Are Remote Play Streaming Systems Doomed to Fail? A Network Perspective

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***Abstract*—Digital games represent one of the most compelling fields in computer science, embodying a wide variety of technical challenges. Thanks to the evolution of streaming and broadband technology, new service provisioning schemes have emerged. Remote play streaming services represent an interesting case study deserving a thorough investigation. To this end, we present a network measurement study that can be useful to create traffic models and help researchers identify issues, guiding architecture and protocol design. Moving beyond latency and jitter issues, our purpose is to understand whether remote play streaming services can operate through regular connectivity or, on the contrary, are doomed to fail as happened to some pioneer providers. We have hence deployed a testbed to test the impact of network limitations and, different from previous studies, we particularly emphasize the role of the available bandwidth in this context.**

1. Introduction

GAMES embody one of the most successful entertainment media and, thanks to new emerging technologies, the experience offered to the users is becoming more and more spectacular and immersive with each passing year. To reach a good level of interaction and graphic complexity, dedicated devices as personal computers and consoles are generally required, while smartphones and tablets are generally not suited for a prolonged and comfortable gaming experience.

However, dedicated game devices are generally expensive and users are restricted to play with time, place and compatibility limitations. An interesting solution that has gained popularity is represented by the remote play game streaming services allowing users to immediately play with a large selection of games, without the need of a specialized hardware, although at the cost of facing potential network issues [1]. This service allows users to enjoy gaming on a thin client, whereas, the computational burden is offloaded to a remote and more capable machine (a server) that collects the players' actions, elaborates the evolution of the game, renders the scene, and sends to the various players a video stream.

Unfortunately, companies such as OnLive and Gaikai, two of the pioneers of the remote play through the Internet, have gone bankrupt due to high infrastructure costs albeit their products were promising and appealing to the public [2], [3]. Google is currently operating in the market with its Stadia platform, even if the very recent announcement regarding closing down the internal game studio sheds a shadow on the future of Stadia. Yet, other big tech giants are involved in this new market of Netflix-like game platforms: Amazon expanding their Twitch platform, Verizon with Verizon Gaming, Apple expanding their Apple TV service and Microsoft with Project xCloud. The currently available offer also includes Sony PlayStation Now and nVidia Geforce Now, requiring dedicated hardware.

Are these services destined to fail as well as their predecessors did? It is hard to say with the limitations to the fruition and analysis of the few existing services; fortunately, local game streaming services are already available worldwide and ready for use. Even if they operate in a local network, they offer valuable insights into this service provisioning scheme, allowing us to analyze the main critical issues that can occur when the service is delivered through an Internet connection.

Indeed, the high resolution video streaming sent by the game server to the thin clients is a big difference in terms of network stress with respect to classic online games [1]. As research regarding the latter is generally focused on jitter and latency, with bandwidth neglected as an issue due to the very limited amount needed [4], [5], [6], we focus here mainly on bandwidth requirements showing how it becomes a worthy research topic when considering thin client based games. More in detail, we identified six crucial questions:

- **Q1:** What are the network characteristics of the offered services?
- **Q2:** How does their performance change with different client settings?
- **Q3:** How much delay does the game streaming cycle introduce?
- **Q4:** Do they adapt to limited user interaction?
- **Q5:** What are the network characteristics also in comparison with successful OTT video streaming services?
- **Q6:** How do potential users perceive the video stream quality offered by the services?

To this aim, we conduct an experimental study on two different and representative gaming services, embodying central properties of a remote play system; each of the above questions is tackled by a specific subsection of Section 4.

2. Methodology, Selection of Services and Games

The analysis has been structured into six sets of experiments, comparing the services under different settings in order to answer to the six questions listed in the previous section. First, we compare the two game streaming services using the same selection of games. The second set considers different streaming quality settings. The third set investigates the delay issue caused by the game streaming cycle thanks to a debug tool provided by Steam. The fourth set is aimed at testing the reaction of the game streaming services to limited user interaction. The fifth set compares the remote play game streaming services with a different class of popular OTT streaming services. While in the case of video streaming, buffering helps counteract latency issues, in the gaming scenario the Quality of Service (QoS) and Quality of Experience (QoE) requirements are more stringent and shallow buffers are preferred [1], [7], [8], [9]. Finally, we administered a questionnaire on 232 participants to understand the video stream quality as perceived by potential customers.

2.1. Service Selection

Our service selection is based on three main criteria. First, we have opted for services with a high market penetration rate and a large library of available games. Indeed, a wide library of games helps both to have a test variety and to maintain the comparability between the two services. Second, we have chosen services compatible with the most popular operating systems, allowing us to perform network measurements directly on the client device. Finally, we have considered the possibility to have similar quality settings offered by the game streaming services in order to ensure comparable measurements. These criteria helped in choosing services that allow homogeneous comparison of their respective games and configurations.

The chosen platforms are the Sony PlayStation 4 Remote Play and Steam In-Home Streaming. The reasons behind this choice are various: PlayStation 4 Remote Play and Steam In-Home Streaming can currently count on a very large library of games, with thousands of titles, their client software has similar quality settings beside supporting various operating systems and, compared to the services offered by nVidia, they do not require proprietary hardware to be used. It is noteworthy to point out that these services are proprietary and mostly closed source; we hence have to deduce their *modus operandi* through a carefully crafted network measurement.

2.2. Game Selection

A crucial part of the analysis is represented by the selection of the games for our tests. To compare the two considered services, we identified seven main characteristics related to various aspects of the games:

1) Repeatability of the match: it has to be easy to execute matches with consistent settings and the games have to offer a similar experience for every match.
2) Duration of the match: the duration of the match has to be long enough to get a representative sample of the game evolution.
3) Type of input controls: the games have to use the same input controls like mouse, keyboard or gamepad.
4) Gameplay experience: the selected games should provide diverse gameplay styles (simple vs complex, i.e., only two buttons vs multiple combinations of buttons).
5) Graphic complexity: the selected games should cover a wide range of graphics (simple vs complex, i.e., 2D vs 3D).
6) Compatibility and contents: the selected games have to be available and fully compatible with the two game streaming services analyzed, as well as ensuring the same contents.

Considering the aforementioned characteristics, the games selected for our measurement analysis are shown in Figure 1 (a): (i) Titan Attacks (TA), a simple puzzle-arcade game; (ii) Rocket League (RL), a racing game with some football elements; (iii) Resident Evil Revelations 2 (RER2), a third-person shooter game; (iv) Dishonored (DIS), a first-person adventure game.

3. Testbed and Experiments

Figure 1 (a) shows four screenshots, one for each of the considered games, while Figure 1 (b) depicts the testbed adopted for the study. In particular, we used three devices: (i) a remote machine where the game engine resides, (ii) an access point representing the central hub of the WLAN and (iii) a client machine where the game is played. The remote machine is connected to the router via a wired LAN, while the client device is located in the same room but connected via a 802.11n WLAN. It is noteworthy to point out that the testbed is situated in a controlled environment, subject to no nearby wireless interference.

To record the network traffic generated by a specific device or application, we used Wireshark, a dedicated packet sniffing software, performing measurements lasting 210 s. This is a fair time interval to properly play a game level in each of the selected games. The measurements were performed always in the machine hosting the client software and for each game and experimental configuration we performed 50 measurements.

When a game streaming session is launched, the server device bootstraps the chosen game residing on the hard disk. From here on, the client device sends the user's input to the server device while the server, upon receiving the client commands, computes the game state changes and sends back the video outcome. The computation on the server side involves a rendering step of the scene dynamics, whose output consists of a number of video frames that are sent back to the client device. For both the PlayStation 4 Remote Play and Steam In-Home Streaming services, we chose the following settings for the client side:

1) native game resolution: 1280x720 pixels;
2) video stream game resolution: 1280x720 pixels;
3) capture frame rate limit: 60 fps.

Moreover, both the services adopt UDP as a transport protocol and this is straightforward when considering the need for a transmission protocol ensuring fast transmission without the overhead of a reliable transmission protocol like TCP [9]. The video codec being employed is the H.264, a popular coding standard offering a good trade-off between video quality and bit rate, also thanks to its error resilience features [10].

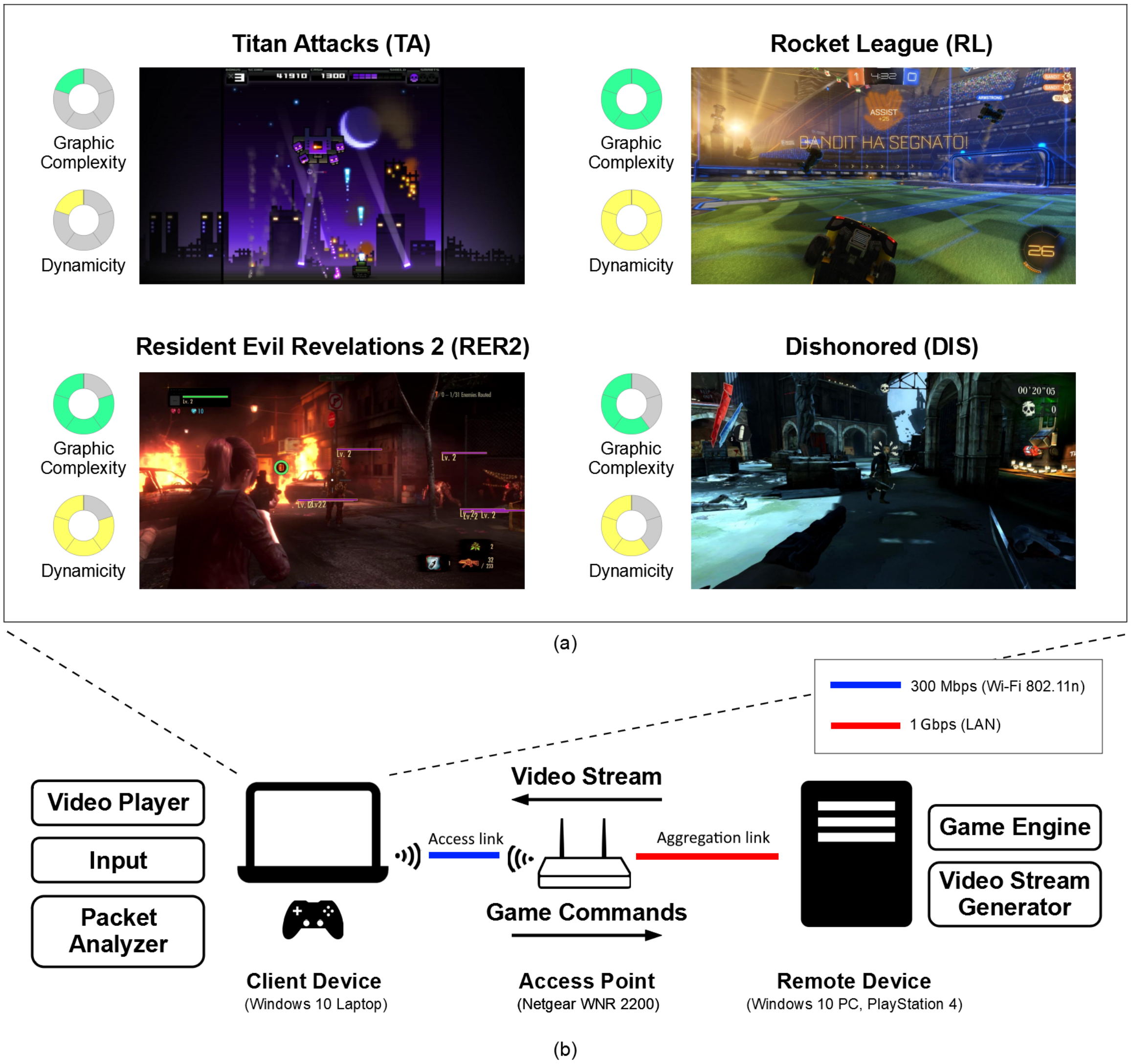

Figure 1: (a) The selected games and their main characteristics; (b) the testbed used for the experiments.

We performed different experiments, each focused on specific objectives, showcasing various aspects of the game streaming services. The first set of experiments aims at comparing the selected game streaming services under different settings related to graphic complexity and game genres. For this set, we selected the same four games for both the services and, for each game, we played several times the same game level.

The second set of measurements is meant to assess the Steam In-Home Streaming service with various video quality settings. This service has the capability to offer various levels of video compression and the user can choose among different approaches: (i) *Automatic* offers a good video quality without saturating the (W)LAN, (ii) *Set Threshold* imposes the Steam service to use a fixed amount of bandwidth (either 3 Mbps or 5 Mbps) and (iii) *Unlimited* tries to reach the best video quality using the whole available bandwidth. For the sake of conciseness, we consider from here on only one game, Rocket League.

The third test regards latency, a crucial issue in interactive gaming services and has been extensively studied especially in terms of an end-to-end problem [11], [12]. Shedding some light from a different angle into this metric, we have measured the game streaming cycle delay of the Steam In-Home Streaming service during a game session. This also includes delay components that can be considered local with respect to the game architecture and hence actually controllable by the service providers. To perform this measurement, we have exploited the Steam debug tool suite, capable of decomposing the delay contribution of specific game engine tasks like the encoding and decoding of a single video frame, as well as the network transmission time and other components contributing to the overall delay. No similar tool or information was available for PlayStation 4.

The fourth set of experiments was designed to assess the reactivity of PlayStation 4 Remote Play and Steam In-Home Streaming to particular events caused by users. We have measured how the streamed traffic is altered when: (i) the game is paused and (ii) the service is in a quiescent state, that is when the player is not sending input controls, but the match is still running.

The fifth set of experiments analyze the network characteristics of the game streaming services also in comparison with a different class of streaming services: in this case we have chosen two of the biggest competitors in the OTT video streaming scene, Netflix and YouTube.

Finally, a survey was administered to university students in our department's lab. The participants compiled the survey after watching two video portions of a Rocket League's match, recorded with two different video quality levels in the Steam In-Home Streaming client.

4. Results

In this section, we delve into the details of the measurement analysis. In particular, the following subsections are presented in the same order as the questions asked in Section 1 as they are aimed at responding to each of those questions

4.1. Answer to **Q1**

Comparing the Two Game Streaming Services We compare the considered game streaming services employing four games of various genres, with different graphic complexity levels. The measured performance metrics are the bandwidth usage and the distribution of the packet size.

The bandwidth usage of the Steam In-Home Streaming and PlayStation 4 Remote Play presents distinguishing characteristics despite having the same settings. Both the services use a large quantity of bandwidth even with simple games like TA, as visible in Figure 2 (a) and Figure 2 (b), even if less than with the other three games. The downstream bandwidth usage of RL, RER2 and DIS is located between 10.4 Mbps and 11.2 Mbps for Steam In-Home Streaming (Figure 2 (a)), and between 7 Mbps and 9.6 Mbps for PlayStation 4 Remote Play (Figure 2 (b)). Furthermore, the average downstream bandwidth usage for Steam In-Home Streaming presents a generally homogeneous trend; on the contrary, PlayStation 4 Remote Play values show more fluctuations. This suggests that the service offered by Sony may employ a more efficient video compression when generating the video stream, taking advantage of the peculiarities of the gameplay. Overall, the PlayStation 4 Remote Play uses a lower quantity of bandwidth when compared to Steam In-Home Streaming, generating very similar video streams despite the differences between games. In particular, this can be observed in the TA results, where the bandwidth usage of Steam is more than twice the one used by Remote Play, 9.44 Mbps versus 3.76 Mbps.

The packet size distribution is consequently different, with Steam In-Home Streaming having around 67% of the packets located in the interval 1500-1600 bytes (Figure 2 (c)). Instead, PlayStation 4 Remote Play has a more spread distribution (Figure 2 (d)). Table 1 shows that the upstream bandwidth usage is very low in both the platforms: this is expected since the upstream packets are just user issued commands sent by the client to the remote device. Yet, the average packet size for the considered games is significantly bigger than the values reported in literature about classic online games [13], [14].

4.2. Answer to **Q2**: Different Client Settings

To gain a better understanding of the behavior of the Steam In-Home Streaming service, we focus our attention on one specific game (Rocket League) analyzing the behavior under different video stream settings quality. To this end, we have selected four levels of video compression based on the bandwidth usage: 3 Mbps, 5 Mbps, Balanced and Unlimited. The game resolution, 1280x720 pixels, has been kept constant for all the experiments. Even in this case, we analyzed the bandwidth usage and the packet size distribution for the considered video stream settings.

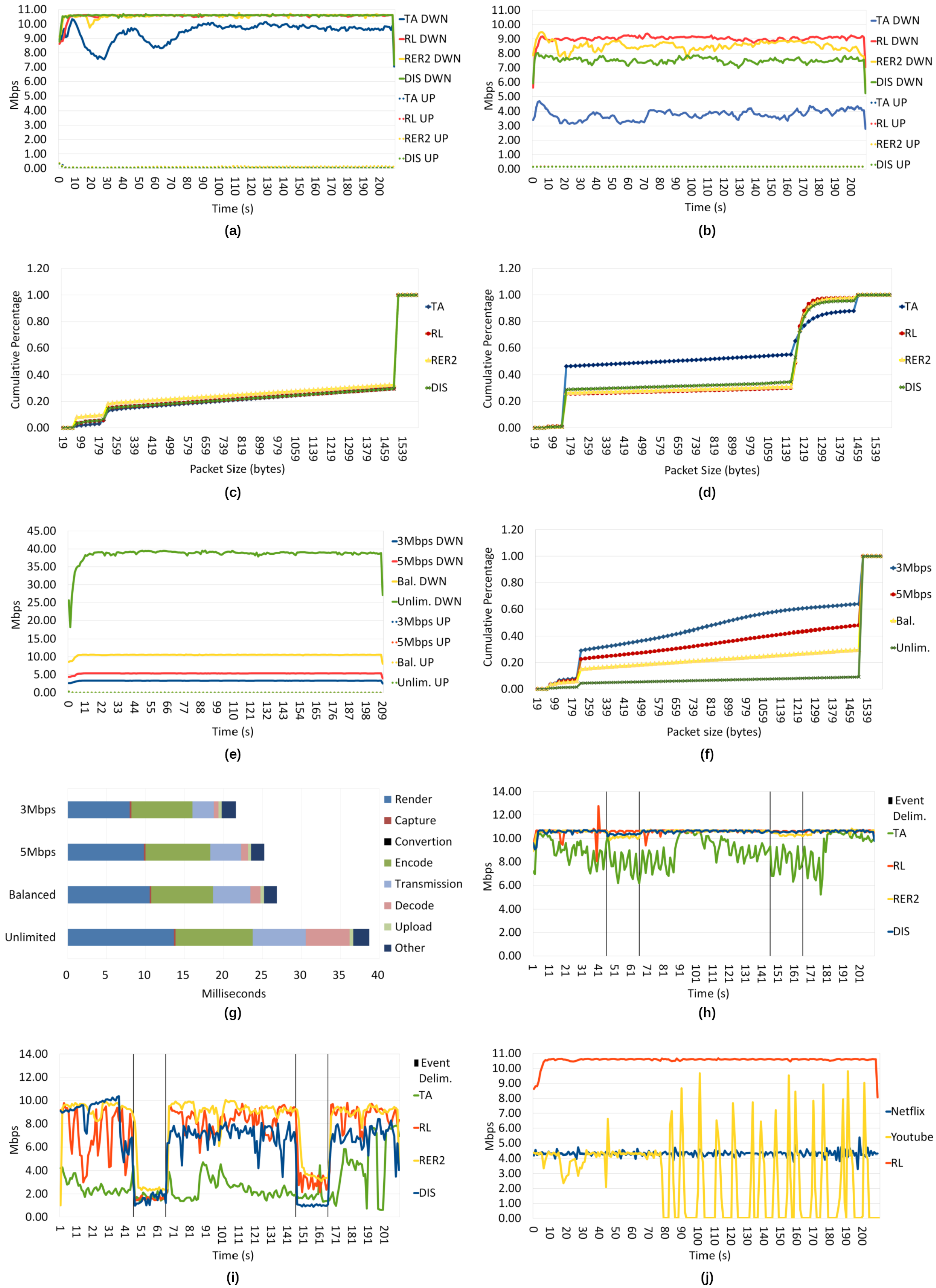

Figure 2: (a) Steam bandwidth usage, downstream and upstream; (b) PS4 bandwidth usage, downstream and upstream; (c) Steam downstream packet size distribution; (d) PS4 downstream packet size distribution; (e) Steam bandwidth usage for different video quality settings; (f) Steam packet size distribution for different video quality settings; (g) Steam game streaming cycle delay time for different video quality settings; (h) Steam, no input during a match; (i) PS4, no input during a match; (j) comparison among games and other OTT video streaming services.

Table 1: Detailed measurements regarding the first set of experiments.

	Titan Attacks		Rocket League		Resident Evil		Dishonored	
PC	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**
Tot. stream size (MB)	247.64	0.6	276.78	1.2	276.85	2.96	277.61	1.28
Tot. packets sent	203,119	4,621	228,475	10,536	237,722	26,871	229,142	11,378
Packets/s	967	22	1,088	50	1,132	128	1,091	54
Avg. packet size (B)	1,219	129	1,211	114	1,165	110	1,211	112
Avg. bandwidth usage (Mbps)	9.43	0.02	10.54	0.05	10.54	0.11	10.58	0.05
PS4	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**
Tot. stream size (MB)	99.11	4.49	236.64	4.71	223.56	4.75	197.14	4.52
Tot. packets sent	141,215	56,244	260,297	58,845	247,401	58,566	224,802	56,347
Packets/s	672	268	1,240	280	1,178	279	1,070	268
Avg. packet size (B)	702	80	909	80	904	81	877	80
Avg. bandwidth usage (Mbps)	3.78	0.17	9.02	0.18	8.52	0.18	7.51	0.17

Table 2: Detailed information about the second set of experiments.

	3 Mbps		5 Mbps		Balanced		Unlimited	
	Down	**Up**	**Down**	**Up**	**Down**	**Up**	**Down**	**Up**
Tot. stream size (MB)	87	0.622	140.900	0.706	276.780	1.200	1,000	1.070
Tot. packets sent	100,313	5,455	134,829	6,152	228,475	10,536	711,741	6,643
Packets/s	478	26	642	29	1,088	50	3,389	32
Avg. packet size (B)	871	114	1,045	115	1,211	114	1,419	162
Avg. bandwidth usage (Mbps)	3.328	0.024	5.368	0.027	0.046	0.046	38.496	0.041

Figure 2 (e) shows that the bandwidth usage for the selected game with various quality settings has quite a regular trend in all the four experiments. This tells us that the Steam In-Home Streaming tends to use all the available bandwidth in each session. This can be observed by checking the 3 Mbps, 5 Mbps and Unlimited downstream flows. The only exception is the Balanced flow, which tends to use a quantity of bandwidth that does not saturate the network bandwidth while guaranteeing a good QoS. However, the most interesting outcome is related to the bandwidth utilization in case of the Unlimited settings. Our tests recorded an average of 38.4 Mbps amounting to a near total of 1000 MB of video stream for a match lasting 210 s (Table 2). In terms of video quality, this means that the Unlimited settings tries to replicate the same video quality of a dedicated gaming device through streaming, applying a low level of compression.

Coherently with these outcomes, the distribution of the packet size shows that the Unlimited downstream flow uses a very low quantity of packets in the interval 0-1500 B, around 10%, with the remaining 90% located in the interval 1500-1600 B (Figure 2 (f)). This is expected considering that Steam In-Home Streaming applies a low image compression to improve the QoE.

4.3. Answer to **Q3**: Delays Introduced by the Game Streaming Cycle

To measure the delay introduced by Steam In-Home Streaming, we used the Steam debug tool that reports the delay performance of the service. The delay that we are describing is not comprehensive of the Internet latency as the original contribution of our analysis is specifically on the game streaming cycle delay added by the considered service, whereas the impact of the Internet-related lag has been already largely discussed in literature [1], [11], [15], [16].

The measured delay includes 8 different parts/values, each representing various phases of the game-streaming cycle. *Render* represents the time taken by the server to generate (render) the new game state based on the user's inputs. *Capture*, *conversion* and *encode* denote the capture and generation of a frame on the server machine. *Transmission* corresponds to the time taken to send a frame to the client, while *decode* represents the time taken to decode and render the content on the client-side. *Upload* denotes the time needed to detect and transmit the client-side inputs to the server. Finally, *Other* represents the time that elapses among the 7 phases.

As can be observed in Figure 2 (g), the delay distribution for the first three video stream quality settings is quite similar, with $encoding$, $transmission$ and $decoding$ accounting for the main portion of the time. Things change in the Unlimited scenario: all quantities generally increase, with decoding being the one subject to the highest increment, that is the decoding time on the client machine. There is in fact a general increment of 44% from the balanced delay (26.38 ms) to the unlimited delay (38.71 ms). This is interesting as it implies that the use of a client device not equipped with dedicated video decoding hardware could represent a source of additional non-negligible delays.

In the tested configurations the total delay added by the play streaming service remains quite below the maximum lag of 100-150 ms endurable by players [1], [11]. This leaves enough delay budget to compensate for possible Internet latency, at least when avoiding excessive distance among game servers and players [12]. Different from classic online games, the available bandwidth turns out to be the toughest challenge here.

4.4. Answer to **Q4**: Limited User Interaction

The third set of experiments includes two types of measurements. We tested PlayStation 4 Remote Play and Steam In-Home Streaming considering two different users' actions: (i) when a game is paused and (ii) when the player is not sending input controls even if the match is still running. To better highlight the occurrence of these actions, in Figure 2 (h) and Figure 2 (i) we delimited the time-lapse between two couples of vertical lines.

Regarding the first measurement, the Steam In-Home Streaming service performs a moderate video compression when the games are displaying the static image of the pause menu with a drop of bandwidth usage from an average of 9 Mbps to an average of 5.6 Mbps. The only exception is Dishonored, a game that has a pause menu involving a dynamic background. On the other hand, the behavior of PlayStation 4 Remote Play is perfectly coherent with what was detected previously: as presented in Figure 2 (i), the static pause menu pushes the service to an extreme image compression that drops the bandwidth usage from an average of 8 Mbps to less than 1.2 Mbps.

The second user action we tested showed very different results depending on the considered service. Steam In-Home Streaming is more sensitive to what is happening on screen and does not compress the video stream even if the camera is stationary and the game shows very few moving elements on the screen. Instead, PlayStation 4 Remote Play applies a more efficient compression during the parts of the match where no input is transmitted with a considerable drop of bandwidth usage from 8 Mbps to 2.4 Mbps.

4.5. Answer to **Q5**: Comparison against Video Streaming Services

As depicted in Figure 2 (j), this set of experiments is aimed at comparing the bandwidth usage of a game streaming service against popular OTT video streaming services like Youtube or Netflix. In this case, we can observe that Netflix, for example, uses less than half of the bandwidth consumed by RL run on Steam In-Home Streaming, when they both use the same resolution (1280x720 pixels). Indeed, games require a higher quantity of details on screen and are generally more lively than movies. Also, redundancy is added to compensate for packet loss and, to preserve interactivity, video compression uses extremely fast (and less effective) encoding modes without bi-directional frame dependencies.

4.6. Answer to **Q6**: Perceived Stream Quality

Direct feedback from potential users can provide useful information about the goals to achieve. To this end, we administered a questionnaire to university students about the perceived quality of the streaming service. In particular, we presented two recorded video streams regarding the same portion of the same match of Rocket League played through Steam In-Home Streaming. The two videos only differ from each other for the video stream quality settings of the Steam client. In particular, for the first video we used a bandwidth limitation that we called Netflix-like settings (Figure 3 (a)) in order to represent the typical network configuration of the Netflix standard subscription on the official Windows application, for the second video, instead, we used the Unlimited settings (Figure 3 (b)).

The survey involves 232 subjects, respectively 210 males and 22 females; 213 of them have an age between 19 and 25 years and only 19 from 26 to 43 years. As shown in Figure 3 (c), the majority of them (49%) play video games daily and another consistent portion (31%) plays video

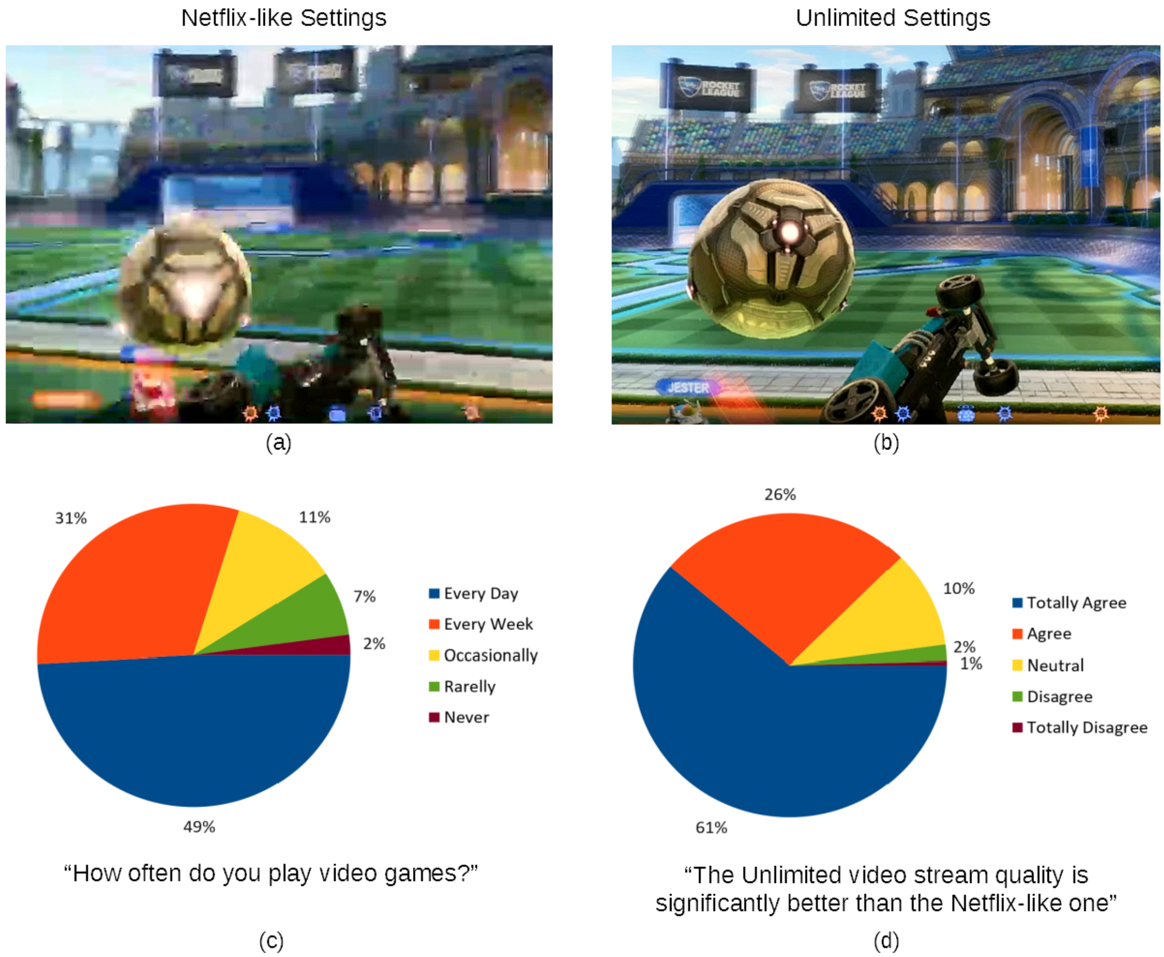

Figure 3: (a) Game screenshot with the bandwidth of the Steam client set to Netflix-like settings; (b) game screenshot with the bandwidth of the Steam client set to Unlimited settings; (c) survey results about the types of players; (d) survey results about the quality of the game settings.

games at least once per week. Only 20% of the subjects plays occasionally or not at all.

When the subjects were asked about the perceived quality of the two different video streams, 87% of them agreed or totally agreed that the Unlimited settings is widely better than the Netflix-like one (Figure 3 (d)). Moreover, 88% of the subjects answered that a price of 14.99€, the official price for a monthly subscription to PlayStation Now at the time of the questionnaire, is not appropriate for a game streaming service with the quality achievable with the Netflix-like settings; they suggested instead an average price of 5.20€. When the same question was asked about the Unlimited service quality, 63% of the subjects answered that the price of 14.99€ is adequate.

5. Concluding Remarks

Our analysis demonstrates that, despite similar configuration settings, the PlayStation 4 Remote Play and Steam In-Home Streaming show some significant differences on how they compress the video stream. The former applies a more efficient compression that takes advantage of the specific characteristics of the played game, whereas the latter blindly uses a larger quantity of bandwidth.

Furthermore, when Steam In-Home Streaming is in Unlimited mode, trying to offer a video quality as near as possible to a game device, about 40 Mbps are required. This makes it difficult to support a visual experience on par with a dedicated game device given the current broadband access speed, even in western countries.

The delay of these services increases on the basis of the video quality and we observed that even the computational capabilities of the client devices could impact the global performance. Finally, the outcome of our survey reports that the users are interested in purchasing similar services only if the video stream quality is adequate and can guarantee a visual experience similar to the one obtained with dedicated devices.

The unhappy ending already experienced by other game streaming services like OnLive and Gaikai is still a real threat. To compete with classic dedicated game devices or online game options, game streaming services have both to go beyond the well known Internet latency issue and heavily rely on a wide availability of broadband connectivity. Unfortunately, this is not yet a common domestic scenario. Therefore, either researchers and developers succeed in improving the real time compression of high quality game streaming into smaller downstream flows, without sacrificing interactivity, or service providers have to partner with broadband providers to offer joint subscriptions. In any case, game streaming services represent an opportunity for researchers to address even tougher networked multimedia issues than those experienced so far.

6. ACKNOWLEDGMENT

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