X3D Earth Requirement Recommendation:

Peer-to-Peer (P2P) Streaming Content Delivery

Shun-Yun Hu and Jehn-Ruey Jiang

Adaptive Computing and Networking Lab (ACNLab)
National Central University, Taiwan

Abstract

Web3D Consortium's new initiative *X3D Earth* will attempt to create a browsable environment of planet Earth in full 3D, providing access of a vast amount of 3D contents to a wide range of users that include the general public. Scalability of the system architecture and delivery mechanism thus is recognized as an important goal and requirement for *X3D Earth*. However, today's predominant client-server based content delivery mechanism has shown inherent scalability limits and possesses a single point of failure, while server-cluster based solutions such as content delivery networks (CDNs) may be expensive in both cost and maintenance. This paper recommends the use of peer-to-peer (P2P) network as the main delivery mechanism, in order to solve the scalability problem in a cost-effective manner.

What is P2P?

Peer-to-Peer (P2P) is a method to network large number of commodity computing resources for a collective goal. It has gained widespread attention and popularity in recent years via file-sharing software such as Napster, Gnutella, Kazza, eDonkey, as well as voice-over-IP (VoIP) software such as Skype [1]. P2P distinguishes itself from the more traditional client-server paradigm by providing high scalability without incurring the costs of dedicated servers that provide equivalent services. This is achieved through utilizing resources (CPU, bandwidth, and storage) provided by the users of the network, so the amount of total usable resources actually increases with the number of concurrent user, as opposed of being consumed only in client-server architectures.

Why P2P?

The major benefits of a P2P architecture are scalability and affordability. A system reaches its scalability limit when its resources are depleted. For most network applications this limiting resource is the bandwidth at the server. For example, if a web server has a T1 connection (1.544Mbps) to the outside and each user consumes 10 kbps (a little more than 1KB per second), it will have a theoretical limit of about 150 concurrent users (1544 / 10 = 154). Although the amount of server-side resources may increase by provisioning more servers and server-side bandwidth (e.g. content delivery networks, or CDNs, such as Akamai [2]), this will introduce the issues of design complexity, over-provisioning, load-balancing, and maintenance. On the other hand, P2P systems take advantage of the CPU and bandwidth resources of user computers, so the amount of total usable resources actually increase with user size. If designed well, P2P systems can provide superb scalability with only light server-side provisioning.

As the required amount of server resources is limited, P2P systems can be easier to maintain and cheaper to host than client-server architectures that provide equivalent services. This can be seen from the example of BitTorrent [3], a popular P2P design for delivering large files. Measurement studies have observed an average download rate between 240 kbps and 500 kbps (30 ~ 60KB/s) [4, 5], while many content providers have used BitTorrent to provide large-scale distributions of their contents without incurring expensive bandwidth bills (for example, one student distributed a total of 750 GB of contents by paying only USD$4 for the bandwidth [6]). If the costs to host an *X3D Earth* server is sufficiently low, one important implication is that interested parties may develop and host extensions using other datasets by using *X3D Earth*'s open source codebase.

For *X3D Earth*, scalability in terms of the number of concurrent users has been recognized as the key challenge. Scalability will be a concern given the potential popularity and wide interests from its diverse user groups, and the issue is compounded by the fact that real-time 3D data transmission can be both CPU and bandwidth intensive (i.e. visibility determination requires CPU power, while the delivery of 3D contents requires bandwidth). Without a scalable design built into its delivery mechanism, the popularity and adoption of *X3D Earth* will likely be hindered.

Challenges

Given P2P's benefits, it may be desirable that the basic content delivery mechanism of *X3D Earth* is based on a P2P architecture. However, there are at least two technical challenges involved:

1. Compressed and progressive encoding of 3D contents
   In order for users of *X3D Earth* to access the vast amount of 3D contents, sending the contents progressively and compactly (i.e. via streaming delivery) is essential. This will allow clients to render the screen as soon as a few data pieces are obtained, and the view can then be progressively refined as more data pieces arrive.

2. Adaptation of P2P streaming for 3D contents
   Although solutions for P2P-based file delivery and media streaming exist [7, 8], unlike static file or media contents, 3D streaming requires the delivery of many 3D objects based on visibility calculations, existing approaches therefore may not work out of the box [9]. For example, although BitTorrent is efficient at delivering large non-sequential data files, it was not designed for streaming. Modifications or new schemes may thus need to be devised.

What we can contribute (our capabilities):

Our lab has been investigating the usage of P2P architecture to support multi-user virtual environments, and recently on the streaming delivery of 3D contents. Our P2P work has appeared in *IEEE Network* [10], one of the leading academic journals in computer networking, and our P2P-based 3D streaming proposal was presented during *Web3D 2006* [9]. Simulation results showing significant bandwidth saving by P2P delivery is also described in a recent technical report [11]. Starting from August 2006, we have a three-year research project funded by the National Science Council of Taiwan to conduct P2P-based networked virtual environment research, where the first research topic is on P2P-based 3D streaming [12]. We are thus able to contribute research concepts and prototype implementation of P2P-based streaming solutions for 3D contents that are usable by the *X3D Earth* project.

What do we need?

As the main research direction of our lab is on distributed system, P2P networking and content delivery, but not computer graphics, we will likely need the inputs and collaborations from graphics experts in the first challenge of P2P-based 3D streaming -- the compressed and progressive encoding of 3D contents usable for *X3D Earth*. We therefore welcome and seek collaborations with academic or industrial partners on the graphics aspect of this challenging task.

Conclusion

X3D Earth is an ambitious yet worthwhile project where the results may benefit diverse groups of users. The system needs to be both scalable, in order to service large number of concurrent users, yet at the same time, be affordable so that independent services and additional sites may be created by interested parties. Peer-to-peer architecture thus is a more sensible choice over the traditional client-server based delivery mechanisms. We recommend that P2P delivery be included as part of the requirements of *X3D Earth*, and our lab is willing to provide the necessary research and implementation support. However, we do need the inputs and collaborations from graphics experts, in solving some of the unique issues of compressed and progressive encoding of 3D contents, and devising suitable P2P-based streaming mechanisms for 3D contents.

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