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An Overview of the Networking Issues of Cloud Gaming: A Literature Review

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ABSTRACT

With the increasing prevalence of video games comes innovations that aim to evolve them. Cloud gaming is poised as the next phase of gaming. It enables users to play video games on any internet-enabled device. Such improvement could, therefore, enhance the processing power of existing devices and solve the need to spend large amounts of money on the latest gaming equipment. However, others argue that it may be far from being practically functional. Since cloud gaming places dependency on networks, new issues emerge. In relation, this paper is a review of the networking perspective of cloud gaming. Specifically, the paper analyzes its issues and challenges along with possible solutions. To accomplish the study, a literature review was performed. Results show that there are numerous issues and challenges regarding cloud gaming networks. Generally, cloud gaming has problems with its network quality of service (QoS) and quality of experience (QoE). The poor QoS and QoE of cloud gaming can be linked to unsatisfactory latency, bandwidth, delay, packet loss, and graphics quality. Moreover, the cost of providing the service and the complexity of implementing cloud gaming were considered challenges. For these issues and challenges, solutions were found. The solutions include lag or latency compensation, compression with encoding techniques, client computing power, edge computing, machine learning, frame adaption, and GPU-based server selection. However, these have limitations and may not always be applicable. Thus, even if solutions exist, it would be beneficial to analyze the networking side of cloud gaming further.

1. INTRODUCTION

The prevalence of video games remains to rise as technology advances and time passes. People turn to video games for entertainment and relaxation. They are also being used for non-recreational activities such as teaching and learning. As discussed by Maheswara and Wibowo [1], video games are increasingly being used for various societal pursuits and are thus becoming even more popular. Its increasing popularity, therefore, serves as an incentive for companies to invest in the innovation of video game-related paraphernalia, such as better hardware and graphics. As seen throughout the years, gaming has evolved considerably, from computer games in the 1950s to video games that run on advanced consoles in the 21st century [2]. Now, gaming is expected to evolve even further. Specifically, the next innovative phase for the gaming industry is known as cloud gaming. Cloud gaming is envisioned as the way of the future and the possible change in how people could play video games [3]. As stated by Browning [3], now is the time wherein cloud gaming could be crucial. Various companies are expanding to provide cloud gaming because the industry is projected to grow into billions of dollars in the following years.

Essentially, cloud gaming aims to revolutionize gaming by allowing users to play a video game through any of their existing equipment as long as they can access the internet [4]. To function, it

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leverages cloud computing for computational offloading, which enables the utilization of resources from strategically placed cloud data centers [5]. With it, users would no longer be required to spend large amounts of money on the newest gaming equipment to play certain video games. Instead, they can use their existing smartphone, tablet, laptop, or other devices regardless of hardware [6]. Using any internet-enabled device, users only need to interact with the cloud gaming application through a thin client. The thin client collects the user's commands and interactions to be sent to the cloud. The cloud then renders the video game's scenes and components which are forwarded to the user through the internet [5], [7].

Overall, the functions run by the cloud servers for cloud gaming include game status updating, executing the game's code, interpreting user input, video encoding, graphic rendering, and transmitting game scenes [8], [9]. By performing these functions, the cloud gaming approach relieves the computational processing effort in the user's devices, thus delegating them to the cloud [10]. Therefore, cloud gaming offers cost reduction for equipment, enhancement of processing power, video game platform independence, and piracy prevention because a game's source code can be stored solely in its respective server [8].

However, even with the various advantages of cloud gaming, new issues emerge because it places dependency on networks. The cloud-based video game architecture is disadvantaged regarding networks [11]. Since the network requirements depend on the game content [12], different video games would have different traffic characteristics, which could overall negatively affect the users' Quality of Experience (QoE) [13]. Therefore, most users still perceive cloud gaming to be far from being fully serviceable [3]. Various studies also share the sentiment that cloud gaming still has a lot of areas that can be analyzed and further improved.

As discussed by Domenico et al. [14], cloud gaming platforms, in relation to networks, are still struggling and have work needed to be done. Therefore, they suggest that a literature review considering innovations or breakthroughs could be beneficial. More specifically, as stated in the research of both Domenico et al. [14] and Peñaherrera-Pulla et al. [15], such future work would involve analyzing cloud gaming and its network infrastructure, available platforms, and new or novel technologies that can further optimize it. Through a literature review, cloud gaming developers could have a source of information for possible solutions they can use. Moreover, it could assist researchers in further understanding cloud gaming, which, in turn, can help create and develop solutions to evolve it. Therefore, to further analyze cloud gaming, this paper examines its challenges from a networking perspective. It will serve as a review of the problems that affect its functionality, along with possible solutions.

2. METHOD

Three main processes were performed to accomplish the literature review. Initially, literature was searched and selected. Next, the collected pieces of literature were examined to determine the network-related problems of cloud gaming and, after which, solutions that have been utilized for them. These processes are further discussed in the following subsections.

2.1. Literature Search and Selection

Literature was gathered from different research databases, which include arXiv, IEEE Xplore, MDPI, ResearchGate, and others. For this, a systematic literature search was performed using Google Scholar. Google Scholar was chosen as the primary tool since it returned scholarly literature from various research databases and sources. Thus, it enabled a wide variety of literature to be found.

2.1.1. Formulating Research Questions

Before using the tool, two research questions to be answered were first formulated. The following were the established research questions.

1. What issues and challenges related to networking currently affect cloud gaming?
2. What solutions have been proposed or used to solve the identified networking issues and challenges of cloud gaming?

2.2.2. Establishing Search Terms and Settings

Based on the identified research questions, general search terms were established. The search terms determined to search for literature using Google Scholar were "cloud gaming" and "cloud-based game." These were selected so that the results would include literature that overall discusses cloud gaming or cloud-based games. The advanced search settings of Google Scholar were then used to require both sets of keywords to be in the literature title. This helped ensure that the results would be directly related.

To further minimize the results yielded by Google Scholar, the selected literature also had to be published less than five years ago. The general rule when selecting literature for a literature review related to fast-developing fields, such as information technology, is to choose literature published in the past five years [16]. Thus, the starting year selected for the date of the search range was 2017. Also, only literature written in English was selected.

2.2.3. Selecting Literature

From the returned results, full-text links were opened to scan the papers. Initially, the title of each piece of literature was read to identify if it was relevant to the topic. If the title was related, the abstract was read to check the relevance of the content. The content was then skimmed through to identify their significance further. From the papers, those published in a journal or conference were prioritized. However, other papers were also considered if they contained information that was applicable to the research.

2.2. Identifying the Issues and Challenges Related to Networking That Currently Affect Cloud Gaming

After selecting relevant literature, each was read to be associated with the stated research questions. First, to identify the issues and challenges related to networking that currently affect cloud gaming, it was determined if a piece of literature accomplished any of the following objectives:

1. Discovered or listed and then discussed any network issue or challenge when implementing, using, or analyzing a cloud gaming platform.
2. Reviewed and discussed other scholarly literature on network issues and challenges affecting cloud gaming.

From the selected literature, discussions with similar keywords such as “latency,” “delay,” “bandwidth,” and others were then related to each other.

2.3. Discovering Solutions for the Networking Issues and Challenges of Cloud Gaming

After identifying the issues and challenges related to networking that affect cloud gaming, solutions were discovered by also reading each of the collected pieces of literature. The selected literature had content that proposed or discussed solutions related to the identified issues and challenges. These solutions can be strategies, frameworks, or other technologies. Based on the content of each piece of literature, solutions with similarities were then associated.

3. RESULTS AND DISCUSSION

3.1. Selected Literature

A total of 33 pieces of literature were selected for the literature review. Table 1 presents the number of selected literature based on the search term used.

Table 1: The selected literature based on the search terms used.

Search Term Used	Number of Results Scanned	Number of Literature Selected
cloud gaming	168	32
cloud-based game	69	1

The various literature was collected from different research databases and sources. Namely, the sources of the literature were SpringerLink, ResearchGate, arXiv, ACM, HAL Open Archive, IEEE Xplore, IntechOpen, MDPI, and organizations or companies. Figure 1 shows the percentage of how much literature was collected from each research database or source.

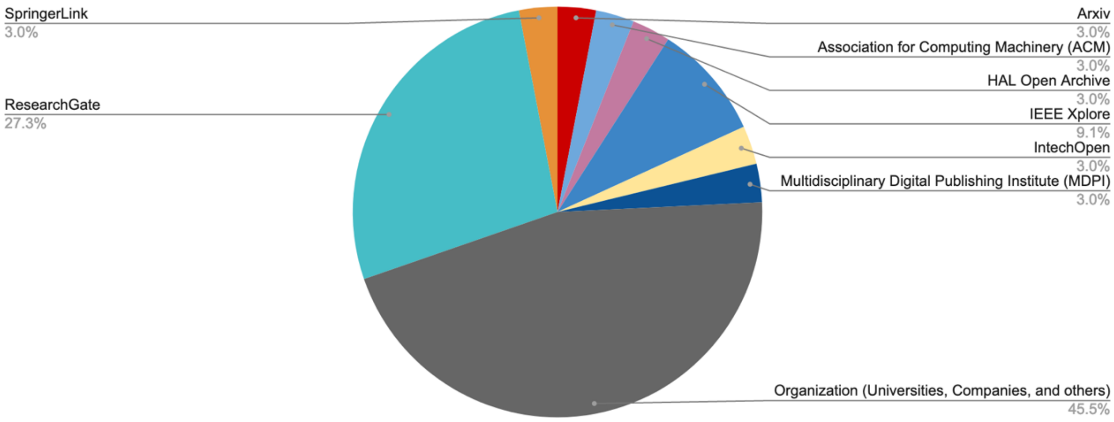

Figure 1: Pie chart of the selected literature organized according to the source.

Following the selection of literature, information was gathered to answer the established research questions. The extracted content is discussed in the following sections.

3.2. The Issues and Challenges Related to Networking That Currently Affect Cloud Gaming

Overall, 23 pieces of literature were selected to identify issues and challenges related to networking that currently affect cloud gaming. The identified issues and challenges are quality of service (QoS) and quality of experience (QoE) [17]–[21], latency [20], [22]–[30], bandwidth [20], [24], [26], [27], [31]–[33], delay [17], [23], [27], [31], [34]–[39], packet loss [17], [19], [22], [30], the cost of providing the service [31]–[33], complexity (video encoding, compression, and game content) [20], [34], [36], [38], and graphics quality [23], [34]–[36]. Figure 2 presents these issues and challenges along with the number of corresponding literature mainly cited to discuss them.

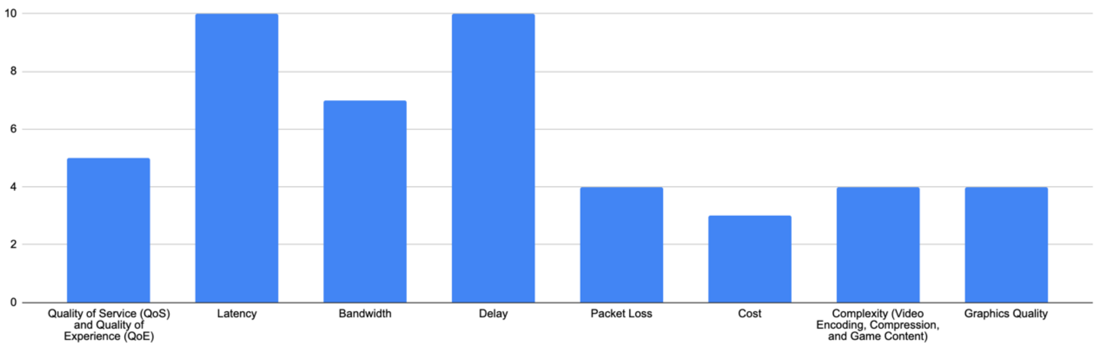

Figure 2: Bar graph of the number of reference literature mainly cited to discuss the network-related issues and challenges of cloud gaming.

3.2.1. Quality of Service (QoS) and Quality of Experience (QoE)

One challenge of cloud gaming is its need for a sufficient level of network QoS or quality of service, which also affects the users' QoE or quality of experience. There are various network QoS factors that, if degraded, may negatively impact the user's QoE or experience when using cloud gaming [17]–[19]. For QoS, cloud gaming providers should be able to provide high constant bandwidth and low latency [20]. Such a problem is applicable to various types of games. For instance, VR games in a cloud gaming setting may not be as useful if the delay is high [21]. The other pieces of collected literature, references [21]–[35], also correlate QoE with other factors. These factors include latency, bandwidth, delay, packet loss, and graphics quality. However, since these factors have also been solely identified as network issues and challenges regarding cloud gaming, these are further discussed in their own subsection instead.

3.2.2. Latency

About latency, user input needs to be instantly processed because if the response is late, the average user may notice the delay [23]. Therefore, low latency or at least an acceptable level of latency is needed to ensure that the service is usable [24]–[27]. If a game has high latency, it may feel unresponsive [20]. In general, Sužnjević and Homen [22] stated that cloud gaming systems would require a Round Trip Time (RTT) network latency of less than 70ms. However, the latency may depend on the type of game genre. For example, Jaya et al. [26] discussed that in a massively multiplayer online role-playing game (MMORPG) such as Diablo, a 100ms latency could be tolerable.

Another problem with latency is that defining latency requirements may be a challenge. It is because the cloud gaming server may have limited control and many sources of delay that can affect it [27], [28], [30]. As discussed by Sun and Claypool [29], cloud-based game clients cannot instantly process user input but instead need to send it to the cloud server, let the server process and render the input, then send the output back to the client. Thus, for example, players of multiplayer games would experience an added layer of latency that may be affected by a bad network connection or poor network protocols for transmission [24]. As an effect, low latency also becomes a design challenge for game developers when developing cloud-based games [25].

3.2.3. Bandwidth

A major challenge for cloud gaming is its possible need for high network bandwidth [20], [24], [31]–[33]. If the bandwidth is inadequate and network congestion happens, frames could disappear or become delayed, which would make playback choppy [20]. Moreover, if there is a high number of users, the cloud server may not have the ability to supply sufficient downstream bandwidth [31]. Therefore, when playing a cloud-based game, users must experience high responsiveness even with limited bandwidth capacity [26]. For this, Slivar et al. [27] suggested that there is a need for the game server to be able to dynamically satisfy varying bandwidth availability. They stated that a challenge encountered by cloud gaming providers is configuring encoding parameters for game streaming when it comes to diverse bandwidth conditions.

3.2.4. Delay

Concerning bandwidth and latency, a challenge that may be experienced with cloud gaming is a delay. Gaming is supposed to be highly interactive [27]. Therefore, low interaction delay is needed because cloud gaming is delay-sensitive [31], [35], [37]–[39]. To elaborate, cloud gaming can experience round trip delay or latency and response delay or lag [17]. Li et al. [17] explained that sending user input to the game server must be kept uninterrupted through standard methods that can eliminate the consequences of negative network conditions, such as high levels of jitter and buffering. For instance, the input sent through the network must be processed instantaneously to avoid delay [23]. As specified by Mossad et al. [36], the time between the input of a user and the response played on their device must range from 100ms for action games to 150ms for slow-paced games. Still, regarding various types of games, Wahab et al. [34] discussed that varying network conditions may have different effects. For example, they stated that a slow game such as FIFA would be less affected by the delay.

3.2.5. Packet Loss

When network congestion occurs and the queue size is reached, packet loss occurs [17]. As an effect, cloud-based games become unplayable with a packet loss of 1% [19], [22]. Thus, packet loss is a challenge to the creation of a user-friendly cloud-based game since it may cause decoding errors depending on the type of packets lost [30].

3.2.6. Cost of Providing the Service

For cloud gaming service and server providers, the network requirements and components for cloud gaming are considered to lead to higher costs. In general, cloud gaming service providers would face the challenge of operational costs for the data centers and the profitability of the service [33]. The limited scalability of cloud gaming would require higher bandwidth consumption for data centers and more cloud servers which may result in a higher cost paid by the providers [31], [32].

3.2.7. Complexity (Video Encoding, Compression, and Game Content)

Video encoding, compression, and game content for cloud gaming systems are considered to be complex for networks. For video encoding, as discussed by Mossad et al. [36], optimizing video encoding for cloud gaming for reduced bandwidth is a challenge. Specifically, they stated that player heterogeneity and modularity are obstacles. First, player heterogeneity is the difference between the skills, experiences, and interactions of players. These differences may have varying responses which video encoders have to consider. Second, modularity is the need to keep games and video codecs unmodified [36]. For compression, Doyle et al. [20] discussed that there needs to be a balance between compression efficiency and complexity that may affect the capability of the user's device. They explained that various compression types must be considered depending on the network and hardware conditions of the user's device. Regarding game content, game scenes could vary and lead to a dynamic workload of processes. Since the workload would be unpredictable, computing a strategy would be impracticable [38]. Furthermore, games with a high level of graphics and complexity could perform worse in varying network conditions [34].

3.2.8. Graphics Quality

Compared to traditional gaming, the graphics quality of a cloud-based game could significantly degrade or cause bad performance depending on the network condition [34], [35]. Regarding degraded graphics quality, the video encoder may have no way of identifying future game frames since these need to be rendered instantly. Therefore, the video encoder's challenge is to properly distribute bits to different portions of the frames while ensuring that the stream is high-quality [36]. Additionally, graphics have a heavy load which can be affected by latency and network congestion [23].

3.3. The Solutions for the Networking Issues and Challenges of Cloud Gaming

Based on the identified issues and challenges, 20 pieces of literature were selected to discuss solutions. From the literature, the identified solutions include lag or latency compensation [17], [29], compression with encoding techniques [20], [32], [40], [41], the use of client computing power [29], [35], [42], edge computing [23], [25], [31], [43], machine learning [36], [38], [44], [45], frame adaption [46], [47], and GPU-based server selection [48], [49]. Figure 3 presents the identified solutions along with the number of references cited to review them.

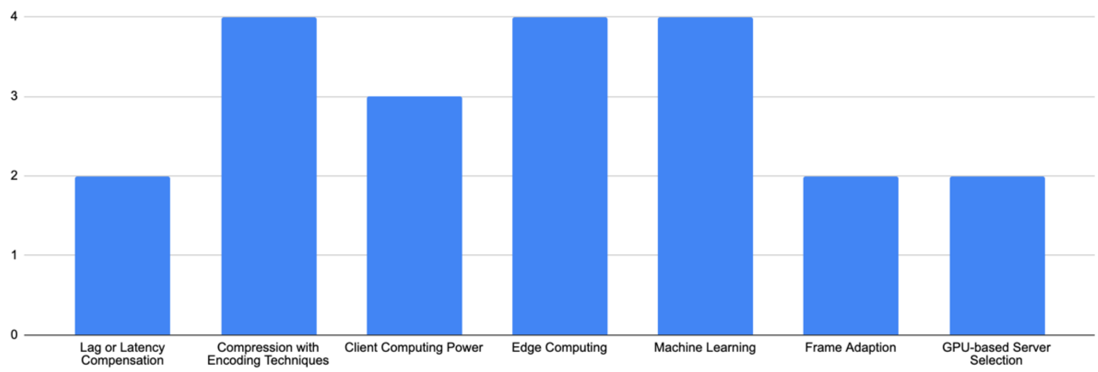

Figure 3: Bar graph of the number of reference literature that discussed solutions to the identified network-related issues and challenges of cloud gaming.

Each of the solutions was correlated to an identified issue or challenge. The solutions and the issue or challenges they can solve are summarized in Table 2.

Table 2: The solutions and the network-related issues and challenges of cloud gaming they can solve.

Solutions	Quality of Service (QoS) and Quality of Experience (QoE)						
	Latency	Bandwidth	Delay	Packet Loss	Graphics Quality	Cost of Providing the Service	Complexity
Lag or Latency Compensation [17], [29]	✓		✓				
Compression with Encoding Techniques [20], [32], [40], [41]		✓			✓		✓
Client Computing Power [29], [35], [42]					✓		
Edge Computing [23], [25], [31], [43]	✓	✓	✓	✓			
Machine Learning [36], [38], [44], [45]	✓	✓	✓				✓
Frame Adaption [46], [47]			✓				
GPU-based Server Selection [48], [49]						✓	

As shown in Table 2, the solutions could solve only one to four issues and challenges. First, latency can be solved by lag or latency compensation, edge computing, and machine learning. Second, bandwidth can be solved by compression with encoding techniques, edge computing, and machine learning. Third, delay can be solved by lag or latency compensation, edge computing, machine learning, and frame adaption. Fourth, packet loss can be solved only by edge computing. Fifth, graphics quality can be solved by compression with encoding techniques and client computing power. Sixth, the cost of providing the service can be solved only by GPU-based server selection. Lastly, complexity can be solved by compression with encoding techniques and machine learning. For QoS and QoE, even if these were considered issues and challenges themselves, their solutions were linked with others. As identified from references [17]–[35], QoS and QoE can be related to latency, bandwidth, delay, packet loss, and graphics quality. Thus, the solutions for the previously mentioned issues and challenges are also considered for QoS and QoE.

3.3.1. Lag or latency compensation

To reduce the adverse effects of lag, latency, and delay for cloud-based multiplayer games, Li et al. [17] proposed a lag equalization strategy which they described as an approach to equalizing lag for all players in one cloud gaming environment. In their research, they used the Gaming Anywhere (GA) open-source cloud gaming platform and the game Assault Cube to apply the strategy of equalizing delay to all players. For example, if two players are playing the same multiplayer cloud-based game, an artificial delay will be added through the server to the player who is experiencing less lag. Therefore, both players will have a fair experience. Their findings show that the strategy is possible to be used in real-time but state that more comprehensive tests may still need to be done. Comparatively, Sun and Claypool [29] proposed a latency compensation strategy for the cloud gaming server of multiplayer cloud-based games. They call their technique “Time Warp,” which they discussed would allow the server to warp the time in the game world for the players playing the game. They used this technique for a custom cloud-based game system. The difference with their technique is that the game server rolls back time to player input as a response to server-to-client latency. For example, if a player uses an action towards an opposing player and then experiences lag, the server turns back time for the player to then determine the result of the action. After this, the server then forwards the time. Their results showed that Time Warp was able to alleviate some effects of latency but may be inconsistent for other games, such as those with projectile weapons.

3.3.2. Compression with Encoding Techniques

Doyle et al. [20] stated that the bandwidth required for streaming decreases if there is better compression for encoding and decoding. However, traditional techniques may increase the delay since the server has to operate with the new compression strategy. In their paper, they proposed a system called "Strife," which allows proper compression depending on the bandwidth of the client. The Strife system can adapt the compression type based on the characteristics of individual cloud-based game clients as opposed to other systems which use the same compression type for all clients. Their results showed that dynamic compression selection increases QoS except if there is excessive network congestion. Correspondingly, Ghafari et al. [40] were able to improve compression to improve the QoE for cloud gaming while supporting a lower data rate or bit rate. They stated that more compression could instigate a lower data rate for minimum bandwidth. In their experiment, they found that the main10 high-efficiency video coding (HEVC) encoder was efficient for improving visual quality but may cause additional network delay. In relation, Illahi et al. [41] achieved less bandwidth requirement through foveated video encoding (FVE). They stated that FVE leverages the sporadic acuity of the human visual system (HVS) for encoding. Their strategy, therefore, encodes the rendered game video with a gradient that matches the HVS acuity by tracking the user's gaze and using it during encoding. They concluded that this strategy results in a lower bitrate and thus reduces the bandwidth requirement for cloud gaming. Using compression for 2D planar maps, Wang et al. [32] proposed a technique that allows increased quality for cloud-based games at the same bitrate compared with other video streaming platforms. Their technique uses 2D planar maps that are further compressed to decrease the required network bandwidth to stream to the client. Their findings show that the proposed technique enables a fast running time for clients while allowing scalability to high resolutions without bitrate problems. This, therefore, shows that there can be an appropriate compression technique to support high graphics quality while also considering a low bandwidth requirement.

3.3.3. Client Computing Power

Chan et al. [35] proposed a hybrid-streaming system that utilizes the available rendering power of both the cloud server and client device to improve the graphics quality of cloud gaming without increasing the bandwidth requirement. Their findings show that the system reduced the server's workload for graphics processing and attained better graphics quality. This is similar to the technique of graphics streaming [29], [42]. Sun and Claypool [29] discussed that graphics streaming could reduce bitrates. With the technique of graphics streaming, the server would send graphics information to the client, which would be rendered by the client. They concluded that graphics streaming could reduce bitrates, but the client must know how to render the image from the sent data. Chen and El-Zarki [42] also discussed graphics streaming and the collaborative rendering. Their findings show that image quality can be improved by utilizing the computing power of the client. They stated, however, that the technique may have a trade-off with the delay because of the additional computation for rendering that is needed to be done by the client.

3.3.4. Edge computing

Lin [23] discussed that edge computing could solve some of the issues of cloud gaming. In his experiment, he utilized cloud and edge servers with a GA platform and the Assault Cube game. The findings for the edge cloud gaming system show that it had less packet loss and faster RTT. The edge system was able to keep more packets than the traditional cloud system. However, he did state that there might still be more jitter and delay depending on the user input. In contrast, this may depend on how the system was set up, as Tsipis et al. [25] stated that cloud-edge hybrid gaming systems could surpass traditional cloud gaming systems regarding delay and latency. They discussed that most related studies express placing rendering servers at the edges of the cloud for lower latency. In their experiment, they were able to infer that increasing the edge renderers would reduce latency for cloud-based games. Similarly, Zhang et al. [31] proposed "EdgeGame," which they also explain would offload the intensive rendering of cloud gaming to the network edge. They stated that EdgeGame was able to use the computation and caching resources in the edge to reduce network delay and bandwidth consumption. Furthermore, they were able to integrate deep learning in the edge to make bitrates adapt depending on network characteristics. However, they stated that the cost could become higher and that stability may be lower as more edge nodes are needed and added. On the other hand, for mobile users, Franco et al. [43] stated that a hybrid mobile edge and cloud computing system could increase reliability and reduce load.

3.3.5. Machine Learning

Integrating machine learning into cloud gaming is a strategy that can also be used to reduce delay. Li et al. [38] proposed “Themis,” which they explained uses reinforcement learning to adaptively partition resources for reducing delay in cloud gaming. They stated that it is able to understand complex relationships between resource partition and performance. In their experiment involving the use of GA and various games, they discovered that Themis could reduce response delay. In another research paper, Li et al. [44] also proposed “GAugur,” which uses machine learning to accurately model the complex relationship of the performance interference of colocated games. They evaluated GAugur on 100 games and then used it for cloud-based game colocation. As a result, they found that GAugur was able to improve the resource utilization of cloud gaming. In relation to the machine learning techniques used by Li et al. [38], [44], Cai et al. [45] applied cognitive computing to learn each cloud-based game player’s status and also optimize resource allocation for different components of the game. Their experiments exhibited that better resource allocation leads to better performance and latency. Similarly, Mossad et al. [36] proposed “DeepGame,” which applies deep neural networks. Their technique learns the player’s contextual interest in the cloud-based game to reduce the required bandwidth without impact on player QoE. They discussed that DeepGame encodes specific zones of the video game’s frames with varying quality depending on their importance to the player. Through conducting experiments through gaming sessions with various games, they found that DeepGame could reduce the required bandwidth without sacrificing quality for the players.

3.3.6. Frame Adaption

Anand and Wenren [46] utilized a novel predictive paradigm to hide latency in cloud gaming. Specifically, they used the predictive paradigm to pre-generate future resulting game frames to the client so that it can immediately respond to user input. The results of their experiment showed that their strategy could reduce response delay. Relative to their findings, Nguyen et al. [47] combined frame skipping and frame discarding to improve quality without added delay. With their system, there is a decision engine that would use necessary information from a measurement engine to decide the optimal frame rate of a video game. The system would compute if the game would benefit from less delay or higher smoothness. Their findings showed that their proposed method could eliminate the buffering delay. However, they state that the solution may cause a trade-off between buffering delay and smoothness.

3.3.7. GPU-based Server Selection

For cost-effective server selection for multiplayer cloud gaming, Dinaki and Shirmohammadi [48] proposed two methods to maximize GPU utilization. They applied metaheuristic algorithms called Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). Each algorithm maximizes GPU utilization and allocates the maximum frame rate to the players based on server constraints. Their experiment, which involved varying loads and numbers of players, showed that the PSO-based algorithm performs better than the GA-based algorithm. In another study, Dinaki et al. [49] further improved the two metaheuristic algorithms, PSO and GA, which they named boosted-PSO and boosted-GA. Their new model also allows each available server to be simultaneously used for multiple players depending on the game load. In addition, it also efficiently uses the GPU. They stated that leveraging the GPU can increase the profit of cloud gaming service providers and enable them to achieve cost-effectiveness. From their experiment, they then discovered that boosted-PSO achieved higher efficiency and stability for a varying number of players. Therefore, they concluded that boosted-PSO supports higher utilization, a lower number of used GPUs, and higher stability.

In summary, Table 3 compares the solutions based on content from the collected literature. It presents the solutions, the issues and challenges they may solve, their usage and favorable outcomes, and their drawbacks or possible repercussions.

Table 3: Comparison of the solutions for the network issues and challenges of cloud gaming.

Solutions	Issues and Challenges Solved	Favorable Outcomes When Used In Other Research	Drawbacks
Lag or Latency Compensation	QoS & QoE, latency, and delay	- Li et al. [17] were able to equalize delay for all players with no decrease in QoE. - Using Time Warp, Sun and Claypool [29] were able to alleviate latency with the best CPU load compared to traditional techniques.	- May be inconsistent for other games, such as those with projectile weapons [29].

Compression with Encoding Techniques	QoS & QoE, bandwidth, graphics quality, and complexity	- Using the Strife system, Doyle et al. [20] were able to increase QoS for the players. - Wang et al. [32] achieved better video quality while having fast performance with less than or equal to 0.83ms to render each frame and no increase in bitrate. - Using main10, Ghafari et al. [40] decreased bandwidth consumption by 0.183. - Illahi et al. [41] reduced bandwidth consumption without affecting QoE.	- May be ineffective if there is excessive network congestion [20]. - May cause additional network delay [40].
Client Computing Power	QoS & QoE and graphics quality	- Using graphics streaming, Sun and Claypool [29] were able to reduce bitrates by about 20% compared to video streaming and less than 5% compared to image streaming. - Chan et al. [35] achieved better graphics quality without a large overhead. - Chen and El-Zarki [42] improved the visual quality of the cloud-based game while reducing bandwidth.	- The client must know how to render the image from the sent data [29]. - May have a trade-off with the delay because of the additional computation for rendering [42].
Edge Computing	QoS & QoE, latency, bandwidth, delay, and packet loss	- Lin [23] achieved a 27% faster ping, faster RTT, and less packet loss compared to the other tested systems. - Tsipis et al. [25] found that as the number of renderers is increased, the latency is reduced. - Using EdgeGame, Zhang et al. [31] reduced bandwidth consumption, decreased the network delay by 50%, and improved QoE by 20%. - Franco et al. [43] were able to alleviate load reduction.	- There might still be more jitter and delay depending on the user input [23]. - The cost may become higher and the stability may be lower as more edge nodes are needed and added [31].
Machine Learning	QoS & QoE, latency, bandwidth, delay, and complexity	- Using DeepGame, Mossad et al. [36] reduced the bandwidth requirement by up to 19% to 36%, depending on the game, while improving the visual quality of the game. Latency requirements were also unchanged. - Using Themis, Li et al. [38] were able to reduce the delay by 17% to 36%. - Using GAugur, Li et al. [44] increased resource utilization by 20% to 60% and achieved up to 15% better performance than other solutions. It also helped them understand the complexities of colocated games. - Cai et al. [45] were able to achieve better system performance and latency.	None
Frame Adaption	QoS & QoE and delay	- Anand and Wenren [46] improved QoE by improving delay. - Nguyen et al. [47] were able to eliminate buffering delay while also improving the video quality and increasing the frame rate.	- May cause a trade-off between buffering delay and smoothness [47].
GPU-based Server Selection	Cost of Providing the Service	- Using PSO and GA, Dinaki and Shirmohammadi [48] increased the performance of GPU utilization while reducing capacity wastage without sacrificing QoE. - Using boosted-PSO and boosted-GA, Dinaki et al. [49] achieved high GPU utilization efficiency while reducing capacity wastage.	None

4. CONCLUSION

As discussed, cloud gaming still needs more research to be done. Thus, this paper investigated the networking perspective of cloud gaming. In the paper, a literature review was conducted by formulating and answering relevant questions. The first research question asked what issues and challenges can affect cloud gaming. In relation, the second research question aimed to find possible solutions for the identified issues and challenges. Under the results, it was identified that cloud gaming could suffer from network-related quality of service (QoS) and quality of experience (QoE) problems. QoS and QoE can then be affected by specific issues, which are poor latency, bandwidth, delay packet loss, or graphics quality. Moreover, the cost of providing a cloud gaming service and the complexity of implementing cloud gaming were also challenges. Given these issues and challenges, various solutions were identified. These solutions include lag and latency compensation, compression with encoding techniques, client computing power, edge computing, machine learning, frame adaption, and GPU-based server selection. Each solution could solve one or multiple issues and challenges but may have repercussions. Thus, these solutions are not often applicable.

Overall, the paper serves as a reference for researchers investigating the networking issues of cloud gaming along with possible solutions to these problems. In addition, it is also a contribution to the existing body of knowledge. Future research could still examine the networking side of cloud gaming to a greater extent. Since the literature used was limited, other studies could extend the content of this research by using more research databases and tools. With this, supplementary literature not used for the literature review could be added. Therefore, further research could lead to the discovery of other network-related issues and challenges with cloud gaming, as well as additional solutions for them.

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