Understanding Internet Naming: From the Modern DNS Ecosystem to New Directions in Naming

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Introduction

- Mapping human-usable and meaningful names to objects in computer systems is crucial to usability
- Name to object mapping systems also allow for late binding
- The DNS provides this usability and agility with respect to Internet addresses, and is a crucial component of today's Internet

Topics of Study

- Understanding the Modern DNS ecosystem

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Introduction - Understanding the Modern DNS Ecosystem

- While the original purpose of DNS was to provide hostname lookups, its role has evolved over time
  - Load balancing, geographically-sensitive traffic distribution, blacklists
- DNS behavior varies based upon ISP resolvers and client devices
  - What devices are involved in the DNS resolution process? How do these devices color that process?
- DNS behavior is also driven by users and the hostnames embedded in content by providers

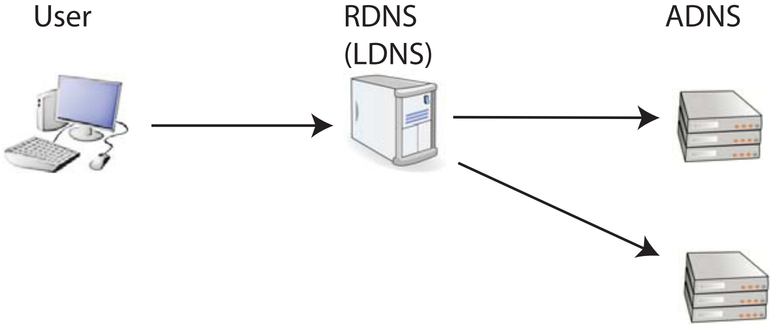

Figure: Simple Resolver Topology

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- DNS behavior is also driven by users and content providers
- Modern DNS behavior informs design decisions in both current applications and future naming systems
- **We must keep an up-to-date understanding of modern DNS operation through empirical study of both system components and operational DNS traffic**

Introduction - Communicating without Fixed Infrastructure

- Internet transactions need a well-known rendezvous point to establish communication
  - Often a DNS name
- Well-known rendezvous points are inherently brittle
  - To adversaries: censors often block IPs or hostnames used for peer-to-peer traffic
  - To other failures: network problems, power failures, lapses in domain registration for DNS

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  - To other failures: network problems, power failures, lapses in domain registration for DNS
- **We introduce a mechanism that allows users to communicate without any centralized hub, using a secret name never manifested in the network**

Introduction - New Directions in Naming

- DNS does not encourage user-to-user information sharing
  - Publishing DNS records is often a manual process
  - DNS typically stores mappings to hosts, while users are interested in content and other users
  - DNS has no types suitable storing content URLs or instant-messaging screen names
- Modern names are typically controlled by service providers, rather than users (e.g., "trc36@case.edu")
  - This creates lock-in

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- **We propose a new naming system centered around users, allowing for secure publication and consumption of records by users and their applications**

Understanding the Modern DNS Ecosystem
Part of this work joint with Kyle Schomp

Goals

- Evaluating DNS system components
  - How does client-side DNS resolution work? What devices are involved? How do they behave?
  - We probe over 1M open resolvers on the Internet to measure topology, security, and protocol compliance

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  - How does client-side DNS resolution work? What devices are involved? How do they behave?
  - We probe over 1M open resolvers on the Internet to measure topology, security, and protocol compliance
- Understanding real DNS traffic
  - What is the nature of DNS traffic on the Internet? How to clients use DNS responses?
  - We examine traffic generated by users of the "Case Connection Zone" to study client requests, server responses, and response usage

Evaluating System Components - Methodology

- Use PlanetLab to scan IPV4 for open resolvers by sending a query falling under a domain we control
- When a resolver is found, send a variety of queries to evaluate aspects of resolver behavior
- By controlling both the initial query and the authoritative response, we get a more complete view of behavior than studies only examining a single aspect

Resolver Structure

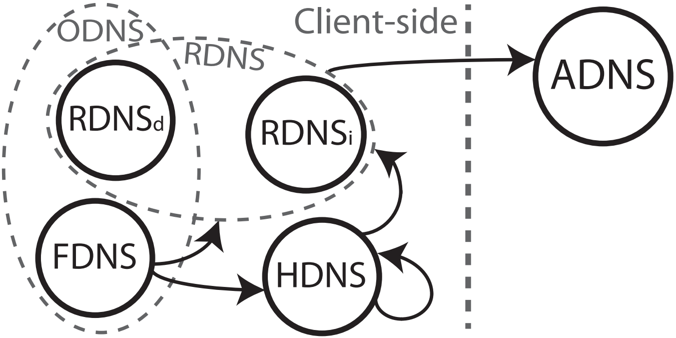

Figure: General structure of the client-side DNS infrastructure[1]

[1] This figure courtesy of Kyle Schomp

High-level Findings

- Measured nearly 1.1M IP addresses providing open recursive DNS service (ODNS)
- Observed 55K IP addresses visiting our Authoritative DNS (ADNS) server on behalf of these ODNS
- 1.37% (about 16K) of ODNS actually visited our ADNS directly (we define these as $RDNS_d$)
- Of the *approx* 44K $RDNS_i$ tested for reachability, only 38% would successfully resolve direct query

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- Of the *approx* 44K $RDNS_i$ tested for reachability, only 38% would successfully resolve direct query
- **Measuring RDNS through their ODNS allows evaluation of firewalled/otherwise prohibited resolvers**
- Full details in dissertation

Topology

- Most ODNS access the DNS through a pool of RDNS
- Many ODNS are close to their RDNS – 50% of all ODNS:RDNS pairs have a GeoIP distance of < 100 miles
- Some ODNS are quite far from their RDNS – 7% of pairs have a distance of > 6000 miles (subject to GeoIP accuracy)

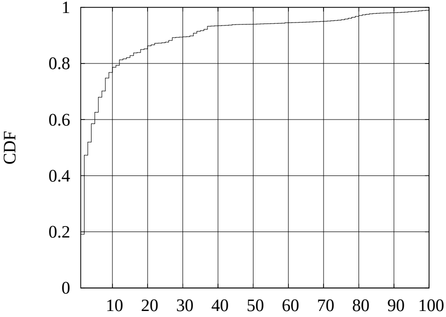


Figure: # RDNS seen on behalf of each ODNS

Security

- We find that 12.9% of RDNS and 8.3% of $RDNS_i$ remain vulnerable to the Kaminsky attack
- Only 0.3% of RDNS encountered use 0x20 encoding to incorporate additional entropy
  - This may be an underestimate, as some RDNS providers (Google) are known to use 0x20 with only whitelisted ADNS
- NXDOMAIN rewriting is widespread – 25% of ODNS experience this

Caching

- We find 41% of ODNS disappear before the end of third day
- Little competition for cache space – the median duration a record stayed in an ODNS cache is 4.5 hours.

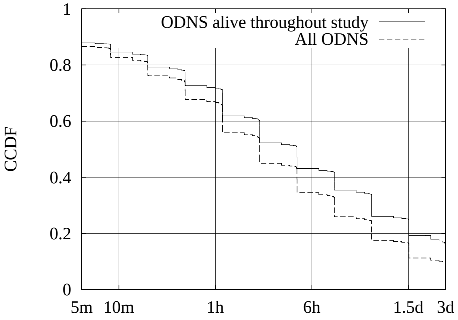


Figure: Cache Evictions over Time

TTL Modification

Expected (sec)	% Liars	Most Common Lie	% of Liars
0	11.43%	10,000	27.19%
10	11.1%	10,000	28.7%
100	2.96%	300	26.85%
1Ks	1.76%	80	30.07%
10K	2.85%	3,600	26.14%
100K	21.82%	86,400	52.6%
1M	89.35%	604,800	74.43%
10M	89.57%	604,800	74.16%
100M	89.58%	604,800	74.11%
1B	89.57%	604,800	74.12%

Table: Summary of TTL Deviations

Methods - Understanding Real DNS Traffic

- We examine DNS traffic logs from the Case Connection Zone (CCZ) in Cleveland, OH
  - Fourteen months of daily logs with visibility into Client$\Rightarrow$RDNS traffic
  - 200M DNS queries of which 162M returned an IPV4 answer

TTL Treatment

- Per-hostname, there is a variety of TTL modes from a few seconds to a day

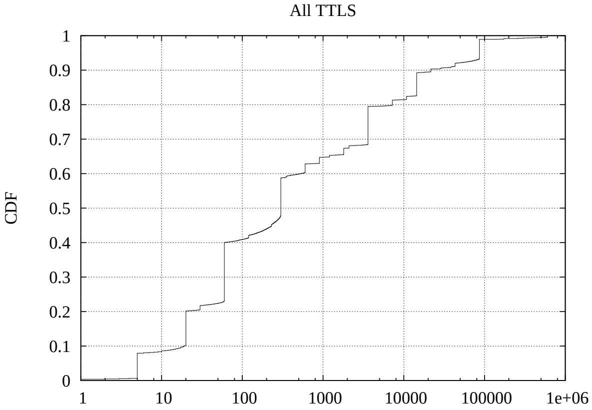


Figure: Max. Observed TTL for each answer record

TTL Treatment (cont'd)

- TTLs of commonly requested DNS records and DNS records corresponding to large data transfers are lower than average

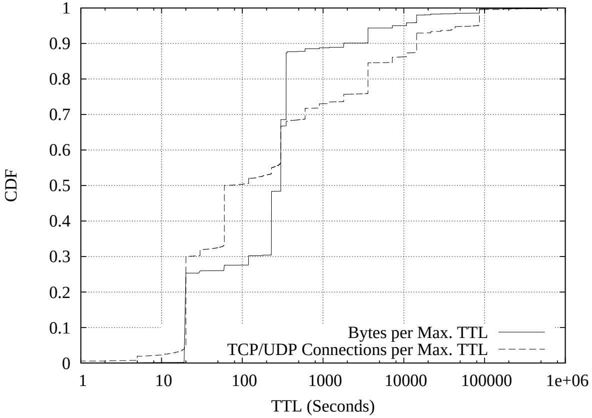


Figure: Weighted Record TTLs

Record Usage

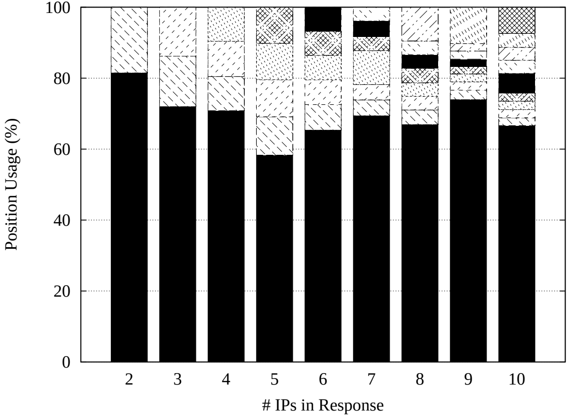
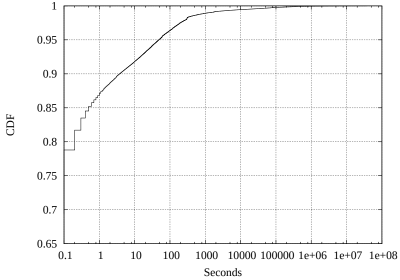
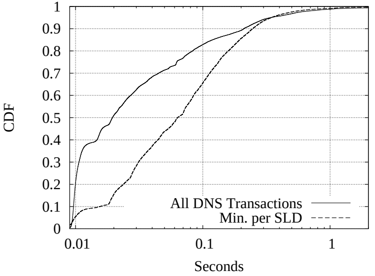


Figure: Position of DNS answer that is used

Performance



(a) Time from DNS response to first connection



(b) Duration of uncached transactions

Figure: Performance

Other observations

- Akamai and Google dominate in the set of DNS answers. 23.5% of successful DNS responses include a mapping to an Akamai server and 13.4% of responses include a mapping to a Google server.
- We generally find a lower cache hit rate than previous work [1]. While others have observed a 90% cache hit ratio, CCZ users fulfill 2/3 of requests from the cache.
- Our performance observations indicate generally faster DNS performance for CCZ users than in the literature. However, when we examine response time on a per-SLD basis, we find behavior much closer to the literature.

Enabling Decentralized Communication

Goal

- Enable users and applications to communicate free of tethers to fixed infrastructure
- Some applications are already free of fixed infrastructure (e.g., peer-to-peer networks)
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  - Notable exception: finding an initial set of peers (bootstrapping)
- We design a decentralized mechanism for users sharing some secret (string) to communicate

Components

- Utilize the 15M [2] to 30M [Kyle Schomp] ODNS on the Internet as rendezvous points
  - One out of every 300 IP addresses is suitable
- We utilize these ODNS as independent storage devices
- Leverage the caching and aging properties of DNS records to encode arbitrary information in FDNS/RDNS caches
  - Without using a domain we control

High-level Method

- Publisher uses the secret to generate a list of IP addresses to scan for DNS service
  - Collect a set of suitable IP addresses
- Publisher uses the secret to generate a list of DNS names that will correspond to message bits
  - Store message on each IP address in set

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- Publisher uses the secret to generate a list of DNS names that will correspond to message bits
  - Store message on each IP address in set
- Using the same secret, the recipient discovers the same set of IP addresses and queries for the same domain names
  - Decodes the message

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- Both clients do the following:
  - First IP to scan: sha1("secret"+"IPNumber1")[Last4Bytes]
    - "secret" and "IPNumberX" are only strings
  - Second IP to scan: sha1("secret"+"IPNumber2")[Last4Bytes]
  - Scan until X DNS servers found
- This discovery process is independent of the IPs of the clients.

Scanning

- At full speed, hundreds or thousands of packets can be sent per second on a home Internet connection
- Median # of probes sent between detected open DNS server IPs is 194, mean 281.
- 99th percentile is 1,284 probes
- Even at slow scanning rates, this is tractable

Storing Data

An RDNS Server certainly won't accept arbitrary data, but we can insert any valid record into the cache.

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eecs.case.edu.    86388    IN    A    129.22.104.78
```

From the TTL we can determine how long a record has been in the cache

Storing Data - TTL Method

- Compare the TTLs of multiple records
- Publisher requests messagebit1.tk before or after requesting belowmeare1.tk, based upon bit to transmit
- The recipient requests both records.
  - If the received TTL for messagebit1.tk $<$ TTL for belowmeare1.tk, call this a “1” bit
  - Else, consider this a “0” bit

Obtaining DNS Names

- We leverage DNS wildcarding
  - Many domains constructed such that *.domain.com $\Rightarrow$ 1.2.3.4
  - We can therefore leverage the cache hits of bit1.domain.com, bit2.domain.com, etc

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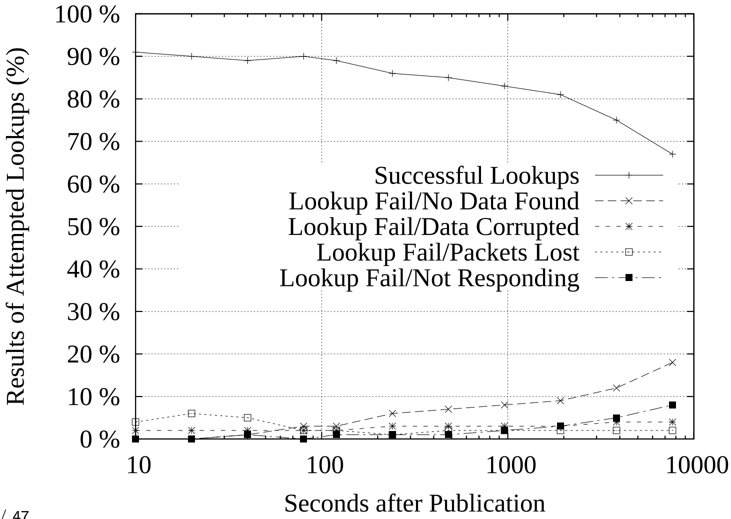
  - including .ws and .tk

Success Rate (Publication)

Given a usable server:

Attempted Publications	104K	100 %
Success	92K	88 %
No Data Found	3.6K	3.4 %
Corrupt data	5.0K	4.8 %
Packet loss	3.6K	3.4 %

Success Rate (Lookup)



Extending

- Generic bit-pipe, so we can implement:
  - Forward Error Correction
  - CRC Checking
  - Encryption

Enhancements

- Successfully widened the channel by using the value of the difference between TTLs instead of binary comparison
  - We were able to publish and retrieve 140 character tweets
- Eliminated the reliance on wildcard domains
  - When a domain does not exist, an SOA record is returned with the negative response
  - This SOA record has a TTL that counts down
- Enabled communication using a different method relying on cache presence and not TTL

New Directions in Naming

Goals and Use Cases

- Simplify user-to-user information sharing by enabling ordinary users to publish name $\Rightarrow$ object mappings
- Move beyond the host-centric naming scheme of DNS to enable users to name arbitrary meta-information
  - Web Bookmarks - “misha:webpage” or “misha” in lieu “of http://engr.case.edu/rabinovich_michael/”
  - Service-specific identifiers - “misha:skype”
- Combat service-provider lock-in by giving users control over names untangled from specific providers or protocols
  - “mark:email” can be repointed to a new email provider at will

Goals and Use Cases (cont'd)

,

- Enable device mobility by allowing applications to publish configuration meta-information
  - An email account configured on one device could be available on all of a user's devices
  - Browser tabs on one device can be opened on another device in a different browser
- Composable Services - publish desired spam settings to be implemented by all of a user's email servers

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- Enable new functionality based on widespread access to meta-information
- We propose *MISS*, a new naming system centered around users, allowing for secure publication and consumption of names by users and their applications

Requirements

- Extensibility: MISS must be agnostic to the to the types of data stored and able to handle future applications
- Accessibility: MISS must allow users to expose records at their discretion and on a per record-basis to user-defined groups
- Integrity: Records must be modifiable only by their owner and verifiable by others
- Portability: Users' MISS collections must not be permanently entangled with a particular service provider
- Usability: The complexity of MISS must be abstracted away by applications so that general users find it usable

Collection

- A container for all of a user's meta-information records
- Represented by the fingerprint of a user's public key
- Naming collections by keys ensures that collections may be generated by users without any external help or control
- MISS itself maps these collection identifier's to human-readable, context-sensitive names

Record

- Each record is identified by the collection it is in as well as a name and type (arbitrary strings)
- Names may be provided by users or by applications, types will usually be application-based
- Much like transport port numbers, MISS types and names may be well-known or ad-hoc
- Each MISS record is encoded in XML, and MISS is agnostic to the content of the data portion of the record

```
<miss_record>
  <name>foo</name>
  <type>frob</type>
  <expires>1278597127</expires>
  <signature> [...] </signature>
  <frob>
    <ex1>foo.example.com</ex1>
    <ex2>userA</ex2>
  </frob>
</miss_record>
```

Figure: Example MISS record.

Local Interface - Missd

- Runs on the same device as applications
- Provides a general interface into the global database without application-specific configuration
  - Insofar as its lookup capabilities, this is similar to a DNS resolver
- Provides applications with get() and put() primitives for accessing data repository
- Constructs records using application data, user's encryption keys and privacy settings, and uploads
  - Keeps items in the global repository up-to-date w.r.t. TTL
- Performs lookups on other collections and verifies data received

Global Access - MISS Server/DHT

- Hold and provide access to collections on behalf of users
- Participate in the MISS DHT, a global DHT holding only MISS master records
  - MISS master records identify the MISS server responsible for hosting a given collection ID
  - MISS master records are self-certifying, as they will be self-signed

MISS System Overview

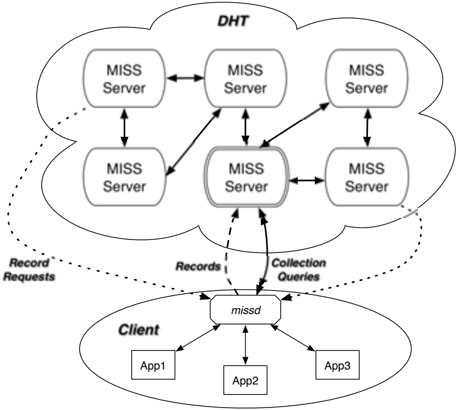

Figure: Conceptual diagram of MISS system.

Bootstrapping

- In order to associate a collection ID with a human-readable name, collection ID's could be shared:
  - Via NFC using smartphones
  - Using X- headers in emails
  - By embedding meta tags in HTML pages
  - Using vCards
  - Via standard directory services (e.g. LDAP, Active Directory)
  - etc...

Experiments

- Built a prototype MISS system
- MISS Server (Apache) could sustain up to 27K requests/second
- MISSD imposed parse/validation overhead of 26ms in the 95th percentile
- Built MISS DHT on 100 Planetlab nodes
  - Median record fetch time of 500ms
  - Likely an overestimate due PL performance
  - Fetches mitigated by caching and prefetching
- Undergraduate students were able to build user-facing apps on top of this structure

That's all, folks!

Questions?

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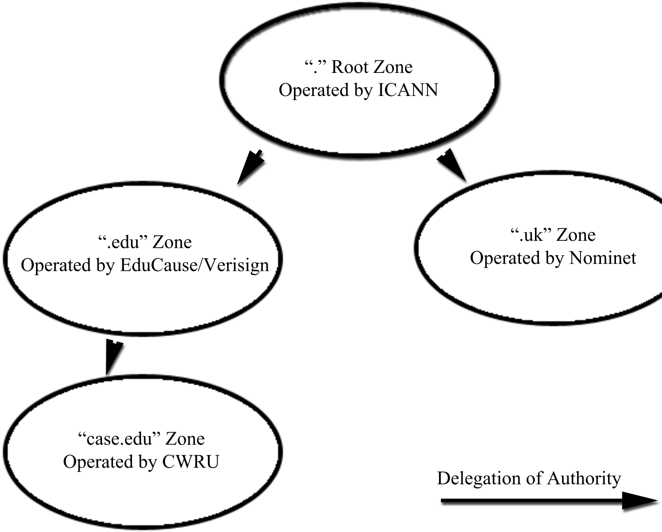
D. Leonard and D. Loguinov.
Demystifying service discovery: Implementing an internet-wide scanner.
In *Proceedings of the 10th annual conference on Internet measurement*, pages 109–122. ACM, 2010.

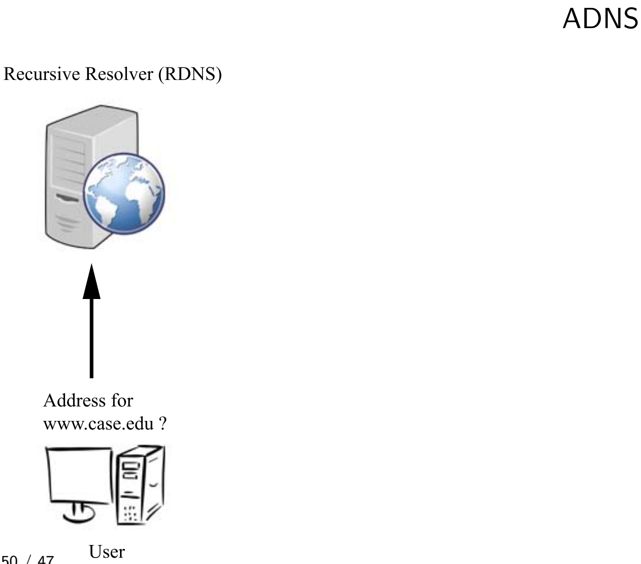
DNS Introduction

- DNS is responsible for converting names to IP addresses
  - www.case.edu ⇒ 129.22.104.136
- Responsible for identifying well-known services
  - case.edu mail exchange (MX) ⇒ smtp.case.edu
- UDP-based protocol with two major actors
  - Recursive DNS Resolvers (RDNS)
    - Do the work of looking up names
  - Authoritative DNS Servers (ADNS)
    - Responsible for handing out answers
    - "Own" a portion of the namespace

DNS Namespace



DNS Resolution Process



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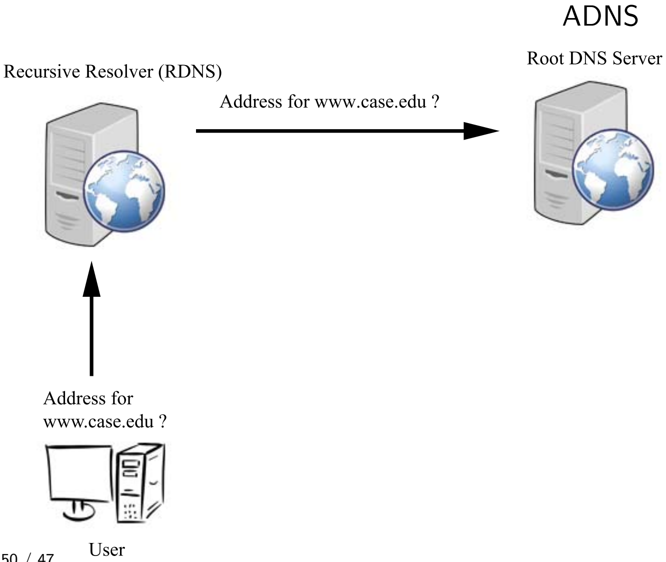

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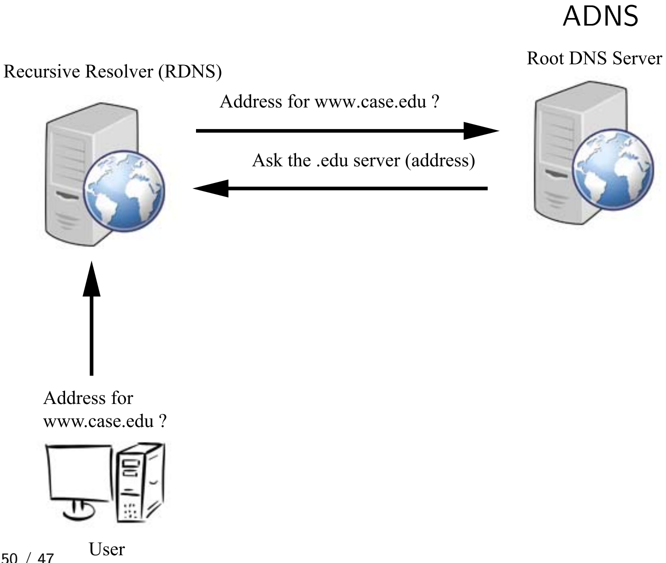

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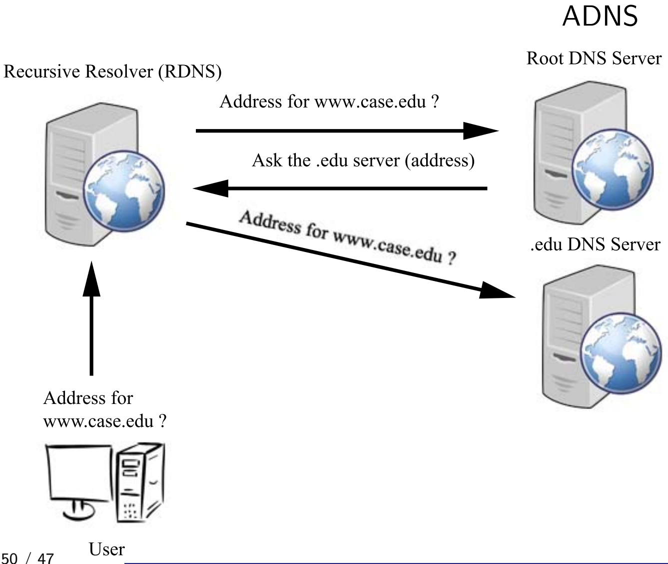

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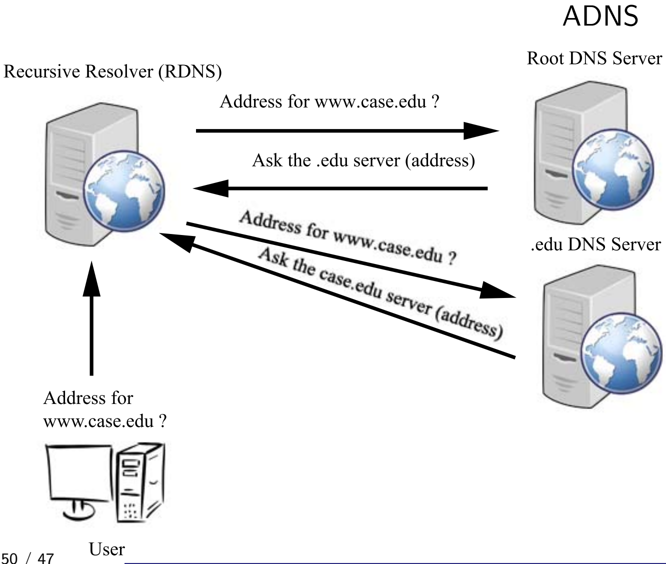

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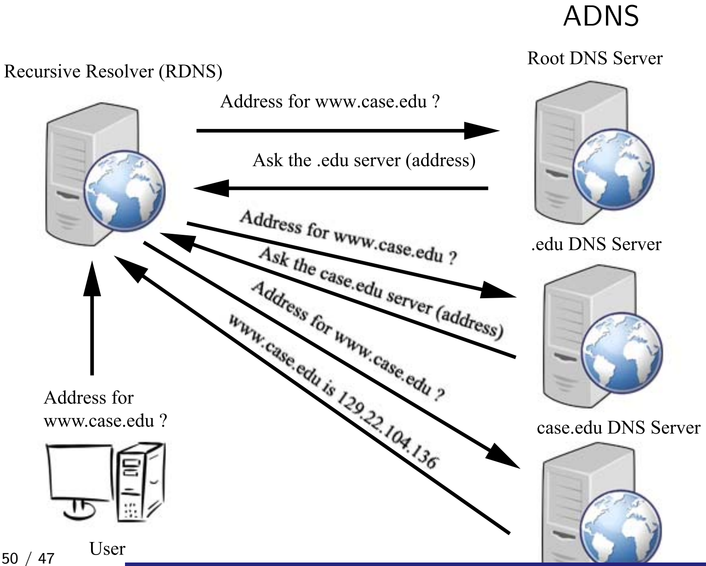
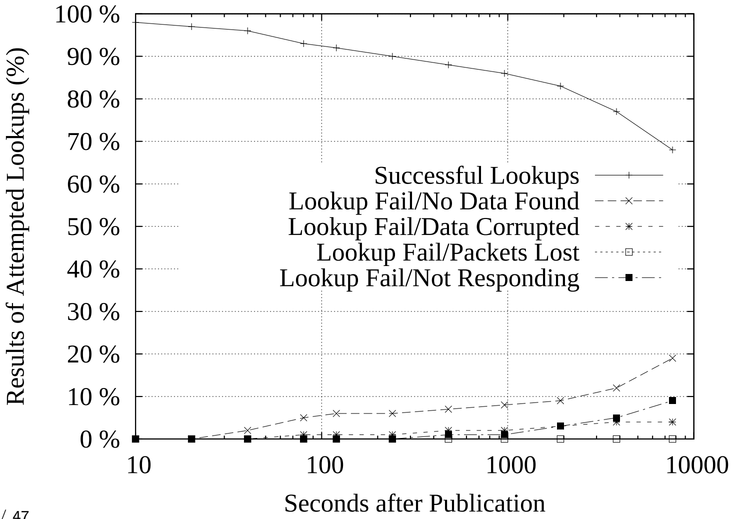
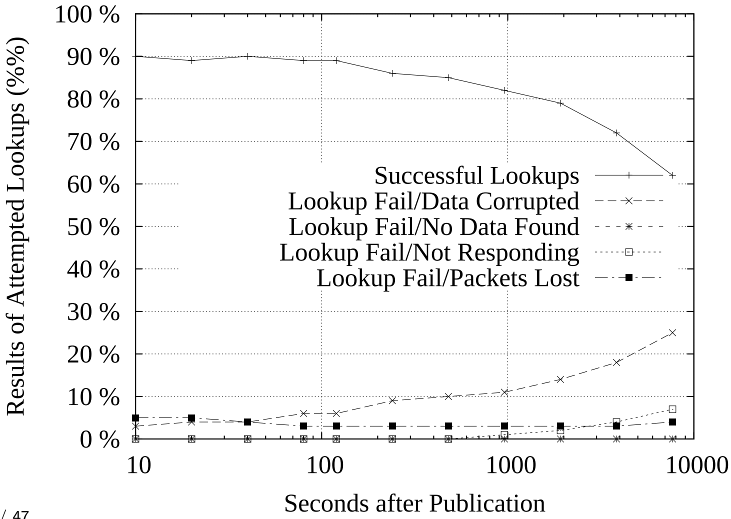


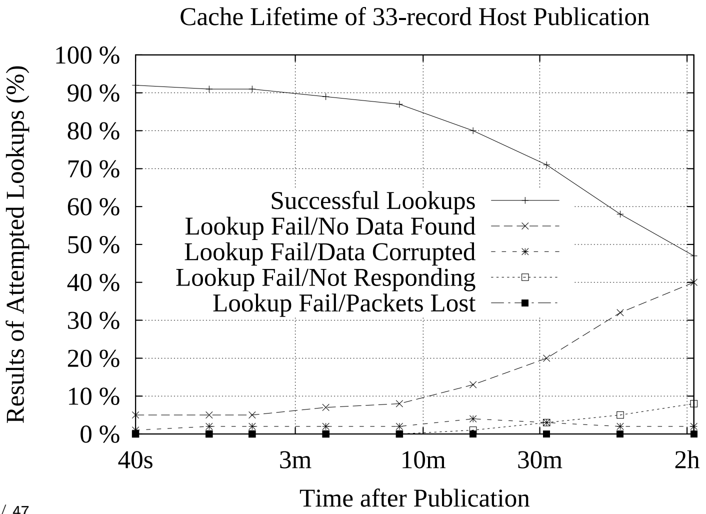
RD Success Rate (Lookup)



Twitter Success Rate (Lookup)



SOA Success Rate (Lookup)



Publications

- PhD papers:
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