Web Caching

by Geoff Huston, Telstra

Web browsing dominates today's Internet. More than two-thirds of the traffic on the Internet today is generated by the Web. In looking at how to improve the quality of service delivered by the Internet, a very productive way to start is examining the performance of Web transactions. It is here that Web caching can play a valuable role in improving service quality for a large range of Internet users.

There are two types of Web caches—a *browser cache* and a *proxy cache*. A browser cache is part of all popular Web browsers. The browser keeps a local copy of all recently displayed pages, and when the user returns to one of these pages, the local copy is reused. By contrast, a proxy cache is a shared network device that can undertake Web transactions on behalf of a client, and, like the browser, the proxy cache stores the content. Subsequent requests for this content, by this or any other client of the cache, will trigger the cache to deliver the locally stored copy of the content, avoiding a repeat of the download from the original content source. In this article we look at proxy caches in further detail, particularly at the aspects of deployment of proxy caches in Internet Service Provider (ISP) networks.

What Is Proxy Web Caching?

When a browser wishes to retrieve a URL, it takes the host name component and translates that name to an IP address. A HTTP session is opened against that address, and the client requests the URL from the server.

When using a proxy cache, not much is altered in the transaction. The client opens a HTTP session with the proxy cache, and directs the URL request to the proxy cache instead (Figure 1).

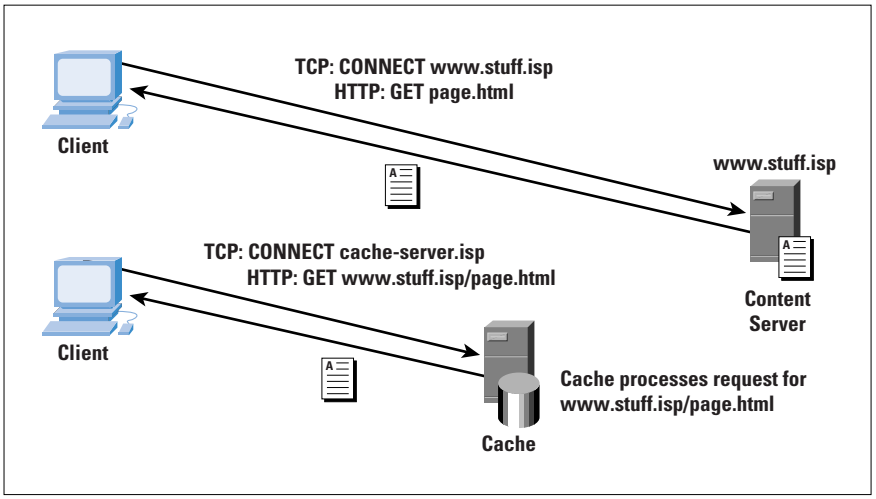


Figure 1: A Proxy Web Transaction

If the cache contains the referenced URL it is checked for freshness by comparing with the "Expires:" date field of the content, if it exists, or by some locally defined freshness factor. Stale objects are revalidated with the server, and if the server revalidates the content, the object is re-marked as fresh. Fresh objects are delivered to the client as a *cache hit*.

If the cache does not have a local copy of the URL, or the object is stale, this is a *cache miss*. In this case the cache acts as an agent for the client, opens its own session to the server named in the URL, and attempts a direct transfer to the cache.

The Pros and Cons of End-to-End Web Access

The original design principle of the Internet architecture is that of the end-to-end model[2, 3]. Within this model the network is a passive instrument that undertakes a best effort to forward packets to the specified destination. Each packet generated by a host is assumed to be forwarded to the addressed destination, and any response to the datagram is assumed to come from that destination address.

The World Wide Web transaction protocol, the *Hypertext Transfer Protocol* (HTTP)[4, 5], is constructed upon this model, where a client's Web fetch causes a TCP session to be opened with the specified target host. The ensuing HTTP conversation identifies the requested data on the destination host, and this data is then passed back to the client. This delivery model is best expressed as a *just-in-time delivery model,* where the data is passed to the client on demand.

This delivery model has many significant advantages. The content server can modify the content, and all subsequent client requests are provided with the updated information, so that updates are immediately reflected in the delivered data. The content server is also able to track all content requests, allowing the content provider to track which particular content is being requested, the identity of each requestor, and how often each content item is referenced. The content provider can also differentiate between various clients, and, using some form of security model, the content provider can authenticate the client and deliver privileged information to certain clients. In this model the content provider can also differentiate between clients, delivering certain information to some clients, and *different* information to other clients of the content server.

Many web systems have been constructed based on the capability of this end-to-end delivery model. Continuously updating Web pages that use either *server push* or *client pull* to regularly update the content on the client's display are used to display stock market prices, weather maps, or network management screens. Client identification can be used to create combined public and virtual private information servers, where a class of identified users can be directed to internal content environments, while other clients are passed to a default public content environment. Such systems form the basis of extranet environments, and can also be used to form part of a virtual private network.

Where information has a defined locality, this tool is very useful. Security and authentication is also used to provide services where the transaction requires some level of privacy. Electronic trading systems, credit card transactions, and related financial systems on the Web make use of such client authentication capabilities. The individual transaction can be encrypted using socket-level encryption,[13] or the entire TCP session can be encrypted using an IP session-level encryption tool such as IP Security (IPSec).

For all these benefits available in an end-to-end model of Web content delivery, there are some balancing drawbacks. A server providing very popular content is placed under considerable stress, both in the number of simultaneous client connections active at any time and in the total volume of data being delivered from the server in the surrounding network. This load is expressed both as a server system load, and as load on the surrounding network. Improving the performance of such systems may entail improving the server throughout, increasing the number of servers through the use of server farms and a traffic manager, and improving the capacity of the local network to deliver the increased volume. However, all these measures may not address all the problems in maintaining quality of the content delivery. Modem-based client systems, and low-bandwidth wireless-based client systems are constrained by a combination of the restricted bandwidth of this last hop and the associated imposed end-to-end delay in conversing with the server. Improving the capacity of the server may not necessarily reduce the number of simultaneously active client connections. Reducing the delay between the client and the point of delivery of the content will improve the performance of content delivery.

In addition, the network itself may not be efficiently utilized. Web traffic does have considerable levels of duplication, where a set of clients request copies of the same content, and the network carries duplicates of the data to each client. For a network provider, where transmission capacity is a business cost, importing the content just once, and then passing local copies of this content to each client, is one method of improving the carriage efficiency of the network.

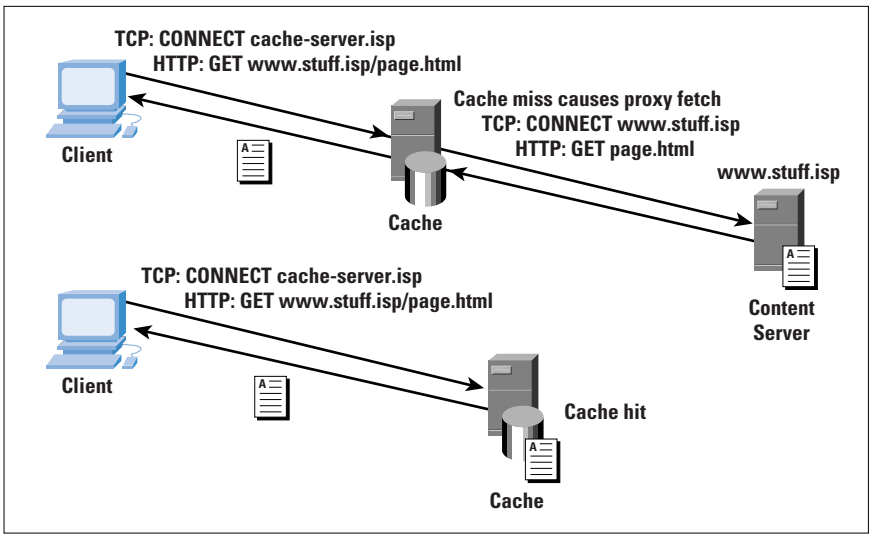
In terms of the ability to improve the service performance of delivery of content to a global network of clients, and in terms of the ability to improve the carriage efficiency of the network, caching of content makes some sense to the content provider, to the ISP, and to the end client.

The Pros and Cons of Web Proxy Caching

The same benefits of improved performance and reduced outbound traffic loads can be realized for World Wide Web traffic through the deployment of Web caches. Web caches are basically no different from any other form of caching. The client request is passed through a *cache agent,* which makes the request to the original source as a proxy for the client. The response of the server is retained in a local cache, and a copy

is passed to the client. If the same request is passed to the cache agent soon after the original request was serviced, the response can be generated from the cache without further reference to the original source. The operation of a Web cache is shown in Figure 2.

Figure 2: A Web Cache



Measurements of ISP traffic profiles indicate that some 70 percent of a typical ISP's traffic is Web-based traffic. An analysis of Web requests indicates that the typical level of similarity of requests (for the same object as one previously requested) can be as high as 50 percent of all Web-based traffic.

There are two hit-rate measures, a *page hit rate* and a *byte hit rate*. A page hit rate measures the proportion of individual HTTP requests that can be served from the cache, irrespective of the size of the page. A byte hit rate measures the ratio of the number of bytes delivered from the cache in hits against the number of bytes in misses. Experience to date has indicated that page hit rates of somewhere between 40 to 55 percent are achievable for a well-configured cache. In such circumstances the associated byte hit rate is between 20 and 35 percent. The major contributor to the hit rate is in image files.

For many ISPs, particularly those operating outside of North America, transmission costs dominate the cost profile of the ISP's operation. If the cache performed at even 60 percent of a theoretical maximum caching performance, the ISP could reduce its external traffic volume requirements by some 13 percent. When the costs of caching are compared to the costs of transmission, this difference can be a significant one in the cost base of the ISP's operation.

For example, if the average cost of transmission is $150 per gigabyte, and the ISP has a typical carriage profile of purchasing 1000 gigabytes per month from an upstream ISP with a 70-percent Web traffic profile, then a cache operating at a 25-percent byte hit rate can save the ISP a recurrent expenditure of $26,250 per month. If the cache costs $100,000

as a capital expenditure and $2000 per month in operational costs to support the service, then a business case analysis would see the cache activity return some $18,000 per month to the business, net of annualized capital and operational expenditures.

The other benefit is to the client, where the reduced network delay between the client and the local cache results in an increase in speed of Web page delivery for cached content.

The average size of a Web transaction is some 16 data packets within the TCP flow. Within a TCP slow-start flow-control process, the first cycle will transmit one packet and wait for an ACK. The reception of the ACK will trigger transmission of two more packets in the second round-trip cycle, and then the sender will await two ACKs. Reception of these two ACKs will trigger a further four packets in the third cycle and eight in the next cycle, and the remaining single packet in the fifth cycle. Therefore, allowing for optimal behaviour of the TCP slow-start algorithm, this average Web transaction takes some five round-trip times. If a user is located some distance away from the Web page, and the round-trip time to the source is 300 ms, the propagation delay of the page load will be 1.5 seconds. In comparison, if the round-trip time to the local Web cache is 2 ms, then the propagation delay of the page load will be 10 ms. These latency figures assume an uncongested network in both cases. In this case, as long as the Web cache search can complete within 1 second, the cache will appear to be far faster to the user.

A slightly different analysis is possible when comparing the performance of a cache configured at the headend of a cable-IP system versus the performance of direct access. The difference in latency in this case is due to both the closer positioning of the cache to the user and the greatly increased effective bandwidth from the cache to the user. A cache download can operate at speeds of megabits per second, as compared to kilobits or tens of kilobits per second when using dialup modem or ISDN services. For a 100K image download, the dial user may experience a 60-second delay, and the same delivery from a local cache via cable-IP may take less than half a second.

The trade-off with caching is that of balancing the the cost of carriage capacity, both in terms of monetary cost of the carriage and the performance cost of the transaction time of the application, against the cost of the use of caching. For non-North American ISPs, in which there is typically a large cache hit rate against North American server locations, the benefits of widespread use of caching are quite substantial. For cable-IP operators, the benefits of local cache operation lie in the ability to exploit the benefits of the very-high-speed final hop from the headend to the end user. For other ISPs, the benefits of caching may be less dramatic, but nevertheless, there are tangible positive outcomes of caching in terms of performance and cost that can be exploited.

As with direct-access models, this approach also has drawbacks. We have already noted the various ways in which the end-to-end model of Web content delivery has been exploited to provide time-based content, client-based content, and secure delivery of content. Caches insert themselves within the end-to-end semantics of the original transaction model, and intercept the transaction by presenting a proxy of the original endpoint. The content delivered from the cache is the content based on the time the cache undertook its request to the server, and the content delivered from the server is based on the server's view of the identity of the cache, rather than the identity of the end client.

With cached content in operation, the cached-content server no longer has an accurate picture of the number of times an item of content is viewed, and by whom. The server cannot authenticate the client, nor can the server deliver any information that is based on the supposed identity of the client. Equally, the client has potential problems, because the client may not be aware that the content has been delivered by the proxy cache. The content may not properly reflect the client's identity, and the information may be based on the security trust model of the server to the cache, rather than the server to the end client, and again the client may not be aware of such a change in security domains. If the content is time-dependent, the content will reflect the time at which the cache retrieved the content, rather than the time the client made the request.

All of this tends to suggest that caching is not a universally applicable tool. Part of the challenge in deploying cache servers is to understand the models of cache deployment and Web content delivery, and ensure that the cache does not intrude in ways that distort the integrity of content delivered to the end user.

Web Cache Hits Versus Web Server Hits

One of the biggest tensions is the balance between the cache operator's desire to maximize the hit rate of the cache system and the desire of many Web page publishers to maintain an accurate count on the number of hits of the page and from where those hits occur. In most cases, it is the requests that are of interest here, rather than the control of delivery of the content. The Web publisher is not necessarily interested in absorbing the hits for Web content. Indeed, many Web publishers see value in distributing the load of content delivery of fixed-content material further out toward the client base, rather than the Web publisher bearing the cost of the distribution load from the local site.

Static pages, composed of plain text and images, are readily cached. As a consequence, the original page publisher may not obtain an accurate count of the number of times the page was displayed by users if the Web server's log was analysed. Some Web page designers place information in the Web page directives; this information directs the Web cache server not to reuse a cached page. The most common way of doing this is to set the "Expires:" Web page information header to the current date and

time, so the next time the page is referenced, a new fetch will be undertaken. One of the more common hacks to cache servers to attempt to improve the hit rate is to allow this directive to be ignored.

This server hit-count problem has plagued cache deployment for many years now. Although there are real requirements in the areas of authentication and security, time-based content, and client-based content that mandate certain types of content being flagged as non-cacheable, much of the data that is marked as non-cacheable has been marked in this way simply for the server to capture the identity of the client. Such "cache-busting" practices are unnecessarily wasteful of network resources, and can overload the content server. There is an Internet Proposed Standard extension to HTTP[6] intended to provide a "Meter" header, where a cache can communicate demographic information relating to client "hits" back to the original content server. The extension also proposes usage limiting, where a server can provide content with a limit on the number of times the information can be used by the proxy cache before revalidating the content with the server.

Web-Caching Models

There are many models of how to invoke a proxy cache.

Explicit Caching

Some proxy cache systems are deployed as a user-invoked option, in which the user nominates a cache server to the browser as a proxy agent, and the browser then directs all Web requests to the proxy cache. At any stage, the user can instruct the browser to turn off the use of the proxy cache, and request the browser to undertake the transaction directly with the client. Modern browsers when configured with a proxy cache may also use the approach of attempting direct access when a request via a proxy cache results in a fetch error. In the proxy cache mode of operation, the destination address of the underlying transport session is then the address of the cache server, while the HTTP content of the transaction remains unaltered. Such caches can be deployed within a client's local network, with the intent of minimizing the amount of traffic passed to the external provider ISP. Additionally, The ISP can operate such a voluntary cache for use by its clients. If the ISP operates in this mode, the benefits to the user in using the cache need to be clearly stated and understood by both the client and the ISP, and the client must be made aware of the location of the cache in configuring his or her local browser.

Forced Explicit Caching

Some ISPs, notably in the dialup service provider sector, operate in a highly cost-competitive market. In such a market service performance and service price are critical business factors, and the provider may choose to operate its network in a forced-cache mode. Here, all Web traffific on TCP port 80 (the port used by the HTTP Web transport protocol) is blocked from direct outbound access, and the ISP's clients are forced to configure their browsers to use the provider's cache for external Web access. This technique is commonly termed *forced caching*.

Transparent Caching

The use of a cache for all Web traffic also can be undertaken by the ISP, without the explicit configuration of the identity of the proxy cache into the user's browser. Irrespective of precisely how this setup is engineered, and there are numerous ways of engineering it, this technique is termed *transparent caching*. With transparent caching the user, and the user's browser, may not be explicitly aware that caching is being undertaken when processing the user's requests. Here the network has to intercept HTTP packets destined to remote Web servers, and present these packets to the proxy cache. Once the page is located, either as a cache hit or a cache miss, the cache must then respond to the original requestor by assuming the identity of the original destination (Figure 3).

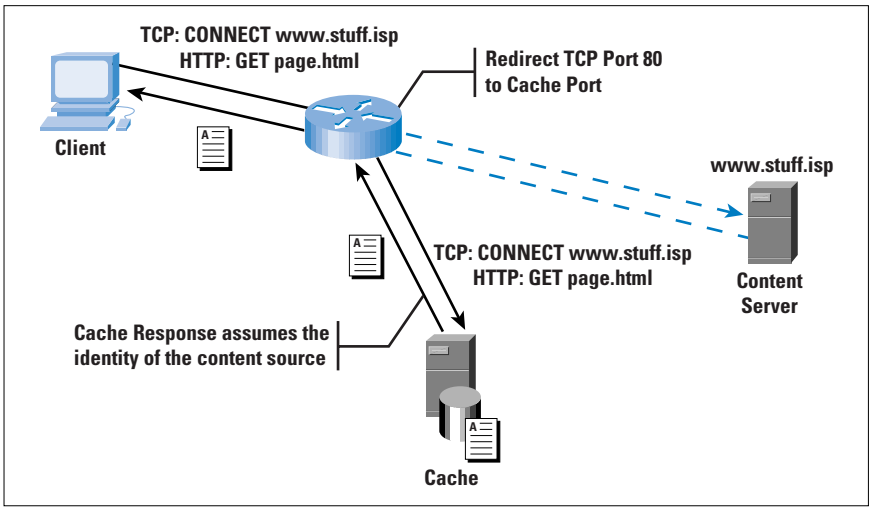


Figure 3: Transparent Caching

It should be noted that no mechanism to date of explicit or transparent caching is completely transparent to both the Web client and the Web server. Where the Web server uses an end-to-end security access model the transparent cache may fail, because the cache will present its address as the source of the request, rather than that of a client. This scenario may result in a page-denied error to the cache request, whereas the client could have completed the transaction directly with the server. In those situations where the use of the cache is mandated, either through filters and a forcing function, or through transparent network redirection, there is no user-visible workaround to the error, and the level of user frustration with the entire cache service rises dramatically.

Under some circumstances it may be possible to work around transparent cache fetch errors. One approach is for a cache fetch error to trigger the cache subsystem to establish an HTTP session with the content server using the source address of the client, and then pass the original HTTP GET request to the server. The server's response is then passed to the client using a TCP bridge. (A TCP bridge is where the connecting device is required to translate the sequence numbers of the TCP headers between the two TCP sessions). Having the cache subsystem intercept the server's packets addressed to the client does require careful coordination with the cache router, and TCP bridging is also quite complex in its

operation, so such solutions tend to be somewhat unstable under load stress. An alternative approach is for the cache to pass a TCP RST back to the client, and instruct the cache router to insert a temporary entry in its redirection filter so that any subsequent TCP port 80 connection from the client to the server's address is not redirected to the cache.

If the sole benefit to the client is improved speed of response, then the ISP must understand that the performance of the Web cache systems must be continually tuned to be highly responsive to Web requests under all load conditions experienced by the ISP. Performance of cache hits must be maintained at a level consistently faster than the alternative of direct client access to the original client site. Performance of cache misses must be at a level that is not visibly slower than that of direct access to the original site. If the user's perception of performance of the cache drops, the benefit to the user also drops. In the case of user-selected caching, the users will turn off the cache option in their browser and return to a mode of direct access.

The business model of a cache is that the capital and operational costs associated with localizing traffic to the cache result in cost reductions to the ISP, when compared to the operation of a noncached network. These cost reductions can be passed on to all users through operation of the entire service at a lower price point or selectively passed on to those clients who make use of the cache through some form of cache-use tariff. The generic model of applying the cost reduction to the ISP's service tariff is certainly an advantage in a price-competitive marketplace. However, unless the performance of the cache is consistently very high, and the transparency of the cache is close to perfect, each individual user may attempt to use direct-access methods.

The alternate business model is to pass on the marginal cost savings to those clients who make use of the cache, and at a level that corresponds to the client's use of the cache and its effectiveness in operating at a high cache hit rate. If, for example, the ISP uses a charging model that includes a tariff component based on the amount of data delivered to the client during the accounting period, this tariff component could be adjusted by the amount of use the client made of the cache system and the relative operating efficiency of the cache in generating cache hits.

As an example, if traffic is tariffed at $100 per gigabyte as delivered to the customer, a discounted value can be derived for traffic delivered from the Web cache. If the average cache byte hit rate is 30 percent, then after factoring in the costs of capital equipment and operational support, the traffic from the cache could be tariffed at $80 per gigabyte. Here, the benefit of using the Web cache is passed directly to those clients who make use of the cache, who both enjoy lower tariffs in direct proportion to their use of the cache and derive superior performance through using the cache. The accounting for this marketing model is certainly a more involved process, involving additional accounting systems and processing to undertake an accurate per-client view of cache usage.

It is becoming increasingly evident that a robust business model associated with a model of discretionary use of a Web cache is that of access to a lower unit price of traffic. In this way, the user sees the incentive of immediate financial benefit in choosing to use the cache system. When the provider deploys transparent or forced caching, translating the benefits of caching into an overall reduced tariff structure for all clients is a more robust business model.

Web-Cache Systems

Cache systems can take a variety of forms. The original Web server from CERN, the original location of the development of Web software, allowed a mode of proxy behaviour. This cache server model was developed significantly in the Harvest Project, a research project at the University of Colorado. As an evolutionary path, the *Harvest* cache server is being further developed within the scope of the development of the *Squid* cache server software and the associated *Internet Caching Protocol* (ICP).

Currently numerous freely available proxy cache systems are available, such as Squid, and many systems are available commercially, such as the Cisco Systems *Cache Engine*. Some of these systems are software packages that operate on a conventional operating system platform, while some use a customized platform kernel, which is optimized for the demands of a cache-delivery environment.

Many of the characteristics of Web caching systems are relevant to the performance of the caching environment. The first is the *size* of the cache server. The relationship between the size of the cache and its hit rate is not a linear relationship. For typical patterns of Web use generated from a relatively large user population, a cache of 1 gigabyte or so will yield reasonable hit rates. Further increase of the cache size will yield incremental improvements in the cache hit rate, where the incremental rate is best described by a negative exponential relationship. Thus, caching systems with 10 gigabytes of storage do not produce performance characteristics markedly different from larger 100-gigabyte caching systems. No objective best size of cache system can be determined, because local environments differ, but every environment exhibits the law of diminishing returns, in which the addition of further cache capacity yields no tangible difference in the cache effectiveness. Large caches take some time, in the order of days or even weeks, to build up a sufficiently large repository of cached data to produce an improved cache hit rate. Generally, 10- to 100-gigabyte cache systems provide extremely effective cache performance, as long as the cache is allowed to stabilize for some weeks following startup. Memory demands in a cache also need to be carefully configured. The URL index of the storage system is stored in memory in most cache architectures in order to perform fast cache lookups, so that the more disk storage configured, the larger the memory requirements.

The next parameter is the *number of simultaneous cache requests* that the cache server can manage efficiently. Note that this metric is different from the number of requests per second that the cache server can manage. The number of simultaneous sessions that the cache server can support is related to the amount of resources allocated to the cache request and the total resource capacity of the box.

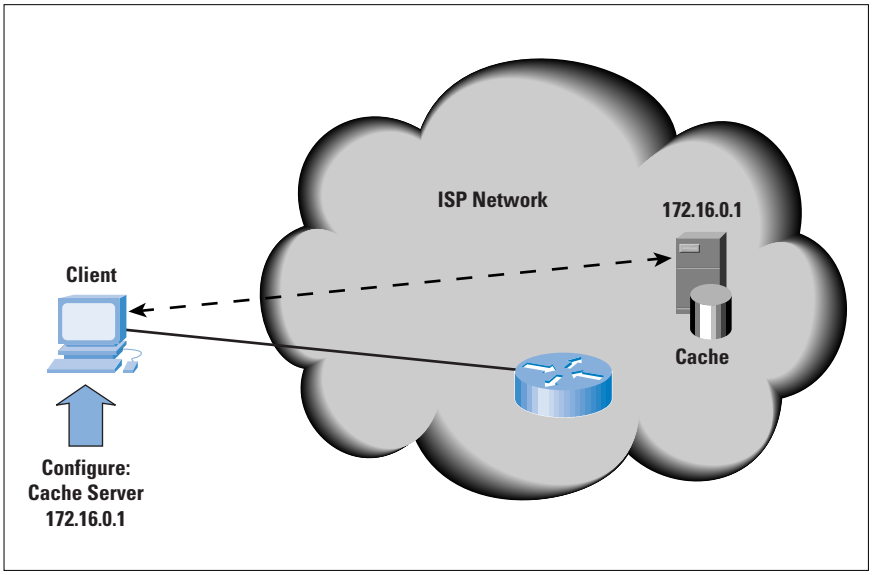
The environment of deployment is very relevant to the performance of the cache environment. The related metric to the number of simultaneous requests that can be managed is the average time to process a request. Combining these two metrics provides the number of requests per second that the cache system can process. The same unit will have a different performance metric of requests per second when deployed in different parts of the Internet. If the cache system is deployed with a satellite-based feed, then the average time to process a cache miss is considerably longer because of the higher latency of the satellite path. This scenario leaves the process of managing the original request open for a longer period, blocking other requests from using this process slot. If the same unit is deployed in a location where cache misses take fractions of a second to process, the process slot can be quickly reused. Each active client connection also consumes memory, and the client connection will remain open for as long as it takes to complete the Web transaction, either for a hit or a miss. The greater the mean round-trip delay for a miss, the greater the number of concurrent active sessions held in the cache. Similarly, the greater the number of low-speed modem or wireless-based clients, the greater the number of concurrent active sessions in the cache. Whether the client operates in transparent mode or in explicit proxy caching mode is also an important consideration. Browser clients use an explicit proxy cache with a persistent connection, while if the cache is a transparent cache, the cache will see clients bring up and drop HTTP connections each time the base URL changes. This session reestablishment, together with the additional Domain Name System (DNS) resolution load imposed on the client, can add up to half a second to the transparent cache response time as compared to the explicit cache response.

Web Cache Deployment Models

In this section we first examine scaling issues for explicitly referenced cache configurations, and then look at the changes to the model introduced through transparent caching.

The simplest deployment model of an explicit cache is that of deployment of a single cache system as a browser-selectable resource. This system can be deployed within an ISP's server environment with a TCP port-80 interface opened for client access. Such a deployment model is shown in Figure 4.

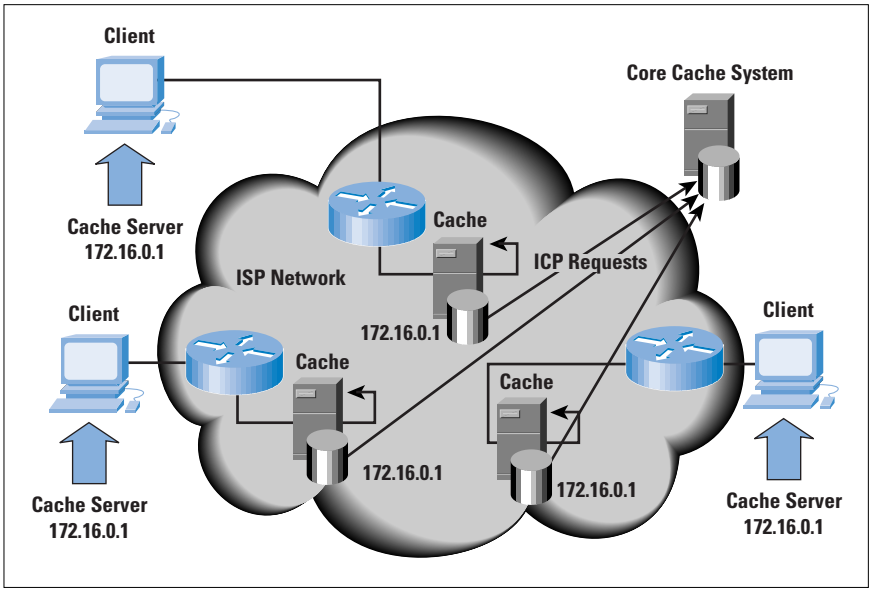
Figure 4: A Selectable Web Cache



Single Web proxy cache systems can be placed under some significant load, and an overloaded and poorly performing cache is perhaps worse than no cache at all. However, scaling this deployment model can prove challenging. Where an ISP operates multiple access points, or points of presence (POPs), one scaling solution is to deploy a server at each POP and use the same IP address for each server. This solution allows the ISP to provide a consistent configuration to all clients and to augment capacity at any location seamlessly. If the cache itself is responsible for advertising the common IP address into the routing system, the caches can also act in a mutual backup role. Failure of a single server will shut down the local route advertisement. Traffic directed to this address will then be carried by the routing system to the next closest proxy cache. There may be some level of TCP session resets for sessions that were active on the failed unit, but in all other respects the switchover is seamless to the client base, and the recovery of an operational state among a set of such servers can be left to the routing system. This deployment model is indicated in Figure 5. Such servers can be configured as a set of local satellite systems to a larger caching core, using an *Internet Cache Protocol* (ICP) configuration to set up a caching hierarchy.

ICP is a lightweight message format for communicating between Web caches[7]. The message format is a simple two- packet exchange, where a Web cache passes a URL query to another cache. The response is either a hit or a miss, indicating the presence of the URL object on the remote cache. On top of this protocol can be constructed cache hierarchies, to allow multiple neighboring caches to pool their resources effectively.

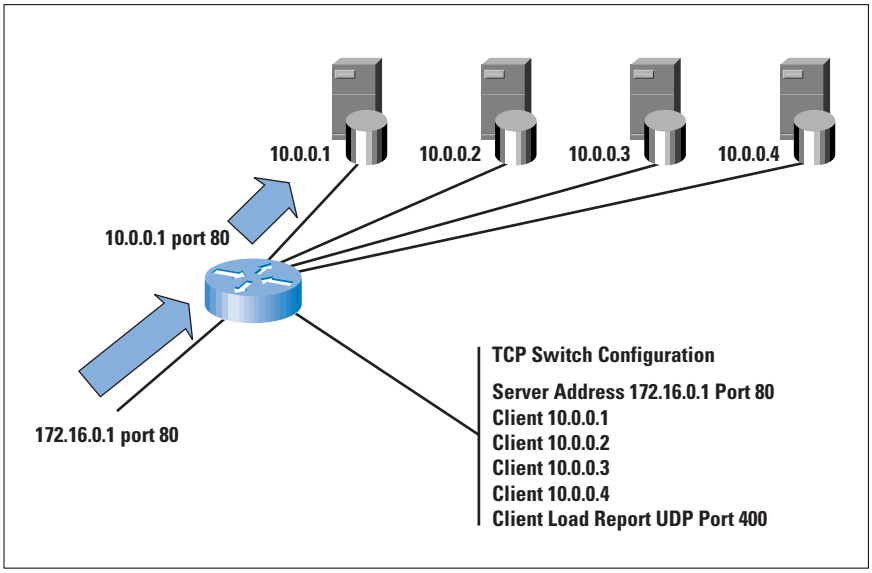
Figure 5: Replicated Web Caches



The proposed mode of configuration of caches is into a tree-structured hierarchy[8]. In such a hierarchy every participating cache is organized with a connection of neighboring peers and an ICP parent. When a cache request cannot be serviced from the local cache, the cache first uses a set of local configuration rules to determine if the server is local. If so, the cache queries the server directly for the content. If the server is remote, the cache issues a set of simultaneous ICP queries to all its cache peers. If any peer responds with an ICP hit, the cache then requests the peer to provide the referenced content. If all peers respond negatively to the ICP query, or a two-second timeout elapses, the cache then requests the URL from its designated parent. The parent may use a peer referral, or the parent may refer the query to its parent, or perform a cache retrieval on behalf of the original request. The intent of this mode of operation is to use a lightweight query response protocol to allow a local collection of caches to pool their cached data. ICP has also been used with additional policy constraints, although the protocol itself is not capable of describing or carrying overly complex retrieval policies. Other intercache protocols are available, including the *Hyper Text Caching Protocol* (HTCP) and the *Cache Array Routing Protocol* (CARP), which offer functionality in terms of intercache cooperation similar to that of ICP[9].

Another scaling measure is to alter the single server to multiple servers, using a TCP-based, load-sharing mechanism in the switching system to ensure that the servers are evenly loaded. This setup is shown in Figure 6. Such a simple load-sharing system may even the load on each server, but it will cause each server to act independently of its sibling servers. It is essential in such an environment to use ICP to coordinate the servers so that they will refer to each other before initiating a new fetch from the content server.

Figure 6: Load-Balancing Web Caches



In such a configuration each cache will contain content also held in neighboring caches. Although this scenario may allow some form of server load balancing, particularly when the servers continually communicate their current load conditions to the load-balancing switch, there is still some inefficiency in the cache farm operation through the potential replication of content on each of the component caches. One direction of scaling the cache servers is to take a collection of cache servers and allow each cache server to specialize in the content it holds. However, the outer TCP destination address does not help the server determine which URL is being requested. In an explicit cache configuration, the browser is directing the TCP session to the externally advertised TCP address of the server farm. The URL information is embedded within the HTTP payload. Some developments have been made in this area, where, with a combination of TCP spoofing and TCP session bridging, a server switch can select the appropriate cache for each HTTP-referenced URL, and then logically connect the client's TCP session to a TCP session to the selected cache to deliver the URL to the client.

Transparent caching presents some further deployment challenges. The functional requirement is to pass all Web requests through a proxy cache server without the explicit knowledge of the client. Two generic techniques exist to achieve this goal:

- *Inline caches:* The first of these approaches is to pass all traffic through a two-port cache server. All non-HTTP traffic is simply passed straight through the device without alteration. HTTP traffic is intercepted and passed to a cache module. The major concern with this approach is the introduction of a single point of failure with an active network element. Any failure of the cache may well prevent all further traffic from entering or leaving the served subnetwork.

- *Redirection caches:* A technique that does not place the cache as a critical point of potential failure is to use policy redirection within the router, redirecting all port-80 traffic to the attached cache. Normally such a policy redirect would infer that the cache is located one hop away from the router, so that such a redirection is normally a local solution. Redirection to a tunnelled interface does allow some greater flexibility in this setup, and the one cache farm could, in such an approach, service a collection of redirecting routers. The failure mode of this form of operation remains a concern, because the redirection mechanism in the router would not normally be aware of the operational status of the cache.

Transparent caches need to ensure that the full URL is inserted into the HTTP level request. When the browser assumes that the request is directed to the content server, the GET request may specify a URL relative to the server. In such cases, the transparent server will need to perform a DNS lookup of the destination IP address of the TCP session in order to reconstruct the complete URL.

Although the DNS lookup does have some performance implications to transparent caches, the major issue for transparent caches is to devise a fail-safe mechanism, so that if the cache server fails for any reason, the caching redirection is disabled. One solution is to use a redirection function within the router in conjunction with a keepalive-based Web cache management protocol. This scenario is the basis of the *Web Cache Coordination Protocol* (WCCP)[10]. WCCP also adds the ability to load share across multiple cache servers through content distribution. Transparent caching assists in this task because the destination address in the IP packets can be used as the basis of the cache selector. The keepalive exchange between the router and the cache server system allows the router to cease redirecting Web traffic upon failure of the servers.

Alternative solutions rely on the cache itself participating in a local routing environment. The redirecting router uses policy-based redirection to forward all port-80 traffic to an address announced by the cache system at a high routing priority. The same address is also announced by the default path router at a low routing priority. Failure of the cache system will result in a withdrawal of the high-priority route, and while the redirection will remain in place on the router, the redirection will be in the direction of the default route.

Another challenge is to process cache misses at a speed comparable with normal noncached Web retrieval. A process of pulling the document into the cache and then serving the document to the original requestor does not meet that objective. The transparent cache has to feed the document to the requestor while simultaneously creating a stored copy for subsequent cache serving.

However, the largest challenge to the transparent cache is that it can serve only documents that are not dependent on the identity of the requestor being preserved. Web servers that use an end-to-end model of access, based on source address identification, or Web servers that attempt to present different documents to the client based on the client's source address, do not fit within the transparent caching model. There is much interest in solutions that allow a transparent cache to effectively shut down in the case of a Web retrieval error, and allow the original requestor the ability to conduct a HTTP conversation directly with the server in such situations. Although there is interest in a network-only solution, it appears at this stage that some level of assistance from the browser may be required. One model of operation is that a transparent cache records the network-level flow identification of a failed Web retrieval, and passes a retry signal back to the requesting browser, and also passes this flow identifier back to the redirector as a temporary filter entry. When the requestor retries the query, as per the signal from the cache, the redirecting router will refrain from redirecting the flow to the cache, and allow an end-to-end session to operate.

Accounting for Web Cache Use

These deployment systems allow for user-optional cache configuration. If the ISP wants to account for the use of the cache, then the cache server or the switch that feeds the cache server must play an active role in accounting collection.

If every network address is uniquely advertised to the ISP by a particular client, then the task of accounting for cache use can be performed using the logged records of the cache system itself. Because every IP address can be uniquely mapped to an ISP client, it is possible to also associate the volume of bytes delivered by the cache to the identified client.

Unfortunately, two factors make this supposition of address uniqueness somewhat weak. First, dialup address assignment implies that the association of an IP address to a client is held only within dialup accounting records in the first instance, and the binding is valid only between the times referenced in the start and stop records. This scenario can be configured into an accounting model by simultaneously processing the dial accounting records when attempting to associate a particular IP address at a particular time to a client.

The second factor is slightly more challenging. For an ISP that offers permanent access transit services, the potential exists that any particular IP address may not be uniquely routed. Normally, such multiple access environments are part of a Border Gateway Protocol (BGP)-based interaction with multiple clients. Knowing the IP address of the query agent is not enough. Ascertaining the next-hop Autonomous System (AS) number as well as the IP address is now necessary to determine the client using the cache.

The implication is that the accounting records now need to be generated on the router that is also the entry point to the cache. In addition, the router must participate in the interior BGP (iBGP) core mesh to maintain current AS path-selection choices. Given the considerable overheads that such an engineering design entails, an alternative approach is to restrict the cache accounting role to account for those cases where the cache client is readily identified. A common measure is that the lower tariff is available only to customers who are "singly homed" with the ISP. Not only is this a strong market incentive for customer loyalty, it also allows simple engineering solutions for cache accounting, because the lookup from the IP address in the cache log to a customer account is then relatively straightforward. Such measures allow a cache-use tariff to be very competitively positioned in the market.

As well as accounting issues, another component for the consideration of optional use of Web caches is that of the necessity of restricting the use of the cache to clients of the ISP. The motive for so doing is to ensure that the cache is available only to clients of the service and not to clients of peer ISPs. It may not be an issue worth the effort of solving, and the first questions ISPs should ask is, "To what extent does this happen, and what impact does it have on the operation of the Web cache systems?" In most cases, the accounting of cache usage may reveal that this issue is one of negligible proportions, and any effort expended in devising an engineering solution would far outweigh the loss to the ISP through such use of the service.

If the measurement of such usage is considered sufficient to warrant engineering solutions, then the mechanisms available to the ISP are to ensure that the Web cache access is filtered at the edges of the ISP network and to ensure that access is possible only by ISP clients, or that the address of the cache is not exported in the routing system to peer ISPs or upstream ISPs.

Further Deployment Challenges

It is highly likely that further development will occur with cache servers in the near future. Large-scale backbone IP networks that use OC-3c (155 Mbps) or OC-12c (622 Mbps) transport cores may carry tens of thousands of requests per second. Designing transparent caches that fit within a transport core at such a scale does present dramatic scaling issues in terms of cache system performance. This factor continues to elude many of today's products available on the market. The generic architecture today is to use a cache network that attempts to place the cache systems closer to the access edge of the network, where the Web request volumes are within the scale of today's cache systems.

Transparency of the cache remains an issue, and it is perhaps an area of further refinement within the specification of the underlying HTTP Web server protocol, as well as further refinement of the operation of Web browsers and transparent cache systems. A potential implementation within Web browsers may allow the user to state the acceptability of using a cache to complete a request, and allow noncache Web page retrieval attempts on cache failure, in the same way that the provider can use page expiration directives to direct a cache not to store the presented data.

References and Further Reading

[1] Huston, G. *ISP Survival Guide,* ISBN 0-471-31499-4, John Wiley & Sons, November 1998.
A more comprehensive view of the technology, business, and strategy behind the Internet service sector.

[2] Clark, D.D. "The Design Philosophy of the DARPA Internet Protocols," Proceedings of SIGCOMM 88, ACM *Computer Communications Review* (CCR), Volume 18, Number 4, August 1988, pp. 106–114 (reprinted in ACM CCR Volume 25, Number 1, January 1995, pp. 102–111).
The original paper describing the end-to-end design philosophy used within the Internet protocols.

[3] Carpenter, B., Ed. "Architectural Principles of the Internet," RFC 1958, Informational RFC, June 1996.
A summary of the design principles underlying the current Internet architecture.

[4] Berners-Lee, T., et al. "Hypertext Transfer Protocol—HTTP/1.0," RFC 1945, Informational RFC, May 1996.
The specification of Version 1.0 of the HTTP protocol.

[5] Fielding, R., et al. "Hypertext Transfer Protocol—HTTP/1.1," RFC 2616, Draft Standard RFC, June 1999.
The specification of Version 1.1 of the HTTP protocol.

[6] Mogul, J., and Leach, P. "Simple Hit-Metering and Usage-Limiting for HTTP," RFC 2227, Proposed Standard RFC, October 1997.
A proposed extension to HTTP to allow a content server to receive hit reports from a proxy cache.

[7] Wessels, D., and Claffey, K. "Internet Cache Protocol (ICP), Version 2," RFC 2186, Informational RFC, September 1997.
A description of the ICP protocol.

[8] Wessels, D., and Claffey, K. "Application of Internet Cache Protocol (ICP), Version 2," RFC 2187, Informational RFC, September 1997.
A description of the structure of cache hierarchies, and their ICP-based interaction.

[9] Melve, I. "Inter Cache Communications Protocols," Internet Draft, Work in progress, **draft-melve-intercache-comproto-00.txt**, November 1998.
An overview of intercache communications protocols currently available, and a collection of references that describe these protocols in further detail.

[10] Cieslak, M., and Foster, D. "Web Cache Coordination Protocol V1.0," Internet Draft, Work in progress, **draft-ietf-wrec-web-pro-00.txt,** June 1999.
A description of Version 1 of the WCCP protocol to support the operation of transparent caches. The protocol defines the interaction between a router and a neighboring cache system.

[11] "Squid Internet Object Cache"—Resource Web page.
http://squid.nlanr.net
A very useful page of resources and references related to the Squid implementation of Web caching.

[12] "Distribution of Stored Information on the Web," Online Tutorial, Ross, K., Institut Eurecom, October 1998. Available at:
http://www.eurecom.fr/~ross/CacheTutorial/DistTutorial.html
A good overview of proxy caching technologies, and also a good analysis of their efficiency of operation.

[13] Stallings, W. "SSL: Foundation for Web Security," *The Internet Protocol Journal*, Volume 1, Number 1, June 1998.

[This article is based in part on material in The ISP Survival Guide, by Geoff Huston, ISBN 0-471-31499-4, published by Wiley in 1998[1]. Used with permission].

GEOFF HUSTON holds a B.Sc and a M.Sc from the Australian National University. Closely involved with the development of the Internet for the past decade, particularly within Australia, he was responsible for the initial build of the Internet within the Australian academic and research sector. Huston is currently the Chief Technologist in the Internet area for Telstra. He is also an active member of the IETF, and is the chair of the Internet Society Board of Trustees. He is author of *The ISP Survival Guide*, ISBN 0-471-31499-4, and coauthor of *Quality of Service: Delivering QoS on the Internet and in Corporate Networks*, ISBN 0-471-24358-2, a collaboration with Paul Ferguson. Both books are published by John Wiley & Sons, E-mail: **gih@telstra.net**