Categories of Cloud-Based Interactive Applications

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A cloud-based interactive application (CIA) is an application running in the cloud with stringent interactivity requirements, such as remote desktop and cloud gaming. These services have experienced a surge in usage, primarily due to the adoption of new remote work practices during the pandemic and the emergence of entertainment schemes similar to cloud gaming platforms. Evaluating the quality of experience (QoE) in these applications requires specific metrics, including interactivity time, responsiveness, and the assessment of video- and audio-quality degradation.

cloud-based interactive application (CIA) quality of experience (QoE) remote desktops cloud gaming interactive web applications

1. Introduction

Cloud computing is a growing computing paradigm [1] that promises on-demand computing resources. It is possible to differentiate between three types of cloud deployments: public clouds, private clouds, and hybrid clouds. In the public cloud, an off-site third-party provider offers computing resources and management. These resources are accessed through the Internet. In this paradigm, there are new billing schemes whereby customers pay for the use of the infrastructure. Users can access high-power computational resources from client machines, with the only requirement being a connection to the Internet. Thus, individuals and companies can reduce the cost of deploying and maintaining their computing infrastructures by delegating system maintenance to the cloud service provider, which offers infrastructures with high bandwidth and low latency [2].

In contrast, the private cloud refers to computing resources within a private network. Private clouds are for the exclusive use of a single customer, and the customer's service administrators manage computational resources. On the other hand, hybrid cloud computing offers an infrastructure in which public and private clouds communicate with each other, sharing data and applications between them. Although the use of private clouds has been widespread within the industry, the migration from private clouds to hybrid or public clouds is booming. In particular, the costs associated with the public cloud and the data protection policies of each country make the hybrid cloud option attractive [3].

In this research, cloud-based interactive applications (CIAs) are focused on [4], also known as cloud-based distributed interactive applications (CDIAs) [5] or real-time interactive applications (RIAs) [6]. CIAs are applications

running in the cloud with strict interactivity requirements. Users expect a near real-time response to their actions, which occur through keystrokes or mouse clicks. The response leads to a screen update so fast that the user cannot perceive that the application is not running locally. CIAs can be deployed on any type of cloud. The existing literature identifies three types of CIAs: remote desktop services, cloud gaming services, and interactive web applications [5]. Services such as video on demand or voice over IP are not considered CIAs because they do not involve interactions as defined above. They use streams of audio/video data with temporal requirements but without requirements about how the user interacts with the service.

The International Telecommunication Union (ITU-T) defines quality of experience (QoE) as “the overall acceptability of an application or service, as perceived subjectively by the end-user” [7]. Laghari et al. defined QoE as “a blueprint of all human subjective and objective quality needs and experiences arising from the interaction of a person with technology and with business entities in a particular context” [8]. One of the main network metrics related to the QoE in CIAs is the time elapsed from when the user interacts with the application until receiving a graphical response. This metric is called the interactivity time [9] or responsiveness [10]. Increased interactivity time can reduce the usability of a CIA. In traditional desktop applications or local services not deployed in the cloud, interactivity time is important. However, in the case of CIAs, servers can be located further away from the user, thus increasing interactivity time, at least on a scale directly proportional to the round-trip time (RTT). In addition, the sharing of remote servers can lead to slow applications. These services can be considered elastic because the perception of interactivity time is gradual and influenced by network and service conditions [11]. Other metrics that influence the QoE are the quality of the video image and, to a lesser extent, audio quality.

Ensuring quality of experience (QoE) in interactive services is of great interest to service providers. For example, an increase of 500 ms in interactivity time for interactive web services can result in significant costs and reduced user activity [12]. The growing deployment of cloud services, especially those with interactivity requirements, highlights the need to quantify and monitor the QoE.

The COVID-19 pandemic has enforced measures in favour of public health, requiring the facilitation of remote work for a significant portion of the workforce. Many employers and employees, who had not previously participated in remote work arrangements, have transitioned to this new model. Studies in the literature [13] have suggested that approximately 40% of large and small companies expect that 40% or more of their workers who switched to remote work would continue to do so even after the health crisis. These estimates indicate that at least 16% of workers will perform their jobs from home at least two days a week as a result of the COVID-19 pandemic. A significant number of services enabling remote work fall within the domain of CIAs [14][15][16]. Ranging from office automation to remote desktops, these services are increasingly prevalent and require the development of precise ad hoc monitoring to ensure the necessary QoE [17]. Remote employees relying on services like remote desktops benefit from a seamless experience and good interactivity, resulting in fewer complaints for the support centre and allowing end users to concentrate on their tasks. Companies are actively working to guarantee a high QoE for these services, ultimately ensuring the productivity and satisfaction of their remote employees [18][19].

2. Remote Desktops

A remote desktop is a CIA that allows users to connect from a local computer to a remote one as if they were sitting in front of the remote computer. The local computer may have low computing resources, and it is called a thin client. The remote computer is usually a virtual machine running on a shared server, although it can also be a dedicated computer. In this CIA, the thin client captures the mouse movements, clicks, and keystrokes to be sent to the remote computer where the application is running. These interactions can prompt screen updates that are then sent back from the remote computer to the thin client. The thin client is only a kind of forwarder of user actions. Remote desktops allow mobility for users (the remote computer can be accessed from any device and at any place) and reduce management and maintenance costs. Some remote desktop applications specialise in performing remote assistance functions, such as TeamViewer [20] and Google Remote Desktop [21]. Other solutions are designed for continuous use, such as Windows Remote Desktop [22], VMware View [23], and Citrix [24]. Remote desktop solutions based on the deployment of remote computers on virtual machines are referred to as virtual desktop infrastructure (VDI) solutions. Amazon Inc. provides this type of infrastructure through a public cloud with the Amazon Workspaces service [25]. The use of remote desktops increased drastically due to the pandemic situation in 2020–2021. For example, in the information technology sector, the increase in remote desktop deployments was 258% in 2022, with more than three-quarters of employees using remote desktops [26][27]. The percentage of companies offering remote work, and therefore, remote desktop solutions, increased from 51% at the start of 2023 to 62% in 2024 [28][29].

In this type of CIA, the user wants to control a remote computer as if it were a local computer, without any noticeable delay or loss in image quality. For example, by clicking to close a window, the user expects the window to close immediately. Two main human perceptions can influence the final QoE. The first is interactivity or responsiveness. The lag between user interactions (keyboard or mouse) and the screen updating as a result of these interactions can affect user experience. For example, clicking a window and moving it around the desktop. The user is accustomed to a local environment. The shared virtualisation server and access network in remote desktops can increase the response time to user actions, with a serious impact on QoE. In most remote desktop services, the server sends the screen updates as it generates them. For example, Sun Ray [30] and Lap Link [31] prepare and send screen updates using this method. In other cases, such as Citrix or Windows Remote Desktop, the server bundles multiple intermediate screen updates to send only a single relevant screen. The client may also send a display update request to the server instead of waiting for a triggered update. The VNC protocol [32] specifies that the server does not send updates until it receives a request for the latest version of the display. Some remote desktop services, such as Lap Link, Windows Remote Desktop, and Citrix, cache part of the screen state locally. Local caches allow for incremental screen updates, taking advantage of regions of the previous screen that could have been moved to other coordinates without receiving an unchanged portion of the screen.

The second human perception that influences QoE in remote desktops is the video quality perceived by the user. Some remote desktop communication solutions, such as VNC and Sun Ray, send the screen corresponding to the user's desktop as a video stream or as a sequence of individual video frames. The video stream is compressed with losses, compromising the perceived visual quality and influencing the final QoE. Other solutions, such as LapLink, Citrix, and Windows Remote Desktop, send graphical screen primitives, such as "plot a window of this size in that position of the screen", to the thin client. The client receives primitives that indicate which regions of the

screen must be modified and which content must be represented. The thin client reproduces screen content without any video quality degradation caused by video compression artefacts. However, video quality can be degraded in both alternatives by network packet losses. In addition, the transmission may freeze due to communication problems. This causes stuttering and affects the video quality of the remote desktop. Audio quality is generally less important in remote desktop services, but when needed, the service has to consider the effect of the compression codec, the network packet losses, and synchronisation with the video stream.

3. Cloud Gaming

Cloud gaming services are also a category of CIAs. In cloud gaming, users access a remote video game as if it were local. Similar to remote desktops, processing and rendering take place on the remote server, and the user device collects user interactions with the controller, sends them to the server, and displays the resulting screen updates. Using these services, players do not require expensive video consoles with large computational resources. The user device can be a smartphone, tablet, PC, laptop, or even a traditional video console. This flexibility allows the user to play in the cloud from anywhere and resume their games from other devices. In cloud gaming CIAs, there may be increased sensitivity to delay for some types of games. CIAs allow video game developers and publishers to use the cloud resources of cloud gaming platforms. This simplifies their deployment, maintenance, and costs. Additionally, game developers can develop games for a single platform instead of multiple platforms. There are commercial cloud gaming deployments such as Nvidia GeForce NOW [33], Amazon Luna Cloud Gaming [34], PlayStation Now [35], and Xbox Cloud Gaming [36]. The cloud gaming industry is expected to reach a value of USD 3856 million by 2025, which represents an increase of 54.1% from 2019 [37].

The three human perceptions described in Section 2 influence the final QoE perceived by the user of a cloud-based game. The player wants to play a video game as if it were running on their game console and not a remote server. There are two main components of a cloud gaming platform: (1) the game logic, responsible for transforming user inputs into actions, and (2) the scene renderer, responsible for generating the screen updates in real time. A scene in a video game is composed of all the elements present at a specific time and in a specific position. On the client's computer, the command interpreter captures the user interactions that are then sent to the server. The video capturer must capture the scenes of the video game rendered on the server and make a video stream that is later compressed to save bandwidth. Compression influences human perceptions when it is lossy. In multiplayer sessions, each player's game scenes can be used together to perform compression, taking advantage of the redundant information and compressing multiple users' streams together [38]. Additionally, cloud gaming platforms can detect the regions of the game scene of interest to use compression with more bits and, therefore, higher quality [39][40]. Other compression strategies use information from the rendering of video games to estimate movements and save compression time [41]. Graphics compression strategies generate a 3D coordinate space with information on the points of the objects that make up the scene and the 2D texts that cover them [42]. The server compresses this scene and sends it to the client, who must render that information. This strategy is more demanding for the client since it has to perform rendering in the case of the server compressing the video. Lossy compression influences the visual quality perceived by the player and adds a delay to communication.

In gaming, the user expects the service to respond graphically as quickly as possible with good interactivity. The game should quickly execute actions, such as rotating a geometric figure or moving a player, so that the user does not perceive the involvement of a remote cloud platform. The codec directly influences the time spent on compression and, therefore, the perceived interactivity. The cloud server sends an audio stream alongside the video stream. Human perception of audio quality is more important in cloud gaming services than in remote desktop CIAs. Compression, network packet losses, and network packet delays affect audio quality. Furthermore, sound stimuli produced in response to player actions must be presented in a synchronised way.

4. Interactive Web Applications

Interactive web applications are also a category of CIAs. They differ from typical web browsing, where each click on a link requires a new webpage download. Instead, interactive web applications refer to single-page web applications that have functionality similar to that of a desktop software application. Users utilise a browser to interact with these applications, relying on JavaScript on the browser side for a substantial portion of the functionality. Communication with the cloud is performed using asynchronous AJAX requests. The server that receives the JavaScript requests must calculate and send the associated response in near real time. Interactive web applications simplify the deployment of applications. The developer does not need to create an application for every operating system, and the user does not have to install different applications on their device. Examples of interactive web applications include Google Docs [43], Office 365 [44], and mapping services like Google Maps.

In this type of CIA, users want to use an application through the browser as if it were a traditional program installed on a desktop computer, without noticeable additional latency. For example, web-based mapping services such as Google Maps or Bing Maps allow users to interactively navigate a map service through a web interface. It is essential that when the user wants to move the map or zoom in on a specific region, the time elapsed between their keyboard or mouse actions and the associated graphical response is as short as possible. Developers of interactive web applications divide the application logic between the client and the server. Interactive web pages consist of four main components: the user interface, client logic, communication, and server logic. The user interface is made up of HTML elements, structured by CSS. The client uses JavaScript to develop part of the CIA's processing logic and capture keyboard or mouse interactions, modifying the structure of the HTML DOM on the fly. Unlike traditional web pages, in these CIAs, screen updates are not generated by a click on a link that opens another static HTML or by periodic JavaScript or CSS updates. Instead, updates are interactively triggered by user interactions. Two main strategies for rendering graphic elements and updating them on the fly are used: modifying the structure of the HTML DOM and interactively drawing on an HTML element called a canvas. The strategy of using the canvas element for graphical rendering is becoming increasingly important for performance reasons. In the canvas element, different graphical elements can be drawn and modified in real time without propagating changes in the structure of the HTML document that can compromise the appearance of the CIA. For example, Google Maps has used the canvas for a long time, and other services, such as Google Docs and Google Sheets, have recently adopted this strategy to improve user interactivity. The client must communicate with the server that executes a significant part of the logic of these CIAs. Web interactive applications normally use AJAX for

communication with the server. Some services, such as Google Docs, can generate local graphical updates and wait for the server to confirm them later. However, this is not possible for all types of CIAs since the service may need active communication with the server side (e.g., Google Maps, where the satellite images are sent by the server).

References

1. Markets and Markets Cloud Computing Market by Service Model (Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS)), Deployment Model (Public and Private), Organization Size, Vertical, and Region-Global Forecast to 2028. 2020. Available online: https://www.marketsandmarkets.com/Market-Reports/cloud-computing-market-234.html (accessed on 25 February 2024).
2. Xu, M.; Liu, S.; Yu, D.; Cheng, X.; Guo, S.; Yu, J. CloudChain: A Cloud Blockchain Using Shared Memory Consensus and RDMA. IEEE Trans. Comput. 2022, 71, 3242–3253.
3. Ramchand, K.; Baruwal Chhetri, M.; Kowalczyk, R. Enterprise Adoption of Cloud Computing with Application Portfolio Profiling and Application Portfolio Assessment. J. Cloud Comput. 2021, 10, 1.
4. Markatchev, N.; Curry, R.; Kiddle, C.; Mirtchovski, A.; Simmonds, R.; Tan, T. A Cloud-Based Interactive Application Service. In Proceedings of the 2009 Fifth IEEE International Conference on E-Science, Oxford, UK, 9–11 December 2009; pp. 102–109.
5. Wang, H.; Shea, R.; Ma, X.; Wang, F.; Liu, J. On Design and Performance of Cloud-Based Distributed Interactive Applications. In Proceedings of the 2014 IEEE 22nd International Conference on Network Protocols, Raleigh, NC, USA, 21–24 October 2014; pp. 37–46.
6. Menychtas, A.; Kyriazis, D.; Gogouvitis, S.; Oberle, K.; Voith, T.; Galizo, G.; Berger, S.; Oliveros, E.; Boniface, M. A Cloud Platform for Real-Time Interactive Applications. In Proceedings of the CLOSER 2011, Noordwijkerhout, The Netherlands, 7–9 May 2011; p. 7.
7. International Telecommunication Union. Recommendation P.10/G.100: Definition of Quality of Experience (QoE); International Telecommunication Union: Geneva, Switzerland, 2007.
8. Laghari, K.U.R.; Connelly, K. Toward Total Quality of Experience: A QoE Model in a Communication Ecosystem. IEEE Commun. Mag. 2012, 50, 58–65.
9. Arellano-Uson, J.; Magaña, E.; Morató, D.; Izal, M. Protocol-Agnostic Method for Monitoring Interactivity Time in Remote Desktop Services. Multimed. Tools Appl. 2021, 80, 19107–19135.
10. Safaei, F.; Boustead, P.; Nguyen, C.; Brun, J.; Dowlatshahi, M. Latency-Driven Distribution: Infrastructure Needs of Participatory Entertainment Applications. IEEE Commun. Mag. 2005, 43, 106–112.

11. Song, F.; Ma, Y.; You, I.; Zhang, H. Smart Collaborative Evolvement for Virtual Group Creation in Customized Industrial IoT. IEEE Trans. Netw. Sci. Eng. 2023, 10, 2514–2524.
12. Boronat, F.; Montagud, M.; Salvador, P.; Pastor, J. Wersync: A Web Platform for Synchronized Social Viewing Enabling Interaction and Collaboration. J. Netw. Comput. Appl. 2021, 175, 102939.
13. Bartik, A.; Cullen, Z.; Glaeser, E.L.; Luca, M.; Stanton, C. What Jobs Are Being Done at Home During the COVID-19 Crisis? Evidence from Firm-Level Surveys. SSRN Electron. J. 2020, w27422.
14. Cho, J.; Kim, S.; Kim, N.; Kang, S. Development of a Remote Collaboration System for Interactive Communication with Building Information Model in Mixed Reality. Appl. Sci. 2022, 12, 8738.
15. Lee, K.; Shin, J.; Kwon, S.; Cho, C.S.; Chung, S. BIM Environment Based Virtual Desktop Infrastructure (VDI) Resource Optimization System for Small to Medium-Sized Architectural Design Firms. Appl. Sci. 2021, 11, 6160.
16. Rodríguez Lera, F.J.; Fernández González, D.; Martín Rico, F.; Guerrero-Higueras, Á.M.; Conde, M.Á. Measuring Students Acceptance and Usability of a Cloud Virtual Desktop Solution for a Programming Course. Appl. Sci. 2021, 11, 7157.
17. Liang, B.; Gregory, M.A.; Li, S. Multi-Access Edge Computing Fundamentals, Services, Enablers and Challenges: A Complete Survey. J. Netw. Comput. Appl. 2022, 199, 103308.
18. Ralph, P.; Baltes, S.; Adisaputri, G.; Torkar, R.; Kovalenko, V.; Kalinowski, M.; Novielli, N.; Yoo, S.; Devroey, X.; Tan, X.; et al. Pandemic Programming: How COVID-19 Affects Software Developers and How Their Organizations Can Help. Empir. Softw. Eng. 2020, 25, 4927–4961.
19. Bakaç, C.; Zyberaj, J.; Barela, J.C. Predicting Employee Telecommuting Preferences and Job Outcomes amid COVID-19 Pandemic: A Latent Profile Analysis. Curr. Psychol. 2023, 42, 8680–8695.
20. TeamViewer Website. Available online: https://www.teamviewer.com/es/ (accessed on 25 February 2024).
21. Google Remote Desktop. Available online: https://remotedesktop.google.com/?pli=1 (accessed on 25 February 2024).
22. Windows Remote Desktop Client Website. Available online: https://docs.microsoft.com/en-us/windows-server/remote/remote-desktop-services/clients/remote-desktop-clients (accessed on 25 February 2024).
23. VMware View. Available online: https://www.vmware.com/products/horizon.html (accessed on 25 February 2024).
24. Citrix-All in One Workspace Solution for Secure Access. Available online: https://www.citrix.com/ (accessed on 25 February 2024).

25. Amazon Workspaces. Available online: https://aws.amazon.com/es/workspaces/ (accessed on 25 February 2024).
26. Teradici, H.P. Hybrid Work Report 2022: The Strategic Role of Digital Workspaces. Available online: https://reinvent.hp.com/hybrid-work-report-2022 (accessed on 25 February 2024).
27. Teradici, H.P. Remote Work 2020 Report—The Separation of Work and Place. Available online: https://connect.teradici.com/remote-work-2020 (accessed on 25 February 2024).
28. Dennison, K. Forbes-How The Flexible & Remote Work Debate Will Carry Into 2024. Available online: https://www.forbes.com/sites/karadennison/2024/01/24/how-the-flexible--remote-work-debate-will-carry-into-2024/ (accessed on 25 February 2024).
29. Vena Solutions-Remote Work Statistics and Trends for 2024. Available online: https://www.venasolutions.com/blog/remote-work-statistics (accessed on 25 February 2024).
30. SunRay-Clients. Available online: https://docs.oracle.com/cd/E35310_01/E35309/html/DesktopClients.html (accessed on 25 February 2024).
31. Laplink® Website. Available online: https://web.laplink.com/ (accessed on 25 February 2024).
32. Real VNC Website. Available online: https://www.realvnc.com/es/connect/download/viewer/ (accessed on 25 February 2024).
33. NVIDIA GeForce Website. Available online: https://www.nvidia.com/es-es/geforce-now/ (accessed on 25 February 2024).
34. Amazon Luna Website. Available online: https://luna.amazon.com/ (accessed on 25 February 2024).
35. PlayStation. PS Now Website. Available online: https://www.playstation.com/es-es/ps-now/ (accessed on 25 February 2024).
36. Xbox Cloud Gaming. Available online: https://www.xbox.com/play (accessed on 25 February 2024).
37. Markets and Markets, Cloud Gaming Market by Offering (Infrastructure, Gaming Platform Services), Device Type (Smartphones, Tablets, Gaming Consoles, PCs & Laptops, Smart TVs, HMDs), Solution (Video Streaming, File Streaming), Gamer Type, Region–2023 to 2028. 2021. Available online: https://www.marketsandmarkets.com/Market-Reports/cloud-gaming-market-62740366.html (accessed on 25 February 2024).
38. Cai, W.; Shea, R.; Huang, C.Y.; Chen, K.T.; Liu, J.; Leung, V.C.M.; Hsu, C.H. A Survey on Cloud Gaming: Future of Computer Games. IEEE Access 2016, 4, 7605–7620.

39. Illahi, G.K.; Gemert, T.V.; Siekkinen, M.; Masala, E.; Oulasvirta, A.; Ylä-Jääski, A. Cloud Gaming with Foveated Video Encoding. ACM Trans. Multimed. Comput. Commun. Appl. 2020, 16, 1–24.
40. Liu, Y.; Dey, S.; Lu, Y. Enhancing Video Encoding for Cloud Gaming Using Rendering Information. IEEE Trans. Circuits Syst. Video Technol. 2015, 25, 1960–1974.
41. Abdallah, M.; Griwodz, C.; Chen, K.T.; Simon, G.; Wang, P.C.; Hsu, C.H. Delay-Sensitive Video Computing in the Cloud: A Survey. ACM Trans. Multimed. Comput. Commun. Appl. 2018, 14, 1–29.
42. Zhao, J.; Wang, Y.; Cao, Y.; Guo, M.; Huang, X.; Zhang, R.; Dou, X.; Niu, X.; Cui, Y.; Wang, J. The Fusion Strategy of 2D and 3D Information Based on Deep Learning: A Review. Remote Sens. 2021, 13, 4029.
43. Google Docs. Available online: https://www.google.es/intl/es/docs/about/ (accessed on 25 February 2024).
44. Microsoft Office. Available online: https://www.office.com (accessed on 25 February 2024).