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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- Communicating without Fixed Infrastructure
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- Understanding the Modern DNS ecosystem
- Communicating without Fixed Infrastructure
- New Directions in Naming
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
Introduction - Understanding the Modern DNS Ecosystem

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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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  - This creates lock-in

- 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
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

- **Understanding real DNS traffic**
  - What is the nature of DNS traffic on the Internet? How do 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 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
Topologies

- 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

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

**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⇒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)
  - Notable exception: finding an initial set of peers (bootstrapping)
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- Some applications are already free of fixed infrastructure (e.g., peer-to-peer networks)
  - 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
High-level Method

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  - 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
- Using the same secret, the recipient discovers the same set of IP addresses and queries for the same domain names
  - Decodes the message
Finding the same servers

- Both clients share some secret “secret”
- Both clients do the following:
  - First IP to scan: sha1(“secret” + “IPNumber1”) [Last4Bytes]
Finding the same servers

- Both clients share some secret “secret”
- Both clients do the following:
  - First IP to scan: \( \text{sha1} \left( \text{“secret”} + \text{“IPNumber1”} \right) \text{[Last4Bytes]} \)
    - “secret” and “IPNumberX” are only strings
  - Second IP to scan: \( \text{sha1} \left( \text{“secret”} + \text{“IPNumber2”} \right) \text{[Last4Bytes]} \)
  - 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.

```
anomaly@paragon ~ $ dig eecs.case.edu
eeecs.case.edu. 86400 IN A 129.22.104.78
```
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```
  eecs.case.edu.  86392 IN A 129.22.104.78
  eecs.case.edu.  86388 IN A 129.22.104.78
```
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We just stored a piece of data in our RDNS Server!
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neeecs.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 ⇒ 1.2.3.4
  - We can therefore leverage the cache hits of bit1.domain.com, bit2.domain.com, etc
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- Several TLDs are themselves wildcarded
  - including .ws and .tk
Success Rate (Publication)

Given a usable server:

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attempted Publications</td>
<td>104K</td>
<td>100%</td>
</tr>
<tr>
<td>Success</td>
<td>92K</td>
<td>88%</td>
</tr>
<tr>
<td>No Data Found</td>
<td>3.6K</td>
<td>3.4%</td>
</tr>
<tr>
<td>Corrupt data</td>
<td>5.0K</td>
<td>4.8%</td>
</tr>
<tr>
<td>Packet loss</td>
<td>3.6K</td>
<td>3.4%</td>
</tr>
</tbody>
</table>
Success Rate (Lookup)

![Success Rate Graph](image)

- **Successful Lookups**
- **Lookup Fail/No Data Found**
- **Lookup Fail/Data Corrupted**
- **Lookup Fail/Packets Lost**
- **Lookup Fail/Not Responding**

Results of Attempted Lookups (%)

<table>
<thead>
<tr>
<th>Seconds after Publication</th>
<th>Successful Lookups</th>
<th>Lookup Fail/No Data Found</th>
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<th>Lookup Fail/Not Responding</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 ⇒ 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 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

```xml
<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?
Bibliography


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

“.” Root Zone
Operated by ICANN

“.edu” Zone
Operated by EduCause/Verisign

“.uk” Zone
Operated by Nominet

“case.edu” Zone
Operated by CWRU

Delegation of Authority
DNS Resolution Process

Recursive Resolver (RDNS)

Address for www.case.edu?

User
DNS Resolution Process

Recursive Resolver (RDNS)

Address for www.case.edu?

ADNS

Root DNS Server

Address for www.case.edu?

User
DNS Resolution Process

Recursive Resolver (RDNS)

Address for www.case.edu?

Ask the .edu server (address)

ADNS

Root DNS Server

Address for www.case.edu?

User
DNS Resolution Process

Recursive Resolver (RDNS)

Address for www.case.edu?

Ask the .edu server (address)

Address for www.case.edu?

User

ADNS

Root DNS Server

.edu DNS Server
DNS Resolution Process

Recursive Resolver (RDNS)

Address for www.case.edu?

Ask the .edu server (address)

Address for www.case.edu?

Ask the case.edu server (address)

ADNS

Root DNS Server

.edu DNS Server

User

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DNS Resolution Process

Recursive Resolver (RDNS)

Address for www.case.edu?

Ask the .edu server (address)

Address for www.case.edu?

Ask the case.edu server (address)

Address for www.case.edu?

www.case.edu is 129.22.104.136

ADNS

Root DNS Server

.edu DNS Server

case.edu DNS Server

User
RD Success Rate (Lookup)

![Graph showing RD Success Rate over time](image)

- **Successful Lookups**
- **Lookup Fail/No Data Found**
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Results of Attempted Lookups (%)

Seconds after Publication
Twitter Success Rate (Lookup)

Results of Attempted Lookups (%):
- Successful Lookups
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- Lookup Fail/Not Responding
- Lookup Fail/Packets Lost

Seconds after Publication
SOA Success Rate (Lookup)

Cache Lifetime of 33-record Host Publication

Results of Attempted Lookups (%)

Time after Publication
Publications

- **PhD papers:**
  
  
Publications (cont’d)

- PhD papers:

- MS paper: