

Networking technologies in online gaming: Current status and future development

Victor Yuan

School of Computer Science, University of St Andrews, St Andrews, KY16 9SX Fife, Scotland, UK

vyl@st-andrews.ac.uk

Abstract. The markets for cloud gaming and online games are growing fast. Although the development opens up a lot of possibilities, making decisions in related fields demands a basic comprehension of the current state of networking technologies used in the gaming industry today. In this article, the functionalities, technical designs, and social impacts of network technologies on modern online gaming are introduced and discussed. To assess the current worth of online gaming technology, a SWOT analysis was conducted. Based on our extensive research into related subjects, we offered several forecasts regarding the future development of online gaming. It can be concluded that technologies in the current online gaming industry are undergoing a major transformation, mostly due to the standardisation of QUIC and the rise of cloud and VR gaming, which determine the future trend of the gaming industry in the next decade.

Keywords: Games, Cloud Gaming, Networking, QUIC, SWOT.

1. Introduction

Computer games have exploded in popularity as a form of entertainment media since the development of “Tennis for Two”, the first computer game, in 1958. With about 2.7 billion players globally, the gaming industry in 2021 was valued at \$195.65 billion and is anticipated to continue increasing until 2030 with a 12.9% annual growth rate [1, 2]. The growth of the gaming industry is heavily dependent on technological advancement and ongoing innovation in both hardware and software. Nowadays, video games, particularly online video games, have become popular media all over the world. Meanwhile, online games are heavily dependent on and pose significant challenges to communication networks, and numerous concepts have emerged to cope with such challenges in pursuit of a high-quality player experience. As a result, an examination of pioneering technologies is critical to assessing the future of the internet in online gaming.

This paper aims to offer an overview of the considerations in game networking and highlight some of the state-of-the-art technologies developed by game developers to optimise the performance and achieve a better player experience in online gaming. The work covers the functionalities, the technical design, and the impacts of gaming networking technologies. An analysis of the strengths, weaknesses, opportunities, and threats (SWOT) in online gaming is also provided with a prospective view of the potential development in the future.

2. Functionalities of Networks in Online Gaming

The use of the internet is extensive and can be distributed in multiple layers of the network during online gaming. A work by Metzger et al. suggested that the use of networks in gaming can be roughly divided into two categories: direct and indirect communication [3].

Direct communication refers to the in-game communications that are a fundamental part of basic gameplay. Typically, such communication involves the exchange of data between gaming clients and servers, which includes the upload of game inputs and the download of game states. The upload of game inputs are the commands sent by input devices that alter the game state, and the download of game states ensures that all clients are updated and synchronised with the changes in the shared game state. Together, such data transmissions enable the synchronisation of game states among all clients, so that users can ultimately interact with each other in a multiplayer world, constituting the basis of online games. The discussion of the technical designs used to achieve game state synchronisation will be continued in the next section.

Other communications that do not directly affect the core logic of the game are referred to as indirect gameplay communications. Such communication is still essential to the gameplay or contributes to other elements of the game. For example, the distribution and delivery of games, which are the absolute prerequisites of playing the game, are primarily driven by the internet nowadays [4]. Such needs also cultivated the birth of several online game distribution services, such as Steam, Uplay, and Origin, most of which are developed by the game manufacturers themselves. Another example of indirect gameplay communication is the social activities within the player community, such as ranking, forums, or in-game voice communications.

In recent years, improvements to overall network performance have also brought growing popularity to cloud gaming. Such technology allows an expanded range of devices to play games that are usually much more demanding to hardware at the cost of a marginally increased latency [5]. Essentially, the user device only needs to handle user inputs, which are sent to either a more capable remote client or a dedicated rendering server. The remote side then processes the input and streams a rendered video back to the device, which mostly functions as a video player. The transmission of user inputs and videos would unavoidably incur additional latency, which is acceptable in some game genres and is shortening while the underlying network performance progresses.

There is no perfect solution for every online game due to the heterogeneous needs obtained from distinct gaming genres, diverse operating environments, and different user acceptance. As such, developers often design the in-game mechanics based on the specific requirements of the content. The next section illustrates the various elements considered during the development of modern online games with regard to their heterogeneity.

3. Technical Design of Current Use of Networks in Online Gaming

Due to the comprehensive involvement of networks in online gaming, the operation of the game is directly influenced by numerous aspects of the technical designs of the network, the execution of the game, and external environments. The underperformance or failure of any of the systems could result in a frustrating final user experience. Therefore, developers have been implementing mechanics in several layers of networks to optimise the game and minimise influences caused by external factors.

3.1. Transport Layer Protocol

Manufacturers usually use IP networks to send data and have limited influence over the physical setup of the communication network outside of the game server. Therefore, the program's transport and application layers are where most feasible optimizations are usually done. The connection-oriented Transmission Control Protocol (TCP) and the message-oriented User Datagram Protocol (UDP) are the most frequently deployed transport layer protocols today, while other transport protocols are also being developed to accommodate the characteristics of online gaming. The features of the desired gameplay experiences heavily impact the choice of the underlying protocol. For instance, games that demand intensive interaction, such as First Person Shooter (FPS) games, should be accompanied by frequent and

responsive UDP packets, whereas content-centric games, such as Turn-Based Strategy (TBS) games, would benefit from enhanced reliability, a trait inherited from TCP [6].

The nature of TCP also makes it suitable for games requiring reliable connections, congestion control, and ordered transmissions. However, this protocol has drawn criticism for being inadequate for time-sensitive gameplay: TCP transfers data in a rigidly ordered stream, thus any missed packets must be delivered again before gameplay can continue, even though only the most recent data is required to update the game state in most cases [7, 8]. Due to the outdated information, this Head of Line (HOL) blocking behaviour raises a transmission delay and necessitates additional processing in the subsequent responsive frame. Therefore, TCP is only used by certain non-time-sensitive games that require high reliability or is implemented in other indirect gameplay communications such as voice chats. As opposed to TCP, which causes blocking at the transport layer, the message-oriented design of UDP enables lossy data delivery with significantly reduced latency. Although UDP does not provide built-in measures for reliability or ordering, such requirements can be achieved as added extensions under the application layer and are not always required in every type of game [9].

Despite the advantages of UDP, web-based games like Slither.io typically have no alternative other than to use TCP because most browsers offer limited support for unreliable UDP communications as of recent [10]. Developers have created external frameworks, such as geckos.io, that uses Web Real-Time Communication (WebRTC), a set of APIs created for online conferencing applications, to overcome the performance bottlenecks in present networked games and achieve better results compared to TCP-based web games [11]. Furthermore, the replacement of TCP as specified in the newest 3rd version of HTTP as of writing this manuscript, Quick UDP Internet Connections (QUIC), is another recent development that could benefit web-based online gaming [12].

WebRTC and QUIC both rely on UDP, which has been widely used previously in a substantial range of non-web-based online multiplayer games. Other transport layer protocols, including Stream Control Transmission Protocol (SCTP) and Real-time Transport Protocol (RTP), have also been examined and recommended as options for online gaming [13]. SCTP, a more flexible transfer protocol, offers message-oriented data transmission with performance comparable to UDP while allowing connection-oriented communication similar to TCP [14]. With such features, latency is reduced, blocking behaviour is avoided after package loss, and security and reliability are addressed. Google originally designed QUIC to boost the efficiency of web systems and solve the HOL problem, and it was an ideal transport layer protocol for many general-purpose usages [15, 16]. By reducing packet latency significantly when there is a packet loss, QUIC is advantageous in most gaming environments, including client gaming. According to a study by Armir et al., QUIC has achieved a performance comparable to that of UDP, which was often chosen merely because of the raw performance it provides [17]. Moreover, data transmissions over QUIC are encrypted with an integrated security layer, unlike those sent over TCP or UDP, where security is often done with an additional security protocol like Transport Layer Security (TLS) [18, 19]. Because of its seamless integration of security and performance enhancement, QUIC is an excellent option for modern networked gaming.

3.2. Application Layer Frameworks

The deployment of a transport layer protocol is often driven by measurable factors, such as the protocol's performance and dependability. The application layer technologies, on the other hand, are dependent on a variety of usabilities and are frequently not standardized due to the diverse requirements of various game genres. Dedicated frameworks or libraries are frequently used to implement the specific functionality needed for particular user experiences. For instance, HTTP, a popular application layer protocol among web developers, is presently utilised in many different genres of games, such as TBS games, where speed does not directly affect player experiences [20]. Conversely, interaction-intensive games like multiplayer online battle arenas (MOBA) or first-person shooters (FPS) demand a serialised and responsive connection, which can be done by using performance-focused frameworks like Google Remote Procedure Call (gRPC) [21].

Developers are often equipped with a collection of pre-assembled tools to implement specific network functionality, depending on the game engine used for development. Unity developers, for example, can use Photon Unity Networking (PUN), which features preassembled technologies designed to meet the majority of needs in multiplayer games, such as anti-cheating, matchmaking, and multiplayer scalability [22]. These frameworks often implement data serialisation and state manipulation, resolving the lacking functions in UDP and adding additional features like data encryption. Such frameworks provide established and community-supported networking solutions, making them convenient and competitive for small game manufacturers.

3.3. Network Architecture

Most current online games use the Client-Server (CS) architecture, in which a client transmits input to the game server, which produces continually updated game states [23]. Occasionally, one of the clients is allowed to take on the function of the game server in certain online games, such as Minecraft. Such design is different and is to be distinguished from pure Peer-to-Peer (P2P) systems, in which each client has access to an identical set of permissions and data. The CS structure is ideal for the architecture design where a single game state is maintained by the authoritative server, simplifying the synchronisation complexities significantly and inhibiting cheating attempts.

Multiplayer scalability is a crucial concern of the CS design, particularly in massive multiplayer online role-playing games (MMORPG). Numerous technologies, such as zoning, instancing, and replication, are used to allow a large number of active users to interact with the game environment at the same time [24]. Zoning divides the in-game virtual scenes into distinct zones and assigns them to multiple resources; instancing creates different replicates of the same virtual scene and allocates them to different groups of users; and replication allows multiple servers to instantaneously perform calculations on the same game zone, distributing the amount of processing physically. Frameworks such as BigWorld and Photon often assist developers with the described techniques when developing games that need to adapt to large-scale multiplayer gameplay.

3.4. Game State Synchronisation

The synchronisation of game states is extremely important and fundamental, serving as the basis of most multiplayer games. Throughout history, several mechanisms have been used to ensure the correct synchronisation between users. An early example is called deterministic lockstep, which states that every client has to execute the same code at the same speed and that every user input is shared with every other client, composing a peer-to-peer structure [25]. This design ensures that the game states on each client are synchronized and serialized in the same way, so that each player is kept up to date with the determined action taken by other players. However, the logic of deterministic lockstep means that the game state of each client can only be updated once the input uploads from all other clients are successfully received, and any unstable connection would be suffered by all users in the game. Such a characteristic is not concerned by most turn-based games as the game progresses with player input regardless, but would be much more obvious in real-time games where the game states are changing at a high tick rate. Combined with the faster-growing transmission complexity of $O(n^2)$ for n users, the mechanism is not suitable for most large-scale or real-time games. Nevertheless, deterministic lockstep is still widely used in some competitive games where a correct view of the game state, in particular the actions of other players, is essential to the user. The drawbacks of potentially high latency can be improved using another concept called deterministic rollback, where the client predicts the actions of other players for a sooner update of the local game state. Afterwards, the local game state is compared to the actual game state when the input uploads from other clients are received and is rewound to the correct state accordingly only if there is a discrepancy [26].

A more popular mechanism to achieve synchronisation is the combination of an authoritative server and predictive clients. Such a system is comprised of multiple clients connecting to a central server, which runs the game and provides an authoritative game state to the clients [27]. Specifically, the inputs from clients are uploaded only to the central server, which calculates the game state accordingly and

sends back a message to every client. Typically, such messages only contain the information that is necessary for each client to recreate the part of their local game state (i.e., a snapshot). The partial transmission of the authoritative game state effectively reduces the amount of data and prevents exposing the complete game state to clients, which could exploit the communication data for cheating behaviour. Since network latency inevitably exists in online gaming, the aforesaid technique of client prediction can also be applied to conceal the latency perceived by the user, but the incidental discrepancy and rollbacks could become another negative factor in the final gaming experience.

3.5. Cloud Gaming Technologies

The development of the internet infrastructure over the past several years has led to a rise in the popularity of cloud gaming. The client, which effectively acts as a video player in a cloud gaming situation, collects and controls user inputs while the real graphically intensive rendering occurs on a more capable distant device. Inevitably, user input and video transmission produce additional delay. However, this delay may be tolerated in some game genres and is becoming shorter as internet infrastructure advances. A significantly larger range of devices, including mobile phones and laptops without strong hardware configurations, can now play demanding games at the cost of slightly increased latency thanks to cloud gaming.

The consideration of protocols could be different for cloud gaming providers, as such services are based on a more complex structure compared to traditional gaming and would need to accommodate the need for video streaming. A study by Di Domenico et al. found that cloud gaming providers usually adopt more customised protocols or technologies developed for online conferencing applications, such as RTP (used by Geforce Now and PSNow) and WebRTC API (used by Stadia) [28]. As a result, such platforms can typically withstand up to 5% packet loss before content degrades noticeably.

4. Benefits and Negative Impacts of the Internet on Online Gaming

The growth of the gaming industry has promoted the birth of numerous dedicated studios, departments, and companies. Being the creators of the market, these entities under the scope of the exploding online gaming industry were undoubtedly the closest beneficiaries of online computer games. Other stakeholders, such as investors and software companies establishing related businesses would also gain tremendous profits. For example, the PlayStation Network has generated around \$14 billion for Sony until 2022 [29].

The benefits brought by online gaming can also be perceived on a social scale. Greitemeyer et al. proposed that certain video games have positive effects and could promote prosocial behaviours [30]. Vuorre et al. suggested that games, especially online multiplayer games, could be a protective factor for mental health, especially during the pandemic era [31].

However, related works in Psychology also showed concerns regarding the potential negative effects on individual mental health and society. Specifically, Tobias and Dirk concluded from existing works that video games with violent content would promote hostility and undermine prosocial behaviour [32]. Addiction to games is also a major topic nowadays and is often used to prove the negative influences of games.

5. A SWOT Analysis of the Current Online Gaming Industry

SWOT analysis is a strategic and structured planning methodology that identifies and evaluates the four factors (strengths, weaknesses, opportunities, and threats) related to the commercial value of a topic. In this work, SWOT analysis is used to analyse the situation of online gaming as a whole to reveal the future of network technologies.

5.1. Strengths

- The industry for online gaming is expanding quickly due to the vast user bases of PC, mobile, and gaming console platforms.

- Video games have been termed "the ninth form of art" due to the high quality of such creations and widespread acceptance.
- After the COVID era, social connection through online gaming is especially welcome.
- There are numerous producers, creators, and service providers who specialise in video games and offer a variety of resources and guidance.
- In order to provide an immersive experience, responsive interactions are essential, which are already made possible by contemporary network architecture.

5.2. *Weaknesses*

- The physical internet infrastructure in use nowadays has very few technologies specifically designed for online gaming.
- Playing video games takes time. As a result, each game would be fighting with the others for player attention.
- Even with the tools already in existence that were designed for game development, creating a networked game that functions without deviations is challenging.

5.3. *Opportunities*

- Cloud gaming solutions enable games that need powerful hardware to run on a variety of devices, expanding the user base.
- Better-performing web games are now possible thanks to the formal inclusion of QUIC in HTTP/3.
- Some online game distributors provide subscription services, increasing the likelihood that users will start to explore more games.
- Open-source or free materials and technologies are widely available for the creation of networked video games.
- A new and more immersive platform for online gaming is developing with the emergence of virtual reality (VR) and the metaverse.

5.4. *Threats*

- Video games may develop an addiction and encourage antisocial behaviour [33].
- The general internet infrastructure may be under pressure from the growing user activity and bandwidth.
- The prevention of video game piracy is difficult.
- Harmful actions in multiplayer games such as abusive language or cheating require continuous attention, and cannot be eliminated completely.

6. **Future Development of Network Technology**

The present state of networked gaming is developing more rapidly than ever due to the rising popularity of cloud gaming, VR, and QUIC. With such developments, it is anticipated that the present norms would unavoidably and significantly shift in many dimensions. In light of this, several predictions for the future of online gaming are proposed and provided below.

6.1. *Both Web-based Games and Client Games Will Adopt QUIC*

The performance of current online web games is limited by TCP-induced HOL blockage. As such, web game developers would use QUIC if it were supported by more widely used browsers to get performance levels comparable to those of gaming clients with UDP implementations. Client-game developers no longer have to create a unique protocol with ordering and security functions thanks to the secure and optionally ordered characteristic of QUIC.

Although the usage of QUIC solves the HOL issue, several middlewares and frameworks now in use have not taken this new technology into account. This might lead to compatibility issues with modern games that extensively rely on external frameworks in the near future.

6.2. Online Gaming in VR Platforms Will Rise

Only a small number of the VR games published so far are intended to be played online. The restricted bandwidth, computing power, and player count are possible causes. However, as the number of VR device owners grows, more multiplayer games for the VR platform will be released [33].

The heads and hands of players are currently the only parts of their bodies that can be accurately tracked in most VR games, and reliable full-body tracking systems (e.g., HTC trackers) are typically costly and space-constrained. The amount and diversity of data transmitted via VR gaming will expand further as computer vision-based tracking and facial tracking develop.

6.3. Increased Popularity of Future Cloud Gaming

More and more processing power is needed to play modern games. In the past, players would have to invest in and put together gear, including graphics units practically specialised for gaming applications, to locally run the game. Nowadays, the rise of cloud gaming gives access to high-end games with the most calculation-heavy visuals at a significantly lower cost, while the generated delay under optimal network circumstances is nearly imperceptible [34].

However, due to the increased latency, competitive gamers are hesitant to utilise cloud services, even if cloud gaming is becoming more and more popular among other players. This also holds for VR cloud gaming: when players are immersed in a virtual setting, latency or low frame rates become increasingly noticeable and unbearable. VR devices would no longer require a strong local client to deliver superb immersion if cloud service performance continued to improve and cross this barrier.

Terminal devices would no longer be constrained by their hardware configurations if the potentials are realised and the constraints are overcome. Anything that is only feasible on a high-end device may be presented to players on mobile phones with negligible latency. Meanwhile, game creators would no longer have to take hardware restrictions into account when creating games and are even able to implement optimisations that are dedicated to the more unified remote rendering hardware, which would simplify the development process and lead to better performances. Existing mobile devices may potentially swap out the rendering hardware for network-enhancing modules, which typically require less space and battery power. Such enhancements would be particularly noticeable on mobile phones, VR, or other wearable technology.

New opportunities in cloud gaming are also promised with the increase in web-based network speed. Several contemporary cloud services, like Parsec, offer WebRTC-built browser clients, albeit less responsive than the client versions that must be downloaded and installed [35]. Cloud services accessible via websites could eventually reach a performance comparable to that of an installed version thanks to the growing support for QUIC in web browsers.

6.4. Additional Online Gaming Frameworks

Although UDP has already been used by developers to get satisfactory results, a significant number of improvements must be made before the protocol can be utilised for data transfer to assure a fundamental degree of security and serialisation. The adoption of specific frameworks that offer the capabilities required for various game genres would be advantageous for developers.

Such technologies might further diversify into different frameworks aiming at various game genres and gaming environments in the future. The networking procedure for an online game might be made simpler by such developments, but creators could find the growing number of possibilities to be daunting. Such genre-specific networking solutions could be integrated into current frameworks as templates, which could be better maintained and documented while requiring fewer context switching. To identify possible dependencies and conflicts between network techniques and other frameworks, package management like npm may also be utilised.

7. Conclusion

As one of the fastest-growing markets, the online gaming industry is continuously gaining audiences and economic significance. The integration of network services as part of online gaming experiences

will continue to develop as technology progresses, and numerous opportunities are opening up for the gaming business thanks to network technology improvements. As such, this summary of the use of network technologies in online gaming would provide some understanding of the most influential technologies hitherto and offer some predictions regarding the future of the gaming industry.

Although the predictions may not be thorough, they should offer a helpful introduction and encourage future discussion. This paper limits the topic to the software design of the gaming network as a whole, and there are still multiple detailed topics that require further research: resources are still scarce regarding the designs and traits of data transmission in the application layer of online gaming, and the overall topic could also be perceived with other new concepts such as 5G, video streaming, home broadband and local area network in mind. Future studies could supplement other factors or designs, both in hardware and software aspects, that could as well contribute to the quality of service in online gaming, or perform more thorough research or discussion on a single related topic.

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