a preliminary and indicative sight of what users think about the offered streaming services but those results cannot be extrapolated to all the population.

The good point is that results offered offered a "common answer" for our surveys and that made us to know which streaming serviced of the studied had better *QoE* depending on the weights given to the two main problems in streaming, the continuity and the resolution from a video.

Other very good data obtained from answers and previous research work is the minimal necessary bandwidth to get streaming services run smoothly for given resolutions. This knowledge will be very useful when creating player or streaming servers servers that avoid trying to play very high resolution streaming when bandwidth conditions are very bad.

3.4.4.1 Grouping answers

We have asked for 6 questions:

- Has the streaming good resolution?
- Have you noticed any pixelated images in any moment?
- Have you noticed any cuts during playing?
- Have you noticed any discontinuity?

- Was your computer slow when playing streaming?
- Did you notice any abrupt transition between resolution changes?

Those questions can be grouped in two main sections:

Video quality

- Has the streaming good resolution?
- Have you noticed any pixelated images in any moment?

Video continuity

- Have you noticed any cuts during playing?
- Have you noticed any discontinuity?
- Did you notice any abrupt transition between resolution changes?

and an external question that was added to check the performance of the streaming on clients computer.

- Was your computer slow when playing streaming?

3.4.4.2 Scoring the answers

As told in section 3.2.6.4 we are looking for quantitative data so we will have to weight the answers and give them a numerical value in order to compare them.

We have asked for two main factors:

- Continuity
- Video Quality (resolution)

Table 3.3: Numerical value for continuity answers

Evaluated value	Numerical value
Very bad	0.1
Bad	0.5
Normal	1
Good	1.5
Very Good	2

Under our criteria the most important value for a video streaming has to be the continuity, so we will weight responses as follows 3.3:

And for the video quality we will weight the responses can be found in table 3.4:

Table 3.4: Numerical value for quality answers

Evaluated value	Numerical value
Very bad	1
Bad	2
Normal	3
Good	4
Very Good	5

This way we have some kind of quantitative data from each answer but we need to combine those quantitative value to get a definitive numerical value.

3.4.4.3 Getting calculation formula

As hypothesis we estimate that the continuity of the streaming will be the most important element in our scoring of QoE, so all answers that belong to that group must be multiplier.

Quality related answers are the elements that are going to be multiplied so they must be added together.

Resulting formula for this *QoE* calculation will be:

cutsanswer*discontinuity:*abrupttransition*(goodresolution+pixelated)

That mathematical formula will give a numerical value for each response obtained from questionnaires. If we take the median for all users and their responses we will get a valuable and quantitative data to compare *HLS* vs *MPEG-DASH*.

3.4.4.4 Comparing results

As an obvious answer to the question of which streaming technology offers betters results in terms of *QoE*, higher is better, so best *QoE* result will determine which streaming technology is better for this research work purposes.

3.4.4.5 Minimum acceptable *QoE*

Another term to be measured and defined is what is the minimum *QoE* that a video streaming must have to be considered good enough to be offered to the client.

Taking the given formula we could calculate a numerical value that, under our criteria, can be considered an acceptable *QoE*:

Most important thing under our criteria is not having cuts into transmission, so

- cutsanswer
- discontinuity
- abrupttransition

must be at least a *normal* value.
On the other hand video video quality must be normal, so answers

- goodresolution

- pixelated

must be *normal* value too.

Calculating with the formula given in section 3.4.4.2, acceptable QoE under the above criteria and giving it the values for “normal“ answer defined on section 3.4.4.2 :

$cutsanswer * discontinuity : *abrupttransition * (goodresolution + pixelated)$

$1 * 1 * 1 * (3 + 3) = 6$
So minimum acceptable QoE value must be $\boldsymbol{6}$.

3.4.5 QoS metric definition

In this section we will determine the QoS of a certain session in order to be compared with QoE to determine their relationship.

The best way to do it will be measuring some factors from *HTTP streaming* sessions like:

- Segment resolution
- Segment size in MB
- Segment download speed

At the end of this research work we couldn't determine a valid QoS metric formula that contained those parameters because the lack of time.

4

Discussion

In this chapter results obtained from questionnaires from chapter 3 will be exposed, evaluated and discussed.

4.1 Obtained data

Answers from questionnaires are presented in the following tables.

In each table are represented the resulting *QoE* for *HLS* and *MPEG-DASH* and for each bandwidth studied. *QoE* values were the result of the application of the mathematical formula cited in section 3.4.4.3 to given answers from questionnaires.

Table 4.1: QoE values for 150Kbs

User	HLS	MPEG-DASH
1	0.2	0.2
2	0.2	0.16
3	0.18	0.9
4	0.15	0.16
5	0.135	0.18
6	0.2	0.16
7	0.2	0.18
8	0.2	0.135
9	0.2	0.2
10	0.2	0.18
Median	0.2	0.18

Table 4.2: QoE values for 200Kbs

User	HLS	MPEG-DASH
1	5	1.25
2	4	0.05
3	12	4
4	8	4.5
5	6	4.5
6	6	0.8
7	12	0.675
8	6	0.675
9	7	0.9
10	7.5	0.9
Median	6.5	0.85

Table 4.3: QoE values for 250Kbs

User	HLS	MPEG-DASH
1	32	5
2	24	1
3	40	5
4	40	0.8
5	32	1
6	32	0.8
7	24	3.375
8	32	1
9	32	0.75
10	40	4.5
Median	32	1

Table 4.4: QoE values for 300Kbs

User	HLS	MPEG-DASH
1	45	54
2	80	54
3	30.375	45
4	27	72
5	54	80
6	80	80
7	27	40
8	72	72
9	60	80
10	64	54
Median	57	63

4.2 Conclusions

Observing the results obtained from section 4.1, it can be determined that, in a general way, *HLS* streaming gets better results in terms of *QoE* than *MPEG-DASH* in all possible *bandwidths* studied except in the *300kbps bandwidth* case where results are quite similar.

According to these results, users think that *HLS* offers more quality than *MPEG-DASH* technology for low bandwidth network environments.

Another factor studied was the minimum acceptable *QoE* for an streaming service that was defined in section 3.4.4.5 and it took **6** as value. According to obtained data from questionnaires, it can be observed that streaming based on *HLS* with a *bandwidth* higher than *200Kbps* will accomplish with that criteria and could be considered acceptable in terms of *QoE*.

Taking into account the above paragraphs following conclusions can be reached:

1. *HLS* is much better than *MPEG-DASH* for low bandwidth environments
2. *MPEG-DASH* is better than *HLS* for high bandwidth environments but not in a significant way
3. Minimum bandwidth for acceptable *QoE* is *200 Kbps*

4.3 Discussion

4.3.1 Player dependency

The architecture of most *HTTP adaptive streaming* technologies determines that the client side will be the part where resides most of the logic and intelligence for choosing the most appropriate content depending on network environment of each streaming session. That makes the quality of the session very dependent of the used player.

In this research work we have used web based players to get operating system independence. Based on this, can be deduced that using different Javascript playing libraries could offer different results in terms of *QoE*. Because of that can be considered that making some research improving the state of the art could be a good idea to get a better research work.

4.3.2 Questionnaire planing

Halfway of the execution of this research work was noticed a question that will be determining for it's implementation;

Bandwidth limitation of the streaming samples was determining to establish a limit for content's quality to be played. Without that limitation, no difference would have been noticed by answerers of the questionnaire.

This factor could have been foreseen with some previous tests and would have helped to design a questionnaire deployment in a distributed system that could have manage that bandwidth limitation instead of making the questionnaires in a local area network.

As a consequence of this limitation to local area network, the number of people who was asked to answer the questionnaire was much lower than the foreseen one in section 3.2.4.6.

4.3.3 Number of answers

As result of the issue from section 4.3.2, only 10 people could answered to this questionnaire. It may be a low number, but they have been obtained after an exhaustive research getting user's answers from very different network conditions and using different streaming technologies.

This knowledge has enriched this work by getting a deeper knowledge of the opinion of the use under controlled situations. This obtained data could be used as a base to generate questionnaires with a wider base of answerers.

4.3.4 Answers scoring

The given score to the answers to the questionnaire will be decisive when getting the quantitative results. If we weight that streaming continuity is much more important than video resolution of quality we are conditioning the quantitative value from the answer.

This aspect could have been solved making a decisive and general question about *oE. Do you think that this video has good or bad quality?*

This way could have drive us to determinate if our answers weighting was right or not.

4.4 Contribution to knowledge

Main contribution of this research work to the knowledge could be focused in two areas:

4.4.1 Minimum bandwidth settings

As contribution to the knowledge we can emphasize that we have got the minimum bandwidth necessary to play a 4K definition *HTTP adaptive streaming* without any interruptions. This data could be decisive when offering some kind of personalized streaming service to clients.

This way streaming resolution could be limited on server side depending on client available bandwidth. Main problem for this architectures is that the necessity of having two intelligence systems, one on server side and the another one in client side, but this architecture assures offering minimal acceptable quality to clients by limiting maximal available resolution in server to be offered. This way system could avoid bad implementations of quality selection on client side.

4.4.2 Answers weight

Although this is a short research work, weighting and process of answers from questionnaires is mature enough to be considered valid for similar research works.

Future work in this area would involve the validation of this kind of weighting by another questionnaires.

4.5 Future work

A very important factor to get good *QoS* measures will be determining if a segment download from server side from streaming server is fast enough to feed a *HTTP player*.

It wasn't possible be established it in this research work but we think that it would be a great advance to calculate a good *QoS* measure that will help in a great way to complete section 3.4.5.

Another factor we want to highlight is the relationship between service cuts and *QoE* perception, under proposed hypothesis every streaming that has a lot of cuts in service or big ones trends to be qualified by users as bad quality in higher percentage than an streaming with lower resolution but more fluent one.

A possible way to establish this relationship will be design of an experiment that would offer two different streaming to a client, one of them with lots of cuts but very good resolution and video quality and other one with lower resolution but no cuts. After this streaming has been played, user should answer a questionnaire giving a punctuation for this streaming.

5

Materials & methods

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Declaration

I herewith declare that I have produced this paper without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This paper has not previously been presented in identical or similar form to any other German or foreign examination board.

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