DEPLOYMENT OF LIVE-VIDEO SERVICES BASED ON STREAMING TECHNOLOGY OVER AN HFC NETWORK

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Abstract: This paper presents an approach to the deployment of a live-video service based on streaming technology over an HFC network. This approach covers most of the issues that may arise while putting one of these services into operation, taking into account new aspects such as those oriented to the improvement and prior analysis of the service's behaviour. An accurate and continuous service analysis can contribute to boost the service's performance and thus to lead the service to the so called *excellence of service*. This paper also presents a service architecture specifically designed for HFC networks that takes advantage of the structure of this kind of networks. Furthermore, a complete framework that facilitates most of the tasks that are needed to deploy and manage a live-video service over the internet is presented.

1 INTRODUCTION

The emergence of the World Wide Web has changed the Internet world. This service has become a powerful medium. Daily, an important number of web accesses is produced and a huge volume of information is delivered. The bandwidth increase in subscribers' access capabilities has given rise to the appearance of a new complementary service: the Internet video. There are two types of video services on the Internet: live-video and video-on-demand. In video-on-demand services, the user requests the information at any time and the server delivers it exclusively. This system allows users to interact with information: Pauses, backward and forward jumps are allowed. Its behaviour is similar to a videotape. On the other hand, in live-video services, contents are received directly by the server, which broadcasts them straight out to the audience.

Nowadays, most video services on the Internet are based on streaming technology. The advantages of video streaming and the subscribers' expectations are important. However, this technology presents some problems. Video delivering consumes an important bandwidth in the network and requires a constant quality of service. What is more, live-video services require much more transmission capabilities than video-on-demand services, due to the fact that all the users connect at the same time. To maintain service quality under control and select the most interesting contents, the use of proper engineering techniques and good analysis methods is fundamental. The analysis systems must provide the necessary information to ensure the correct configuration of the streaming service, and take as much advantage as possible of the subjacent network technology.

In this paper, an approach to engineering and analysis methods for live-video services over HFC networks is presented. The main aim of this work is to provide useful tips to help service managers in planning, deploying, configuring and improving live-video services. Furthermore, the paper has followed an interesting practical approach, based on the improvement of these services through the analysis of the information provided by existing technologies.

The improvement in the transmission of multimedia contents over the internet is a fact in the current research world. There are abundant papers that cover most of the topics related to the technologies involved in the distribution of live-video contents. Some of them, such as (Chow, 2000) or (Turletti, 1994) commented on new engineering techniques to deploy live-video services, but assuming the availability of multicast technologies. Others like (Ortega, 2000) or (Tham, 2003), are mainly oriented to the study or the development of new data formats for the transmission of live-video. There are others such as (Chawathe, 2000),

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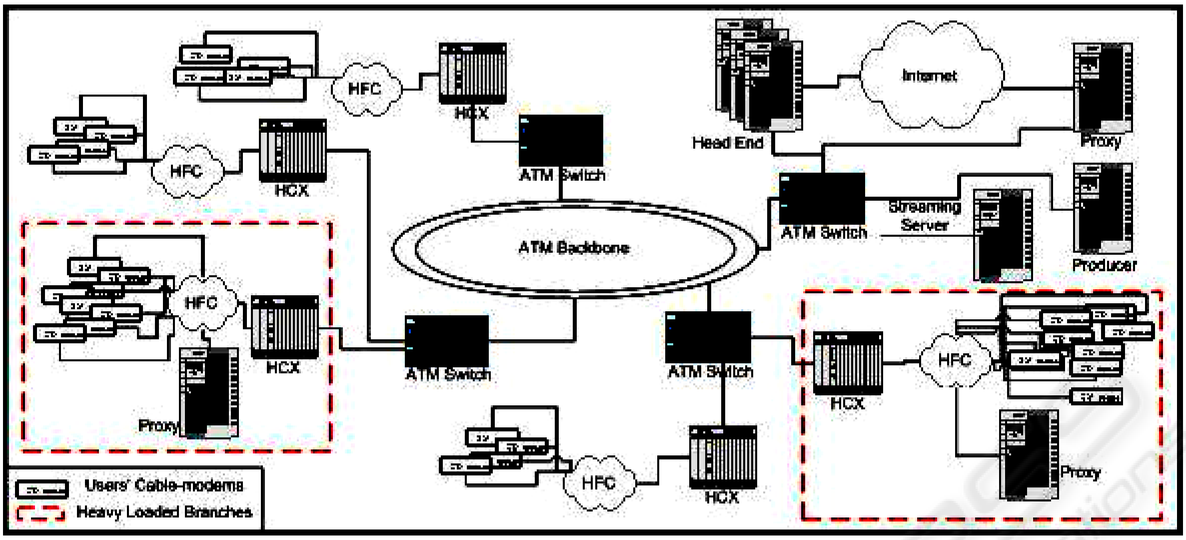

Figure 1: Service Architecture

(Deshpande, 2001), (Nguyen, 2002) or (Padmanabhan, 2002), that offer different approaches to the deployment of a streaming service over a network, but using proprietary solutions or basing their research on service models or simulations.

Although some of the topics covered in this paper have been revised in other publications, the main difference is the practical point of view that has been followed. The conclusions have been obtained through the analysis of the available data from one of these services and the solutions have been designed to improve a real service.

The rest of the paper is organized as follows: Section 2 shows the proposed service architecture over an HFC network. A detailed explanation of live-video services engineering methods is set out in section 3. Section 4 covers an approach to live-video services analysis. An introduction to service configuration is offered in Section 5. Finally, conclusions will be presented in section 6.

2 SERVICE ARCHITECTURE

A live-video service requires the installation of several devices to support the content distribution over the network. The main components that any of these services need are the production software, the streaming server, a set of proxies and the multimedia clients that should be installed in the customers' computers. The distribution of these devices over the network is clearly connected with the type of networking technology that is being used, and the future performance of the service will be determined by the placement of each of the systems involved. Figure 1 shows the proposed distribution over an HFC network.

HFC networks are commonly structured hierarchically around a central spot that delivers all the services to the users that are connected to the network (García, 2003). Although the physical structure of most of these networks may seem different due to the use of ATM backbone rings or other redundant architectures, the logical structure is always hierarchical around this central point, called the *head end*. The *head end* manages all the services in a centralized way: the accesses to the internet, the compilation and distribution of the TV channels, the connection to the telephone networks, etc. It is also in charge of assigning the proper resources to the users whenever they try to use one of the services provided. Therefore, the best place to install the streaming server, whose mission is to deliver contents to the users, is precisely close to the *head end*. This location will permit both a better management by the owner of the network and an increased assignment of output bandwidth rate, in order to avoid problems while distributing the contents to the network.

On the other hand, the mission of the production software is to capture live or stored contents, adapt them for streaming transmission, and deliver them to the streaming server. This device should be as close to the streaming server as possible, in order to avoid cuts during the transmission of contents between both systems. If the contents are being captured live in a remote location with access to the HFC network, a proper *constant bit-rate* connection should be allocated to preserve transmission quality. If that location is outside the HFC network, two alternatives need to be considered: either to subcontract an external connection, or to store the contents and retransmit the saved files later. If an external connection is subcontracted, the external provider must guarantee transmission quality on the route between the producer and the streaming server.

The optimal type of connection for live transmissions is a multicast connection, which reduces the amount of traffic in the network and the load on the server. But multicasting can not be used in most of the existing networks due to hardware incompatibilities, so proxies could be used in order to improve network performance. The mission of proxies is to receive multimedia streams from the main server and retransmit them to final customers or to other proxies. Furthermore, the use of this kind of devices may reduce the load on the streaming server, and avoid possible cuts during the transmission of contents due to a hypothetical overload of that machine. Proxies can also be installed following an *on-cascade* service architecture. This architecture allows proxies to serve contents to other proxies, acting as servers, and reduces the load on the main server.

Every heavy-loaded branch of the HFC network should have, at least, one proxy running in order to serve the customers in that branch. If one proxy is not enough to serve one of those branches, more can also be placed following the *on-cascade* architecture mentioned before. On the other hand, branches with a small number of users can be served from a remote proxy, possibly allocated at the *head end* with proper connection capabilities. If the contents are also going to be delivered outside the HFC network, an additional proxy could be placed to attend all the requests coming from the Internet.

Should the service be offered to external connections, it is also important to consider the placement of several proxies in the networks used by potential users, through some kind of service level agreements with the corresponding access providers.

3 SERVICE ENGINEERING

The deployment of any high-cost service that may suffer problems due to several different circumstances, requires an intense development of engineering tasks in order to reduce service costs, improve service performance and increase customer satisfaction. These engineering tasks should be oriented to improve the service in the following areas: the network, devices and contents.

The network is a critical aspect in any distributed service. It is even more critical in services like live-video distribution, where contents need to be sent with a constant rate to avoid cuts during their reproduction in the customers' computers. Although the optimal network design for these services is not always available, the use of some alternative solutions may mitigate most of the transmission problems that can arise during the delivery of contents. In most cases, transmission difficulties appear in the network's segment known as *last-mile*. One of the features of HFC technology is that it combines optical fibre and coaxial cable infrastructures, relegating the latter to the last extreme of the network, shared between 100 and 200 customers. The fact that these network extremes work under a best effort strategy, combined with the limits of the coaxial cable, reduces transmission capabilities and the network's grade of scalability. If there are a high number of users that demand the transmission of live-video contents in one of these extremes, the only way to avoid transmission problems is to bring the optical fibre closer to users, or to reduce the number of users that can be connected to the network in those extremes. It is clear that these solutions are not always feasible, so the only way to deliver live contents to those users is to produce them with a decreased video quality.

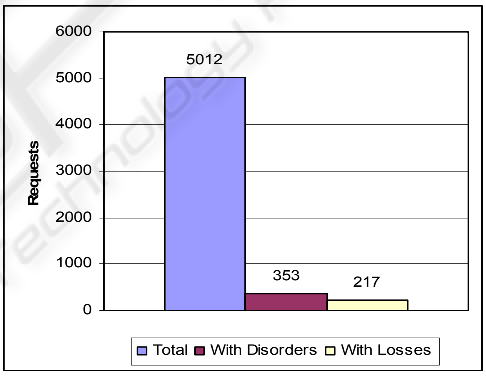

Figure 2: Requests with delivery problems

There are also technologies available in the market designed to ensure the content delivery, such as *surestream* (RealNetworks, 2002). This technique is capable of adapting contents' quality in real time, depending on the transmission capacity that is perceived in the customers' computers.

To detect transmission problems it is necessary to analyze the network's behaviour, and both the server and proxies log files in order to identify late arrival of packets, disorder of packets, loss of packets, reduced reproduction times, etc. Figure 2 shows requests with delivery incidences registered during a real live event.

Although not common, there are sometimes other problems produced in the network due to incorrect routing configurations that may produce the loss of packets or their late arrival. The existence of this kind of problems may affect not only the transmission quality of live-video, but also the quality of all the delivered data. Although the detection of this type of errors is even harder than in the previous case, a high loss packet rate or late packet rate of the customers of a determined network branch, can be the definitive clue to identify incorrect routing policies in the network. Again, the solution to this problem can be found through the analysis of the server and the proxies log files.

Moving forward, the second issue that was expressed as critical was related to the devices that are being used during the transmission of live contents. The simpler live-video service consists of a machine where both the production and the distribution software are running. This initial configuration may suffer several problems such as a high CPU load, huge memory consumption, elevated hard disk utilization and a possible overload in the output connection to the network.

The execution of both programmes in the same machine may overload the computing capacity of the latter, and so affect service performance in a severe way. It must be taken into account that as users' requests reach the server, higher resources are needed to maintain service quality. It is necessary to observe CPU load and memory consumption in order to detect performance problems in this kind of services. If overload errors occur, an inexpensive investment is to dedicate one machine to produce the contents and another to host the streaming server.

This new configuration requires a high connection quality between both devices. If a direct or dedicated connection is not possible, it is essential to analyse the producer's log files to detect problems that may arise during the delivery of contents.

It is necessary to comment that there are some connection policies used in commercial applications that do not report about transmission problems between the producer and the server. An example is one of the *push* methods provided by *Realnetworks' Helix Producer*, where streaming servers do not establish a feedback channel with the producers. Special care must be taken in these cases, and other connection methods should be used if quality can not be assured. As far as the connection method is concerned, this will depend on the distribution and the number of connections that the server receives. If there is a constant connection rate in the server, one of the available *push* methods should be used. On the other hand, if there is a variable arrival of requests, a *pull* connection may be the best solution to save resources in both machines.

Although the split of production and delivery applications between two computers is a clear improvement, a high connection rate in the server may cause the previously commented overload. If all the requests are attended by a single machine, several problems may again be encountered: high CPU utilization, memory overload, elevated bandwidth consumption, and license limitations.

Commercial licenses usually affect the number of simultaneous connections, or the output bandwidth that servers can handle. If delivery problems are being caused by license restrictions, the simplest solution is to acquire a less restrictive license. To detect this type of problems, it is necessary to observe the server's log files, calculate all the simultaneous connections that are being handled in every moment, and compare them to the number of simultaneous connections that are permitted by the existing license. It is also necessary to calculate the output bandwidth that is being used, and compare it with both the license limitations and the capacity of the line that is being used to deliver the contents to the users. If there is high bandwidth consumption in the server's output, network reengineering must be carried out in order to mitigate these problems. More capacity should be allocated, or clustering solutions should be applied by distributing several proxies in the network that will support the delivery of contents to the users. The latter solution is also applicable when performance problems have been detected in the machine that hosts the streaming server, and a computing capacity increase is not feasible.

Proxies are in charge of forwarding the contents to the users. Although in *on-demand* transmissions they operate following caching strategies, in live transmissions they mainly receive the streams sent by other devices and forward them to the users that request the contents. The origin devices could be the main server or another proxy that works under an *on-cascade* architecture.

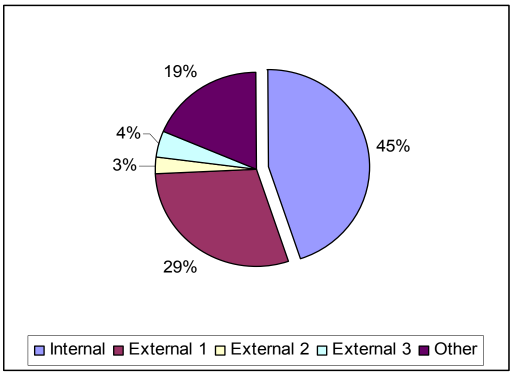

Figure 3: Origin of Requests

In networks where multicasting is not available, proxies can be used to bring the transmission closer to users, reducing the load on the main server and decreasing traffic in the network. In HFC networks, proxies could be allocated in heavy-loaded branches where there is an important number of users requesting the transmission of contents. A step forward is to install several proxies *on-cascade*, depending on the evolution of demand in those branches, or in the load that has been registered in the proxies. On the other hand, network branches with a low number of requests could be served directly from the main server, or for further performance, from a centralized proxy that could be used to redirect transmissions to external networks. In any case, it is very important to collect data from the network and the proxies that have been installed, and analyze said data in order to detect possible performance deficiencies or loss in transmissions. Figure 3 shows the origin of users' requests, registered during a real live event

An extremely important issue is that of *content management*. Contents are usually provided by a different entity than the network operator. Sometimes it is a communications media, such as a TV company or a digital newspaper, other times a movie producer, and most of the times a media management company that sells contents to other businesses. Once those contents are delivered through the network, it is very important to analyze whether they have been successful or not. An inadequate selection of contents may greatly influence the budget of the service or its profitability. Although it is very difficult to calculate audience statistics in other services such as conventional TV, with live-video transmissions it is possible to obtain detailed information about users' accesses. There are different aspects that could drive the production of contents, and are available in this kind of services: number and length of connections, preferred time ranges, users' installed language and computing capacity, etc. These are very important data that should not be underestimated. Servers and proxies log files provide this type of information that needs to be analyzed in detail in order to calculate user's satisfaction and preferences. This information is usually owned by network operators, who could give consultancy support, or reporting services to content providers.

4 APPROACH TO SERVICE ANALYSIS

Once the service has been deployed over the network, it is necessary to monitor the transmissions and check if everything is working properly. It must be taken into account that live-video services do not allow second chances, after they occur their live transmission is no more interesting. Other services such as video-on-demand could be improved using continuous analysis and configuration cycles, but live-videos are slightly different due to their temporary nature. Errors during a live transmission are complete failures, so everything must work properly to ensure the success of the service.

Although live-video transmissions with problems can not be fixed, their analysis can be considered as a continuous learning tool to improve future emissions. The traditional *learn through experience* thesis is perfectly applicable to these services. So it is necessary to analyze live-video transmissions to know what is happening, why it is happening and how it can be improved.

The analysis of live-video services consists of the detailed observation of three of the different stages that can be identified in any live transmission: production, distribution and visualization. Hence the division of service analysis in the following phases: Production Analysis, Distribution Analysis and Visualization Analysis. At the same time, these three analyses consider the issues that were laid down in the previous section –network, devices and contents- from different points of view.

4.1 Production Analysis

Production analysis is centred on the contents production phase. During this stage, the contents are captured and coded using a particular algorithm. After digitalizing contents in the proper format, they are sent to the server using the streaming technology. It is necessary to ensure that the device that is in charge of this task does not suffer any performance incidence. It is also very important to check the connection between the producer and the streaming server. Among others, such as CPU throughput, or memory consumption, the following quality metrics can be used for the analysis of production phases: Production Loss Rate and Production Bandwidth Consumption.

Production Loss Rate calculates losses in the transmission channel between the producer and the streaming server. It can be obtained through equation 1.

$$PLR = \frac{RP - SR}{PS} \qquad \text{Eq. 1}$$

Where RP is the number of resent packets, SR the amount of successful resends and PS the number of packets sent to the streaming server. All this data can be gathered from the producer's log files.

This metric is designed to calculate the losses of information during the production phase, generated by problems in the connection between the production software and the streaming server. It must be taken into account that, although some transmission problems can be mitigated thanks to the input buffer allocated in the streaming server, severe conditions in the connection between both devices can mean an important decrease in the quality of the service. Should these problems appear, an improvement in the network infrastructures needs to be requested in order to guarantee a constant transmission quality to assure the delivery of contents to the streaming server.

Production Bandwidth Consumption calculates the bandwidth that live production is consuming. It can be obtained using equation number 2.

$$PBC = \frac{TBR}{AVB} \qquad \text{Eq. 2}$$

Where *TBR* is the total bit-rate generated in the production phase, and *AVB* is the available bandwidth in the output of the production device. The first parameter is obtained from the producer's log files, adding the output quality that is being generated for each of the targeted audiences of the service, whereas the latter is the bandwidth that is available in the connection where the production device has been plugged into. It is obvious that *AVB* can never be less than *TBR*, because this situation would lead to an increase of the losses in the channel between the production device and the streaming server. Moreover, it must be taken into account that other applications running in the production device may consume output bandwidth, so *PBC* should never be greater than 0.75.

On the other hand, there is no available information in this phase to analyze contents. But it must be taken into account that the media selection is closely related to the analysis of the users' preferences. So this phase depends entirely on the results obtained in the Visualization Analysis phase.

4.2 Distribution Analysis

Distribution analysis is designed to control the quality of the transmissions established between the main streaming server, the proxies and the final customers of the service.

Each of the devices that need to be used to deploy a live-video service over an HFC network, need to be analyzed in detail, to detect performance issues that may affect the final results of the transmission. Hence, it is necessary to analyze the evolution in the resources' consumption of those devices: CPU utilization, memory load, bandwidth consumption, etc. These devices are usually owned by network operators, so no transmission limitations have been considered, except those inherent to the HFC technology and the available network infrastructures. Apart from the typical performance analyses, it is also necessary to consider the license consumption in the main streaming server and the proxies spread throughout the network.

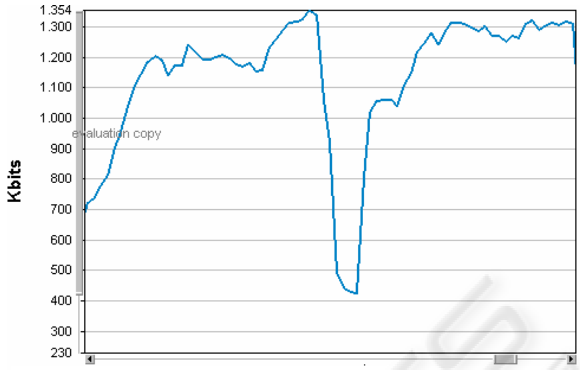

Figure 4: Evolution of *TBR*

These licenses usually limit the number of concurrent connections accepted by each device, or the output bandwidth that is being dedicated to deliver multimedia contents. It is important to mention this feature, because it can severely damage the growth of the service, rejecting connections requested by new users. The licenses utilization can be obtained calculating one of the equations 3 or 4.

$$ULC = \frac{CC}{MAC} \quad TLC = \frac{TBR}{MBR} \qquad \text{Eq. 3 and 4}$$

Where *ULC* is the users' license consumption, *CC* is the number of current connections, *MAC* is the maximum accepted connections, *TLC* is the transmission's license consumption, *TBR* is the total bit-rate used to deliver the contents, and *MBR* is the maximum bit-rate accepted. If *ULC* or *TLC* reach 1 during long periods of time, it is necessary to consider the acquisition of a higher license. Figure 4 shows the evolution of *TBR* in the output of a streaming server, during a real live event.

It is also necessary to evaluate the origin of requests, in order to detect network branches that may be overloaded due to an elevated number of users, or high network utilization by means of distinct applications like *p2p* clients or other heavy consuming software. As has been said, heavy loaded branches in HFC networks may require the existence of a proxy that could bring the transmission of contents closer users. For these cases, it is good practise to assign specific IP ranges to each of the network branches, to identify the origin of users' requests. This policy may also be useful to locate other transmission problems and solve them with high efficiency and precision.

Another interesting study is to analyze the deterioration of the expected quality, understood as the problems that users are suffering due to an incorrect selection of audiences –or qualities- during the production phase. During the configuration of production, the most critical step is the selection of the audiences that will be supported during the transmission. If this selection is incorrect, customers may suffer visualization problems due to poor bandwidth availability. The detection of this kind of situations can be done using equation 5.

$$EQD = \begin{cases} OB \geq EB & 0 \\ OB < EB & 1 - \frac{OB}{EB} \end{cases} \quad \text{Eq. 5}$$

Where EQD is the expected quality deterioration, OB is the user's obtained bandwidth, and EB is the expected bandwidth set during the production phase. The higher this value is, the poorer the reproduction quality has been. An elevated number of high values in this metric should be interpreted as an incorrect selection of audiences during the production phase that needs to be reconsidered for future events.

4.3 Visualization Analysis

Visualization analysis has been designed to check service performance from the users' point of view. Therefore, this analysis considers both the quality of visualization, and the quality of the contents that are being delivered.

Issues regarding quality of visualization are most frequently caused by transmission problems, but users are not aware of the problems that may arise during the delivery of contents. What users are aware of is that sometimes the transmission cuts, the image stops or the initial load time is very high. To bring this analysis closer to users' minds or expectations, all these problems have been grouped into what can be called *Transparency of Service*.

Apart from technology evolution, the different technical solutions or their applicability, the new services that they offer, etc. every single distributed service has one goal, and that is *Transparency*.

When software began to be distributed new problems arose that had not been considered: transmission problems, synchronism issues, format incompatibilities, etc. Live-video, like any other distributed service, has to assure *Transparency*. Users must perceive the reproductions as local to their computers and have to be unaware of the real location of the source of the transmission.

Every incidence that takes place in the delivery of contents, from the production phase to the visualization of the media in the users' computers, has a certain impact on the final reproductions. This impact is a clear deterioration in the *Transparency of Service*. Users' are aware that there is a problem and realize that contents are not stored in their computers. Moreover, they automatically tend to think that this new –or different- product is worse than the previous service they already know, e.g. live Internet video versus conventional TV or video-on-demand. A metric has been developed to evaluate this *Transparency of Service*, using equation 6.

$$ToS = \frac{\lambda * (AQ + VQ + CI) + ES + WC}{3 * \lambda + 2} \quad \text{Eq. 6}$$

Where ToS is the *Transparency of Service*, AQ is the audio quality, VQ is the video quality, CI is the coefficient of interruption, ES is the value of the expected stop metric, WC is the waiting coefficient, and λ is the coefficient that adjusts the results of the metric to the preferences of service managers. A value for λ greater than 1 corresponds to analyses that give more importance to the quality of visualization. On the other hand, a value less than 1 gives more importance to the rest of the features.

Audio quality, or AQ, is calculated as the percentage of requests without lost or delayed audio packets, and no failed audio resends. Video quality, or VQ, is obtained equally to AQ, but using video packets information.

On the other hand, the coefficient of interruption, or CI, indicates the quality of reproductions from the point of view of buffer reloads. Whenever a client's buffer is consumed, the current reproduction is stopped until new packets have filled a certain amount of this buffer. A high percentage of buffer reloads is symptom of a poor quality in the reproductions. Thus, this coefficient tries to obtain the impact of those interruptions by calculating the percentage of reproductions with no buffer reloads.

The expected stop metric or ES, considers the fact that, sometimes, the reproductions do not end for natural reasons, but for transmission problems. Therefore, it tries to estimate the control level that users have while viewing the contents, obtaining the percentage of requests that end with the interaction *STOP*, or because the transmission has finished.

The waiting coefficient, or WC, estimates the effects of the time that users have to wait until their reproductions start. During this interval, the communication between the clients and the server is established, and the client's buffer is loaded. If these tasks require too much time, users may feel disappointed and decide to abandon their requests. This metric tries to obtain the influence of this effect by calculating the value of equation 7.

$$WC = \begin{cases} t_{PreRoll} \geq t_{load} & 100 \\ t_{PreRoll} < t_{load} & 100 * \frac{t_{PreRoll}}{t_{load}} \end{cases} \quad \text{Eq. 7}$$

Where $t_{PreRoll}$ is the estimated load time during the production of contents and t_{load} is the real load time measured in the users' clients.

Once the quality of the reproductions has been checked, it is also very important to ensure that the offered contents meet the customers' preferences. Several metrics have been developed regarding this issue, the most important being the Impact of the Service or *IoS*. It must be taken into account that while in Web services the only metric that evaluates the quality of contents is the number of accesses, in video transmission two different aspects must be considered: the number of accesses and their length, the information being continuous. *IoS* evaluates both aspects, and checks the quality of the offered contents using equation 8.

$$IoS = \sum \frac{VP * RIU}{100 * IU} \qquad \text{Eq. 8}$$

Where *VP* is the visualized percentage, *IU* is the interested users metric, and *RIU* is the really interested users metric. *VP* is the amount of transmission that users have been through. It compares the duration of the requests with the length of the full transmission, obtaining the resulting percentage. It must be taken into account that this metric is not eligible for continuous broadcasts (like conventional TV), because there are no time limitations. Although in continuous transmissions it could be applied to specific time ranges or programmes, a value of 100 should be used to calculate the *IoS*. *IU* represents the users that have been attracted by the access pages or the advertisements that have been distributed. For its calculation, the total number of different users shall be counted in the server or proxies log files. *RIU* considers all the users that, apart from being attracted by the access information, have spent certain time connected to the service. This time depends on the provider's preferences and can range from a few seconds to several hours.

5 CONCLUSION

The configuration and deployment of live-video services is an extremely complex process, due to the high resource consumption of these services, and the difficulty of transmitting continuous information over a shared data network. Nowadays, this task is mainly based on managers' experience. However, a formalization of the steps which must be followed to attain a service of quality, could improve the obtained results increasing service performance and profitability. The proposed engineering method and the expounded approach to service analysis have a direct applicability in HFC networks and they are perfectly compatible with other types of networks. It could also be the base for the development of a complete analysis and configuration methodology that could support service management tasks using production information.

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