The Prospects of Cloud Gaming: Do the Benefits Outweigh the Costs?

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***Abstract*—In recent years, cloud gaming has become a popular research topic and has claimed many benefits in the commercial domain over conventional gaming. While, cloud gaming platforms have frequently failed in the past, they have received a new impetus over the last years that brought it to the edge of commercial breakthrough. The fragility of the cloud gaming market may be caused by the high investment costs, offered pricing models or competition from existing "à la carte" platforms. This paper aims at investigating the costs and benefits of both platform types through a twofold approach. We first take on the perspective of the customers, and investigate several cloud gaming platforms and their pricing models in comparison to the costs of other gaming platforms. Then, we explore engagement metrics in order to assess the enjoyment of playing the offered games. Lastly, coming from the perspective of the service providers, we aim to identify challenges in cost-effectively operating a large-scale cloud gaming service while maintaining high QoE values. Our analysis provides initial, yet still comprehensive reasons and models for the prospects of cloud gaming in a highly competitive market.**

Preface

This paper was originally written in 2016 as a collaboration between colleagues from the University of Duisburg-Essen and University of Vienna, but was never published. Since then the second wave of cloud gaming platforms have emerged and the paper has, subsequently, been updated in 2020.

Still in 2020, we think it is important to understand why the first wave of commercial cloud gaming services failed to take off in order to understand the merit of the the current second wave of services. While this paper definitely did not provide conclusive answers to this question, it does offer some unique perspectives and discussions from a user- and operator-centric techno-economic point of view. We think, these ideas might be of even more merit today, and might help to better assess the current second wave of cloud services. We are also still engaged in this line of research, and we strive to continue this work in the future, and are looking for scientific exchange on cloud gaming platforms.

Therefore, we wanted to preserve this work in the form it was originally prepared in 2016, with updated affiliations, restored links, other minor updates and corrections, and this preface. Past reviewers of this manuscript mostly criticized a bias against new cloud services, given that they were comparatively young and, thus, naturally had a more limited offering. In addition it was criticized that the inherent underlying quality issues, strict requirements, and additionally incurred costs to the users (e.g., more expensive data plans) of cloud gaming were not tackled here. Our discussion points were based on very specific subjective data (e.g., review scores, game lengths), which might not be entirely representative of users and platforms. On the other hand, reviewers praised the interesting and novel discussions, based on real data and in comparison of multiple platforms using pricing models and engagement metrics.

I. Introduction

Cloud gaming has become quite a popular research topic in recent years and since the initial publishing in 2016 has been commercially targeted with a second wave of cloud platforms, whose merits are still to be determined. Much of the existing research is aimed at comparing the experienced quality of cloud gaming to that of conventional gaming approaches, often with reasonable results for the streaming approach (cf., for example, [1]). So, if there are only negligible quality drawbacks, what about the commercial success of cloud gaming? Intuitively, one would assume that this could yield substantial benefits in terms of cost and flexibility as a result of scaling effects through the used cloud gaming hardware in comparison to equipment-heavy classical home gaming approaches. However, the cloud gaming market seems to stagnate with a high rate of fluctuation on the market, i.e., a constant stream of market entrances and exits. For example, one of the most prominent services in the past, OnLive, ceased to exist in 2015.

Many cloud gaming approaches that vary by means of technical, service and pricing model differences, have been tested so far, but the public interest remains low. This might be attributed to the broad range of available, established substitutes, e.g., non-cloud gaming platforms such as video game consoles or PCs — with Steam[1] as one of the largest contenders. The move to digital distribution made gaming on PCs quite popular, and PC games pricing became much more dynamic and affordable in the process.

On the surface, current cloud gaming services attempt to adopt a *fixed fee subscription* model over the traditional *à*

[1] http://store.steampowered.com/

la carte model. Fixed fee subscription proved to be hugely successful for other types of media, e.g., NETFLIX for movies and shows or SPOTIFY for music. However, these two types of services offer a much larger catalogue of content at a comparable or even lower price than cloud gaming services. Additionally, streaming asynchronous non-interactive media is technically less demanding (and thus cheaper to operate) than maintaining a quality level on par with that of locally running games.

The two main research questions that this work aims to tackle are thus: *"Can cloud gaming be attractive for users in today's highly competitive market?"* and *"Can you operate a cloud gaming service with acceptable margins while maintaining acceptable quality levels?"*. Both questions are strongly intertwined as in order to make such services attractive one would have to offer sufficient quality and quantity of games with a competitive pricing while not operating at a loss. Given the current market situation, one could actually paraphrase both questions into one: *"Can you compete with the PC gaming and Steam ecosystem (in terms of quality, prices, and variety)?"*

In order to answer these questions, this paper looks at the perspectives of users and service providers separately, and provides arguments backed by data and simple models. To investigate the customer's perspective we employ domain-specific user engagement metrics (like review scores and lengths and playtimes of games) to compare various services, cloud gaming as well as conventional, to each other. Additionally, using this data models are set up that project the value (in terms of the number of games) a user gets for a certain amount of money. We find that in the investigated cases the cloud gaming services' offer is limited, yet still charges relatively high prices, thus reducing the attractiveness for users in comparison to alternative services. We find this to apply especially for gamers with higher budgets and interest in a larger selection of games.

Due to the limited amount of freely available data on operating a cloud gaming service, the perspective of the cloud gaming operator is investigated by setting up efficiency models centered around the analysis of overbooking practices for server resources. Our initial results hint at the problematic nature of cloud gaming in terms of scaling and cost efficiency. When compared to other cloud services that achieve high values of cost efficiency and capacity utilization, we believe that cloud gaming platforms will be much more peak-oriented and thus achieve much lower values of server utilization. The end-to-end lag requirements of games demand servers located in the user's vicinity, which eliminates most multiplexing gains that a centralized data center could garner over the course of a day. Thus, the scaling benefits may be substantially lower than for other cloud services. Additionally, games require dedicated hardware support, which is of less use to most other cloud service use cases, diminishing the potential of cross-service reuse.

These initial insights do not shed a bright light on the commercial future of cloud gaming services in general. Unless major cost reductions are achieved, while the streaming quality is maintained or even improved, the future of cloud gaming might be bleak. But there still might be some niches to place a cloud gaming service where the competition is less strong — a route that one of the current cloud gaming services already takes. We plan to take a deeper look at all these aspects and provide more detailed models in the future.

This paper is structured as follows: § II provides a brief overview of the related work. Afterwards, § III explains the necessary terms and technical details. The main part of this work encompass §§ IV and V, which conduct the dual-perspective investigation of the cloud gaming providers' service offering and business case. The paper concludes in § VI with some remarks and an outlook.

II. Related Work

This section first revisits operational benefits of cloud gaming and cloud services in general, but also encompasses energy consumption issues. Furthermore, literature on Quality of Experience (QoE) aspects of gaming in general and cloud gaming in particular is covered. These reflect the users' quality expectations but can also outline the requirement for a service's operation.

A. Operational and Efficiency Factors

Many publications on cloud gaming only consider the client's side and often restrict their view to mobile cloud gaming. For example, [2] overviews some general issues of mobile cloud gaming. Several other publications, e.g., [3] and [4] investigate the client device's energy saving potential of mobile cloud gaming but find rather marginal energy savings. A 2014 publication [5] describes some potential benefits of a centralized cloud gaming platforms, however operates under questionable assumptions. Two further papers ([6] and [7]) suggest an optimization model to place and provision cloud gaming VMs in order for a service provider to operate at profits. The impact on QoE, however, seems to be significant but is concealed through the lack of absolute data given. The efficient placement and selection of servers is focal for Cloud services (e.g., [8]), but the optimization potential is limited for cloud gaming due to more stringent requirements both in terms of compute resources as well as latency. This restricts the server selection problem to relatively narrow geographic regions.

B. Gaming QoS/QoE

The quality of games is revisited along the axes of end-to-end (E2E) lag, image quality, and frame rates. Considerable research efforts have been put into the network delay component of the E2E lag for both online games and cloud gaming. The results, however, remain inconclusive. Studies of multiplayer games often focused on First-Person Shooters (FPSs) such as *Quake 3* [9] or *Unreal Tournament 2003* [10]. Concerning cloud gaming, Chen et al. [11] for example find very high and variable delay values even when neglecting the network delay. Furthermore, [12] gives some insights on the delay requirements of streamed games and the implications for data center distance as well as placement.

Image quality represents a further QoE factor. Gaming adds another dimension to typical image quality assessments, as most games allow for changes to their graphical fidelity, be it either the resolution or more demanding graphical features, such as ambient occlusion or anti-aliasing. Cloud gaming usually locks these options at one specific setting for a specific quality-to-resource-demand trade-off, resulting in an often lower source quality than what local games can offer. As an example, the work in [13] takes a look at different encoding parameters for cloud gaming.

Finally, and often neglected, is the game's frame rate and the streaming frame rate. Due to the interactivity of the media the requirements are generally higher than for video streaming, e.g., $60\,\mathrm{Hz}$ is an accepted standard for many games. Too low frame rates will result in a reduced quality due to observable stuttering and issues with inputting commands. An overview of some further QoE taxonomy and influence factors especially for mobile games is given in [14]. Several efforts also set up subjective tests of cloud gaming services with specific Quality of Service (QoS) parameters in mind. Such studies can be found in, e.g., [15] and [16]. Efforts have also been made towards an ITU-T recommendation for subjective game testing as reported in [17].

III. Characterizing Platforms and Games

This section covers the basic characteristics of different gaming platform types, most notably the traditional *à la carte* model and *fixed fee subscription* cloud gaming approaches. Section IV will then use these characteristics to reason about player engagement and budget considerations.

A. Platform Characteristics

Below, currently active (cloud and other) gaming platforms are examined with regards to pricing models and hardware requirements and costs. The information presented was collected between July 2015 and February 2016. All costs are from an European, specifically German, perspective. If a product is not available in this region, the prices are converted using the most recent currency exchange rates.

1) Video Game Consoles: A classical approach to video gaming is using dedicated consoles with physical copies of game media (e.g., a BD) bought at a retailer. The price for (non-portable) consoles varies but usually lies between €300 and €400 for the latest console generation, i.e., *Wii U*, *PlayStation 4*, and *Xbox One*. New, major game releases are mostly priced at either €60 or €70. Once on the market, the game prices decrease rather slowly. In recent years, retail stores have been complemented with console-specific, proprietary digital distribution services that also offer the latest game at the full price. These official stores are usually exclusive vendors for digital game codes where competitors are excluded. Subscription fees often apply for the multiplayer mode of games, e.g., *PlayStation Plus* or *Xbox Live Gold* with annual prices of €50 and €60, respectively. These services also include access to a small, monthly changing palette of older titles.

2) The PC Gaming Ecosystem: The rise of easy-to-use digital distribution platforms and the independent ("indie") game scene reinvigorated PC gaming just a few years ago. Today, PC gaming is dominated by large digital marketplaces, with STEAM being the largest. The platform has about 10 million concurrent users at most times of the day. It periodically offers large, often seasonal, sales of recent games at greatly reduced prices (rebates of 75% for a year-old game are not uncommon). In addition, many resellers offer digital codes for other platforms, often at much lower prices. Major releases on PC are usually priced between €50 and €60. However, due to the competition between the vendors, the digital retail prices are significantly lower even at launch, and also drop more quickly. Another recent trend are game bundles, which especially prevalent in the indie games scene, commonly offered with a pay-what-you-want model. *Humble Bundle*[2] is a prominent example.

Hardware viable for PC gaming starts at about €500 but has practically no upper limit for enthusiasts (especially the Graphics Processing Unit (GPU) is a cost driver, but essential for modern PC gaming). Thus, the barrier for customers to start PC gaming is higher than for consoles, which is, however, compensated by an increased flexibility and longevity of hardware.

3) Geforce NOW: NVIDIA's cloud gaming serviceis available in North America and select European countries. Like in all cloud gaming services games are executed and rendered "in the cloud" (i.e., in remote data centers), and an audio/video stream is sent back to the player. In Germany the service currently offers 68 PC titles for a monthly subscription fee of €10. An additional per-game one-time fee between €13 and €60 is charged for the access to the 19 most prominent and recent games. The service is delivered from six specialized data center locations (Dublin and Frankfurt in Europe).

The requirements to use this service are rather steep, demanding $50\,\frac{\mathrm{Mbit}}{\mathrm{s}}$ for a full 1080p60[3] stream ($10\,\frac{\mathrm{Mbit}}{\mathrm{s}}$ in order to use the service at all) and a maximum RTT of $60\,\mathrm{ms}$ to one of the data centers. In addition, streaming is exclusive to *SHIELD* devices which start at €200.

4) PlayStation Now: Sony's cloud gaming service offers to stream titles from previous PlayStation generations, as the latest console generation lacks backwards compatibility. It is currently available in North America and the UK, with a closed beta running in other European countries and Japan. The offered titles and exact pricing vary from country to country. For the UK, about 190 titles are available, and most titles are covered by the monthly subscription fee of about €17. All titles are also available through a separate rental service, costing about €4 for $48\,\mathrm{h}$ and €10 for one month of

[2] https://www.humblebundle.com/

[3] Please note: This frame rate of $60\,\mathrm{Hz}$ represents the rate of the video encoder and not the game's actual frame rate, which might be considerably lower depending on the complexity of the game.

access. This is in addition for the device cost, as the service is only available on PlayStation 4 and 3 consoles as well as some select Sony TVs and other devices with extra game controller.

The streaming itself is performed at a resolution of 720p60 requiring a $5\,\frac{\mathrm{Mbit}}{\mathrm{s}}$ connection. Reports on the video quality have been rather mixed.[4]

B. Characteristics of Games

Following the discussion of gaming platform characteristics, the attention now turns to the properties of the actual games offered on the various platforms: number of games, ages, lengths, prices, and review scores. Table I provides an overview of the data. In order to investigate these characteristics, data was collected from multiple sources and merged (with a few instances of omission and double-count) into a data base. In the interest of repeatability and reproducibility, all of the data reported on in this work, as well as the code used to collect and process it, can be found in public repositories[5]. Please note that due to space constraints and the multidimensional nature of the dataset, only a limited number of findings can be presented in this paper.

1) Number of Games: This basic metric quantifies the range of games on offer. The two cloud platforms offer a very limited number of games when compared to the games available on STEAM, which itself again only represents a subset of all games available either on the PC platform (METACRITIC lists 16192) or across all platforms (45803 listed on the site). Two possible, simple explanations for the low game count on the cloud platforms come to mind: One is that they were launched relatively recently (2015) in comparison to STEAM (2003), leaving little time for the range of games to grow. Secondly, the choice of games for a cloud gaming platform is necessarily curated by the platform operator due to compatibility and performance reasons. This usability burden shifts to the end user for digital storefronts like STEAM, allowing these platforms to offer a larger variety of games, including ones that are very demanding on the hardware.

2) Game Ages: The age of a game is computable from its release date. To this end, the METACRITIC[6] page which aggregates reviews of video games (and other media) was scraped[7]. Game ages appear to be relatively high for all of the investigated platforms, and particularly so for PLAYSTATION NOW. It might be considered a special case, as it is specifically advertised as a backwards compatibility for older, pre-PlayStation 4 games that do not run on the latest Sony platform any more. For STEAM, the distribution is significantly skewed towards recent titles: A quarter of games are less than 10 months old, and the median is at 21 months. The distribution's tail extends well beyond 25 years (due to re-releases of "classic" games on the platform).

[4]http://www.eurogamer.net/articles/digitalfoundry-2015-hands-on-with-playstation-now

[5]The main repository can be found at https://github.com/mas-ude/cost-of-cloud-gaming

[6]http://www.metacritic.com/

[7]https://github.com/mas-ude/metacritic_scraper

Figure 1: Violin plot of the per-platform average game lengths from HOW LONG TO BEAT. The number of games per bin are 68, 209, 7764, and 18433; quartiles indicated by horizontal lines.

3) Game Lengths: Game publishers are usually not outspoken about the intended playthrough length of games (nor do all games necessarily have a logical end, and thus no useful definition of a playthrough length). However, players may self-report their experienced playthrough times on sites like HOW LONG TO BEAT[8], on whose data this analysis is based[9]. Figure 1 shows the distribution of aggregated game lengths for the three platforms under investigation, and an "overall" distribution that includes further platforms and gaming systems. Among the three platforms, the mean and median reported game lengths (approximately 14 h) are largest for GEFORCE NOW. In contrast to the curated choice of games on the Cloud systems, STEAM also offers shorter and longer games.

4) Game Prices: Trying to compare the prices per game is a difficult endeavor, due to the mixed approach of both cloud gaming platforms. The GEFORCE NOW subscription gives you access to a subset of its catalog that can be extended by purchasing additional games. Similarly, PLAYSTATION NOW has a base subscription catalog and additional, rent-able titles. But in addition, every title can also be rented without the need for an active subscription. Nevertheless, for STEAM it is possible to discuss unit prices: Using the official REST API, name and current price of each game were fetched at three different points in time[10]. This data was combined with API data from the 3rd-party site *SteamSpy*[11], which parses all publicly visible STEAM user profiles. Subsequently, *SteamSpy* estimates statistics on the size of the player base and the time each player spends with a title. Furthermore, the site provides a heuristic projection of the total number of owners of each listed title on STEAM. Using the combined data, additional perspectives can be given.

[8]http://howlongtobeat.com/

[9]https://github.com/mas-ude/gamelengths-scraper

[10]https://github.com/mas-ude/steam-data-stats

[11]https://steamspy.com

Table I: Game characteristics on the investigated platforms. Title counts from Web/API scraping, lengths from HOW LONG TO BEAT, ages and review scores from METACRITIC.

Service	Titles	Age μ	Age σ	Length μ	Length σ	Score μ	Score σ
GEFORCE NOW	68	2.87 yrs	1.95 yrs	14.65 h	14.44 h	75.9	9.44
PLAYSTATION NOW	191	5.24 yrs	2.55 yrs	12.26 h	15.47 h	76.72	11.43
STEAM	7749	3.36 yrs	3.95 yrs	13.02 h	20.49 h	71	12

Table II: Average prices for STEAM games.

	2015-07-14	**2015-10-30**	**2016-02-06**
Portfolio price (€)	10.11	8.47	5.65
Weighted price (€)	12.39	10.21	5.30

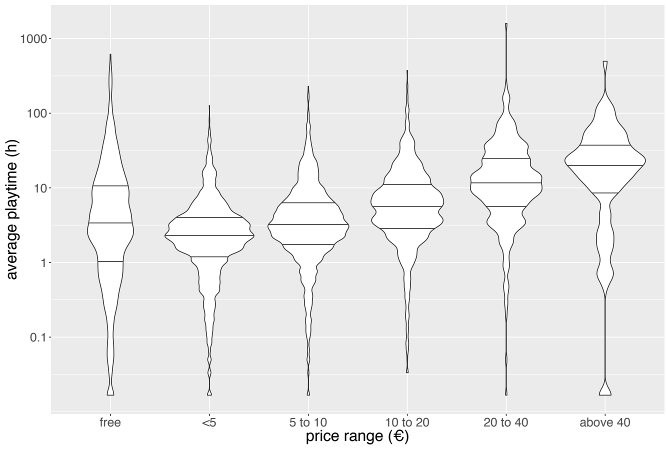

Figure 2: Violin plot of the average playtime of STEAM games, broadly categorized by their prices. The number of games per bin are 1122, 2177, 1946, 1106, 328, and 90.

Table II shows the development of average STEAM game prices for the three measurements taken. Two different types of averages are shown: The portfolio price which averages over all current game prices, and the weighted price which is the product of game price and estimated number of owners, averaged over the total number of games owned. Strong temporal effects are evident from either metric. Note that the last measurement shortly predates 2016's Lunar New Year, around which STEAM ran a large seasonal sales campaign[12].

Figure 2 breaks down the distribution of average playtimes per game price range. The game price ranges are chosen so as to roughly separate the prevalent modes of the price distribution. Playtime is defined as the time game owners spend playing a game, as recorded by the STEAM platform and scraped from *SteamSpy*. As can be seen, the playtimes generally increase with the price range; unfortunately, the data does not explain the cause: E.g., more expensive games might have more playable content, causing the playtime to increase. Conversely, higher upfront costs may incite players to spend more time regardless of game quality, thus avoiding regret for the expense. On the far left in the Figure, playtimes of

[12]http://store.steampowered.com/news/20313/

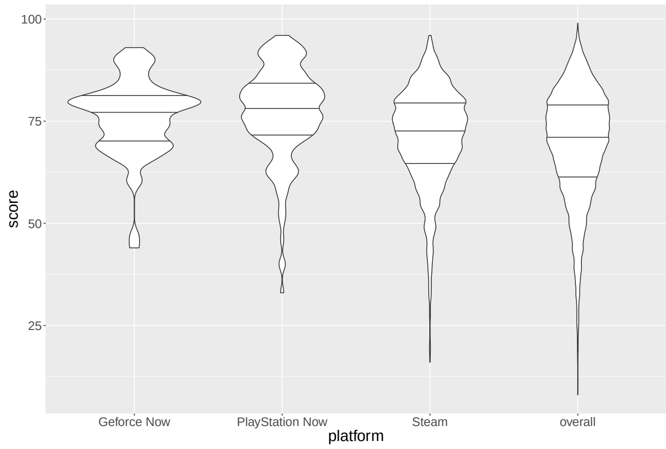

Figure 3: Violin plot of aggregated review scores per platform. The number of games per bin are 68, 209, 7759, and 46197. Overall represents all games scraped from METACRITIC.

"free" titles (including free-to-play games with monetization options other than an upfront payment) span almost the whole playtime range with less pronounced prevalences. Due to the strong popularity of STEAM in PC gaming (even physical retail copies often require using the service nowadays) this set also gives a good general overview of the dimensions of PC gaming in general.

5) Review Scores: The final characteristic in this analysis are game review scores as given by professional gaming media outlets. This relies on the METACRITIC dataset again. This set covers review scores for all current and historic gaming platforms. The review scores are aggregated to average scores ranging between 0 and 100. Some METACRITIC-internal weighing factors are applied to express the importance of some media outlets over others. The average scores seem quite similar across all services, albeit with a slightly lower σ for GEFORCE NOW. Figure 3 shows the distribution of review scores per platform. Both Cloud services seem to favor certain score levels. Specifically, their lowest quartiles (representing the worst-rated games on these platforms) reach much higher values than STEAM's. This could be an effect of the Cloud systems curating the game offer to focus on highly-rated (and thus perhaps more attractive) titles. STEAM on the other side is a more or less open platform, where every game publisher can sell their games at their own volition (platform operator collects a commission fee for sales). Consequently, it is reasonable to assume more variation in the quality of games, which could in turn lead to mixed reviews.

IV. User Perspective and Prospects

This section interprets the previous results from the point of view of an end customer. Section IV-A reviews game and platform characteristics as possible engagement metrics, i.e., measures for the attractiveness of a platform. Section IV-B constructs two simple cost/benefit models based on the platform costs and the number of games affordable as a benefit metric.

A. Engagement Metrics

The benefit that platform and game characteristics create for different types of gamers are diverse, which will be reflected in the following interpretations.

1) Number of games: The number of games for the three platforms are widely dissimilar, making the choice unanimous for gamers that favour wider ranges of offers. Other factors motivating different platform choices might be found in already-owned console hardware, or platform-exclusive titles.

2) Age of games: This has multiple possible effects on attractiveness. Older games might be more likely to be considered "classics". On the other hand, newer games tend to also be topics in the media (and in advertising, increasing their publicity), offer a greater diversity (e.g., regarding game mechanics and control), and feature improved technical quality (resolution, scene complexity).

3) Game lengths: It can be argued that engagement due to game length should be considered differently depending on the player type. For casual gamers, shorter games probably have more appeal, as their limited playtime is more likely to allow players to complete them. "Hardcore" gamers that spend more time gaming overall might find longer games more engaging. If a gaming platform wants to attract members of both crowds, it should thus offer a wide range of game lengths. Figure 4 plots the number of owners of games on STEAM over the combined game length from the HOW LONG TO BEAT dataset. A small positive effect exists (Pearson correlation $r = 0.175$), indicating that longer games attract more buyers, or (swapping cause and effect) that more people tend to buy longer games.

4) Review scores: Published scores for games constitute an additional social factor, in that gamers might be drawn to positively-reviewed titles more strongly. Taking game ownership as a possible indicator for the popularity of a game, the METACRITIC dataset exhibits a small positive correlation between general score and number of game ownerships on STEAM (Pearson correlation coefficient $r = 0.199$).

5) Further Potential Engagement Factors: Due to the limited amount of available data the number of currently observable potential engagement metrics is restricted. However, many more come to mind and are worth investigating in the future. These could include:

- the number of platform "exclusive" game titles,
- the genre as well as other classifications of games,
- the number of game sales and subscriber numbers,
- technical aspects like graphical fidelity, performance, precision and responsiveness of controls,

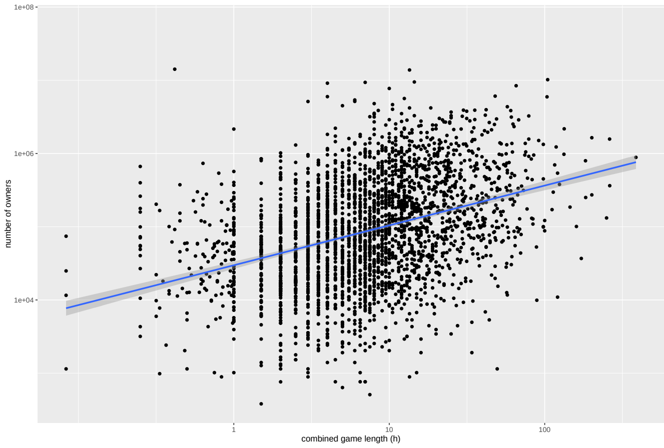

Figure 4: Relationship of game lengths to ownership.

- measures of the game's content like variety and quality of game mechanics,
- or other content-centric factors.

B. Cost-Benefit Models

This section now turns to modeling gamer benefit as a function of cost: The number of games playable, given the amount of money paid. The two models presented express how many games a given budget will buy on the different platforms, as a function of the customer's budget, and over years, given a constant yearly expenditure. (Other benefits could be modeled as well, e.g., the distribution of review scores or hours of gameplay, but this is left for future work.)

A few basic assumptions are made. The initial hardware costs are factored in proportionately to the expected life and depreciation time of the devices, which is assumed to be 3 yrs for PCs, and 6 yrs for the consoles and devices necessary to receive the streaming service. The difference in the service models between the ownership model of STEAM, the hybrid subscription plus permanent rental model of GEFORCE NOW, as well as the subscription and timed rental model of PLAYSTATION NOW were discussed in the previous section already. Since it is difficult to express the different notions of "being able to play" and "owning" a game in simple terms, our benefit models just consider the number of games that one has access to and that could have been played at one point. (This also ignores other means of acquiring games cheaper from alternative storefronts). Lastly, the numbers of games available per platform and the game and subscription fees are considered as fixed at their current values.

a) Affordable Games on a Budget Model: The first model assumes that one has a fixed budget to spend on video games. This model then shows, depending on the size of the budget, how many games one would be able to afford considering all initial and continual costs. Figure 5 shows that all platforms start with relatively high fixed costs (including hardware depreciation and subscription fees as applicable). The subscription models provide instant access to a certain amount of titles (visible as "steps upwards" in the available game count)

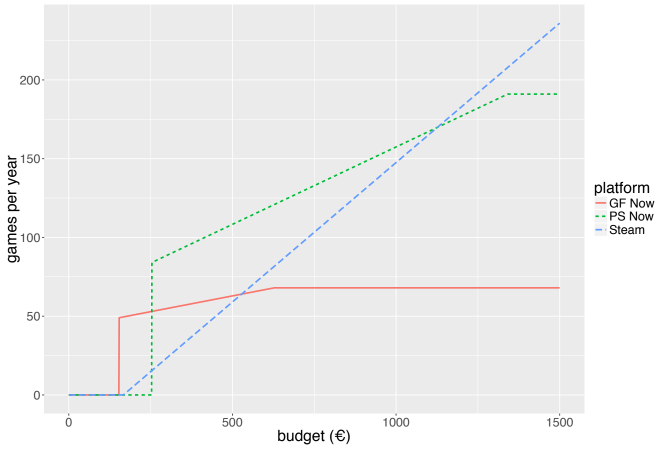

Figure 5: Affordable games per year on different platforms, given the customer's budget

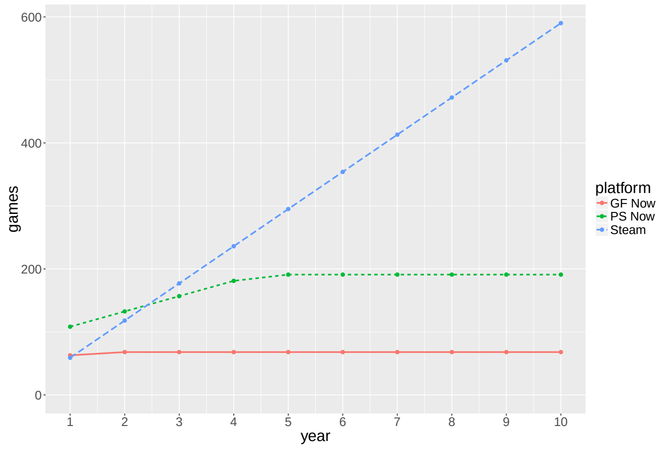

Figure 6: Number of affordable games per platform, assuming a yearly customer expenditure of €500.

which could make them more attractive to newcomers on a low budget. However, both cloud platforms exhibit plateaus due to the relatively small selection of games available. On the other hand, STEAM's offer of more than 7000 titles is far from depleted at above €1000 worth of games.

b) Affordable Games per Year Model: The second model extends the previous one to span a period of multiple years, investigating the value one gets if a constant annual budget is spent. For the exemplary model, the budget is assumed to be €500. Figure 6 depicts this example over ten years. On the two cloud platforms, the continual subscription costs limit the remaining budget for additional rental titles until the maximum number of titles is reached with that particular service, whereas the number of titles from STEAM climbs steadily. The benefits of a multi-year commitment to these cloud gaming services therefore seem to be very limited, especially when considering that no games are retained after ending the subscription.

Increasing the annual budget further (to €1000) exhausts the limited number of games on PLAYSTATION NOW and GEFORCE NOW in or after the first year, respectively. Conversely, if only €260 per year are available to spend on gaming, the cloud platforms' offers are larger than STEAM's for four to six years.

C. Discussion

This section mapped game and platform characteristics into simple user engagement metrics. For example, it is plausible that platforms with more, newer, and better-rated games attract more gamers; diversely distributed game lengths could be seen as catering to casual and dedicated gamer crowds likewise. In terms of cost considerations, our models indicate that the current offers of GEFORCE NOW and PLAYSTATION NOW best fit gamers on low budgets: Limitations on the amount of money that can be spent may somewhat mask the smaller range of offered games. If this is true, it further increases the economical pressure on cloud gaming platforms (as discussed in the following section). Overall, these investigations expose the difference between an open market platform and the curated-by-necessity cloud gaming services.

V. SUPPLY-SIDE EFFICIENCY MODELING

This section assesses the supply-side of the cloud gaming market with a strong focus on costs. The remainder of this section first clarifies typical cost factors in the cloud gaming market and then continues with a specific efficiency model formulation that responds to the demand-side findings of previous sections.

A. Cost Factors

The dominating cost factor in cloud gaming is the server infrastructure, both in terms of CAPital EXpenditure (CAPEX) and OPerational EXpenditure (OPEX). The low latency requirements of many games requires a regionally-oriented cloud infrastructure, i.e., regional data centers are used to provide high-quality and low-latency service. Due to the specific demands of games, specialized hardware is used (e.g., with GPU-enabled CPUs), rather than generic cloud servers. These factors increase the CAPEX for cloud service operators, but also lower the efficiency of the system, as more generic and more globalized cloud services cloud yield scaling advantages. Moreover, the rental of generic cloud service hardware or resources seems to be unrealistic due to the lowered efficiency — cloud services are typically data-centric, while gaming is graphics-intense. The OPEX is limited to maintenance activities, consumables, Internet access fees and energy.

In addition, game license fees have to be considered as noteworthy CAPEX (or potentially also OPEX, depending on the license models). Depending on the licensing model, a flat license (one-time price for an unlimited number of subscribers), volume licenses, or per-use or per usage fees may be arranged with license owners. In all cases, scaling effects probably exist: the initial CAPEX is high in terms of license arrangement costs and initial fees, while marginal costs decrease for additional subscribers.

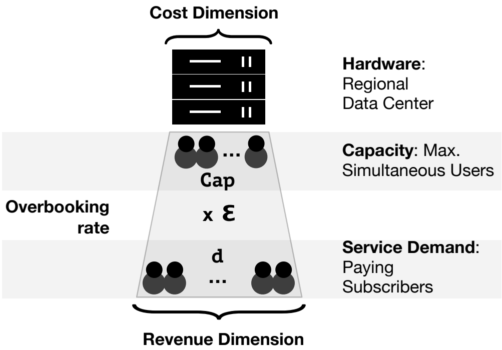

Figure 7: Overbooking of available computational capacity.

On the customer-side, the subscription or per-game prices represent costs that create the revenue for the cloud gaming provider and for the game license owners. Customers typically also require specific gaming hardware to connect to the platform, which can be cheaper than high-end gaming hardware, but may lower the added value over hardware-intensive conventional gaming approaches.

B. Model

Based on the collected consumer price figures, this section will elaborate on the required computational efficiency, i.e., cost per hosted subscriber, in order to successfully establish cloud gaming approaches on the market. Due to the limited available data, this investigation will follow a single data center assumption. Due to the demands of cloud gaming to serve both at high performance and low latency, regional data centers will play a dominant role in the provider side cost modeling. Following this assumption, hereinafter a specific model is created that characterizes at which cost efficiency levels the cloud gaming business can be operated successfully.

The model (Figure 7) is motivated as follows: a cloud gaming operator must provide a certain data center capacity Cap of slots for the maximum number of gamers that can play simultaneously, so as to provide sufficient availability and quality. This incurs an overall cost of $\mathcal{C}_{Cap}$. Active players recruit from the overall number of subscribers, denoted as the total service demand d. In general, not all subscribers will play at the same time. This allows for an overbooking factor ϵ on the data center resources so that $Cap \cdot \epsilon = d$. The larger the overbooking factor can be made without impacting quality for active players, the smaller the data center capacity may be dimensioned. The overall cost must not exceed the average price $\bar{p}$ paid by a subscriber times the the number of subscribers; scaling this limit to the number of concurrently active users yields the maximum cost per active user that the operator can spend

$$\mathcal{C}_u = \frac{\mathcal{C}_{Cap}}{Cap} \leq \frac{\bar{p} \cdot d}{Cap} = \frac{\bar{p} \cdot Cap \cdot \epsilon}{Cap} = \bar{p} \cdot \epsilon. \quad (1)$$

To interpret this relationship, estimates for the overbooking factor and average price are discussed. The costs of the regional data center (CAPEX, OPEX, required game licensing fees) are treated as a black box to simplify the treatment.

A reasonable value for the overbooking factor ϵ may be derived from the number of active STEAM user over the course of two days. As observed[13] between 2016-02-16 and 18, between 6.53M and 11.65M users were connected simultaneously. To gain a conservative estimate, the maximum is set in relationship to the 75 million registered STEAM users[14], and calculate an $\epsilon_{\text{Steam}} \approx 6.44$. For cross-validation purposes, link load levels for other media streaming services may be considered: When comparing the relative load level change between the minimum and maximum utilization of a large Vietnamese ISP's Video on Demand (VoD) streaming server as given in [18], the growth from Steam's minimum to its maximum utilization can be rescaled accordingly. A maximum number of simultaneously connected VoD users of 58.3 million and an ϵ_{sub} of 1.29 are obtained. The discrepancy in overbooking factors may appear high, but the different associated payment modalities may be at cause: While STEAM sells game licenses (of which the buyer may make use any time), VoD services often use a subscription services (a flat rate for a given time period). For the subsequent analysis the range between the minimum of ϵ_{sub} and maximum of ϵ_{Steam} is considered.

The average price $\bar{p}$ is also parameterized on the basis of the collected STEAM data. To reflect the range of the data (see Tbl. II), the minimum and the maximum values are used as inputs for the subsequent cost considerations: $\bar{p}_{\text{min}} = 5.30$, $\bar{p}_{\text{max}} = 12.39$. (For comparison, the monthly subscription rate for PLAYSTATION NOW UK is roughly €16.53.)

Lastly (but ignored in the model), the operator may expect a profit margin of $3\,\%$[15] to $16.9\,\%$[16] (or even higher[17]). Requiring a higher profit margin transitively lowers the maximum cost per active user that the operator can tolerate.

Applying the different mean prices and ϵ values, it can be inferred that the monthly capacity and licensing cost per peak time user $\mathcal{C}_u$ must not exceed $\epsilon_{\text{sub}} \cdot \bar{p}_{\text{min}} =$ €6.81 (lower bound scenario) to $\epsilon_{\text{Steam}} \cdot \bar{p}_{\text{max}} =$ €79.80, both excluding a profit margin. Scaling these costs to STEAM's peak time population of 11.65M yields ranges for the maximum allowable server capacity costs $\mathcal{C}_{\text{Cap}}$ per month of €$79.4\,\text{M}$ to €$929.3\,\text{M}$ for a cloud game service of the size of STEAM.

In that respect, cost optimizations beside the classical capacity dimensioning also deserve attention. Due to the requirement of using special gaming equipment, however, sharing hardware with other cloud applications seems unrealistic. Thus $\mathcal{C}_u$ can hardly be reduced by cloud service collaboration. However, to lower the investment demands, the platform

[13] http://store.steampowered.com/stats/

[14] http://venturebeat.com/2014/01/15/steam-has-75-million-registered-users-third-party-steam-controllers-and-other-tidbits-from-valves-dev-days/

[15] http://www.polygon.com/2012/10/1/3439738/the-state-of-games-state-of-aaa

[16] http://www.forbes.com/sites/georgeanders/2015/04/23/amazons-web-services-delight-16-9-margins-more-joy-ahead/\#73324aa64b4e

[17] http://www.bloomberg.com/news/articles/2015-12-02/microsoft-should-disclose-cloud-revenue-margins-ballmer-says

operator could aim at increasing the overbooking ratio ϵ_{sub} for the subscription case closer to the ϵ_{steam} of the classical purchasing model. The provider could, for example, offer off-peak subscriptions that allow the access to the platform only outside of peak hours.

Furthermore, the maximum per-user cost figures do not consider that the operator may not be able to fully utilize the available capacity or may not hold the optimal game licenses at all times. Thus, in practice, target $\mathcal{C}_u$ values should be lower than the calculated values.

Nevertheless, this cost perspective still points to an interesting observation: the low ϵ_{sub} requires a data center capacity closer to the total service demand. Thus, subscription-based cloud gaming approaches have a higher cost pressure than in the case of a more conventional game sales approach (ϵ_{steam}). When setting the cost perspective in relationship to the product offers, the business challenges of cloud-based game providers become apparent. In particular, the high cost pressures seem to lead to a tightly curated game offering approach — i.e., a small number of offerings (see Tbl. 4), good overall scores (see Figure 3) — where only economically attractive games can be offered for subscription plans. This is very likely caused by the underlying scale-oriented licensing practices that favor high volumes — i.e., the initial CAPEX is high, but the marginal cost decrease afterwards (Update note 2020: This cost modality may have changed over time. We recommend considering models will distinct entrances barriers for new games). The limited game offering for cloud-based services, as a result of cost factors and limited scaling advantages on the hardware side, however, reduces the utility for the customer, which should lower their willingness-to-pay. Obviously, this induces a particularly challenging business environment in which operators go out of business on a regular basis. This further explains why cloud gaming has remained a small niche despite the high interest by industry, research and probably also customers (Update note 2020: It will remain to be seen, if the second wave of cloud gaming platform will use a different licensing scheme or may profit from technical scalability advancements that may generate better prospects than for the first wave of platforms).

VI. Conclusion

While cloud gaming is a topic of strong interest, it comes with a series of problems and limitations, both of technical and economic nature. Our user-side analysis makes apparent the curated nature of current cloud gaming services which entails a narrow offer of hand-selected games and sometimes even a narrow target group (see the case of PLAYSTATION NOW). This naturally limits the value of a subscription-based service model for customers, when insufficient convenience and price advantages can be yielded.

In addition to that, the operator-side also reveals major issues due to the need for highly regional data-centers and specialized hardware. This eliminates any chance for the efficiency gains that general cloud services are intended for. Moreover, subscription-based models suffer from the expected higher peak utilization in comparison to à la carte game purchasing models, which creates a high cost pressure due to enormous infrastructure investments and limited scaling advantages.

However, there might be some niches for specific games or audiences that could be sustained at reduced operational efforts. This might be an angle worth of investigation in the future, especially with better engagement metrics and more detailed models of gaming data center operations. Another economically more feasible alternative to cloud gaming could be game streaming in the local network. This option would still require all the usual gaming hardware and services like STEAM but would bring all the convenience and flexibility of cloud gaming.

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