On the Use of an ADSL2+ Testbed for Video Quality Assessment

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Abstract — In this paper we share our experience in building an ADSL video delivery test-bed. As a result, we are able to measure the impact of important parameters such as the loop length, the presence of background traffic and line protection against transmission errors on video quality. We show that although these access technologies promise a broadband pipe and low delay communication, a careful configuration of line parameters is paramount to achieve optimal access and is needed for the success of multimedia triple play (3P) services. We particularly analyze the delay, jitter, packet loss and bitrate consumption obtained from real ADSL measurements. These results are an important step towards understanding the adequate deployment of such services. As a special case, we study the effect of repetitive noise on SDTV.

Index Terms— ADSL system performance, Measurements, Video over ADSL, Noise, SDTV, HDTV, Triple Play services.

I. INTRODUCTION

Many efforts have been made to stream multimedia content through the existing data network infrastructure and more recently over telecommunication networks. Triple Play Services (Voice, Video and Data) are becoming the business portfolio of telecom companies. With it comes the need to find new approaches for the engineering of solutions capable of the cost effective delivery of Voice over IP (VoIP). Standard Definition TV (SDTV) and/or High Definition TV (HDTV) as well as data access. Video delivery over the last mile has been a challenging task due to its high data rate requirement as compression techniques can only help a little. Despite advances in broadband technologies, such as ADSL, there are a number of physical and link layer impairments that may potentially degrade video quality. In such hostile environments, packet loss along with other factors such as delay and jitter, may lead to poor video transmission.

The main objective of this work is to conduct a detailed investigation of the impact of some ADSL physical and link level parameters on network metrics when carrying video traffic in a real scenario. There are several video quality of service (QoS) or experience (QoE) studies available in the literature, but these are often conducted using simulations and often using over naive, simplistic and even unrealistic error models. We build a test-bed for an ADSL2+ broadband access, using hardware and software similar to those used by 3P telecom operators, in order to identify the impact of noise, loop length and background traffic on video delivery under different scenarios. These scenarios contemplate the variation of impairments such as noise, concurrent background traffic, and the loop distance from the Central Office (CO) to the Customer Premise Equipment (CPE) side. This study is crucial for the successful provision of triple play and particularly video services. The authors hope that their results may serve as guidelines, in addition to the standards’ institutions such as the Broadband Forum [14], for adequate configuration when deploying these new multimedia services on DSL systems.

In the rest of the paper, section II presents some theoretical background and discusses important related work. Section III presents our methodology and scenarios, whereas section IV describes the corresponding results. Section V presents summarized guidelines obtained through the experiments presented in this paper and section VI summarizes and draws some conclusions along with proposals for future work.

II. BACKGROUND AND RELATED WORK

While multimedia applications can tolerate some network impairments, excessive packet loss, delay and jitter yield unacceptably low user perceived quality. Unlike traditional data services that depend on network level quality metrics, video quality also depends on other physical aspects such as the coding process, which introduces perceptual quality degradation. Therefore, it is recommended that additional protection of video frames must be applied to establish an upper bound to packet loss, delay and jitter. In addition, an important impairment in the video streaming process is the noise that can be coupled together with the transmitted signal. Noise can pose a considerable threat to DSL transmission and the analysis of its consequences is a daunting task due to its complex statistical nature and the tangled error mitigation and framing techniques used in DSL systems.

From the transport and network layers perspective, there are an overwhelming number of research studies. Last mile video quality relies primarily on the physical setup used and the techniques employed to mitigate the different forms of noise using adaptive modulation and low power margins. In [6], the author evaluated the impact of several types of noise when streaming MPEG2 video over DSL. Nonetheless, the analysis lacked parameters concerned with DSL systems and lower network layers. In [2] the authors presented a numerical study of the impact of Impulse Noise (IN), an unpredictable and often deadly form of noise impairment over copper lines, on ADSL. They showed that, while a combination of coding,
interleaving, and a 6-dB margin is sufficient for protecting ADSL systems from isolated impulses, an impulse train with long duration can cause a significant number of error bits in the system. In [3] data errors were analyzed in the presence of IN impairments in DSL systems. However, all the parameters regarding the data transmission environment which are subjected to noise interference are described analytically, including noise duration and noise amplitude, leading to unconvincing and not validated results when compared to video transmission through a real packet network. In [4] a framework for estimating data errors due to IN in DSL systems at symbol, bit and frame levels is presented. In [5] the authors developed a theoretical framework for achieving the maximum possible speed on a constrained digital channel and showed its performance over the downstream channel of ADSL loop under a practical noise environment.

In summary, the presented related works reflect the continuing efforts devoted to analyze video streaming over DSL, sometimes in the presence of different noise types. Although our work explores similar issues such as packet losses due to noisy environments and DSL characteristics, it also takes into account a new side of the coin. First, our results were measured in a real test-bed scenario, differently from those in [2], [3], [4], [5] and [6]. Second, we showed the impact of each parameter from a wide spectrum of levels ranging noise, video or ADSL line. This way, we have provided the reader with the possibility of easily reproducing similar results, and help in the design and realizations of future video applications and more realistic simulations.

III. METHODOLOGY

To analyze how video traffic behaves when streaming it through the ADSL architecture, a number of experiments were conducted using a controlled ADSL2+ network.

A. Test-bed Setup and Experiment Procedures

The ADSL test-bed used for the measurements is outlined in Fig. 1. For streaming video, a linux box behaved as a multimedia client, which received the video from the other box acting as a multimedia server. The client was connected to the DSL line through an external DSL modem while the server was connected to the DSLAM (DSL Access Multiplexer) through an Ethernet switch. The public VideoLAN [7] media player (VLC) was used to stream the video content using UDP as the underlying transport protocol. The D-ITG (Distributed Internet Traffic Generator) [8] tool was used to generate background traffic. For time accuracy purposes, client and servers kept synchronized through the Network Time Protocol (NTP).

The line emulator equipment provided the physical media between the CO and CP side, from 0 to 7Km with a granularity of 25 meters and emulating ETSI twisted pair PE04 [13]. An arbitrary waveform generator (AWG) and a noise injection unit were used in conjunction with the line emulator. The line emulator provided a wide range of loop length possibilities, and the AWG different noise patterns into the line.

The main scripts executed in a separate computer to control the multimedia client and server. These scripts were coded in Matlab® and Linux shell scripts, and were responsible for controlling all the experiments, i.e. controlling all devices used in the experiments and collecting DSL line metrics stored in the user Modem and in the DSLAM. The goal of using a controlled traffic flow is to isolate the control flow (NTP and scripts) from the video and background flows. The adopted experiment procedure involved basically four steps: 1) configuration of the experiment’s parameters; 2) activation of the DSL line and waiting for modems synchronization; 3) streaming of the video from the CO to the CPE side; 4) collecting of the metrics.

Metrics from the physical layer, such as Rate (Synchronized Line Rate), were collected directly from CPE and DSLAM via SNMP. These metrics are related to the downstream DSL channel, given that the video traffic flows only from the CO to the CPE side, since our main goal was investigating only last mile concerns. At the network layer, we extracted and analyzed the packet loss ratio, delay and jitter from the video traffic traces captured at each side of the network.

Due to the high number of possible configurations and measurements in each experiment, the time to run each scenario completely was about one entire day. Thus, to obtain results statistically significant in a reduced time, each experiment was repeated 10 times. Despite this small value, through additional simulations/investigations we checked that it ensured statistical significance for our results, since the variability of these scenarios was small. Therefore, the results in the following section show the mean values only.

IV. EXPERIMENTAL SCENARIOS AND RESULTS

A. Impact of Concurrent Traffic over Video Streaming

In this scenario, the performed experiments had the goal of determining the behavior of the video traffic stream with different bitrates when concurrent background traffic is being transmitted under different line configurations and with no QoS. The actual setup is explained next.

Configuration Parameters

For this study we used ADSL2+ with Annex M as the DSL

![Fig. 1. Main components of the test-bed.](image-url)
standard without Crosstalk noise. The choice of Annex M was guided by our focus on the development of triple play services, so it is desirable to use more recent standards. The line configuration settings, given by maximum interleaving delay of 32ms, minimum INP (Impulse Noise Protection) of 0, minimum SNR margin of 0dB, target SNR margin of 6dB, and maximum SNR margin of 31dB were chosen based on the common configuration settings used in ADSL2+ devices. The variable parameters were the loop lengths, from 0 to 5000m with a step of 250m; the stored video sources with bitrates of 4, 6, 8, 12 and 18 Mbps; and the background traffic of 0 and 50% of the synchronized channel bitrate, which is obtained after the modems synchronization.

We used five bitrates in MPEG2 in order to investigate which video quality is more reasonable for each of the analyzed scenarios. These bitrates emulated different classes of service, from a more simple SDTV service to a demanding high definition HDTV service at 18 Mbps [9]. The video was coded and stored in the streaming server before the experiment took place.

The background traffic was set based on the percentage of the channel bitrate using the levels of 0% and 50% occupancy by background traffic. This was generated using 20 UDP sources with packet size generation following a Pareto distribution with shape 1.3 and variable scale [12], and constant inter-packet departure time. This traffic profile ensures a fractal behavior with a Hurst parameter around 0.85 which guarantees the target channel occupancy for each scenario. All traffic shared a single ATM Permanent Virtual Circuit, since no QoS mechanisms were used in this scenario.

**Experimental Results**

The results without background traffic will be presented only when these were notably different from the ones submitted to 50% of competing background traffic.

The available channel bitrate is a major issue when transmitting any sort of data through a network. In the case without background traffic showed at Fig. 2, the point to highlight is that the bitrate of 18 Mbps suffer packet losses at any loop length because its total bitrate (video bitrate and packet header) is higher than the available bitrate.

Fig. 3 shows the total received bitrate of all videos as well as the channel bitrate, when background traffic is at 50%. Higher loop length values decrease the channel bitrate and increase the concurrency between background traffic and video, since no prioritization scheme is used. Thus, for higher bitrate videos, the received rate is lower than their coded bitrates due to the presence of a large portion of background traffic. Differently, for the lower bitrate videos, such as the one using only 4Mbps, the transmitted video rate behaves as a constant until the loop length reaches 2250m where the combination of video and background bitrates overwhelms the available channel bitrate.

Let us not forget delay, in an ADSL2+ system it can be affected by DSL physical level parameters such as the symbol interleaving mechanism (used to spread possible errors for correcting and recovering from them) and by queuing in the DSLAM due to traffic concurrency (when subject to high user loads). Fig. 4 depicts the video delay behavior for different loop lengths without background traffic (the delay for dropped packets were not taken into account). In this case, it can be noticed that for all bitrates the delay is maintained constant until a determined loop length and from this point on, the delay increases – this point differs for each video bitrate. The video traffic delay for different loop lengths with 50% of background traffic was also investigated, see Fig. 5.
The packet delay increases for two main reasons. First, as the channel bitrate decreases, the delay of video packets increases due to queuing at the DSLAM. Comparing the y-axis scales in both delay graphs, one can note that without background traffic the video delay reaches higher values because the DSLAM queue will not be shared and consequently more video packets will be stored. Second, the delay is affected by the physical interleaving delay set by modems. This delay increases with the loop length as presented in Fig. 6 for 50% of background traffic, the other case presents a similar behavior. Note that this second reason may differ according to used equipments, since there is no standard algorithm to set the initial interleave delay and it is up to the manufacturer to choose how to do this setup.

In order to investigate the correlation of higher values of delay and lower bitrates, a graph correlating the packet loss and the delay for the no background traffic scenario (see Fig. 7) was made. The different video bitrates exhibit a seemingly non-linear behavior: higher delays initially, constant delay for rates above 2.5 Mbps (below 3750m), and a sudden decrease is experienced when the DSL system reaches a sufficient rate for the video. Labels A, B, C, D, and E in the graph indicate points where the delay curves suffer this sudden decrease.

Jitter has an important role in video streaming influencing receiver buffers size. Higher jitter values need larger buffers to ensure a continuous playback of the video. Fig. 8 shows that video jitter for 50% of background traffic was slightly affected by different video bitrates for loop lengths lower than 4Km.

Packet loss is an important metric as it may be lead to bad video quality in video streaming, and increases according to the lack of bitrate. The packet loss results with 50% of background traffic are presented in Fig. 9 – higher values of packet loss make impracticable IPTV service without QoS mechanisms.

B. REIN Impact on Video Traffic

In order to investigate the impact of different noise profiles on video traffic, some experiments were conducted. The goal here is to understand how different noise profiles can degrade the video transmission, varying the frequency and the noise burst length and setting the line with minimum protection. The noise modeling and generation, configuration parameters and results for this scenario are presented as follows.
Noise Modeling and Generation

Several types of noise can affect DSL systems and the Repetitive Electrical Impulse Noise (REIN) can be seen as one of the most severe of them [6]. Given this, REIN was chosen for the generation of line impairments in this evaluation. In our study, we generated REIN using an arbitrary wavelength generator based on the model summarized below. More details in this REIN modeling/generation please refer [10].

A REIN signal $x(t)$ is described as a periodic sequence of bursts as shown in Fig 10. The temporal spacing of the bursts is denoted by $T$ indicating the periodicity of the noise signal. A burst $x_B(t)$ itself consists of a sequence of $N_B$ base signals $x_s(t)$ with duration $T_s$. The duration of a burst is denoted by $T_B$ where $T_B = N_B T_s$. The base signal is a sized version of a normalized peak-peak noise shape function $g(t)$ with support $-T_B/2$ to $T_B/2$. The REIN signal is offset in time by $T_o$.

The noise shape function $g(t)$ is defined in the time-interval $|t| \leq T_B/2$ with peak-peak value normalized to 1. It can take different forms depending on the desired frequency content. For our experiment we used the sinc function $(\sin(t)/t)$. When dealing with REIN generation, we focus on four parameters: 1) the periodicity of the bursts, controlled by the parameter $f = 1/T$; 2) the number of base signals per bursts $N_B$; 3) the periodicity of the base signal inside a burst, which is given by $f_R = 1/T_s$; and 4) the power of the burst, which is given in dBm, considering 50 Ohms impedance.

Configuration Parameters

In this scenario we are going to focus on SDTV videos coded in MPEG2, which produce a 4 Mbps signal. We chose a fixed loop length of 2550 meters, as recommend in [11].

Furthermore, since we want the basic configuration of the line, we used a maximum interleaving delay of 1 ms (special value indicating “Fast Mode”, i.e. no interleaving), minimum INP value of 0. In addition, we chose the target SNR margin value of 6 dB, and the maximum SNR margin of 6.6 dB. This configuration guarantees that the line will have no protection against the noise. The variable parameters used in this experiment were the noise powers of -33.01, -23.46, -19.03 and -14.94 dBm; and noise profiles of 1A, 1C, 2A, and 3A detailed in Table 1. They were chosen in order to investigate the noise frequency and the noise burst length impact on the video traffic. Furthermore, the noise was injected in the experiments after line synchronization.

### Table 1. Noise Profiles Parameters.

<table>
<thead>
<tr>
<th>Profiles</th>
<th>$f_R$ [Hz]</th>
<th>$f_R$ [kHz]</th>
<th>$N_R$ [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1</td>
<td>250</td>
<td>1</td>
</tr>
<tr>
<td>1C</td>
<td>1</td>
<td>250</td>
<td>64</td>
</tr>
<tr>
<td>2A</td>
<td>50</td>
<td>250</td>
<td>1</td>
</tr>
<tr>
<td>3A</td>
<td>100</td>
<td>250</td>
<td>1</td>
</tr>
</tbody>
</table>

Results

The downstream rate for this scenario was approximately 7.33Mbps and the synchronized INP value was 0 (no data interleaving or redundancy and hence no protection), as it was configured. The target SNR margin was also respected, according to the results. This verification is important since the configured values for INP and SNR margin can be changed by the DSL modems depending on the line characteristics.

Fig. 11 depicts how packet loss behaves for all noise profiles. For the 3A noise profile, losses started around 100% even when the noise power was the lowest one. Similarly behaved the 2A noise, although for the power value of -33.01dBm losses were lower, having the value of 0.34%. For the 1A, we can see that for powers lower than -14.94dBm losses were around 0%, but the higher power value of -14.94dBm made losses raise to 100%. Therefore, we can point how frequency can affect the video traffic and note that both noise frequency and power might have a crucial role when coupled to the transmission. Regarding the impact of different burst lengths we compared 1A and 1C. The graph shows that 1C makes losses starting around 5% while losses in 1A start having values around 0.5%. When increasing the noise power, losses have a slight increase for both 1A and 1C, but for noise power of -14.94dBm they both raise to a 100% of packet loss level.

Comparing all profiles, we realize that noises with greater frequencies are more harmful to the line than noises with greater burst lengths. This can be seen when comparing losses from 2A and 1C, as well as when comparing other profiles used in this experiment. Regarding delay, for all used profiles it behaved in a similar way, having values around 0.06s. The same occurred with jitter, having values around 0.0013s.
V. SUMMARIZED GUIDELINES

Analyzing all results presented above we derived some guidelines (Table 2) for the best video bitrate for each loop length, according to some assumptions related to the scope of our study. First, the chosen scenario was the one without background traffic that behaves similar of when using some QoS mechanisms, which in turn is the common practice when the operator provides IPTV services. Second, we used Annex M that decreases the downstream bandwidth, and consequently these results are the worst case for the achieved downstream rates. Third, we used PE04 cable and many operators can have other cable types. Fourth, we used MPEG2 video that has a compression rate lower than MPEG4, this means that with MPEG4 we can have the same video quality of MPEG2 at lower rates and consequently achieve greater distances.

In Table 2 the selected video bitrates have packet loss lower than 0.5%. We also separated bitrates in two service groups named HDTV (18Mbps, 12Mpbs, and 8Mbps), and SDTV (6Mbps and 4Mpbs). This table can help network operators to map the services the user could receive based on their distance from the CO. Beyond video bitrate, the table shows delay and jitter, which can be helpful for network operators estimate the overall values of these temporal impairments.

<table>
<thead>
<tr>
<th></th>
<th>250m</th>
<th>500m</th>
<th>750m</th>
<th>1Km</th>
<th>1.5Km</th>
<th>2Km</th>
<th>3Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDTV bitrate</td>
<td>12 M</td>
<td>12 M</td>
<td>12 M</td>
<td>12 M</td>
<td>8 M</td>
<td>8 M</td>
<td>–</td>
</tr>
<tr>
<td>delay</td>
<td>9 ms</td>
<td>10 ms</td>
<td>10 ms</td>
<td>12 ms</td>
<td>12 ms</td>
<td>17 ms</td>
<td>–</td>
</tr>
<tr>
<td>jitter</td>
<td>0.9 ms</td>
<td>0.9 ms</td>
<td>0.9 ms</td>
<td>1.0 ms</td>
<td>1.1 ms</td>
<td>1.5 ms</td>
<td>–</td>
</tr>
<tr>
<td>SDTV bitrate</td>
<td>6 M</td>
<td>6 M</td>
<td>6 M</td>
<td>6 M</td>
<td>6 M</td>
<td>4 M</td>
<td>–</td>
</tr>
<tr>
<td>delay</td>
<td>8 ms</td>
<td>9 ms</td>
<td>9 ms</td>
<td>10 ms</td>
<td>12 ms</td>
<td>14 ms</td>
<td>40 ms</td>
</tr>
<tr>
<td>jitter</td>
<td>0.7 ms</td>
<td>0.7 ms</td>
<td>0.7 ms</td>
<td>0.8 ms</td>
<td>1.1 ms</td>
<td>1.2 ms</td>
<td>2.2 ms</td>
</tr>
</tbody>
</table>

These guidelines were obtained considering default line protection, the configuration used in practice. Line protection mechanisms offer defense against noise impairments, which can be very disruptive for xDSL lines as seen in section III.B. Additionally, protection mechanisms decrease the effective channel rate. Thus, for different protection configurations these suggestions can also suffer some variation. As previously stated, the guidelines were obtained using Annex M, which decreases downstream rate. We did additional experiments, without Annex M, to have some idea of this decrease. In fact, the best video bitrate until 1Km was 18Mbps, until 2Km was 12Mbps, and until 3Km was 8Mbps.

VI. CONCLUSIONS

This work presented results for different triple play scenarios using the ADSL technology. These scenarios are present in real video transmission environments and can be crucial to an acceptable SDTV/HDTV service provision. We presented results on how the distance from the CO to the CP can affect video transmission. For this, we used different video bitrates where we could search for and find a better video bitrate depending on the distance and requirements of an SDTV/HDTV service customer. In addition we analyzed the impact of background traffic sources sharing the same channel and how harmful this background traffic can be to the video transmission. The impact of impulse noise on video transmission was also evaluated. Finally, we did a summary of the overall results deriving some helpful guidelines for IPTV operators.

As future work, we intend to continue this investigation to configure parameters in the Layer 1 and Layer 2 optimizing video traffic which is rolled out through an ADSL access network. The continuity of this work will allow us to investigate further the correlation between physical and network level quality of service parameters and find adequate error and traffic performance models that truly reflect the underlying modem and line configurations. By understanding their effect, we also hope to provide additional guidelines for the adequate configuration of ADSL access networks in order to support emerging triple play services.

REFERENCES