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APPLICATION OF CLOUD TECHNOLOGIES IN GAMING

Video-Based Cloud Gaming Services

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Abstract of Thesis

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The purpose of the thesis was to survey the application of cloud computing in gaming. The main goal of the practical research was to review cloud gaming services and estimate their usability by different parameters.

The brief history of cloud gaming, cloud architecture, video-based cloud gaming systems and technologies were described in the theoretical part of the thesis. In the practical part two different cloud gaming services, NVIDIA GeForce NOW and Playkey were tested, analyzed, compared and estimated as eligible products for gamers.

This thesis can be useful for developers, gamers, engineers and everybody, who is interested in working with cloud gaming solutions.

Keywords cloud gaming, gaming as a service, latency, streaming,

CONTENTS

SYMBOLS AND ABBREVIATIONS

AAA	Triple-A – game, developed by a big studio with a huge budget
CCG	Collectible Card Game
CPU	Central Processing Unit
FPS	Frames per Second
GaaS	Gaming as a Service
GPU	Graphics Processing Unit
IaaS	Infrastructure as a Service
IT	Information Technologies
MMORPG	Massively Multiplayer Online Role-Playing Game
MOBA	Multiplayer Online Battle Arena
PaaS	Platform as a Service
PC	Personal Computer
QoE	Quality of Experience
QoS	Quality of Service
RAM	Random Access Memory
RTS	Real-Time Strategy
SaaS	Software as a Service
TBS	Turn-Based Strategy

1 INTRODUCTION

Streaming of video and music to computers and mobile devices through popular cloud services became the main option to get the content for many Internet users. Nowadays, there are huge libraries of media content with permanent access from any device.

Today, technology and progress in gaming are developing so rapidly that the expensive problem of the constant need to maintain hardware in such a condition that the latest performance-demanding games can be run is particularly acute. Not all PC users can afford to regularly update the hardware to play the latest hits. This is the reason why cloud technologies came to the gaming.

Cloud gaming is a tool created for solving this problem. It is quite a young phenomenon in the market of digital, on-demand services, which is in the stage of active development and implementation. In addition, cloud gaming deserves an attention in terms of research because of a variety of solutions, approaches, and methods of implementation.

One of the purposes of this project is to define what is cloud gaming, how it works and how this technology can change the way people playing games. Moreover, results of the research in this project should show, can this technology replace traditional gaming and is it applicable for eSports.

2 CLOUD GAMING BASIS

2.1 Definition

Cloud gaming, or gaming on demand, is a relatively new way to play games on computers, TV set-top boxes and mobile devices. High-performance games are installed and launched on powerful cloud servers owned by a certain company and then streamed to the player's screen in video format. Input data from the user is delivered with the help of usual devices like keyboard, mouse or gamepad. Data is processed and transmitted to a remote server. Then all actions within the game, including execution and rendering, are performed on the remote server, and the information is transmitted back to the screen of the user device via the Internet. (Cai et al. 2016.)

Thanks to this system, the gamer can use a less powerful computer and do not concern about downloading and updating game files on his device. From the user's side, the cloud gaming service looks like a simple program that, depending on the platform providing cloud gaming services, starts the game on the server either from the library provided by the service or from the user's own collection through services such as Steam and Battle.net. (Cai et al. 2016.)

2.2 Background

The history of video games concludes that initially people played on special game consoles and never had any problems with gaming due to the fact that games were optimized for gaming consoles. The user just inserted an electronic cartridge or a CD with a game, which has been optimized for the performance capabilities of a particular gaming console. The interaction between user and console is the same for now. The user purchases a game in a digital store or on a physical medium and runs it on his game console without thinking about performance settings and not worrying that the system resources are not enough for doing it.

At the end of the 20th century, games with elaborate graphics, animation, plot, and design began to appear on personal computers. Personal computers became partly a replacement for game consoles. This time they were could not only run games but also were ready for using the Internet, office programs and utilities, while the game console were suitable only for games. Over time, thanks to the rapidly developing technologies of graphics and animation, the picture in games began to improve noticeably every year, which meant the need of keeping the computer in a state ready to run the latest gaming titles. It includes a regular update of the hardware: CPU, GPU, and RAM. All this entails regular costs – in addition to spending on expensive games, users are forced to spend money on updating the hardware, which becomes more expensive every year equivalent to its capabilities. Due to the incredible progress made over the past 15 years, users are faced with a serious problem. More than 2.2 billion people play games, but not everyone is ready to buy them and to regularly spend money on upgrades to make their PC able to launch the newest, performance-demanding games. (Jones 2018.)

2.3 Pioneers of the Industry

The concept of remote access to shared computing resources was formulated in the seventies of the 20th century (White 1971). However, it became really popular only in 2006, after Amazon launched its Elastic Compute Cloud service. This solution involved storing and processing data on remote servers. At the same time, the computer from which the request was made received only the result of calculations, which allowed to save a lot of resources. (Barr 2006.) The year 2009 can be considered as the starting point of cloud gaming industry. This year two major cloud gaming projects were announced – OnLive and Gaikai. (Roper 2009.)

OnLive was announced at the international exhibition Game Developers Conference 2009. The service offered gamers the opportunity to play even on PC with outdated hardware – if only there was a fairly fast and stable Internet connection. All information was processed on the service side, and the user received the picture and the ability to control the process. The gaming library contained 250 different games – from consoles, computers, and mobiles.

However, in 2012 the company actually went bankrupt. OnLive had to lay off all employees and sell all assets for $ 4.8 million. As a result of this bankruptcy, the company's investors suffered significant losses. One of the victims, for example, was the company HTC, which had to write off $ 40 million in losses. There is a version that OnLive has problems due to poor management decisions, low profitability and a small library of games. The founder of the company was Steve Perlman – a talented developer and entrepreneur, but an average manager. The company never made profit, used thousands of servers worldwide, spending $ 5 million monthly, but the number of users never exceeded 1,600 players at a time. In addition, only a small percentage of these users actually paid the company for the service provided. (Hollister 2012.)

The technologies used by OnLive were advanced. The developers created a system that worked stable and without problems on the side of the user with good bandwidth. After bankruptcy, all patents and assets of OnLive were sold, and then OnLive service was restarted, but with a new team. The latest attempt to gain a foothold in the market was the service CloudLift, which offered games from Steam and the opportunity to continue an interrupted game session on another device. However, all this did not help, and in 2015 OnLive announced the sale of all patents to Sony and the termination of activity. (Hollister 2012.)

Gaikai was also announced at Game Developers Conference 2009. The company was going to do it later, but the OnLive announcement at GDC 2009 forced the Gaikai team to answer. In July 2009, founder David Perry published demonstration video of Gaikai working process on his personal blog. Some games were shown on the video, including Mario Kart 64 and World of Warcraft running in a browser window. Perry also stated that Gaikai was designed without the need of many patents and in a less time than OnLive. (Perry 2009.)

On the same day, the GameSpot website published an interview with David Perry, in which the developer talked about the Gaikai service overall, differences with OnLive, the relationship with publishers, and its business model. Unlike OnLive, Gaikai did not try to sell cloud services to the end user. Instead, the service provided a platform for game developers, where players could try free demo versions of the latest gaming titles. As Perry told about

OnLive in an interview, they were able to only lure from large companies only a small proportion of players that will not significantly change the market. (Sinclair 2009.)

In 2012, OnLive and Gaikai had similar technologies. However, as history has shown, it was Gaikai's approach that succeeded, and in 2012 it was announced that service was sold to Sony. Sony paid $380 million for Gaikai, and these technologies formed the basis of the company's own product, PlayStation Now. (Bierton 2012.)

2.4 Expert View

Many gaming industry experts and heads of large companies have spoken about the new era of gaming. The chief executive of Ubisoft Yves Guillemot considers cloud gaming to be one of the promising areas of game development due to the development of technology, increasing hardware capacity, and improving the efficiency of data transmission systems. Guillemot has said that sooner or later streaming systems will replace personal computers and game consoles. (Goldfarb 2018.)

The head of EA Sports Peter Moore believes that the era of consoles in their modern form is coming to an end. Moore sees the future of games without bulky devices in front of the TV and other hardware intermediaries. He believes that the only gadgets people need to play games are a monitor, a device with a flash drive and a controller. (Sarconi 2016.)

Bethesda's chief marketing officer Peter Hines agrees with Moore. In his opinion, the future of game industry is centering around streaming and cross-platform gaming, and the next generation of consoles will focus on these technologies. Hines believes that streaming becomes an important part of gaming, and the ability to deliver games to user's devices can be even easier and faster and one time will become a reality. (Evans-Thirlwell 2018.)

3 CLOUD ARCHITECTURE

The main stack of cloud technologies consists of three parts, each of them represents a separate category of services. At the top level is Software-as-a-Service (SaaS) – a cloud application, access to which is provided by a web-interface. It is followed by Platform-as-a-Service (PaaS) – a platform for self-development and deployment of applications. At the third level, Infrastructure-as-a-Service (IaaS) – computing infrastructure that includes servers, storages, networks. The distribution of responsibilities between a customer (company or software developer) and vendor depends on the choice of a particular service model. Differences between service models and allocation of vendor and customer responsibilities illustrated in Figure 1. (Romanek 2015.)

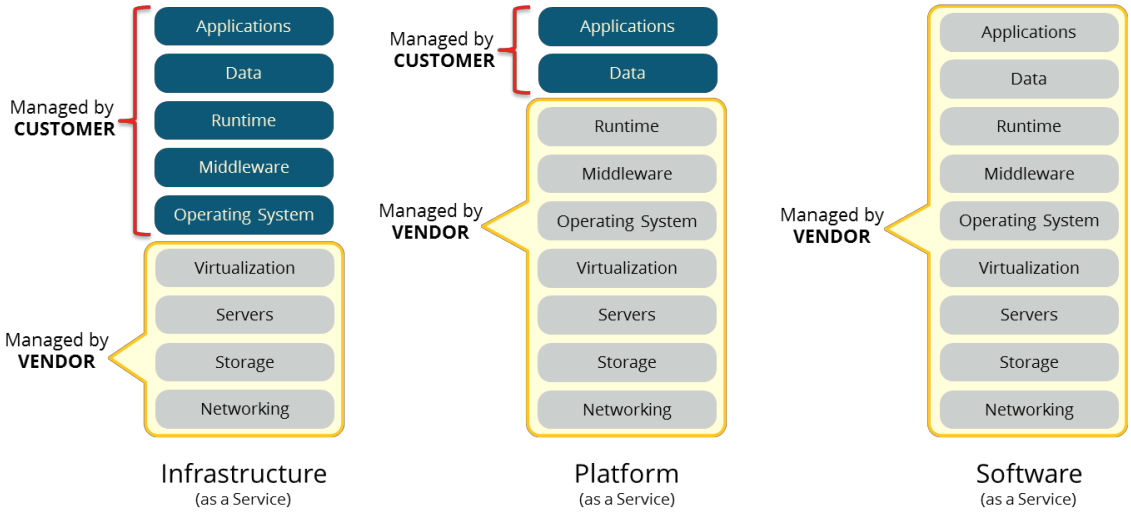

Figure 1. Difference Between Cloud Service Models (Romanek 2015)

Infrastructure-as-a-Service (IaaS) consists of hardware (servers, data storage systems, client systems, network equipment), operating systems, system software (virtualization, automation, basic resources management tools), and bonding software. IaaS based on the technology of virtualization, which allows the customer to divide it into parts that correspond to the current needs, thereby increasing the efficiency of using the available computing power. The customer needs to pay only for the server time usage, disk space, network bandwidth and other resources that are needed. In addition, IaaS provide the customer with a full range of management functions in one integrated platform. IaaS also eliminates the need to support complex data center infrastructures, client and

network infrastructures. Moreover, IaaS allow customer to reduce the expenses and running costs. (Watts 2017.)

Platform-as-a-Service (PaaS) model provides an integrated platform for developing, testing, deploying, and supporting web applications as services. To deploy web applications, the customer does not need to purchase equipment and software. Client access can be arranged on a rental basis. This approach has gained popularity due to scalability, resiliency, virtualization, and security. The scalability of PaaS implies the automatic allocation and release of the necessary resources depending on the number of people using the application. PaaS is an integrated platform for developing, testing, deploying and supporting web applications. It allows to perform a variety of operations in one integrated environment, thus eliminates the running costs of using individual environments for each development stage. (Watts 2017.)

Software-as-a-Service (SaaS) is the last level of cloud computing service models that most often complements PaaS. This is a full-featured user application that performs certain functions, such as working with images or sound. The most popular form of payment in this segment is a subscription. In the case of SaaS, application configuration, monitoring and backup issues are vendor's responsibility. Therefore, this model of work implies that the vendor deals with all the processes. (Watts 2017.)

Cloud gaming, along with microtransactions, subscriptions, and season passes, is one of the forms of Gaming-as-a-Service (GaaS) that can be combined between each other. In the early 2000s with the advent of MMORPG, GaaS appeared as a subtype of SaaS. A typical example is a game that provide the player with a daily challenges and in-game currency for buying new equipment or skins. Such games as Dota 2, Counter-Strike, Destiny, Call of Duty, FIFA or World of Warcraft can be taken as typical examples. (Williams 2014.)

Cloud gaming in the form of GaaS has several distinctive features. One of them is an effective piracy prevention, which presumes that the game files are stored on a secure cloud server and inaccessible for outsiders. Due to that condition users are to purchase licensed games. Furthermore, a cloud gaming services have a variety of payment models, such as pre-payment, post-payment,

subscription, and “pay-per-play”. In addition, another feature of GaaS is “click-and-play” system. This is the process of the quick game launching because files stored and executed in the cloud. Cloud gaming services in the form of GaaS also can retain players involvement due to the high-quality game graphics, stable connection with servers, and the inability to play high-performance games elsewhere. (Cai, Chi & Leung 2015, 524-525.)

4 VIDEO-BASED CLOUD GAMING SYSTEMS

4.1 Classification

The fundamental principle and main advantage of a video-based system is the game files offloading to the cloud. Among such files are game engine, processing and rendering modules. Video-based cloud gaming system allows to directly stream the game as a video to the user's device. This process is similar to the video on demand. All game files are stored and run on the cloud gaming service provider’s server, what allows the user not to worry about the performance of his computer. (Cai et al. 2015, 525.)

Cloud gaming systems can be divided into three types in terms of the remote rendering approach. They differ from each other in the methods of workload balancing between cloud servers and user devices. In the first type, 3D graphics streaming type, cloud servers control graphics commands, compress them and send to the user computer which called thin client. Then, thin client renders game scenes by its own graphics resources. Since this type implies a heavy load on the computer, it is not suitable for mobile devices, TV set-top boxes, and low-performing computers. In the second type which called video streaming type, the server is responsible for rendering 3D commands to 2D video, compressing and streaming it to a thin client, which decodes the video and displays it on the screen. The third type, which is the video streaming with post-rendering operations type, is based on the confluence of the first two types. This implies that 3D graphics are rendered on cloud servers, and operations that do not require high-performance are executed on the thin client. (Huang, Chen, Chen, Hsu & Hsu 2014.)

Cloud gaming systems also can be divided into four types in terms of their architecture, which are video-based, file-based, instruction-based, component-based systems. The architecture in a modern and popular cloud gaming systems is video-based due to the main advantage of this approach, which is the key feature of the whole cloud gaming – the independence of game performance from the client’s computing resources. (Cai et al. 2015, 525.)

4.2 Architecture

The video-based cloud gaming system, as demonstrated in Figure 2, consists of a cloud gaming platform and a thin client. The thin client consists of a user interaction module and a video decoder. The interaction module is responsible for receiving user's commands from the keyboard, mouse, gamepad or other devices and sending them to the server side. The decoder, in its turn, is responsible for receiving and processing the video stream, sent to the thin client in response to user actions.

The cloud gaming platform is responsible for receiving commands from the client, converting them into corresponding game actions and transferring data over the network. User commands are processed by Game Logic module, then GPU Renderer renders a picture, compressed by the encoder and transmitted back to the thin client interaction module. At the end of the process this module decodes the video stream and reproduces the content to the user's device screen. (Gupta & Dutta 2015.)

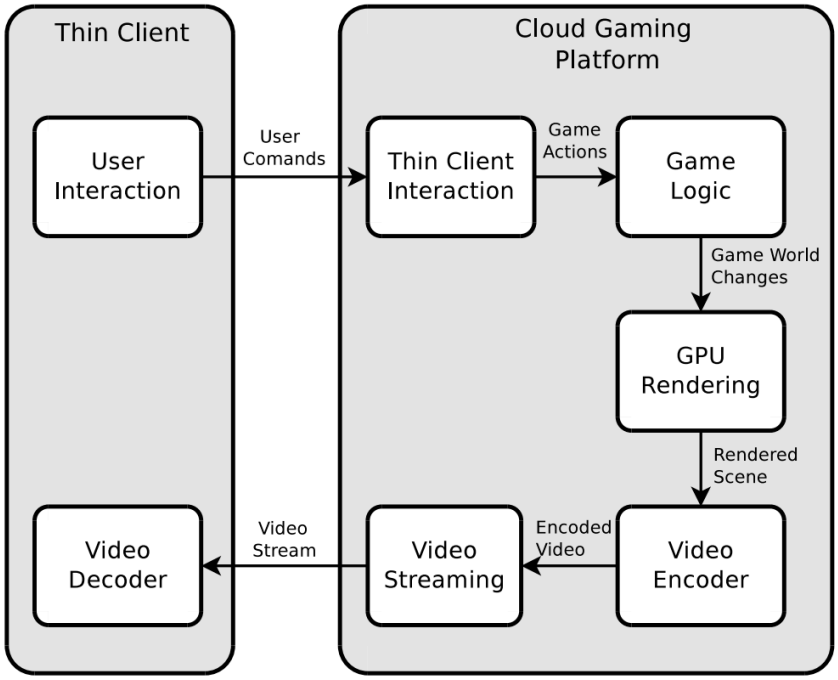

Figure 2. The Framework of a Cloud Gaming Platform (Shea, Liu, Ngai & Cui 2013)

4.3 Measurements

A game, as something integral, is a complex system. As the end goal is the player's satisfaction therefore all elements of this system should work flawlessly. Cloud gaming systems developers must consider many factors influencing the consistent work process. They have to simultaneously resolve the network problems and work on the overall Quality of Experience (QoE). Network parameters such as latency, packet loss, and jitter affect the game playability and the following user experience. In the cloud gaming, these parameters make up Quality of Service (QoS). (Chen, Chang, Tseng, Huang & Lei 2018.)

The latency determines the game responsiveness and is called as Response Delay (RD). RD can be defined as the time between the user's action and the moment of display this action on the screen. RD consists of three components – Network Delay (ND), Processing Delay (PD), and Playout Delay (OD). The full decomposition of RD demonstrated in Figure 3. (Chen et al. 2018.)

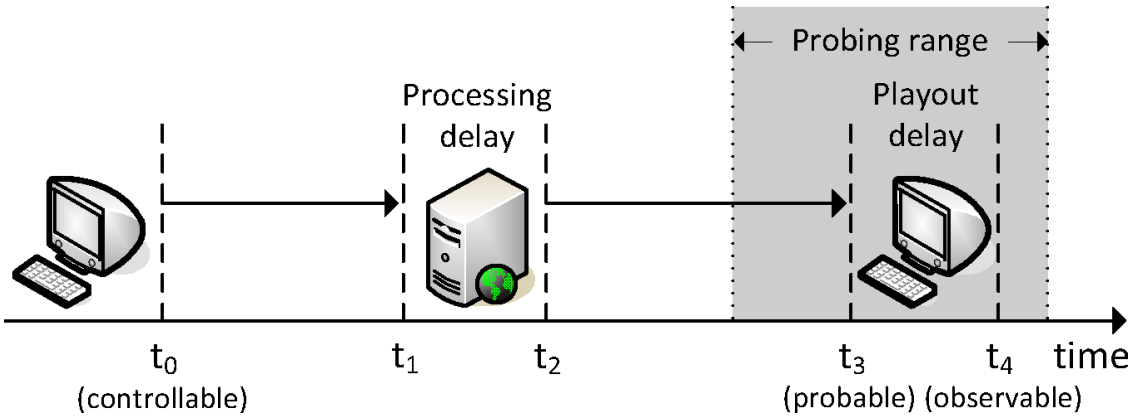

Figure 3. Response Delay decomposition (Chen et al. 2018)

Network Delay (t1 - t0, t3 – t2 in Figure 3) is the time required to deliver the client's command to a server and send back the result to the client screen. It is also known as the network round-trip time and can be measured with help of different tools. Processing Delay (t2 – t1 in Figure 3) is the time required for the server to receive the client's command, then process it and send back the result. Playout Delay (t4 – t3 in Figure 3) is the time required for the client to process and display the received frames on the screen. Like the Processing

Delay, Playout Delay occurs internally in CGS and inaccessible from outside. There is also a Game Delay (GD), which is necessary for gaming software in order to process client's commands and generate appropriate frames. The cloud environment does not usually affect Game Delay. Generally, it depends only on the game code and is equal to the same Game Delay, when the game run on the local computer. The Response Delay is the sum of all four components and is calculated by the following formula: RD = ND + PD + OD + GD. The results of all delays are measured in milliseconds (ms). (Chen et al. 2018.)

Latency is one of the most important criteria for evaluating cloud gaming system performance. In the modern dynamic games, the latency plays a crucial role and has a big impact on the overall user's QoE. Multiplayer games are particularly sensitive to latency due to the need to synchronize user actions. The maximum latency, before Quality of Experience begins to degrade, was calculated for various game genres. The results of this study are given in Table 1. (Claypool & Claypool 2006.)

Table 1. Latency in online games (Claypool & Claypool 2006)

Model	**Perspective**	**Example Genres**	**Sensitivity**	**Delay Thresholds**
Avatar	First-person	FPS, Racing	High	100 ms
	Third-Person	Sports, RPG	Medium	500 ms
Omnipresent	Varies	RTS, Simulator	Low	1,000 ms

First-person games, such as Counter-Strike or Call of Duty, and MOBA-games, such as Dota 2 and League of Legends, become noticeably less playable when the latency reaches 100 ms. Big latency is inacceptable due to the fact that first-person games and MOBA-games are full of actions. These games always require a good reaction both from player and from the system. Therefore, a big

latency makes the whole game process uncomfortable and deliberately puts the player in a losing position. (Shea et al. 2013.)

In games with a third-person view, which is the majority of RPGs and MMORPGs, a bigger latency is possible because of the fact that fast response in such kind of games is not so important. The game process is slower and not so sensitive to the delay. The player may be annoyed by the too slow system response to actions, so they should be executed fairly quickly, however the acceptable delay is 500 ms. (Shea et al. 2013.)

The third type are the games with an omnipresent view, the so-called top-down view when the player controls a large number of different units and buildings. Examples can be Real-Time Strategy (RTS) and various simulators. Comfortable gameplay in such games is possible with a delay up to 1000 ms. This amount of delay is acceptable in the games of such genres like quests and turn-based strategies, where the player's reaction is not significant, and the late execution of commands cannot critically affect the gameplay. (Shea et al. 2013.)

The problem of latency in games on local systems always referred only to multiplayer and did not concern single player. In the case of cloud gaming, all games are launched on a remote server, consequently, all of them, even single player ones, are subject to the problem of delay. When playing on a local system, multiplayer gamers are worried about the problem of unstable Internet connection and latency. In addition to that latency, cloud gaming, in its turn, have the Response Delay. For the sensitive multiplayer games, the maximum total delay when playing through the cloud must be less than 100 ms, while the delay for the other games must be less than 200 ms. In any other cases, the delay will critically affect the user's QoE. (Jarschel, Schlosser, Scheuring & Hoßfeld 2011.)

4.3.1 Quality of Experience

Quality of Experience is the measurement of the game playability, experienced by players. Figure 4 demonstrates the interaction of QoE and QoS in online games.

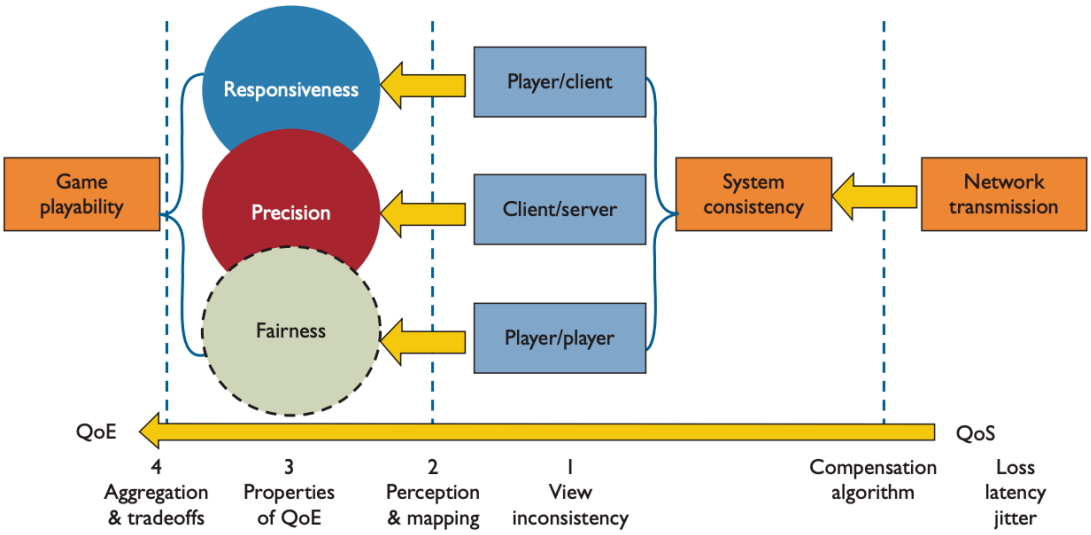

Figure 4. The interaction between QoS and QoE metrics (Shea et al. 2013)

According to Figure 4, responsiveness is the time the system takes to respond to user's actions. It also represents how the user feels the game. Fairness can be explained as a variety of different situations for different players in the same gaming session under the same initial conditions. In addition, there is a precision, that shows the difference between the game state on the server and on the user's computer. The lower this difference is, the better gaming experience will be. All these parameters make up the user overall game perception and its QoE. To achieve this, developers strive to optimize games and minimize latency by hosting more servers and improving their performance. (Shea et al. 2013.)

4.4 Challenges

It is well-known, that computer games are very response-sensitive applications. In addition to the latency, that what discussed above, there are several critical factors that determine the ability to use cloud gaming services.

One of the main cloud gaming industry challenges is bandwidth. The usage of cloud gaming requires sustainable bandwidth and no Internet traffic limitations. Additionally, another problem of bandwidth is the situation when all players suddenly switch to cloud gaming. I such a case, Internet providers may have problems with the incredible network overload, so that traffic can reach up to 10 GB per hour. (Cai et al. 2015, 528.)

In addition to bandwidth, the speed of information transfer and its stability are also important. If there is such problem as frequent changes in Internet connection speed, then the picture transmitted from the server to the user's device will deteriorate or freeze, which will negatively affect QoE. Nonetheless, even with a stable, high-speed Internet, the picture received by the user may not be of the highest quality. In order to solve this problem and optimize streaming video, cloud gaming services are compressing it. As a result, the stream that comes to the user is still inferior in quality comparing to the image of the game running directly on the local powerful gaming computer. (Cai et al. 2015, 528.)

5 CLOUD GAMING SERVICES RESEARCH

5.1 Purpose and Methodology

The purpose of the practical research is to test, analyse and compare different cloud gaming services. To fulfil this purpose several questions should be answered at the end of research:

- How cloud gaming experience differs from ordinary local gaming experience?
- Which game genres are suitable for playing in the cloud and which are not?
- Can cloud gaming fully replace traditional gaming?

The following criteria of estimation of the cloud gaming services were used in the research: availability on the different operating systems, system requirements, diagnostic and connection settings, game library, methods of payment, overall QoE.

5.2 Specification of Environment

For this research two popular cloud gaming services were selected – NVIDIA GeForce NOW and Playkey. There are a lot of other solutions on the market, but because of number of reasons exactly these two were chosen. The main reason is that both of the services have servers in the Eastern Europe due to the fact that research is held in Russia. It allows to estimate the experience of using these services most fairly.

The choice was also influenced by the fact that GeForce NOW is a product of NVIDIA company. Video cards made by NVIDIA dominate the market and are used by the overwhelming majority of gamers, according to statistics on Steam from April 2018 to November 2018, as shown in Figure 5. Playkey is a Russian product launched in 2014, that use the NVIDIA GRID platform. Eventually, the choice was defined by the fact that NVIDIA is the leader in its field, and both of the chosen services use NVIDIA resources and solutions.

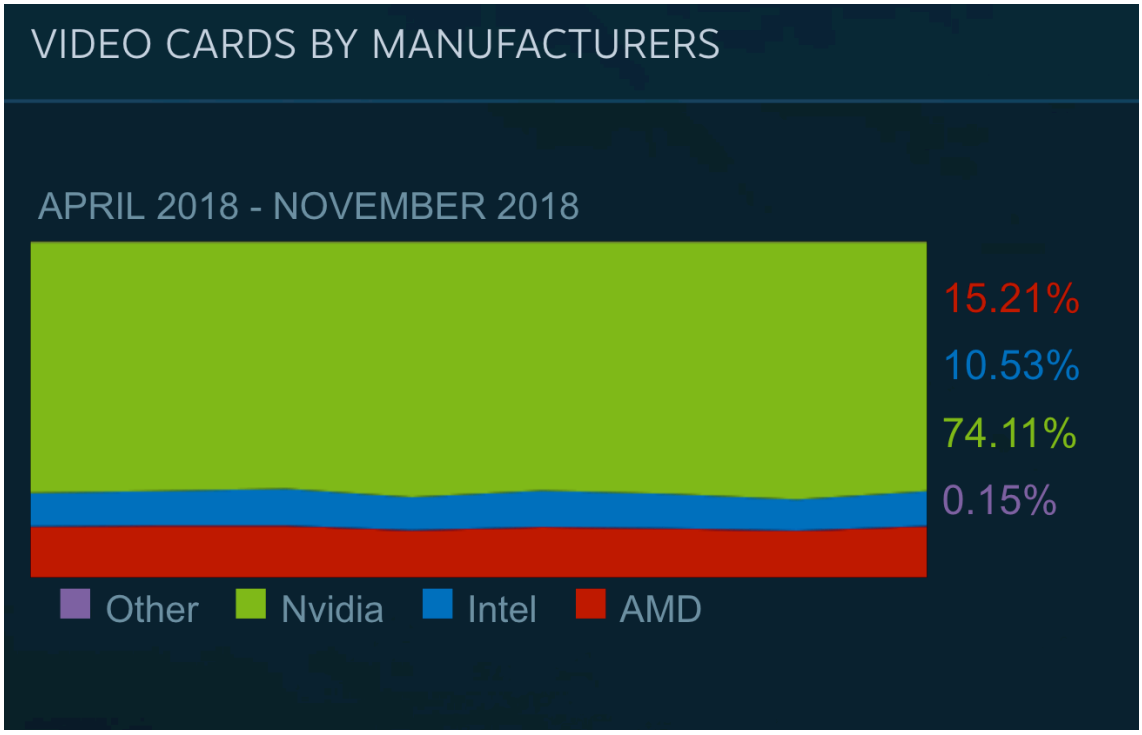

Figure 5. Statistics of video cards by manufacturers used by Steam players

5.2.1 Hardware Selection

A laptop was chosen as a device for testing cloud gaming services. In theory, cloud gaming is needed either to those people whose computer is outdated and unable to run games, or to those who have not the ability to use a powerful desktop PC. As the testing device the laptop ASUS XC550C, released in 2014, was chosen. Its characteristics specified in Table 2.

Table 2. ASUS X550C characteristics

CPU	Intel i3-3217U
RAM	4096 MB
Video Card	GeForce GT 720M
Operating System	Windows 10, 64-bit

This laptop was selected because it does not even cope well enough with the usual tasks such as Web surfing and working with productivity software. As a

benefit for this research, this model has an Ethernet interface, that allows to make tests using highest possible Internet speed. Cloud gaming services claim that even old computer can run games and only high-speed Internet is needed for playing.

5.2.2 Games Selection

Nowadays, the vast majority of popular games are related to such genres as First-Person Online Shooters, MOBA, and Turn-Based Strategies. This is the reason why these genres were chosen for the study. Games for the research were selected according to the criteria of popularity and the high system requirements for comfortable and fair gaming.

For the research, two of the most popular online games that meet all requirements were selected – Counter-Strike: Global Offensive (CS:GO) and Dota 2. Their popularity is confirmed by the statistics of Steam shown in Figure 6. Civilization VI is a popular Turn-Based Strategy with high-performance requirements, whose gameplay can serve as an example of many games that do not require low latency.

RIGHT NOW	MAX. TODAY	A GAME
256,623	632,833	Counter-Strike: Global Offensive
208,441	593,574	Dota 2
123,713	807,682	PLAYERUNKNOWN'S BATTLEGROUNDS
71,901	101,097	Path of Exile
43,987	86,450	Tom Clancy's Rainbow Six Siege
37,550	57,179	Rocket league
35,700	50,314	ARK: Survival Evolved
34,072	49,425	Rusty
33,048	55,910	Warframe
32,497	49,749	Football Manager 2019

Figure 6. Top games by number of players on Steam

5.3 NVIDIA GeForce NOW

NVIDIA GeForce NOW was introduced in 2017 and is currently in open beta-testing on a PC. The service is available on Windows and Mac OS. At the moment, the service is provided to beta-testers free of charge. Due to that fact, there is no opportunity to compare the total cost of using the service with the cost of purchasing and maintaining a personal gaming computer. NVIDIA requires to have the minimum system and Internet requirements, as illustrated in Table 3.

Table 3. NVIDIA GeForce NOW minimal system requirements

Internet	15 Mbps for 720p/60fps; 25 Mbps for 1080p/60fps, Ethernet connection or 5GHz wireless router
Hardware	Dual core X86 CPU with 2.0GHz or faster, 4GB of RAM, GPU with DirectX 9 support
Software	Windows 7 64 bit or newer; Mac OS

The service support more than 400 games that are available in digital stores such as Steam, Epic Games Store, Battle.net, and Uplay. Users can connect their accounts in these platforms to GeForce NOW and play games using their own library. Moreover, it is possible to run games that currently are not supported by the service. When a user tries to launch such a game, a warning window appears as illustrated in Figure 7.

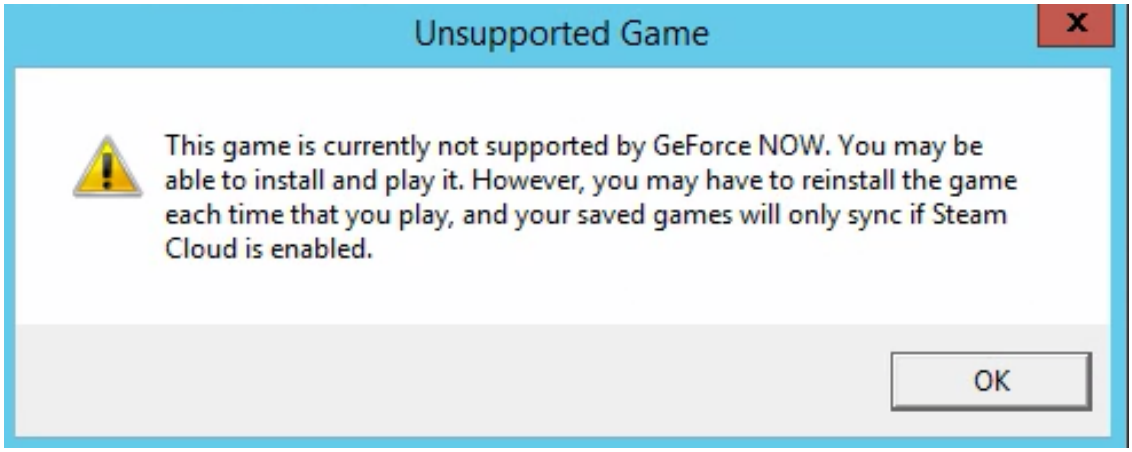

Figure 6. Warning about running an unsupported game

To access the service, the user must register on the site, submit a form for participating in beta-testing and wait for an invite. After access is obtained, the user must download the application, where all the actions take place, to log in on all necessary platforms and then play. The application interface is shown in Figure 7.

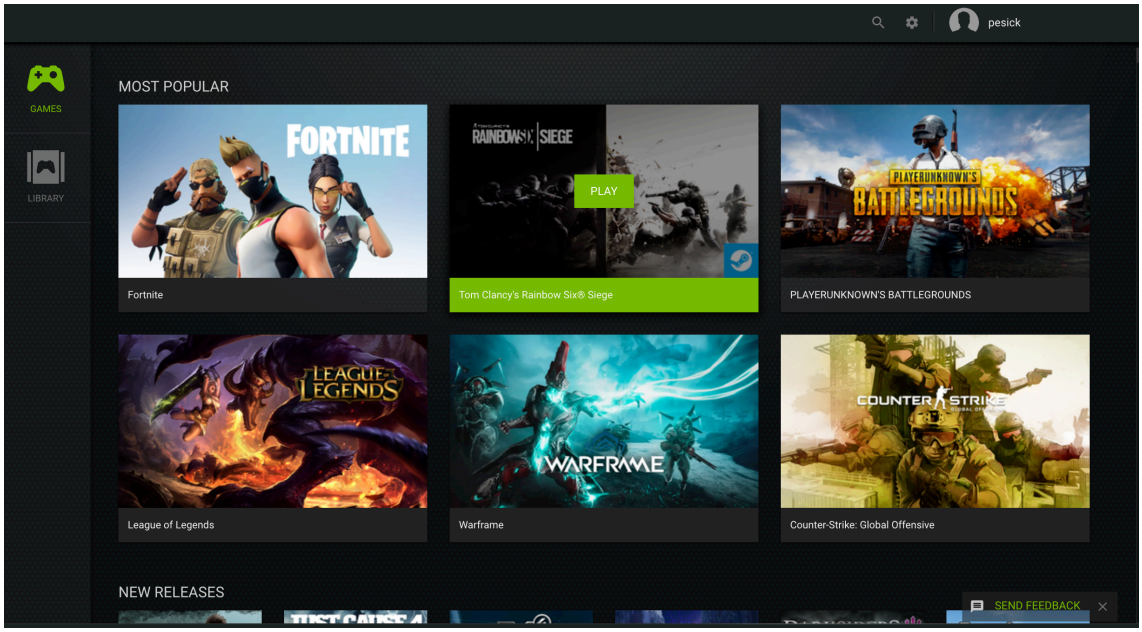

Figure 7. NVIDIA GeForce NOW application interface

GeForce NOW provides the user with the opportunity to analyse Internet connection, comparing it with the required and recommended values. The result of analysis is shown in Figure 8. In the case of using a 2.4 MHz wireless connection, the program shows a warning about possible problems with data

transmission and advises the user to change it to 5 MHz wireless connection or Ethernet. In case of connection deterioration, a warning about packet loss or high latency appears on the screen. In this research an Ethernet connection, that provides the most stable and high bandwidth was used.

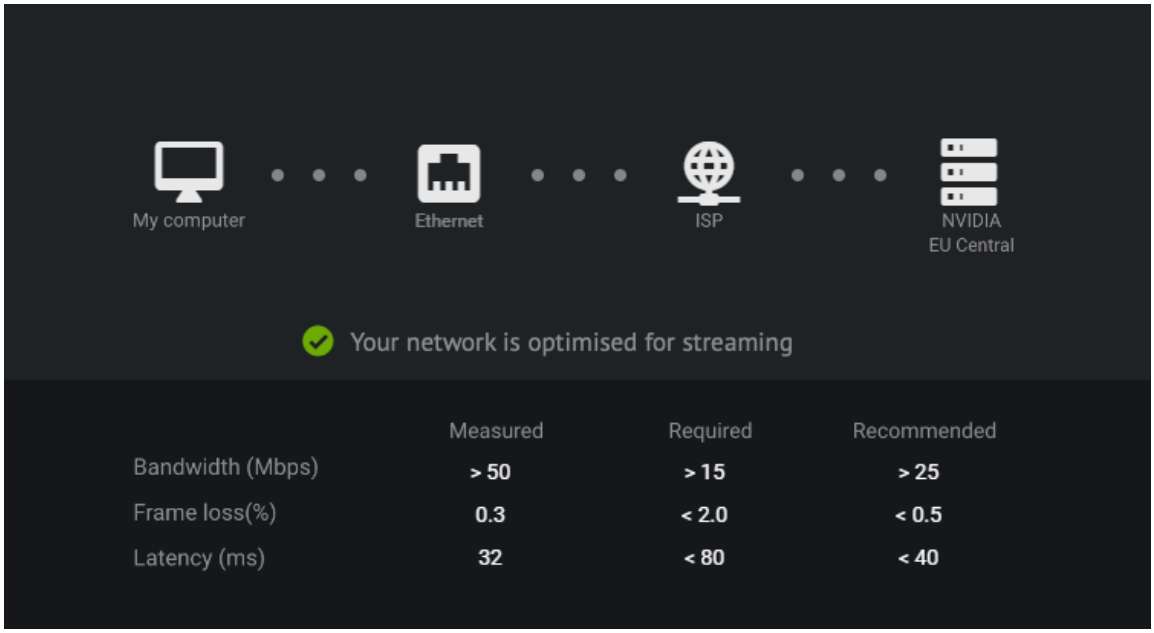

Figure 8. GeForce NOW network test

GeForce NOW gives the user opportunities of flexible configuration of streaming video through standard or custom settings, which are shown in Figure 9. Servers allocated in the United States and Europe. The service automatically selects the nearest server to the user. However, the player can choose any other server manually in settings. In any chosen preset, the application also alerts about the approximate amount of traffic that will be consumed while gaming. This parameter helps to calculate playing time to those who have a limited Internet data. In this research an Internet connection with a bandwidth of 50 Mbps was used. The settings in the application are set to Balanced Streaming Quality, which allows to have the best possible image quality and gameplay.

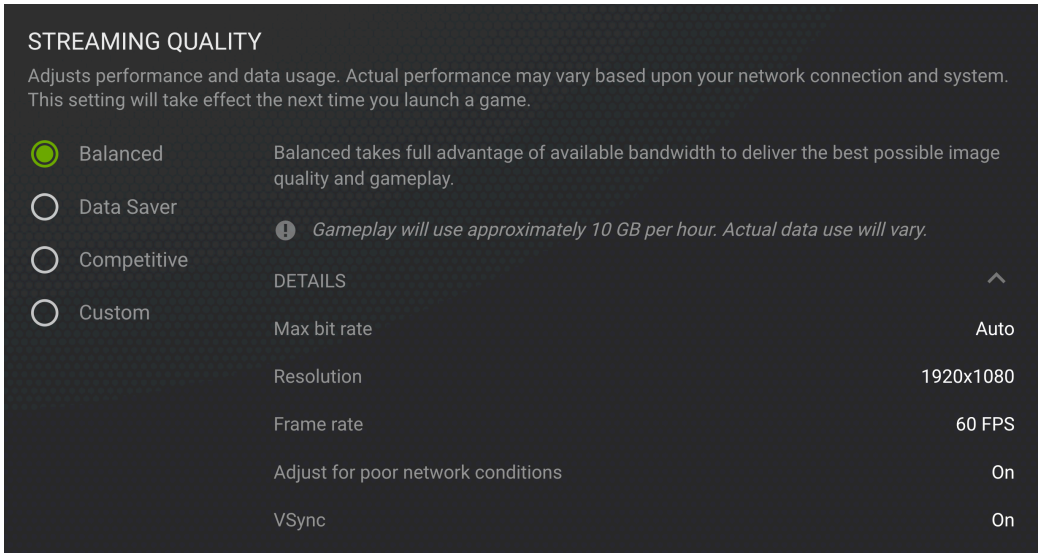

Figure 9. GeForce NOW streaming quality settings

In CS:GO and Dota 2, the user's fast response is very important due to the features of the gameplay. The speed of the game's reaction to the input data is also critically important. As mentioned earlier, the maximum total delay for the dynamic online games cannot be more than 100 ms. However, for the CS:GO and Dota 2, the delay should not exceed 50-70 ms, as well as on the local computer. According to the network test, the latency to the NVIDIA server is 32 ms, and the in-game ping is usually about 30 to 50 ms. It is necessary to add the sum of these two parameters to the delay of the data transmission and processing. Unfortunately, the service does not provide the ability to measure the total delay time.

The combination of listed delays does not allow the user to feel the gaming process as fairly as other players who play from local computers do. The speed of user's reaction and the ability to make quick decisions are neutralized by the large delay, which negatively affects QoE. Moreover, during overload on the network in the game session, about every 3-4 times there is a packet loss or latency increase. This happens due to the feature of video-based technology – the image quality deteriorates significantly or even freezes for a few seconds. In online games such situations are unacceptable for players.

In the situation with the Civilization VI, the delay does not matter because it is a Turn-Based Strategy game in which the player is not required to make fast

actions and have a quick reaction. Time for a player's turn is most often unlimited. A packet loss or latency increase every few minutes is also present, but this does not affect the overall QoE in case of this game genre.

With stable Internet and high bandwidth, the picture quality provided by NVIDIA server is ultra-high and almost cannot be distinguished from the original game image at the same settings on the local computer. The user playing via this service can feel comfortable and get positive QoE in performance-demanding games, in which latency does not affect the gameplay. Such games can be a Turn-Based Strategies, Turn-Based RPGs, Quests, CCG and digital board games. On the other side, First-Person Shooters, MOBA, MMORPGs and other low-delay-demanding games are unplayable, because the gameplay in the cloud cannot be equal to the gameplay on local PC. Consequently the cloud gaming service user is in the lose position beforehand.

5.4 Playkey

Playkey is a cloud gaming service created in Russia in 2014. The service uses NVIDIA GRID and is available for Windows and Mac OS. Minimal system requirements are listed in Table 4.

Table 4. Playkey minimal system requirements

Internet	Minimal required speed is 4 Mbps 10 Mbps for 720p 25 Mbps for 1080p Ethernet connection or 5GHz wireless router
Hardware	CPU ≥ 1.5 GHz with H.264 CPU ≥ 2.6 GHz without H.264 DirectX 9.0c or Opengl
Software	Windows XP or newer; Mac OS

As in the case of GeForce NOW, in Playkey a user can play games from his own library in various digital stores. The service provides a demo mode that allows user to try paid content, test the character of response, picture quality and QoE in general. There is no opportunity to play officially unsupported games. The service is operating through the website, which interface is shown in Figure 10.

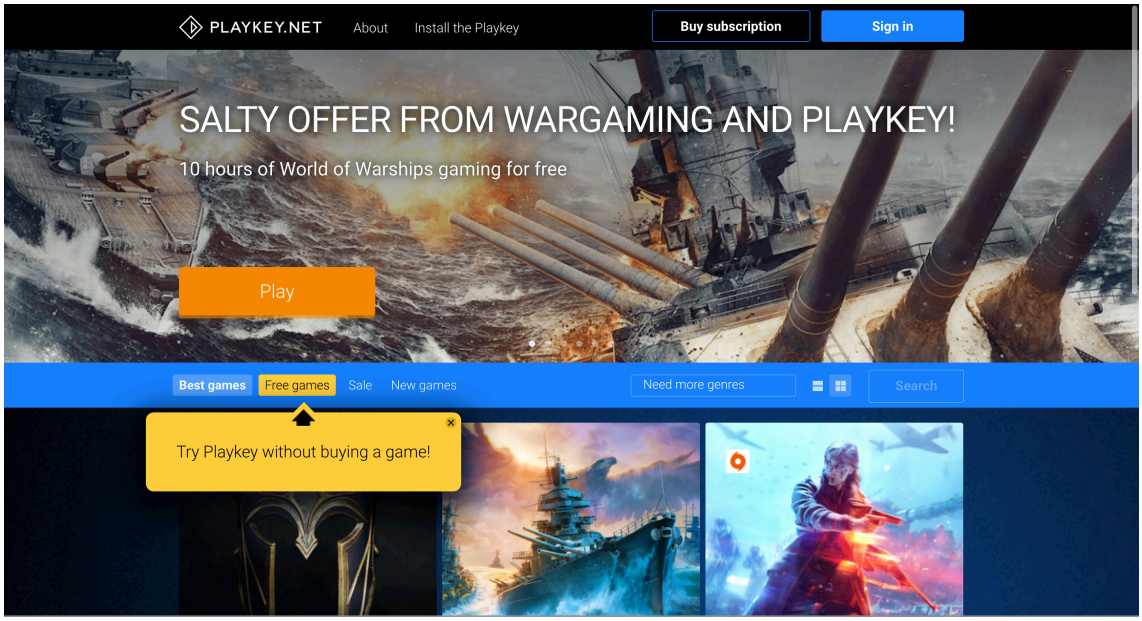

Figure 10. Playkey website interface

To access the service, firstly, the user need to register on the site. Then it is obligatory to add the credit card from which the money will be debited. After that, 20 minutes of free game time will be added to the account. Then the user needs to download the application, the functionality of which implies only displaying the received image. All account management and settings configuration took place on the service website.

The service does not allow to test the network before starting the game. When the game is running, the user can press the shortcut Ctrl+F1 to access the console, illustrated in Figure 11.

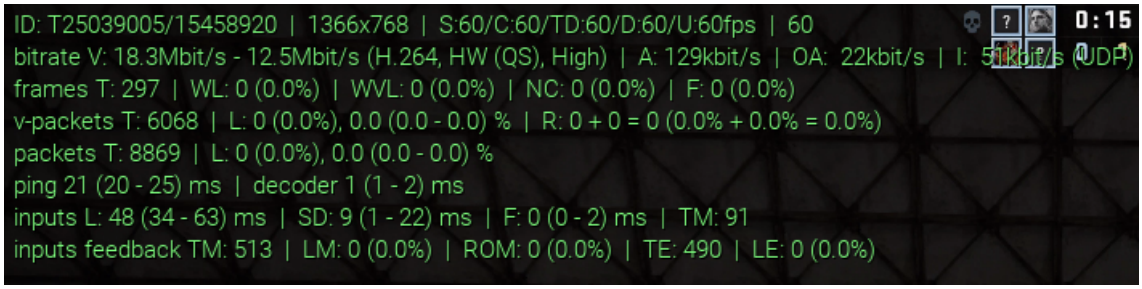

Figure 11. Playkey in-game statistics console

It should be noted that the first line contains the parameters D (the number of fps in the Playkey application on the PC) and U (the number of unique frames displayed directly on the PC). If these parameters are reducing, the user needs to close the programs that can load the CPU or reduce this load by limiting the bitrate. In addition, at the end of the first line there is a numeral parameter (in Figure 11 this parameter is 60). This parameter displays the number of operations in the stream, where the image is rendered and control commands are processed. More often it happens, more often control commands are processed and sent out. Consequently, more smoothly the game control is felt.

When launching the game on the Playkey website, it is available to select resolution of the image only. Despite the fact that Playkey is available in Europe and Russia, and the company has servers in London, Moscow and Frankfurt, to the user cannot choose the server as well as cannot possess any information about connected server.

Generally, after adding the credit card the user has a default payment plan according to which 1 minute of the game costs 1 Russian ruble (approx. 90 cents) for. Playkey does not offer to choose another payment plan. Knowing the fact that a regular gamer plays approximately 3-4 hours a day, the final cost will be about 5400-7200 Russian rubles (80-100 euros) per month. This price does not include price of the game itself.

When researching the site, a page with plan options was found. The service itself does not offer the user on opportunity to choose one of these plans. These rates are much more profitable for users who will play regularly and with long gaming sessions. Playkey offers 70 hours of cloud gaming during 30 days for 17 euro, 200 hours during 30 days for 27 euro and unlimited hours of playing

during 30 days for 33 euro. After selecting and launching the game in the browser, the application opens and starts to show the image of the game. In case of Playkey, with each entry into any game, a user must re-log in the digital store.

Evaluating the data from the console in Figure 11, the image transmitting is perfect, no packet loss is observed. In this case, the ping to the Playkey server is 22 ms, and input delays are 47 ms and 25 ms, which equals about 100 ms of the delay. This measurement does not include the in-game delay from the Playkey server to the game server. The total delay in CS:GO and Dota 2 games is approximately 130-150 ms, which, just like in the case of GeForce NOW, does not allow the player to feel himself in equal position with other players. Civilization VI player feels comfortable, as there is no in-game ping, which directly affects the gameplay quality.

In general, cloud gaming via Playkey feels a little worse than via GeForce NOW due to the slower game responsiveness to user's actions. Since NVIDIA GeForce NOW does not provide data about delay of input, it is impossible to display difference between these two services in the format of numbers.

6 CONCLUSION

The main purpose of this thesis was to investigate how cloud computing technologies are applied in gaming industry today. In the course of the practical research it was aimed to define the usability of cloud gaming services, which were selected by certain requirements. During practical research these services were tested, analysed and compared according to particular criteria of estimation.

It was realized that because of many reasons modern cloud gaming services cannot fulfil the users' needs to replace a high-performing desktop PC with a powerful cloud server. Moreover, these services cannot be used in eSports and competitive gaming due to the high latency and occasionally packet loss. Otherwise, cloud gaming services are usable for a certain games, that do not require a perfect connection and low latency. In addition, these services allow Mac OS users to play games, compatible only with Windows OS.

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