Towards Ubiquitous Mobile Cloud Gaming

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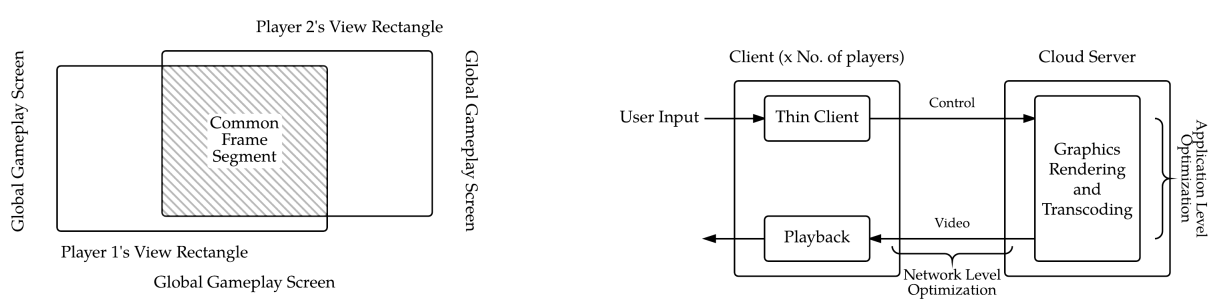
Cloud Gaming is an emerging technology where all the graphics processing required for heavy demanding computer games are off-loaded to the cloud, and the resulting video output is streamed to the player. The client application at the player side is thin, retrieving user inputs and transmitting them to the cloud server, thus allowing the game to be played from almost any device that can stream video. With the advent of services like those of *Gaikai*[1] and *OnLive*,[2] cloud gaming is actively being provided as an in-home service. But a large scale ubiquitous deployment, especially over mobile devices, is still far from conception. There are several issues that affect the practicality of cloud gaming, a major concern being the high-bandwidth requirement for supporting high-quality streaming. Another challenge is to support the low latency needed for the heavy interactivity that games demand. A simple optimization is to add a little more intelligence and data at the client and download the remaining game content real-time as and when needed. Although this approach reduces the amount of data that needs to be retrieved from the cloud gaming server, the bandwidth required to support such deployment, relative to typical internet speeds today, is still significantly high. Our focus is to incorporate novel techniques at the network and application layer to address this challenge.

We work in the context of large scale *multiplayer* cloud gaming, the goal being to reduce the bandwidth requirements for supporting it, and also to reduce latency at the client end. One of the key properties that we exploit is the shared game space across multiple users playing the same game. For example, if two players are playing a multiplayer football game or are part of a role playing game, both of them share the same global gameplay screen, except for the fact that their views maybe offset by a certain value. This property is exploited as follows. Instead of setting up different streaming connections to each of the players, the segments of video frames that are common across their views can be multicasted (or disseminated) to both the players thus reducing the bandwidth needed for video delivery. This is analogous to content dissemination within an information-centric network. A simple way to identify these common segments is to divide each video frame into several blocks (of some empirically chosen size[5]) and look at common blocks across players. Blocks corresponding to portions of the video that are specific or private to each of the players can be individually delivered. To increase the amount of commonality across players, we render video in layers, and deliver in layers. For example, we could choose to render *player score* values on the screen in a separate layer. These values are player specific but are overlaid on top of an otherwise common block. The extent to which the bandwidth requirement will decrease depends on the amount of commonality that exists across different player views. In the context of Information Centric Networking, if we assume that the request for every frame translates into a set of *interests*, one for each of the blocks corresponding to the frame, we then have a framework which implicitly exploits the commonalities while



(a) Exploiting common view segments

(b) Cloud Gaming Architecture

Figure 1

delivering frames to the players. Players can also receive the common blocks from other players who have already received those blocks. We envision that this can result in significant reductions in bandwidth requirements for delivering gaming streams. Application of this technique is limited to games in which player-view changes are translational, which is typical in MMORPGs, e-sports and several large scale multiplayer mobile games.

Current research focuses on improving video compression techniques to address the high-bandwidth requirement. These compression techniques exploit both inter-frame and intra-frame correlations to reduce the amount of information needed to represent the video. In contrast, our technique hinders compression to a certain extent since it involves splitting up the video into blocks. Dealing with each block separately gives less room for the exploitation of intra-frame correlation, since frame data outside the block cannot be leveraged during transcoding. Although this results in a larger total video size, for multiplayer games that involve significant player density in the game space, we believe that the gains obtained from disseminating the common view blocks will overpower the loss incurred in compression.

By working in the context of information-centric networking protocols for cloud gaming, we implicitly enable multi-path routing in the system. This substantially increases the throughput of the system and the achievable content delivery rates. We further enhance this rate by incorporating *network coding,* a technique to achieve maximum flow rates in multicast, to exploit these multiple routes. It has been shown that network coding can help achieve *every* client's maximum flow rate in multicast for the *layered coding* scenario.[4] We believe that the throughput increase that network coding enables can significantly improve Quality of Service in delivering gaming streams. This technique is a network layer optimization for video delivery, and is hence applicable for all genres of computer games, including those in which the player-view changes are projective in a 3-dimensional game space.

In a nutshell, we envision an information-centric network architecture for achieving significant network performance while delivering gaming streams. We have built and deployed a fully-functioning information-centric network following the Named Data Networking[3] (NDN) protocols over the GENI testbed.[6] Over the past year, we have deployed several algorithms for improving throughput and latency measures primarily for video-streaming content (both live and on-demand). Evaluating the benefits of our proposed algorithms for improving multiplayer cloud gaming on GENI has been a challenge owing to the lack of sufficient computing capabilities on GENI nodes for cloud-based rendering to observe real latency impacts for high-performance games. Essentially, thorough evaluation of our algorithms demands two major requirements (1) The ability to create and work with large network topologies, and (2) The need for specialized (Graphics) processing capabilities at selected nodes in this topology. Although GENI allows us to deploy algorithms over large topologies, the computing capabilities of the nodes on the network are limited. It would definitely be in our interest if it is possible to enable *specialized* computing capabilities over at least certain nodes in a large network.

In a slightly orthogonal direction, we explore Information Centric Networking protocols for cloud gaming applications within a home network, in contrast to internet-scale deployment. For example, we envision a system where a tablet computer on a home network is be able to implicitly exploit the graphics capabilities of a powerful desktop computer that is also on the network in order to support high-graphics games, by simply interacting over intelligent application-level protocols.

Overall, we believe that the challenges of achieving a ubiquitous deployment of cloud gaming services requires strong research efforts and experimentation with specialized cloud computing facilities over a large network.

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