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Quality-Based Content Delivery over the Internet

Preface

It is an obvious fact now that the Internet is becoming part of our life. More and more contents are delivered over the Internet. As the heterogeneity in the Internet increases, content providers are considering adaptive content delivery to achieve better user satisfaction. However, so far there are still no thorough study of how contents are delivered over the Internet and how we can achieve better adaptive content delivery.

In this book, we try to illustrate the Internet content delivery mechanism. And based on this mechanism we propose an adaptive content delivery framework which can greatly help Internet Service Providers and Internet Content Providers to achieve quality-based content delivery service. This book can be used as an introduction for Internet content based technology researchers, and can also be used as a reference book for graduate students.

This book is the refined wisdom from the Institute of Information Security Engineering, Shanghai Jiao Tong University. We appreciate all of our colleagues for their great help in this book. And we would also express our sincere appreciation towards Shanghai Jiao Tong University Press. Without their help, we would never have this book published so smoothly.

Xiang Li
Jianhua Li
Feb. 10th, 2010

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Introduction

1.1 Background

The Internet today is everywhere in people's life. With its advantages of multimedia and user interactivity, it is becoming one of the dominant media. Nowadays, it is not only providing all kinds of information, but also a platform for education, business, and entertainment. E-learning, E-business, etc. are no longer abstract concepts, but concrete applications that all people can enjoy. As Internet becomes more and more important in our lives, people expect good service quality from it.

The variety of Internet browsers has never been as diversified as today. Besides traditional PCs, more and more new devices such as PDAs, hand-held PCs, hand phones, etc. are being widely used as browsing tools. And with the people coming from different parts of the world, the Internet is facing a wide variety of users with different access speeds (from 28.8 Kbps modem to T1/T2/T3), language requirement, culture, etc. Under such condition, the "good-quality service" is no longer a simple concept. We believe that there are three issues which are fundamental to the provisioning of quality-based web content delivery. They are (i) retrieval latency, (ii) best-fit pervasive Internet access, and (iii) content access control and policy enforcement.

Retrieval latency is directly related to a surfer's satisfaction towards a website. When the Internet is used as a media for business and news publishing, retrieval latency must be kept low. It is a usual misunderstanding that the only way to improve retrieval latency is to increase the network bandwidth. While this argument is valid, there are other factors that affect the retrieval latency of web browsing. Best-fit pervasive Internet access is to address the browsers' variation and requirements. Since browsing devices might differ so much in their network, hardware, and software condition, they should be served with different versions and qualities of the web content that can best fit their requirements. With surfers of different cultures and age groups all coming into the Internet, content access control and policy enforcement are absolutely necessary to make sure that the resource usage and the surfers are well protected.

There are suggested solutions to address one or two of these three issues. With the traditional structure of client-server architecture, the proposed solutions are often broken down into server side solution and client side solution.

On the web server side, content publishers can make their content more friendly for web delivery. To achieve fast delivery, content publishers can use new data formats that can efficiently decrease the requirement of network bandwidth. Image formats like progressive JPEG and JPEG 2000 can improve the perceived latency of surfers. Video formats like RM, and WMV allow video streaming over the congested Internet. To achieve content customization, one common solution on the web server side is to put multiple copies of one object to fit different user preferences. This solution is very popular to provide multilingual web pages according to the preference information of the visitors' browsers. The main advantage of this solution is that since content publishers own the content, they should know how to customize their content and achieve better quality of the delivered content. However, since their major target is to serve the whole Internet, it will be quite impractical for them to customize the content for minority groups. Very often, the major focus of web sites is to provide content availability. It is quite difficult for them to understand how their content can be optimized for delivery. Furthermore, due to the conflict of interest, it is inappropriate to have access control and content filtering on the web server side.

On the client side, most solutions are in the form of plug-ins for browsers or special software to optimize the OS network operations. For example, a lot of people combine content browsers with some software plug-in like Norton AntiVirus to block the virus or Cyber Patrol to block pornographic materials. This plug-in approach is modular and flexible to fulfill many requirements. However, such solutions might not be efficient in the Internet environment. If every PC needs to install the same plug-in, it might be more cost effective to have a centralized solution for them to share. Distributed solution brings trouble to maintenance and administration. And some applications such as image transcoding to save network bandwidth might not be appropriate to be done in the browser's plug-in approach.

In the Internet environment, people are looking for centralized, one-to-many solution. Such solution is expected to be cost-effective and scalable. This brings out the solution as the network intermediary servers. Researchers believe that by turning the traditional passive web intermediary servers into active ones, the new requirements of content delivery can be fulfilled. By "active", we mean that the network has the intelligence and authority to manipulate data and to make decision on how content should be delivered in the network. The concept of active web intermediary server was first suggested in active network research. Later, researchers find that it is a good solution to the heterogeneity requirement of web content delivery network. Experimental systems such as Pythia and TrenSend were built to explore the feasibility of such active web intermediary server approach. Industry also notices the great potentials of this approach. As a result, several protocols such as I-CAP, SOAP and OPES are defined for web intermediary applications. Some web intermediary server based applications including anti-virus gateway, automatic language translation gateway, and content

filtering gateway are widely discussed today.

1.2 Challenges

Though the direction of active web intermediary server is good to achieve the requirements for "quality-service" web content delivery, there are several questions to be answered before solutions can be practically implemented into the network. To build an application in the network, especially in places such as web intermediary proxy, performance is the most important factor for success. Network itself is expected to have high throughput. And data streaming and real time processing are the basic requirements for network applications, which makes the high performance requirement so critical to the feasibility of active web intermediary servers.

The performance requirement actually leads us to a more fundamental question: what does performance mean in web content delivery? Traditional performance study on web content delivery focuses on the object retrieval latency. We argue that this is not sufficient to reflect the satisfaction level of web surfers. First, in real life, a basic web request is a web page instead of a specific object alone. Therefore, just measuring the object retrieval latency might not be enough to show the visual effect of the network delay. Second, and more importantly, there exist retrieval dependencies among objects within the same web page. Measuring the object's downloading time alone cannot reveal such dependencies. Finally, the situation is made even more complicated with the parallel fetching of web objects. Therefore we need a new performance measuring method to better understand the performance of web content delivery.

Another big challenge is the real-time content transformation itself. An active web intermediary performs transformation on the data that streams through it. Since it needs to be done in a way that the high performance requirement can be met, such transformation needs to be designed with tight constraints, which are quite different from those in normal standalone applications. A good example is the availability of streaming data for content transformation without buffering in the network.

Other challenges include scalable system framework for active network intermediaries and its system requirements in their implementation.

1.3 Research Topics

To meet the challenges mentioned in Section 1.2, several research topics are of our interest. The first one is the performance measurement model for web content delivery. Traditionally, only the object retrieval time is used as an indicator for content delivery. However, the visual effect of the whole page downloading, the retrieval latency, and the inter-object dependencies make the object-based measurement approach insufficient. What we need is a model that can illustrate the inter-object relationship within a page and can show the place where the network delay of a page downloading is introduced.

With this model, we can get a clearer view of the content delivery mechanism on the Internet. This knowledge can also provide hints on where and how the performance of web content delivery can be improved.

Another topic is about the real-time content transformation in the web intermediary server. As transformation in the web intermediate server should not sacrifice the server's high performance, we need to have a good understanding of the constraints of the operation environment. In web content delivery, data is streaming over the network. This means a network node tries to pass the data to the next node without data buffering. However, when an active web intermediary is introduced, this streaming mechanism might be affected. While some applications can be done without holding the transmitted data in the network, there are a lot of applications that need to buffer some or even the whole object data. Currently, not much research is done on performance difference between streaming data delivery and buffered data delivery. However, the difference between them affects the performance of web content delivery significantly when object dependencies and pipelining are considered. No study is done on abstracting the content transformation model from the viewpoint of the network performance. But to develop high performance active intermediary applications, such general transformation model that takes the network's data streaming constraint into consideration is needed; it can provide hints on the algorithm design for web intermediary applications.

To make active web intermediaries feasible and practical, a generic system framework is needed. With a scalable system framework, different applications can be added in smoothly. This system framework needs to consider all possible situations of network-based content transformation in web intermediaries. Furthermore, if it can be combined with the basic cache function of web proxy, it will be ideal since data reuse has already been proven to be an efficient way to reduce network delay and system resource. Together with the specification of the system requirements, the system framework can give researchers and developers insight into how such web intermediaries can meet the requirements of quality-based web content delivery.

1.4 Focus of This Book

In this book, we first propose a chunk-level latency dependence model (C-LDM) to describe the retrieval dependencies of objects within a web page. According to the HTTP protocol, data is streamed through the network chunk by chunk. Hence, the chunk level can be taken as the basic network transmission level for the HTTP protocol. This model not only illustrates object dependencies in web content delivery, but also shows how web page structure contributes to the retrieval latency of a web page. With understanding from both the browser view and proxy view on web page retrieval time, we can draw the conclusion that for a typical network environment, the retrieval dependencies among data chunks of a web page template (e.g. HTML object of the page) and its embedded objects are the dominant factors of the total page retrieval time.

Once we find out that the object retrieval dependence is a major factor for web

page retrieval delay, we propose two mechanisms to improve the web page retrieval by reducing the object dependencies in a page. One proposed solution is the Object Declaration mechanism. With content provider's help, all objects embedded in a web page can be declared at the very beginning of the page. Then the dependencies between the basic page template and its embedded objects are almost reduced to the minimum. Another solution is the page structure table (or PST) mechanism. Proxy as the web intermediary can record the structure of the retrieved web pages; the dependencies among objects can then be reduced by reusing such information. Each method is proven to be effective to improve web page retrieval. Depending on the number of embedded objects in a web page and the cacheability of the objects, performance improvement ranging from 3% to 18% in page download time can be obtained.

In an active web intermediary server, or simply active proxy server, the core concept is the real-time content transformation. Transformation in these servers achieves the purpose of value-added services. In this book, we do a detailed analysis on the modes of real-time content transformation in web intermediary servers. To differentiate between streaming and whole file buffering, we propose the streaming mode and the buffering mode for real-time content transformation in the network. In web content delivery, since chunk is the basic data unit for transmission, we further break down the streaming modes into byte streaming and chunk streaming. We first define a very general basic content transformation model. Then we map different parameter combinations of this content transformation into three modes. Since there exists big performance difference among these three modes, this mapping is valuable as it provides insight information on how the transformation in web intermediary servers should be designed.

When we talk about the actual deployment for this kind of active web intermediary servers, we need not only the theoretical study of the performance, but also the concrete system architecture. In this book, we propose a 4-stage AXForm Framework for web intermediaries. The data flow of a typical web intermediary server (or active proxy server) is well studied. Then we define four stages to further segment a web transaction. Due to the unique properties of the available data, input and output, and their relation with the proxy cache, each stage has its own appropriate transformation application domain. Moreover, besides the unique properties of each stage, there are also common system requirements for building such web intermediaries. We find out that issues such as handling working space, new process, collecting client/server information, etc. are important system considerations for their actual implementation and deployment.

1.5 Book Outline

The outline of this book is as follows. Chapter 2 is the literature review on the related research work. Chapter 3 defines a Chunk-Level Latency Dependence Model for web content delivery. With this model, people can better understand the performance of web

content delivery mechanism. Chapter 4 discusses how to accelerate content delivery based on the Chunk-Level Latency Dependence Model defined in Chapter 3. Chapter 5 discusses the implications of different modes for implementing the "active proxy". Chapter 6 presents the 4-stage transformation framework for active web intermediaries and the design considerations for its system implementation.

2

Related Work

2.1 New Challenges to Web Content Delivery

It is generally agreed that the Internet has already become an important media of our daily lives. With its interactive and multimedia abilities, the Internet has an even greater potential than any of the current media such as television or telephone. It is no longer just a media for personal communication and information dissemination, it is also a platform for education, business, and entertainment. This can be reflected by the fact that despite the fluctuation of e-commerce applications, the numbers of Internet users and web pages published on the Internet keep increasing.

With various kinds of applications being explored on this media, there are always three fundamental issues of content delivery that every Internet infrastructure needs to address. They are (i) retrieval latency (or "world wide wait" problem), (ii) best-fit pervasive Internet access, and (iii) content access control and policy enforcement.

Retrieval latency perceived by a client user is an important performance measurement parameter for every web-based application. In 1998 about 10%~25% of e-commerce transactions were aborted owing to long response delay, which was translated to about 1.9 billion dollars loss of revenue (Wilson 1999). Although network infrastructure and bandwidth availability have been constantly improved in the last decade, they are still unable to meet the increasing network bandwidth demand for multimedia data and the "real-time" expectation of client users. The increasing cost gap between network bandwidth and machine hardware makes this situation worse.

The demand for best-fit pervasive Internet access originates from the growing popularity of personal devices used to access the Internet. These devices include handphones, personal data assists (PDAs), games stations, notebooks, and desktop PCs. With a wide variation of their computation power and display capability, together with their associated different network bandwidth availability, it is a big challenge for a content/service provider with one source to offer the most cost-effective, best-fit presentation to his global client users with different needs. In addition, the changing client's preference and network dynamics make

this situation more complicated to handle.

Content access control and policy enforcement is another important concern in the deployment of Internet infrastructures and applications. From the content side, the flooding of undesirable information on the Internet makes efficient content filtering and blocking essential for Internet deployment (especially in schools and at home). Efficient information dissemination on the Internet also results in a great demand for effective mechanisms to protect the copyright of digital data. On the client user side, when an enterprise deploys an Internet infrastructure, accountability of Internet usage is important and effective enforcement mechanism for the enterprise's Internet related policies is needed. Due to its history of development, the original approach that the Internet adopts for these control and enforcement problems is self-regulatory. However, with the penetration of the Internet into various aspects of our daily life and business world, this approach is found to be very limited and inefficient for obvious reasons.

To address these three fundamental aspects of quality-based web content delivery, researchers turn to intelligent network proxy instead of browser or server for solution at the application level. Since all web traffic needs to pass through the network gateway, proxy solution is a one-to-many, cost-effective solution with centralized management. It does not directly depend on the number of machines (in the form of clients or servers) behind it. It is cost-effective because of its dedicated hardware design for content delivery and one-to-many nature. Policy enforcement can be made easier because it does not require collaboration from the client users or web servers. More important, however, is the fact that there are services that should be done more appropriately in the network proxy than in the browser or the server. Some good examples are the local advertisement uploading and content personalization with maximum data reuse. For a web server to handle these applications, it needs to mark the requested object as non-cacheable. This is highly undesirable because it will imply the disabling of the proven effective web caching technology.

The implementation of intelligence into the network proxy for real-time content transformation and adaptation turns the network into the "active" mode because the network is now involving in the decision making on content creation, presentation, and modification. With its great potential to provide better quality for web services and browsing experience, active network is becoming a new direction for content delivery and pervasive computing. Since this book is focused on active network research, we would like to give detailed literature review on various research efforts related to active network and its associated proxy systems. On the technology side, the survey will cover basic proxy caching, image transcoding, multimedia data format, system framework, markup language, and protocols. On the system side, it will describe the major proxy-based adaptive content delivery frameworks and systems that are proposed and implemented in the past few years.

2.2 Overview of Active Network

Traditionally, a network is mainly focused on the connectivity and delivery speed

between a server and a client. It is considered as "passive" because whatever data enters into the network at one end, the same data content will go out from the other end of the network. There should not be any data manipulation or modification done in the network.

However, as more applications with diversified requirements are put onto the web, researchers and developers start to realize that intelligence in the network gateway is becoming an essential element to determine the success and efficiency of web applications. This starts with the centralized content filtering and blocking proxy approach (Tennenhouse and Wetherall 1996; Psounis 1999) to replace the inefficient, self-regulatory PICS (Platform for Internet Content Selection) approach (PICS) for pornographic and offensive content access control. Pervasive Internet access is the next driving force for network intelligence as one version of the content needs to serve wide variations of clients with different device hardware, preferences, and network bandwidth availabilities. Recently, severe competition in web content delivery market raises great demand for network intelligence to provide value-added functions on top of the basic content delivery network. This includes anti-virus, encryption and watermarking, data compression, language translation, personalization, . . ., etc.

In 1996, the concept of "active network" is proposed (Tennenhouse and Wetherall 1996; Psounis 1999). The basic idea behind is to implement intelligence in the network gateway and proxy and allow data to be manipulated as it passes through the network. The motive of this proposal is to allow more sophisticated web services to be offered efficiently without increasing the burden of or requiring full collaboration from web servers. Furthermore, the concept also goes from the network packet level to the HTTP application level. (Psounis 1999) gives a good overview on the motivations behind active network and suggests three typical network locations (or nodes) where such computation might occur. They are firewall, web proxy, and mobile gateway. All these share the common feature that data manipulation will happen in these nodes. The authors also predict that with the increasing demand of active network capabilities from applications, new network protocols as well as system architectures will be needed over the traditional passive proxy gateway.

There are two basic approaches to implement active network. They are active packets and active nodes. Active packet approach suggests that packets passing through the network can carry data as well as executable code (Tennenhouse and Wetherall 1996). Execution of the code might be triggered in network nodes when some predefined condition is satisfied. Active node approach requires the network nodes to have the executable code installed inside. When data is passed through an active node, they might be manipulated or transformed by executing the code in the node. Again, the triggering is based on some predefined conditions. Some typical examples for active nodes are firewall and request redirection for load-balancing. With the introduction of intelligence and computation into the network, they find that the scalability and efficiency of web services can be greatly improved. The ultimate goal of active network, as is suggested by the authors, is the definition of a small set of APIs upon which wide range of applications can be programmed (Tennenhouse and Wetherall 1996; Psounis 1999;