# DNS-based Ingress Load Balancing: An Experimental Evaluation

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#### Abstract

Multihomed services can load-balance their incoming connection requests using DNS, resolving the name of the server with different addresses depending on the link load that corresponds to each address. Previous work has studied a number of problems with this approach, e.g., due to Time-to-Live duration violations and client proximity to local DNS servers. In this paper, we experimentally evaluate a DNS-based ingress traffic engineering system that we deployed at Georgia Tech. Our objective is to understand whether simple and robust load balancing algorithms can be accurate in practice, despite aforementioned problems with DNS-based load balancing methods. In particular, we examine the impact of various system parameters and of the main workload characteristics. We show that a window-based measurement scheme can be fairly accurate in practice, as long as its window duration has been appropriately configured.

#### **1** Introduction

As cloud services and content delivery become increasingly ubiquitous, multihoming is turning to be an integral part of network infrastructure, to distribute load and for failover. A recent study [4], for example, found that the average AS degree increased by one link per AS over the last 12 years.

Ingress Traffic Engineering (ITE) aims to select an incoming link among a set of possible links for the communication between a multihomed data center (or server farm) and its client population. The primary objective of ITE is to load-balance the incoming traffic to (and consequently, the outgoing traffic from) the data center. A secondary objective is to choose a better path (e.g., minimum delay or maximum available bandwidth) for each client. Typically, however, content providers are primarily interested in avoiding congestion in their own access links, and so the load-balancing objective is their primary concern. Networks today employ two common approaches to do ITE. The first approach relies on BGP and selective prefix advertisements [7, 12]. This approach can balance load at the level of IP address blocks, not client networks, it creates BGP churn at the Internet core, and it may be subject to BGP route dampening and convergence delays. The second approach uses the DNS infrastructure to dynamically select one of k IP addresses to resolve the server's name, where k is the number of incoming links. The DNS-based solution is becoming increasingly popular, since it can balance the server's load at the granularity of individual DNS requests, and it does not require the content provider to use BGP.

The most commonly deployed scenario of DNS-based ITE is the DNS-NAT architecture shown in Figure 1. Consider a multihomed network N that uses IP addresses from two ISPs X and Y. It is easy to control the assignment of outgoing connections (initiated from the data center servers) to egress links. To control the egress link of traffic in client-initiated connections, however, is more challenging. One way to do so it is to rely on NATs and DNS, as follows. A server S in N is statically NATed with two IP addresses  $S_X$  and  $S_Y$ , from X and Y respectively. Clients requesting content from server S first resolve its hostname, and then establish a TCP connection to S. Network N runs an authoritative DNS server for the domain name of S, which resolves each incoming DNS request from a client Local-DNS (LDNS) server with either  $S_X$ or  $S_Y$ . Thus, traffic between clients and the data center is routed on a per-LDNS basis through ISPs X or Y. Of course the same approach can be followed in the case of more than two upstream ISPs.

The ITE method presents some hard challenges. First, the traffic that follows a DNS name resolution can consist of multiple TCP connections, due to DNS caching at the client. Second, multiple client sessions can follow the same LDNS request, due to caching at LDNS servers. Consequently, at DNS resolution time, we do not know the magnitude or duration of the traffic that follows each



Figure 1: The DNS-NAT ingress traffic engineering architecture.

DNS request. Further, that traffic cannot be partitioned between different upstream ISPs. Third, TCP can cause significant variations in the throughput of the incoming load, making it harder to predict the incoming traffic on each interface. Fourth, there can be a significant delay between a DNS request (and the associated load balancing decision) and the arrival of the actual traffic that corresponds to that DNS request.

Previous work has studied a number of issues with DNS-based ITE approaches. First, short advertised DNS Time-To-Live (TTL) durations are not always honored by remote DNS servers or clients [11]. Second, it is not possible to migrate an ongoing TCP connection from one link (i.e., server address) to another. Third, clients are not always near their LDNS servers, which can affect accuracy of ITE methods that attempt to select the best path for each client [8].

Theoretical studies have shown the effectiveness of randomized load balancing [10], and issues with stale measurements [9]. It is known that prior information about incoming jobs can help [3, 6]. In ITE, however, it is not always feasible to predict the arrivals or size of client DNS requests. In addition, empirical studies of ITE that compliment our work include [2, 5, 1].

In this paper, we evaluate a DNS-based ingress traffic engineering system that we deployed at Georgia Tech. Our objective is to understand whether a simple but robust load balancing algorithm can be accurate in practice, despite all known problems with DNS-based load balancing methods. We also examine the impact of the measurement window duration on load balancing accuracy.

The rest of the paper is organized as follows. Section 3 describes our ITE prototype and workload. Section 4 shows experimental results for the impact of key system and workload characteristics on load balancing accuracy. In Section 5, we analyze the impact of window duration on load balancing using a history-based measurement algorithm.

# 2 Workload Characteristics of a Content Provider

In this section, we present measurements from the GTLIB content distribution service at Georgia Tech. This service is provided by four servers whose hostname, www.gtlib.gatech.edu, is resolved in a round-robin fashion by two authoritative DNS servers. We have collected full Netflow traces from the Georgia Tech campus border router. In parallel, we run tcpdump at the authoritative DNS servers of the previous site. The measurements were performed for a duration of 24 hours starting on 10th April 2008 at 9pm. We analyzed the collected traces (the capture clocks were kept synchronized via NTP) to first understand whether remote LDNS servers honor the advertised DNS TTL of 8 hours, and second, to characterize the traffic workload in terms of bytes per client and clients per LDNS.

How many LDNS servers honor the advertised TTL? We first look at the distribution of the minimum inter-arrivals from remote LDNS servers. The A records for www.gtlib.gatech.edu pointed to 128.61.111. [9-12], and the advertised TTL was 8 hours. There were about 46,400 resolutions of type A. Figure 2(a) shows the distribution of minimum interarrival times for each LDNS server that contacted our authoritative servers. The figure shows that for around 60% of the remote LDNS servers, we received requests at most once per 8 hours. We can say that these LDNS servers either follow the advertised TTL and/or have a lower client resolution request rate than one per 8 hours. For the remaining 40% of the LDNS servers, we expect that they either use a TTL of less than 8 hours, or that they do not do caching. In other words, these LDNS servers violated the advertised TTL of 8 hours. Moreover, about 10% of them have a very short minimum inter-arrival period, which implies that they may not be doing any caching.

How many clients correspond to each LDNS server? The challenge in this measurement is how to



Figure 2: Workload characteristics from GTLIB content distribution service.

associate an LDNS request with all subsequent arriving connections from clients that have used that LDNS request to resolve the server's name. We use a simple approach to do this correlation, based on the hypothesis that an LDNS server and its associated clients belong to the same Autonomous System, and thus their addresses would both have the same BGP AS-Origin attribute (even though they often do not belong to the same IP address prefix). First, for each client request from an address A, we find earlier DNS requests from LDNS servers that belong to the same Autonomous System that advertises address A. If there are no such LDNS servers, or if there are multiple such servers, we ignore that client request. Otherwise, we associate that client request with the most recent DNS request from the corresponding LDNS server. Note that we ignore clients which resolved the GTLIB hostname before the start of our 24-hour dataset. We also ignore clients that round-robin between DNS servers in their resolver configurations. Most OSes either do not support this feature or disable it by default. Using the previous approach, we found that we can associate 92% of the client sessions with an LDNS entry from the same origin-AS with the client. In total, we identified 2864 unique LDNS servers that we could associate with specific client requests. Figure 2(c) shows the distribution of the number of clients using a given LDNS. We also show regression curves for Pareto and lognormal distributions. Note that the Pareto distribution is a better fit, showing that the number of clients that correspond to each LDNS is highly skewed.

**How many bytes were received by each client?** Figure 2(b) shows the distribution of bytes that the GTLIB servers sent/received from each unique client address in the course of the 24-hour trace. Note that the lognormal distribution is a better fit to the measured data.

We use the previous GTLIB observations to emulate

realistic workload in the experimental evaluation of a DNS-based ITE system, described in the next section.

### **3** System Implementation and Deployment

In this section, we describe our DNS-ITE prototype. The Georgia Tech campus network has several commercial and research providers. We multihome our server using two IP addresses which are advertised to the Internet through Qwest, Cogent, and Internet2. The server's hostname is dynamically resolved by our DNS server to one of the two addresses.

**Load-balancing Algorithms:** We perform load balancing using two algorithms: (1) round-robin (RR) and (2) measurement-based (MB). The RR scheme selects the server's IP address in a round-robin fashion. The MB algorithm uses recent history of ingress and egress traffic at the interfaces of our server to make a load-based decision about the next name resolution. Our goal is to understand how simple round-robin and history-based schemes work in practice.

**Implementation:** Our ITE system consists of two processes running on the same host, the DNS process and a monitoring process. The DNS process is a non-blocking and concurrent, non-recursive authoritative nameserver, which serves LDNS resolution requests for our domain. The DNS process communicates with the monitoring process to get traffic measurements. This communication is done using shared memory; we have also tested an RPC-based mechanism to run the two processes on different hosts. The monitoring process measures aggregate traffic utilization at the two interfaces of the server. We measure the load on each interface using a *sliding window* of length W=nw seconds, which consists of *n* small windows of length *w*. The sliding window moves in steps of *w* seconds. In our implementation,

we set w = 100ms. Our prototype can be extended to other traffic measurement methods such as Netflow, and to multiple content servers.

**Server characteristics:** We run an Apache server on Linux serving content of client requested size over HTTP. The server, DNS and monitoring processes run on a 2GHz hyper threading-enabled Xeon with 1GB physical memory. At peak experiment loads of 5-10 Mbps traffic, the CPU usage does not exceed 20%.

**Workload:** We emulate a realistic workload by using 40 clients on PlanetLab and 6 clients on RON networks. Some of our workload parameters are drawn from observations of Georgia Tech's GTLIB content distribution mirror. We choose these nodes such that they use different LDNS servers (i.e. have disjoint resolver configurations). Further, we pick LDNS servers that follow the advertised TTL (so that, for example, we can emulate LDNS servers using a minimum TTL). The duration of each experiment is 10 minutes.

The traffic model that we emulate is described next. First, 40% of LDNS servers do not follow the nominal TTL of 15 seconds - we advertise a 15s TTL to those servers. For these LDNS servers, we advertise a TTL that is uniformly distributed in [5,600]s. We always advertise the same TTL to a given LDNS server. The fraction of TTL violations is based on DNS logs from GTLIB. Second, clients follow a closed-loop (or interactive) arrival model, in which they download a file over TCP, sleep for some time, and then repeat this process. Unless stated otherwise, the sleep times are exponentially distributed with a mean of 35 seconds. Third, clients download lognormally distributed file sizes with a mean of 225KB, based on a 24-hour Netflow data from GTLIB. However, we had to truncate the size distribution to 625KB to avoid exceeding PlanetLab byte limits that could trigger ratelimiting. Fourth, there can be many clients behind an LDNS. We refer to these clients as hidden clients. We emulate them by spawning multiple simultaneous processes on the same client host. The number of hidden clients on each host is drawn from the uniform distribution [1,5]. Finally, the emulated clients have diverse path characteristics (RTT and available bandwidth) to our server, as it would also happen in a real content provider.

### **4 DNS-ITE Performance**

The accuracy of any load balancing scheme depends on the job size granularity at which we can "route" jobs to servers. In the context of DNS-ITE, this granularity is the the number of bytes that correspond to each LDNS request. If each LDNS request was followed by only few bytes worth of load, we would be able to achieve much more accurate load balancing than if each LDNS request was followed by a large and long file transfer. In this section, we start with a model that describes the factors on which the DNS-ITE load balancing granularity depends on. We then empirically evaluate how the accuracy of a round-robin load balancer depends on these parameters.

Consider *n* clients behind each LDNS server. Suppose each client downloads *s* bytes from the server in each connection. Let the arrival rate of connections per client be *r*, and the arrival rate of DNS requests from each LDNS be  $\lambda$ . If a remote LDNS server uses caching, the TTL that it follows is *T* seconds. Then,

$$\lambda = \begin{cases} nr & \text{if LDNS is non-caching} \\ \min\{nr, \frac{1}{T}\} & \text{LDNS caches with TTL } T \end{cases}$$

The traffic rate that corresponds to an LDNS server is given by R = nrs (bps). The granularity in which we can balance the arriving traffic is:

$$\frac{R}{\lambda} = \begin{cases} s & \text{if } i \text{ is non-caching, or } nr < \frac{1}{T} \\ nrsT & \text{otherwise} \end{cases}$$
(1)

Next, we quantify the effect of the parameters that control this ratio  $R/\lambda$  on the load balancing accuracy that we can achieve with a simple RR algorithm.

**The error metric:** We quantify the load balancing accuracy in terms of the *relative difference* between the utilization of the two links. measured in an *averaging timescale* of *I* seconds. More precisely, we measure the traffic utilization (in bps)  $U_{I,1}(t)$  and  $U_{I,2}(t)$  of the two links at our server in a sliding window of length *I* that starts at time *t*. Under perfect load balancing conditions, the load on each link during the interval (t, t + I) should be  $[U_{I,1}(t) + U_{I,2}(t)]/2$ . The load balancing error  $\varepsilon$  is defined as:

$$arepsilon_{I}(t) = rac{|U_{I,1}(t) - U_{I,2}(t)|}{U_{I,1}(t) + U_{I,2}(t)}$$

We re-compute  $\varepsilon_I(t)$  every one second.

Figure 3 shows the impact of the sliding window length *I* on the median error  $\varepsilon_I(t)$ , for one of our experiments. As expected, the load balancing error is higher as we decrease *I*, as there are fewer arriving connection requests in shorter intervals. Also note that the error metric tends to stabilize when *I* is larger than about 15 seconds. This shows that the RR load balancing algorithm is not able to eliminate the relative error, even when we use a significantly long (15s) averaging timescale. In the rest of this paper, we use *I*=20s.

**Aggregate load:** Our goal in this experiment is to examine the impact of the aggregate traffic load on the relative error. We do so by varying the number of deployed LDNS servers (and hence the number of active clients) from 10 to 45. Figure 5 shows the distribution of the relative error. Note that the error decreases as the aggregate utilization increases. As we decrease the number of





Figure 3: Variation of median error with averaging timescale *I*.

LDNS servers and the associated clients, the aggregate load drops, decreasing the frequency between arriving DNS requests. Thus, the load balancer has fewer opportunities to distribute the arriving load between the two links.

**File size distribution:** Here, we first examine the effect of the requested file size and second, the effect of the significant variability in the lognormal file size distribution compared to the case of constant file sizes. In order to keep the aggregate load fixed, we adjust the mean idle period between requests from each client. The top part of Figure 4 shows effect of increasing the file size on the error distribution, when clients request fixed-sized files. Note that as we increase the file size from 30KB to 625KB, the errors increase. This is expected, because with smaller flows, our DNS server can take more frequent load balancing decisions, amortizing the load between the two servers at a finer granularity.

The bottom part of Figure 4 shows the differences between fixed-size transfers and lognormally-sized transfers. We use a truncation size of 1MB for the latter. We see that the errors increase when the content size is heavy-tailed. The main reason is that the round-robin scheduler does not consider the current load on each link. Thus, in a heterogeneous workload with transfers of different sizes, it can happen that one link receives several long transfers while another receives mostly short transfers, causing periods of significant imbalance.

Advertised TTL: Next, we illustrate the effect of advertised TTL on the load balancing accuracy. Equation 1 shows that accuracy depends on the TTL T that is adver-

Figure 4: Effect of file size (RR).

tised to LDNS servers, as long as the request rate from each LDNS rn is larger than 1/T. When the request rate is less than that, we expect that the load balancing error will not depend on TTL.

We examined the impact of the advertised TTL on the median of the relative error  $\varepsilon$  as follows. The client request rate *r* is set to once per 35s. Hence, the request inter-arrival *rn* from an LDNS varies between 7s and 35s, depending on the number of clients per LDNS. Figure 6 shows the median error and Wilcoxon-based 99% confidence intervals for different advertised TTLs. Consistent with Equation 1, when the time period between successive DNS requests from the same LDNS is less than the advertised TTL, the error increases with the TTL (TTL values 1, 5, and 15 seconds). For the two larger TTL values, the load balancing error does not increase with the TTL because the client requests arrive too infrequently to be affected by DNS caching.

**Hidden clients:** We also investigate the effect of the number of clients per LDNS. We keep the number of clients constant across all LDNS servers. In order to keep the aggregate load fixed, we adjust the number of active LDNS servers. We also keep the client idle period at 14s (mean) so that in the case of a single client per LDNS, the client request rate is higher than the advertised TTL (15s).

Figure 7 shows the load balancing error when we increase the number of clients per LDNS from one to five. We see that the case for five clients per LDNS shows a clear increase in the load balancing error compared to the case of one and three hidden clients. Hidden clients increase load balancing errors because the amount of traffic





Figure 5: Effect of aggregate load (RR).

Figure 6: Effect of advertised TTL (RR).

that corresponds to each LDNS request grows with their count.

#### 5 Measurement-based DNS-ITE

In this section, we evaluate the performance of a measurement-based load balancing scheme, and examine the impact of the measurement history on its accuracy. Intuitively, the worst-case scenario for a roundrobin scheme is when requests for file sizes arrive in {large, small} pairs. A measurement-based scheme can alleviate such problems by routing clients based on the current link loads.

In the measurement-based (MB) scheme that we consider in this paper, we measure the incoming and outgoing load on each link of our content server using a sliding-window of duration W. On a new LDNS request, we compare the latest utilization measurements of the two links and advertise the interface with the minimum load.

**Comparison between RR and MB:** We compare MB with RR load balancing using the same workload model we used in the previous section. Figure 8 shows the distribution of load balancing errors in the I = 20s timescale with different window sizes, and with the RR scheme. We see that a large window of W = 30s performs worse than the RR scheme, while a small window of W = 100ms performs marginally better than RR. A window size of W = 10s is significantly better than RR. It is clear that the parameter W has a significant impact on the accuracy of MB, and so we need to further understand why.

An important issue in any load balancing scheme that relies on historical data is whether those past measurements are *stale*, meaning that they no longer reflect the current loads [9]. Intuitively, a larger value of *W* is more prone to such errors than a shorter *W*. However, the magnitude of *W* also controls the *variance* of measurements. A shorter *W* introduces more noisy measurements, making it harder to accurately estimate the load on each link. An appropriate value of *W* needs to consider carefully the staleness-vs-variance trade-off based on the dynamics and burstiness of the underlying traffic.

**Staleness-vs-variance trade-off:** To illustrate the effects of measurement staleness and variance on load balancing accuracy we start with an experiment using two simple, synthetic traffic models. In the first model (CBR), each flow has a constant size and duration and the packets are transmitted periodically. Here, the only variability in the aggregate traffic is due to flow start/finish events. In the second model, the traffic is generated from an aggregate of Pareto renewal processes (inter-packet gaps), causing significant variability in the packet interarrivals. There are no flow start/finish events, however, which means that there are no rapid changes in the arriving traffic rate.

Figure 9 shows the load balancing error distribution for the two models, for different Ws. For CBR, a smaller value of W (0.1s) performs best. The reason is that in CBR the measurement variance is minimal (each flow consists of periodic packet arrivals), and even a very short measurement window will suffice to estimate the load of each link accurately. A larger W, say 10s, is detrimental because it is subject to stale measurements



Figure 7: Effect of hidden clients (RR).

(a different number of active flows than currently active). With the Pareto model, on the other hand, we get lower errors when W=1s compared to W=0.1s. The reason is that this traffic is more bursty, and so we need a longer time period in order to reliably know which link is more heavily loaded.

There is no "optimal" value of *W* that is independent of the statistical characteristics of the underlying traffic. The general guideline that we can provide is that *W* should be as short as possible (to avoid the issue of staleness) subject to the constraint that the measurement variance is sufficiently low to reliably show which link has the minimum load. Note that the objective is not how to accurately estimate the load on each link. Instead, we are simply interested in identifying the link with the minimum load.

What is an appropriate value of W for the TCP-based workload that we used in our experiments? To answer this question, we simulated the MB load balancer on packet traces from the W = 10s experiment. Specifically, we partitioned the experiment duration into 100ms intervals, identifying the load from different LDNS servers in each interval. We then used a (hypothetical) window size W to make MB load balancing decisions for any new DNS requests in that interval, and measured the resulting load balancing errors at I = 20s. Figure 10 shows the median error observed with W. We see that a measurement window W in [5, 15]s gives the lowest errors. With smaller window sizes we see the negative effects of variance, while with larger windows we observe the negative effects of staleness. It is interesting that there is a wide range of W in which the load balancing accuracy is al-



Figure 8: RR versus MB load balancing.



Figure 9: Staleness-vs-variance trade-off.

most constant, implying that the selection of W may not need to be fine-tuned in practice.

**Limitations of MB DNS-ITE:** The MB scheme can improve load balancing accuracy compared to RR, but it can still suffer from an intrinsic problem with DNSbased ITE: there can be a significant delay between a DNS request (and the associated load balancing decision) and the arrival of the actual traffic that corresponds to that DNS request. To illustrate this effect, consider the following simplified model of DNS-ITE.

Suppose that we receive DNS requests at a constant rate  $\lambda$ . Traffic associated with each DNS request can



Figure 10: Effect of W on MB accuracy.

originate from multiple TCP connections and from multiple clients. Further, there can be a significant delay between a load balancing decision and the arrival of the actual traffic load. For a single connection, this delay includes the DNS response, the TCP connection establishment phase, or the slow-start phase. Let  $\delta$  be the delay between a DNS request and the time that the associated traffic arrives. During that period, we can receive  $\delta\lambda$  other DNS requests, which will be routed without considering the load that has been already committed (but not arrived) to each link. If  $\delta > 1/\lambda$ , i.e. if  $\delta$ is significant compared to the inter-arrival time of DNS requests, the MB scheme will not be able to correctly amortize the load between the available links, at least in short timescales. We view this as a fundamental problem with the DNS-ITE method, which cannot be avoided given that the delay  $\delta$  is unknown and it varies across LDNS servers and connection requests.

#### 6 Conclusion

In this work, we looked at the problem of ingress traffic load balancing using DNS-based techniques (ITE) in multihomed networks. We implemented an ITE load balancer for a content server, and designed a wide-area client testbed with realistic workload characteristics. Our contributions are two fold.

First, we showed that the accuracy of ITE can be impacted by factors which include (1) aggregate client load, (2) DNS TTL policies in client networks, (3) hidden clients, and (4) heavy-tailed content sizes. We found that large aggregate load (1) can improve accuracy, while TTL violations (2), 3, and 4 can degrade performance. These observations can be used to design a content distribution service which aids load balancing.

Second, we showed that measurement-based (MB) schemes improve performance over a round-robin scheme when the length of measurement history is short enough. We evaluated the impact of high variance and staleness in measurement history. We finally looked at limitations of MB schemes due to inherent nature of the ITE problem.

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