

# A Survey of Cloud Gaming Platforms: Architectural Design and Performance Evaluation of Major Providers

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**Abstract**—Cloud gaming, also known as gaming-as-a-service, is a transformative technology that leverages cloud infrastructure to deliver high-quality gaming experiences by streaming games from remote servers to various devices. This approach eliminates the need for powerful local hardware, making gaming more accessible and cost-effective. Cloud gaming architectures vary significantly across different companies, each leveraging unique technologies and infrastructure to deliver seamless gaming experiences. Microsoft's Xbox Cloud Gaming (formerly Project xCloud) utilizes custom blade servers hosted in Azure data centers to stream Xbox games to various devices, emphasizing low latency and high availability. NVIDIA's GeForce NOW transforms local devices into high-performance gaming PCs by streaming games from NVIDIA's data centers, using advanced video encoding and adaptive bitrate streaming to optimize performance. Google Stadia, built on Debian Linux and Vulkan API, streams games from Google's data centers, offering features like 4K resolution and integration with YouTube for enhanced interactivity. Sony's PlayStation Now, integrated into the PlayStation Plus service, uses custom servers to stream a wide range of PlayStation games, focusing on delivering console-quality experiences across multiple devices. This paper provides a comparison of the different architectures used by various companies.

## I. INTRODUCTION

Cloud gaming has revolutionized the gaming industry by allowing users to play high-quality games on various devices without the need for powerful local hardware. The concept of cloud gaming dates back to the early 2010s, with pioneers like OnLive and Gaikai leading the charge. These early platforms demonstrated the potential of cloud gaming by streaming games from remote servers to users' devices, but they faced significant challenges such as high latency and bandwidth limitations. The acquisition of Gaikai and OnLive by Sony in the mid-2010s marked a significant milestone, leading to the development of PlayStation Now, one of the first major cloud gaming services. The evolution of network infrastructure has further propelled cloud gaming into the mainstream, enabling more stable and responsive gaming experiences.

The architecture of cloud gaming systems typically involves several key components: the cloud server, the client device, and the network infrastructure connecting them. The cloud server is responsible for rendering the game and processing user inputs, which are then streamed as video to the client device. This setup can be implemented using various architectural models, including centralized server-based architectures, edge

computing frameworks, and hybrid approaches. Centralized architectures, like those used by Google Stadia, rely on powerful data centers to handle all processing tasks, while edge computing models, such as those employed by NVIDIA's GeForce Now, distribute processing closer to the user to reduce latency. Hybrid models, like Microsoft's Xbox Cloud Gaming, combine elements of both to balance performance and resource efficiency. Each architecture has its own set of challenges, including managing latency, ensuring high-quality video streaming, and optimizing server utilization.

Several major players dominate the cloud gaming market, each with its unique approach and infrastructure. Microsoft's Xbox Cloud Gaming leverages the extensive Azure cloud infrastructure to stream a vast library of Xbox games to various devices, emphasizing low latency and high availability. NVIDIA's GeForce Now offers a "bring your own game" model, allowing users to stream games they already own from NVIDIA's data centers, utilizing advanced video encoding and adaptive bitrate streaming to optimize performance. Google Stadia, although recently discontinued, was notable for its integration with the Google Cloud Platform, offering features like 4K resolution and seamless integration with YouTube. Sony's PlayStation Now, now part of PlayStation Plus Premium, streams a wide range of PlayStation games, focusing on delivering console-quality experiences across multiple devices. Other notable players include Amazon Luna, which offers a subscription-based model with various game libraries, and emerging services like Ant Play in India, which cater to local markets with tailored solutions. These companies continue to innovate and expand their offerings, driving the growth and evolution of cloud gaming.

This paper aims to compare the different cloud gaming architectures. It provides a deep dive into the technology adopted by different platforms and the upside and downside of each of them. It also gives an overview of the new interventions which are coming up.

## II. GOOGLE STADIA

Google Stadia works by allowing users to stream games directly from Google's servers to a variety of devices, including computers with Chrome, Chromecast Ultra, and certain Android devices. Stadia handles all the processing power on

its remote servers, which means there are no downloads or installations required on the user's device. The gameplay video is streamed to the user's device, while the user's inputs are sent back to the server. Stadia supports high-quality streaming, offering up to 4K resolution with HDR and 5.1 surround sound, provided the user has a fast and stable internet connection. Google Stadia was officially released on November 19, 2019, for those who purchased the Founder's Edition. The service was later made available to everyone else in 2020.

#### A. Architecture

The Core components of Google Stadia are as follows

- 1) **Data Centers:** Stadia's backbone is Google's global network of data centers, which are strategically located to minimize latency and ensure high availability. These data centers house the powerful servers that run the games. Each server is equipped with custom hardware, including Intel x86 processors clocked at 2.7 GHz, custom AMD GPUs based on the Vega architecture, and solid-state drives for storage. The servers are designed to handle the rendering and processing of games, which are then streamed to the user's device.
- 2) **Streaming Technology:** Stadia uses advanced streaming technology to deliver game content to users. The service employs WebRTC for real-time communication, which includes protocols like Datagram Transport Layer Security (DTLS) for key exchange and Interactive Connectivity Establishment (ICE) for setting up multimedia connections. This ensures secure and efficient streaming of video and audio content from the server to the client device.
- 3) **Client Devices:** Stadia supports a wide range of client devices, including desktop PCs, laptops, tablets, smartphones, and TVs via Chromecast Ultra. The only requirement is a stable internet connection with a minimum bandwidth of 10 Mbps for 720p gaming, 20 Mbps for 1080p, and 35 Mbps for 4K resolution. The Stadia controller can connect directly to the data center via Wi-Fi to reduce input latency, although other HID-class USB controllers are also supported

Stadia's software stack is built on Debian Linux servers, using the Vulkan graphics API for rendering. This choice allows for high performance and compatibility with a wide range of games. Stadia also integrates seamlessly with YouTube, allowing users to stream their gameplay sessions directly to the platform or join games from YouTube streams. This integration enhances the social and interactive aspects of gaming on Stadia. Stadia, however was closed down because of poor public response.

### III. PLAYSTATION NOW

PlayStation Now (PS Now) is Sony's cloud gaming service that allows users to stream a wide range of PlayStation games, including titles from the PS2, PS3, and PS4 eras, to their PlayStation consoles and Windows PCs. The architecture of PS Now is designed to deliver high-quality gaming experiences

by leveraging cloud technology and powerful server infrastructure.

#### A. Architecture

The following are core components of PlayStation Now

##### 1) Server Infrastructure:

- **Data Centers:** PS Now operates through a network of data centers equipped with custom server racks. Each rack contains multiple PS3 units or equivalent hardware to run the games. For PS3 games, Sony uses a unique approach by integrating multiple PS3 consoles into a single server rack, allowing the games to run natively rather than through emulation. This setup helps maintain compatibility and performance for PS3 titles.
- **Game Processing:** The games are processed and rendered on these remote servers. The video output is then compressed and streamed to the user's device, while user inputs are sent back to the server, creating a feedback loop that allows for interactive gameplay.

##### 2) Client Devices:

- **Supported Platforms:** PS Now is available on PS4, PS5, and Windows PCs. Users can stream games directly to these devices, and in the case of PS4 and PS5, some games can also be downloaded and played locally to reduce latency and improve performance.
- **Controller Support:** The service supports various controllers, including the DualShock 4 and DualSense controllers for PlayStation consoles, and a range of third-party controllers for PC users. This flexibility ensures a consistent gaming experience across different devices.

##### 3) Network Requirements:

- **Internet Speed:** A minimum broadband speed of 5 Mbps is recommended for streaming games on PS Now, though higher speeds are suggested for better performance and reduced latency. A wired connection is also recommended to ensure a stable and reliable connection..
- **Latency Management:** To minimize latency, PS Now employs advanced video compression techniques and adaptive bitrate streaming, which adjusts the video quality based on the user's internet connection. This helps maintain a smooth gaming experience even under varying network condition

### IV. NVIDIA GEFORCE NOW

NVIDIA GeForce Now is a cloud gaming service that allows users to stream games from NVIDIA's powerful servers to a variety of devices, including PCs, Macs, Android devices, iOS devices, and smart TVs. Launched in beta in 2015 and publicly in 2020, GeForce Now leverages NVIDIA's extensive cloud infrastructure to deliver high-quality gaming experiences without the need for high-end local hardware.

## A. Architecture

The following are the key components of GeForce Now

### 1) Server Infrastructure:

- **Data Centers:** GeForce Now operates through a network of data centers equipped with NVIDIA's high-performance GPUs. These data centers are strategically located to minimize latency and ensure high availability. The servers utilize NVIDIA Tesla graphics cards and, more recently, the RTX 4080 SuperPODs, which deliver over 64 teraflops of graphics horsepower to individual users.
- **Game Processing:** Games are processed and rendered on these remote servers. The video output is then compressed and streamed to the user's device, while user inputs are sent back to the server, creating a feedback loop that allows for interactive gameplay. This setup ensures that even devices with minimal processing power can run graphically intensive games.

### 2) Client Devices:

- **Supported Platforms:** GeForce Now is available on a wide range of devices, including Windows PCs, macOS, Android, iOS, Shield TV, Chromebook, Tizen, and WebOS devices. This broad compatibility allows users to play their favorite games on virtually any device they own.
- **Controller Support:** The service supports various controllers, including standard gamepads and keyboard/mouse setups, ensuring a consistent gaming experience across different devices.

### 3) Network Requirements:

- **Internet Speed:** GeForce Now requires a minimum broadband speed of 15 Mbps for 720p at 60 FPS and 25 Mbps for 1080p at 60 FPS. For the highest quality experience, such as 4K resolution at 60 FPS or 1440p at 120 FPS, higher bandwidth is recommended. The service also employs adaptive bitrate streaming to adjust the video quality based on the user's internet connection.
- **Latency Management:** To minimize latency, GeForce Now uses advanced video compression techniques and NVIDIA Reflex technology, which reduces system latency to below 40 milliseconds. This ensures a smooth and responsive gaming experience, even in fast-paced games

GeForce Now's software stack is built on a custom Linux-based operating system that runs virtual machines (VMs) for game processing. This setup allows for dynamic allocation of resources and scalability, ensuring that the service can handle varying loads and provide consistent performance. The service integrates with major digital game stores like Steam, Epic Games Store, and Ubisoft Connect, allowing users to stream games they already own without needing to repurchase them for the platform

## V. COMAPRISION OF ALL THREE PLATFORMS

Comparing GeForce Now, Google Stadia, and PlayStation Now reveals distinct features, strengths, and limitations of each cloud gaming service, catering to different gamer needs and preferences.

TABLE I  
COMPARISON OF GEFORCE NOW, GOOGLE STADIA, AND PLAYSTATION Now

Feature/Aspect	GeForce Now	Google Stadia	PlayStation Now
<b>Supported Platforms</b>	Windows, macOS, Android, iOS (via browser), Shield TV, Chromebook, Tizen, WebOS	Windows, macOS, Android, iOS (via browser), Chromecast Ultra, Chrome OS	PlayStation 4, PlayStation 5, Windows PC
<b>Game Library</b>	Over 1,500 supported games from Steam, Epic Games Store, Uplay, etc.	Limited to games purchased on Stadia platform	Hundreds of PlayStation 2, 3, and 4 games
<b>Resolution and Frame Rate</b>	Up to 4K at 60 FPS (Ultimate tier), 1440p at 120 FPS	Up to 4K at 60 FPS (Stadia Pro)	Up to 1080p at 60 FPS
<b>Internet Speed Requirements</b>	15 Mbps for 720p, 25 Mbps for 1080p, 50 Mbps for 4K	10 Mbps for 720p, 20 Mbps for 1080p, 35 Mbps for 4K	5 Mbps minimum recommended
<b>Latency Management</b>	Advanced video compression, NVIDIA Reflex technology	Adaptive bitrate streaming, WebRTC protocols	Advanced video compression, adaptive bitrate streaming
<b>Controller Support</b>	Various gamepads, keyboard/mouse	Stadia controller, various HID-class USB controllers	DualShock 4, DualSense, third-party controllers
<b>Unique Features</b>	Integration with existing game libraries, RTX 3080 tier for high-end performance	Integration with YouTube, State Share, Crowd Play	Download option for PS4 and PS5 games, part of PlayStation Plus Premium
<b>Data Centers</b>	North America, Europe, Asia (via partners)	Global Google data centers	North America, Europe
<b>Business Model</b>	Bring your own games, subscription for higher performance	Purchase games on Stadia, subscription for higher quality	Subscription-based access to game library

NVIDIA's GeForce Now stands out for its compatibility with a vast library of games from digital stores like Steam and Epic Games Store, allowing users to play games they already own on various devices. It offers a free tier with session limits and a premium tier with extended session times and access to RTX graphics.

Google Stadia provides a unique cloud gaming experience by allowing users to purchase games specifically for the platform and stream them across various devices. It supports up to 4K streaming with a Stadia Pro subscription and offers features like State Share for sharing game moments.



PlayStation Now, Sony's entry into cloud gaming, offers a subscription-based model with access to a vast library of PlayStation games, including PS2, PS3, and PS4 titles. It allows streaming and downloading of games on PlayStation consoles and PCs, catering to gamers who prefer Sony's gaming ecosystem.

## VI. CONCLUSION

The comparison of GeForce Now, Google Stadia, and PlayStation Now reveals distinct advantages and challenges associated with each cloud gaming platform, catering to different gamer preferences and needs. GeForce Now stands out for its flexibility, allowing users to play games they already own on various platforms, including Steam and Epic Games Store, which can lead to cost savings and a broader game selection. Its performance is highly praised, offering minimal input lag and the option for RTX graphics on higher subscription tiers, making it a strong choice for those seeking high-quality gaming experiences on less capable hardware. Its performance is highly praised, offering minimal input lag and the option for RTX graphics on higher subscription tiers, making it a strong choice for those seeking high-quality gaming experiences on less capable hardware.

Google Stadia offers up to 4K streaming quality, surpassing the 1080p limit of its competitors, and features innovative technologies like direct-to-server controller connectivity for reduced latency. It provides a unique model where games are purchased specifically for the platform, which can be a drawback for those wary of platform longevity or looking for a more extensive library. Despite its technological advancements, Stadia has faced criticism for its limited game selection and the necessity of buying games through its store, which, combined with the eventual shutdown of the service, highlights concerns over stability and game ownership.

PlayStation Now, with its focus on Sony's gaming ecosystem, offers an extensive library of PlayStation games from various generations, making it an attractive option for fans of Sony's exclusive titles. It supports both streaming and downloading of games on PlayStation consoles and PCs, though it is criticized for performance issues like input lag and lower streaming quality compared to its competitors.

In conclusion, each cloud gaming service has its strengths: GeForce Now's flexibility and performance, Stadia's high streaming quality and innovative features, and PlayStation Now's extensive library and support for Sony's ecosystem. The choice between them depends on individual preferences regarding game ownership, streaming quality, device compatibility, and specific game titles or features. As cloud gaming continues to evolve, these platforms may address their current limitations and expand their offerings, further shaping the future of gaming.

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