Management and Operations of Networks, Services, and Systems

Domain Name System

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Domain names

- While browsing the Internet, people are better with names than with IP addresses
  - Easier to remember
  - They can have meaning
- Organizations can choose names that make sense to people…
  - vpn.org1.pt
  - simulator.engineering.org1.pt
- But they don’t have to make sense…
  - l39rsrutuwef39ru4cg3.virtualmachines.org1.pt

Importance of DNS

- Domain names are what people use to access web sites
    - Applications also use them to access other applications
- IP adddresses is how information gets routed on the Internet
- DNS does mapping between domain names and IP addresses

There are two parts to DNS

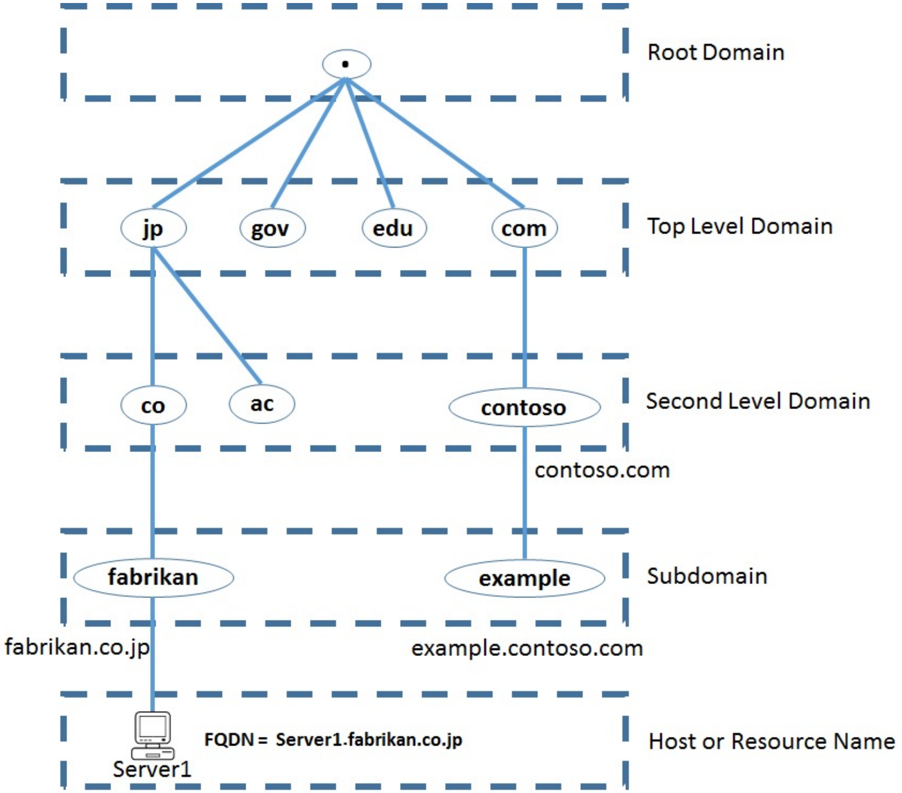
- Establish the map between domain names and IPs
  - Owners of names and IPs do this
  - Using ‘authoritative’ domain name servers
- Answer queries from users
  - Users can issues queries directly to the authoritative name servers

  OR

  - Users group together so that responses can be cached and the burden can be eased on authoritative servers
  - This is done via ‘cache’, ‘proxy’, ‘resolver’ domain name servers

Domain name hierarchy

- Root domain
- Top level domain
- Second level
- Subdomains (possibly)



https://gitlearning.wordpress.com/2015/06/23/dns-server/

Domain names specifications

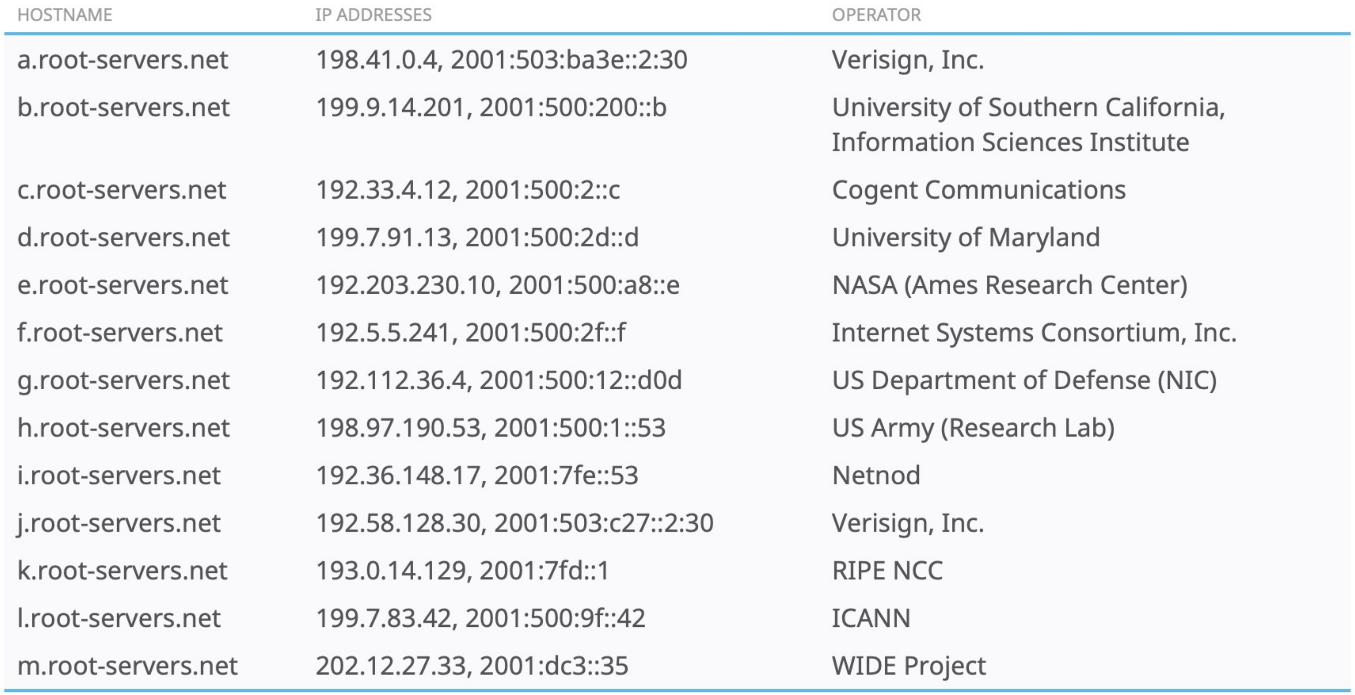
- Internet Corporation for Assigned Names and Numbers (ICANN)
- Internet Assigned Numbers Authority (IANA)

- ASCII (original)
- Internationalized Domain Names
  - Multibyte unicode, encoded in ASCII (punycode)
  - Converted per level, xn--Mnchen-3ya

Root Authoritative Servers

- A DNS zone is a portion of the DNS namespace that is managed by a specific organization or administrator
- The DNS root zone contains all domain names
- Root servers respond to TLD requests

https://www.iana.org/domains/root/servers



HOSTNAME	IP ADDRESSES	OPERATOR
a.root-servers.net	198.41.0.4, 2001:503:ba3e::2:30	Verisign, Inc.
b.root-servers.net	199.9.14.201, 2001:500:200::b	University of Southern California, Information Sciences Institute
c.root-servers.net	192.33.4.12, 2001:500:2::c	Cogent Communications
d.root-servers.net	199.7.91.13, 2001:500:2d::d	University of Maryland
e.root-servers.net	192.203.230.10, 2001:500:a8::e	NASA (Ames Research Center)
f.root-servers.net	192.5.5.241, 2001:500:2f::f	Internet Systems Consortium, Inc.
g.root-servers.net	192.112.36.4, 2001:500:12::d0d	US Department of Defense (NIC)
h.root-servers.net	198.97.190.53, 2001:500:1::53	US Army (Research Lab)
i.root-servers.net	192.36.148.17, 2001:7fe::53	Netnod
j.root-servers.net	192.58.128.30, 2001:503:c27::2:30	Verisign, Inc.
k.root-servers.net	193.0.14.129, 2001:7fd::1	RIPE NCC
l.root-servers.net	199.7.83.42, 2001:500:9f::42	ICANN
m.root-servers.net	202.12.27.33, 2001:dc3::35	WIDE Project

Non-root Authoritative Servers

- Top Level Domains
  - gTLD – Generic Top-Level Domains
    - Original: .com, .org, .net, .int, .edu, .gov, .mil, .arpa
    - 1502 new TLDs as of April 2021, internacionalized
    - https://en.wikipedia.org/wiki/List_of_Internet_top-level_domains
  - ccTLD – Country Code Top-Level Domains
    - 316 ccTLDs as of June 2020, including internationalized
    - https://en.wikipedia.org/wiki/Country_code_top-level_domain

Non-root Authoritative Servers

https://en.wikipedia.org/wiki/Name_server

- Second-level domains
  - Each TLD has a TLD manager organization, responsible for assigning SLDs under that TLD
  - The same happens down the hierarchy until the final host or resource name
- Masters
  - stores the definitive versions of all records
  - identified in start-of-authority (SOA) resource record
- Slaves
  - automatic updating mechanism to maintain an identical copy of the primary server's database for a zone
  - DNS zone transfer, AXFR, https://en.wikipedia.org/wiki/DNS_zone_transfer

Architecture and Protocol

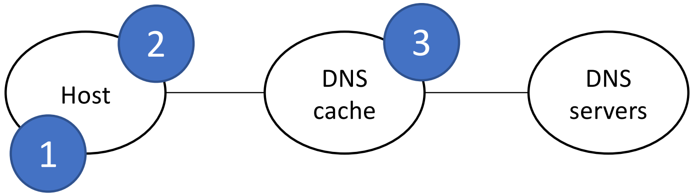
- Local
  - /etc/hosts, resolv.conf, DHCP
  - Non-recursive, recursive, iterative
- DNS Request and reply messages
  - QR, AA, NAME, TYPE
  - Over TCP or UDP ports 53; DoT, DoH, DNS over TOR, …
- Servers
  - Local/remote DNS server/cache/resolver
  - Root name server, TLD, SLD
  - Caching
  - Split server

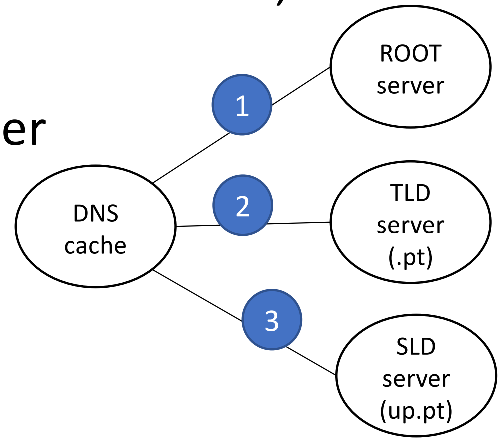
https://en.wikipedia.org/wiki/Domain_Name_System

1 If I know the IP address, use it.

2 If I don’t, ask the local server/cache.

3 If not in cache, ask other DNS servers.





1 Q: What is the IP address of www.up.pt?
A: don’t know, ask .pt server

2 Q: What is the IP address of www.up.pt?
A: don’t know, ask up.pt server

3 Q: What is the IP address of www.up.pt?
A: 193.137.35.140

DNS tool: dig

```
$ dig sigarra.up.pt

;; QUESTION SECTION:
;sigarra.up.pt.                IN      A

;; ANSWER SECTION:
sigarra.up.pt.          49      IN      A       193.137.35.140

;; AUTHORITY SECTION:
up.pt.                  4904    IN      NS      ns4.up.pt.
up.pt.                  4904    IN      NS      ns2.up.pt.
up.pt.                  4904    IN      NS      ns3.up.pt.
up.pt.                  4904    IN      NS      ns1.up.pt.

;; ADDITIONAL SECTION:
ns1.up.pt.              10275   IN      A       193.137.55.30
ns2.up.pt.              2204    IN      A       193.137.55.31
ns3.up.pt.              74589   IN      A       193.137.55.32
ns4.up.pt.              26925   IN      A       193.137.55.33
ns1.up.pt.              11393   IN      AAAA    2001:690:2200:a10::30
ns2.up.pt.              2204    IN      AAAA    2001:690:2200:a10::31
ns3.up.pt.              74589   IN      AAAA    2001:690:2200:a10::32
ns4.up.pt.              26925   IN      AAAA    2001:690:2200:a10::33
```

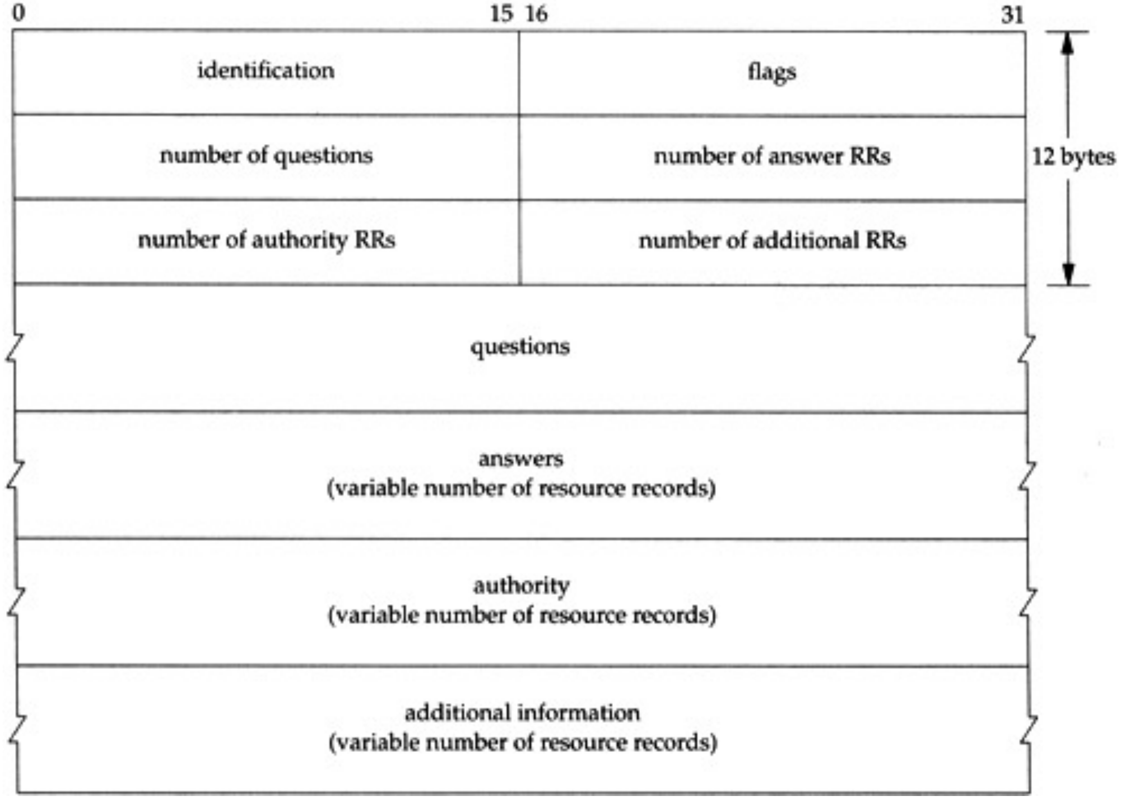
```
$ dig cloudflare.com
(...)
;; QUESTION SECTION:
;cloudflare.com.                IN      A

;; ANSWER SECTION:
cloudflare.com.         300     IN      A       104.16.132.229
cloudflare.com.         300     IN      A       104.16.133.229

;; AUTHORITY SECTION:
cloudflare.com.         6256    IN      NS      ns4.cloudflare.com.
cloudflare.com.         6256    IN      NS      ns7.cloudflare.com.
cloudflare.com.         6256    IN      NS      ns5.cloudflare.com.
cloudflare.com.         6256    IN      NS      ns6.cloudflare.com.
cloudflare.com.         6256    IN      NS      ns3.cloudflare.com.

;; ADDITIONAL SECTION:
ns3.cloudflare.com.     64      IN      A       162.159.0.33
ns3.cloudflare.com.     64      IN      A       162.159.7.226
ns4.cloudflare.com.     64      IN      A       162.159.1.33
ns4.cloudflare.com.     64      IN      A       162.159.8.55
ns5.cloudflare.com.     64      IN      A       162.159.2.9
ns5.cloudflare.com.     64      IN      A       162.159.9.55
ns6.cloudflare.com.     64      IN      A       162.159.3.11
ns6.cloudflare.com.     64      IN      A       162.159.5.6
ns7.cloudflare.com.     64      IN      A       162.159.4.8
ns7.cloudflare.com.     64      IN      A       162.159.6.6
ns3.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:21
ns3.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:7e2
ns4.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:121
ns4.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:837
ns5.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:209
ns5.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:937
ns6.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:30b
ns6.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:506
ns7.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:408
ns7.cloudflare.com.     64      IN      AAAA    2400:cb00:2049:1::a29f:606
```

DNS message format



0 15 16 31

identification	flags
number of questions	number of answer RRs
number of authority RRs	number of additional RRs

12 bytes

questions

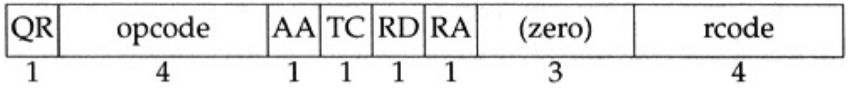
answers
(variable number of resource records)

authority
(variable number of resource records)

additional information
(variable number of resource records)

https://flylib.com/books/en/3.223.1.151/1/

Flags



QR	opcode	AA	TC	RD	RA	(zero)	rcode
1	4	1	1	1	1	3	4

QR: 0 query, 1 response

opcode: 0 standard query, 1 inverse query

RD: recursive query

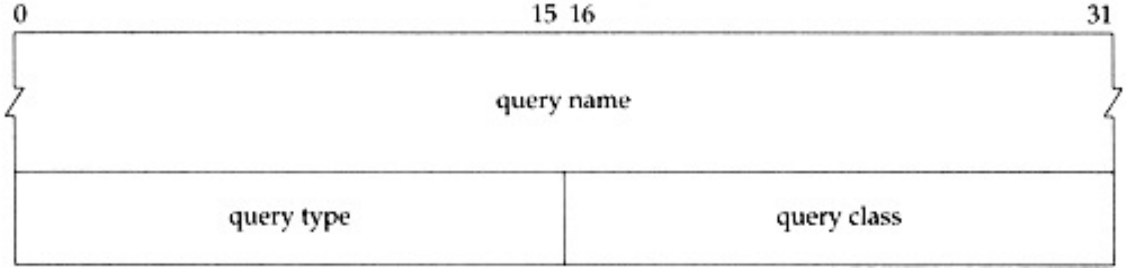
rcode: 0 no error, 3 NXDOMAIN, 5 UPDATE, …

Resource records

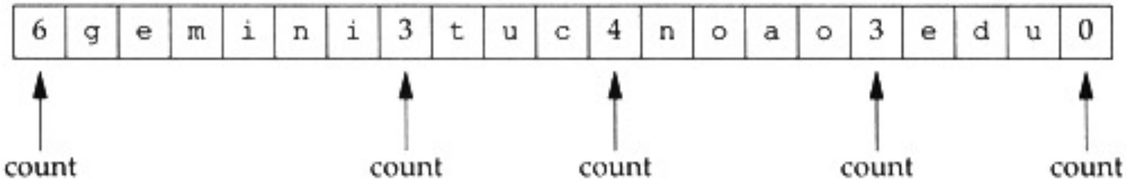
Different types

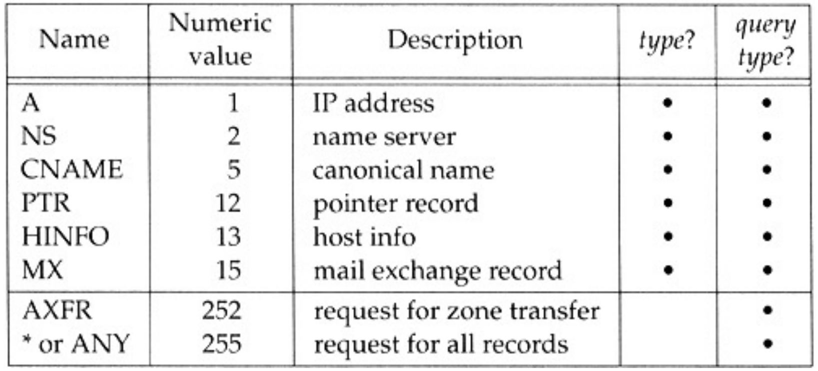
Questions, queries

- Domain name to query
  - Per level, length-value encoding
  - 1 byte: number of characters in level, range **0-63**
  - No limit to total size of domain name, only to levels
  - Query ends with **0**
- Query types
  - ‘type’ is for answer
  - Record resource type requested
- Query class
  - 1, query for IP addresses



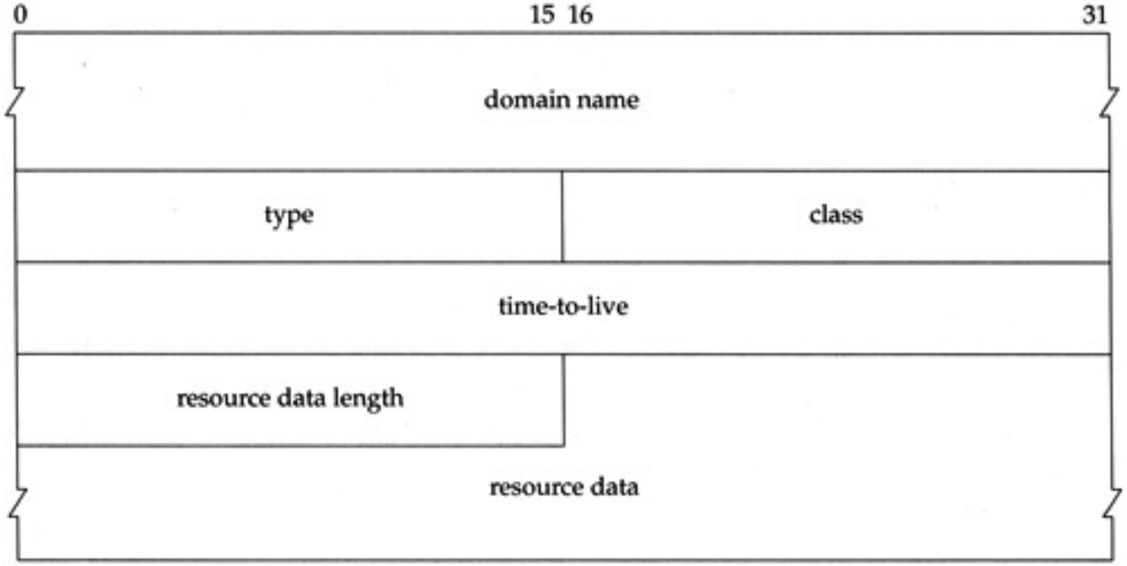
`gemini.tuc.noao.edu`





Name	Numeric value	Description	*type?*	*query type?*
A	1	IP address	•	•
NS	2	name server	•	•
CNAME	5	canonical name	•	•
PTR	12	pointer record	•	•
HINFO	13	host info	•	•
MX	15	mail exchange record	•	•
AXFR	252	request for zone transfer		•
* or ANY	255	request for all records		•

Resource records

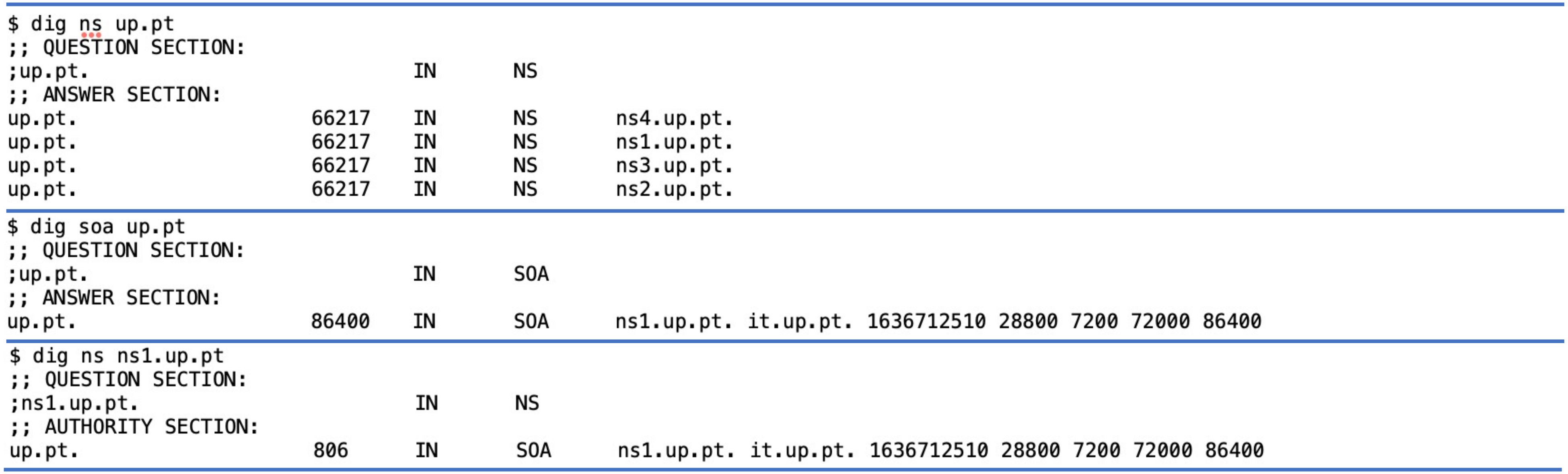


- Assigns resources to names
- Common format for:
  - Answers
  - Authority
  - Additional Information
- Domain name, type, class – similar to question
- Resource data – depends on resource record type

https://datatracker.ietf.org/doc/html/rfc1035#section-3.3.11

https://en.wikipedia.org/wiki/SOA_record

RR examples



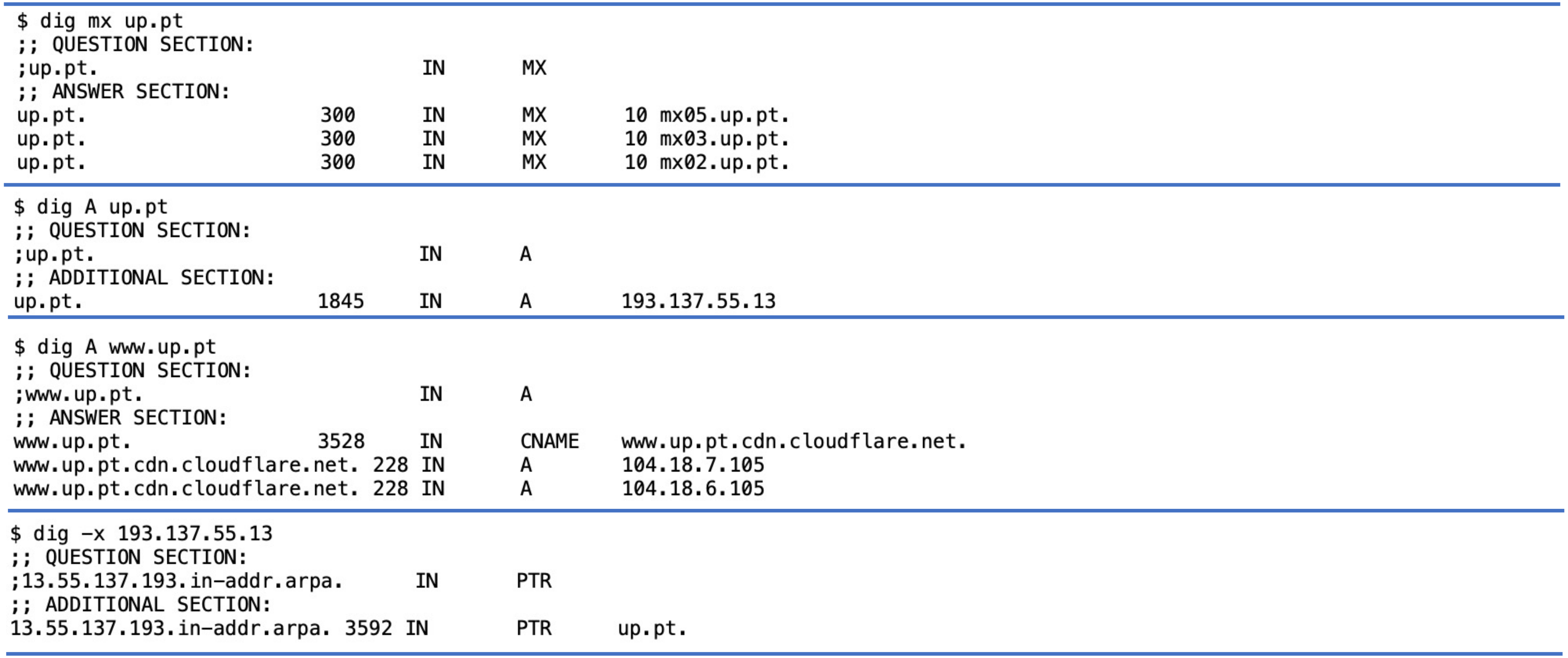
```
$ dig ns up.pt
;; QUESTION SECTION:
;up.pt.                          IN      NS
;; ANSWER SECTION:
up.pt.                  66217    IN      NS       ns4.up.pt.
up.pt.                  66217    IN      NS       ns1.up.pt.
up.pt.                  66217    IN      NS       ns3.up.pt.
up.pt.                  66217    IN      NS       ns2.up.pt.
```

```
$ dig soa up.pt
;; QUESTION SECTION:
;up.pt.                          IN      SOA
;; ANSWER SECTION:
up.pt.                  86400    IN      SOA      ns1.up.pt. it.up.pt. 1636712510 28800 7200 72000 86400
```

```
$ dig ns ns1.up.pt
;; QUESTION SECTION:
;ns1.up.pt.                      IN      NS
;; AUTHORITY SECTION:
up.pt.                  806      IN      SOA      ns1.up.pt. it.up.pt. 1636712510 28800 7200 72000 86400
```

RR examples

https://en.wikipedia.org/wiki/CNAME_record
https://en.wikipedia.org/wiki/MX_record
https://datatracker.ietf.org/doc/html/rfc1035#section-3.3.12



```
$ dig mx up.pt
;; QUESTION SECTION:
;up.pt.                          IN      MX
;; ANSWER SECTION:
up.pt.                   300     IN      MX      10 mx05.up.pt.
up.pt.                   300     IN      MX      10 mx03.up.pt.
up.pt.                   300     IN      MX      10 mx02.up.pt.
```

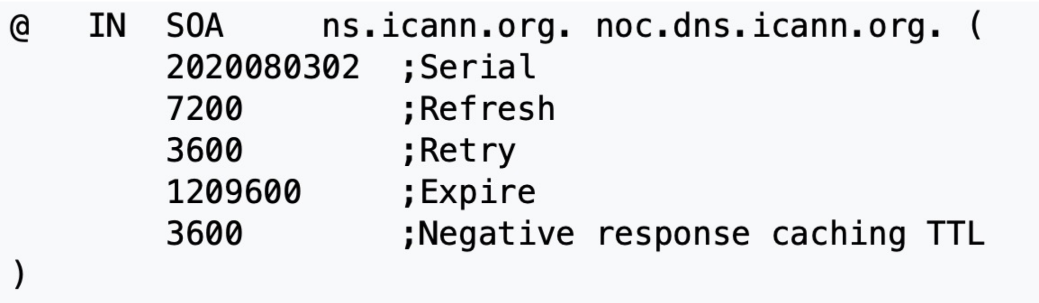
```
$ dig A up.pt
;; QUESTION SECTION:
;up.pt.                          IN      A
;; ADDITIONAL SECTION:
up.pt.                   1845    IN      A       193.137.55.13
```

```
$ dig A www.up.pt
;; QUESTION SECTION:
;www.up.pt.                      IN      A
;; ANSWER SECTION:
www.up.pt.               3528    IN      CNAME   www.up.pt.cdn.cloudflare.net.
www.up.pt.cdn.cloudflare.net. 228 IN     A       104.18.7.105
www.up.pt.cdn.cloudflare.net. 228 IN     A       104.18.6.105
```

```
$ dig -x 193.137.55.13
;; QUESTION SECTION:
;13.55.137.193.in-addr.arpa.     IN      PTR
;; ADDITIONAL SECTION:
13.55.137.193.in-addr.arpa. 3592 IN      PTR     up.pt.
```

Timeouts – Example with SOA and slaves (secondary NS)

- Expire: Number of seconds after which secondary name servers should stop answering request for this zone if the master does not respond. This value must be bigger than the sum of *Refresh* and *Retry*.



```
@   IN  SOA     ns.icann.org. noc.dns.icann.org. (
        2020080302  ;Serial
        7200        ;Refresh
        3600        ;Retry
        1209600     ;Expire
        3600        ;Negative response caching TTL
)
```

https://en.wikipedia.org/wiki/SOA_record

Resolvers and caches

- Recursive

vs.

- Iterative

- Referral
  - NS: ”can’t find this name, try this NS”
  - (2) and (4) in red in the figure

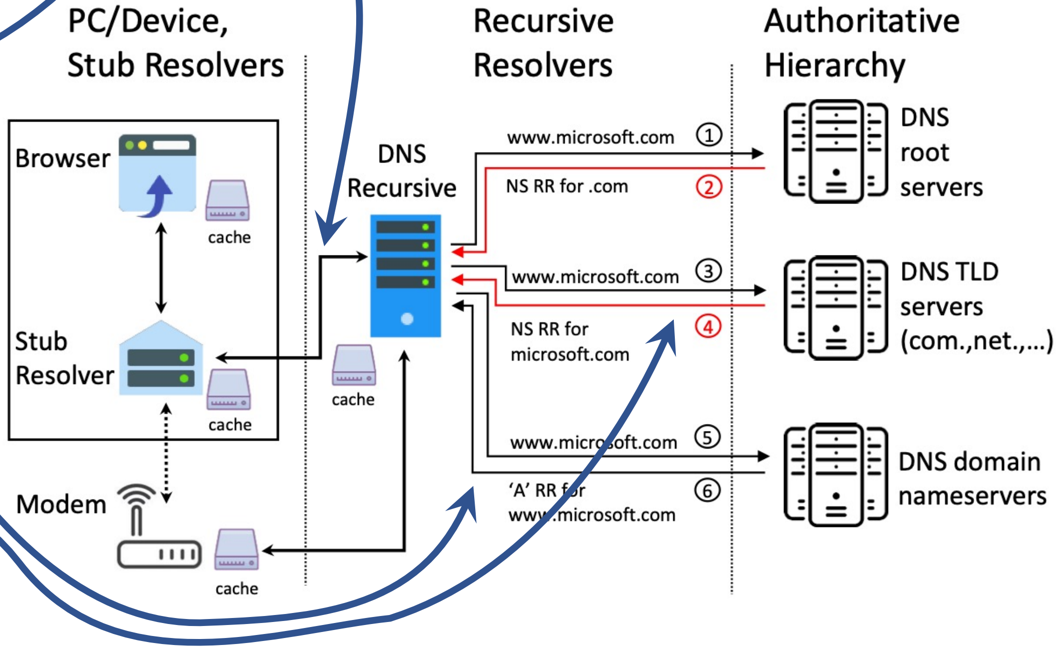


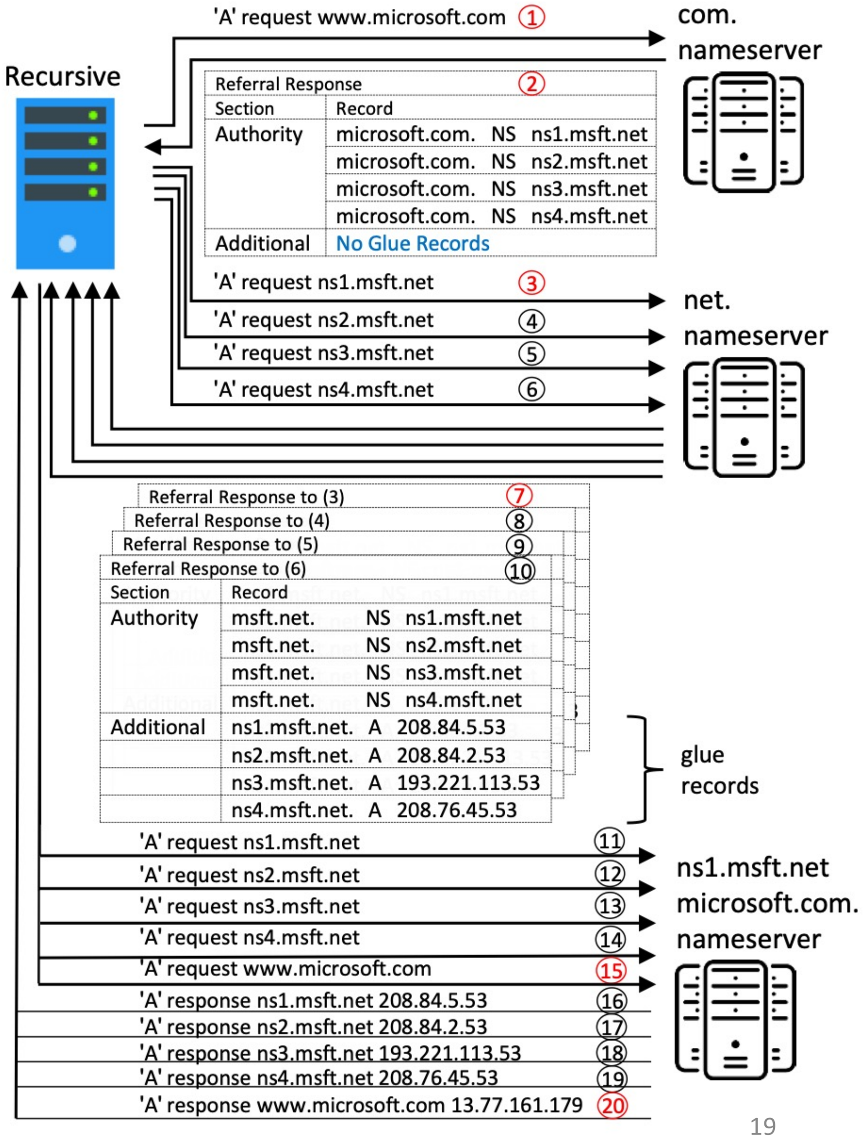
Figure 1: The resolution process, in theory, for the domain www.microsoft.com. The red steps represent NS referral responses.

https://www.usenix.org/conference/usenixsecurity20/presentation/afek

Redundancy overhead

- Multiple name servers for redundancy
- Results in multiple queries to multiple nameservers

https://www.usenix.org/conference/usenixsecurity20/presentation/afek



'A' request www.microsoft.com ①

Referral Response ②	
Section	Record
Authority	microsoft.com. NS ns1.msft.net
	microsoft.com. NS ns2.msft.net
	microsoft.com. NS ns3.msft.net
	microsoft.com. NS ns4.msft.net
Additional	No Glue Records

'A' request ns1.msft.net ③

'A' request ns2.msft.net ④

'A' request ns3.msft.net ⑤

'A' request ns4.msft.net ⑥

Referral Response to (3) ⑦

Referral Response to (4) ⑧

Referral Response to (5) ⑨

Referral Response to (6) ⑩	
Section	Record
Authority	msft.net. NS ns1.msft.net
	msft.net. NS ns2.msft.net
	msft.net. NS ns3.msft.net
	msft.net. NS ns4.msft.net
Additional	ns1.msft.net. A 208.84.5.53
	ns2.msft.net. A 208.84.2.53
	ns3.msft.net. A 193.221.113.53
	ns4.msft.net. A 208.76.45.53

'A' request ns1.msft.net ⑪

'A' request ns2.msft.net ⑫

'A' request ns3.msft.net ⑬

'A' request ns4.msft.net ⑭

'A' request www.microsoft.com ⑮

'A' response ns1.msft.net 208.84.5.53 ⑯

'A' response ns2.msft.net 208.84.2.53 ⑰

'A' response ns3.msft.net 193.221.113.53 ⑱

'A' response ns4.msft.net 208.76.45.53 ⑲

'A' response www.microsoft.com 13.77.161.179 ⑳

NXDOMAIN: performance issues with caching

- Caching tries to save resources on the authoritative server
  - First query for a given name -> goes for the authoritative server
  - Subsequent queries are replied by the cache without using the auth. Server
- This works ok assuming queried domain names are somehow repeated
  - Each client may lookup the same domain name multiple times
  - Multiple clients may lookup the same domain name
- What if the queried domain names are not repeated?
  - Most queries go to the authoritative server
  - Authoritative server gets more queries than designed for

Security Extensions

- DNSSEC: Domain Name System Security Extensions
- Provide integrity in the query answers
  - RRSIG resource record provides the signature to authenticate another RR
- DNSKEY of the server, for the resolver to verify the signature
  - Chain of trust from root servers
- Does not provide confidentiality
  - Eavesdroppers can still know what you’re querying

Dynamic DNS

- Dynamic updating
  - Motivation: update traditional records without manual editing
  - RFC 2136: UPDATE, opcode 5 in DNS message
- Client updates
  - Motivation: client IP addresses change, name-IP mapping must be updated
  - Service to update IP address, often HTTP based

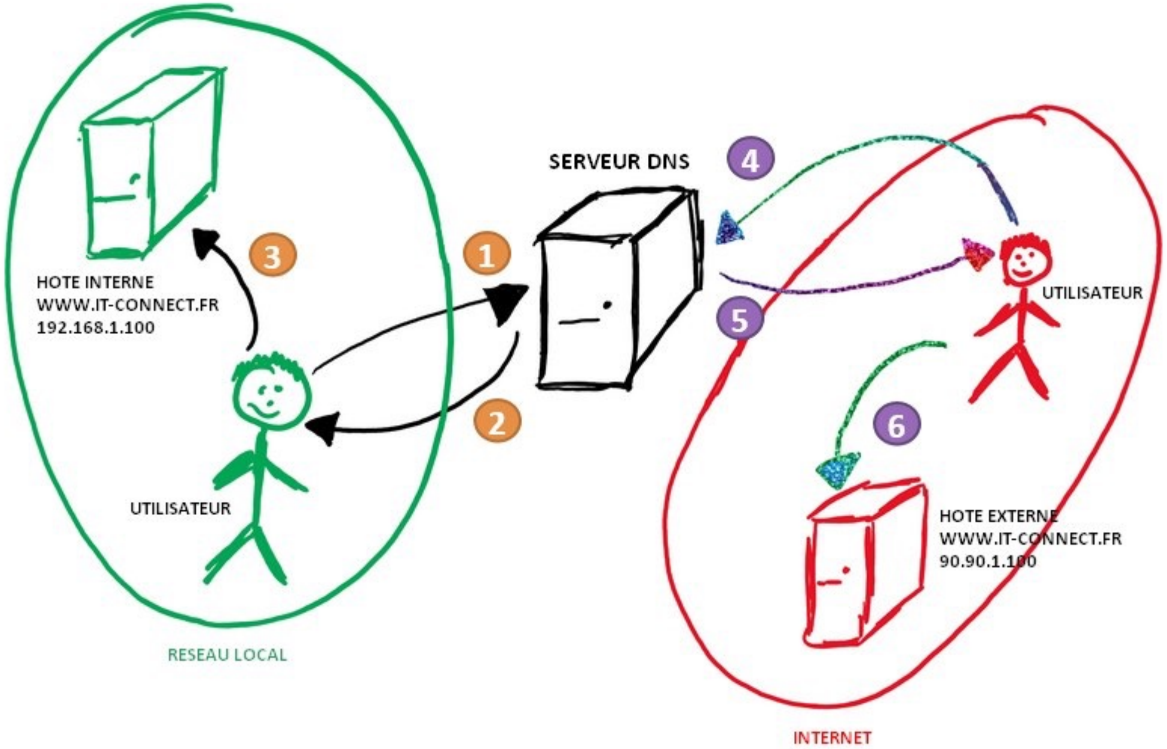
Transport Protocols for DNS

- DNS typically runs on UDP port 53
- Can be used over TCP (also on port 53)
  - When expecting large replies (UDP max 512 bytes)
  - Or for zone transfers to slave servers (AXFR)
- Motivation for using other (encrypted) transport protocols
  - Privacy concerns between the client and the resolver
  - Easy to recover domain name of HTTP request from DNS query
  - Even if HTTP connection is encrypted and Server Name Indicator (TLS) is encrypted
  - Can’t we use DNSSEC? Yes you can/should, but it “only” gives you integrity of query answers

Transport Protocols for DNS

- DoT
  - Establish a TLS connection, send DNS messages over the TLS connection
  - Based on the TCP version of DNS
  - https://datatracker.ietf.org/doc/html/rfc7858
  - https://developers.cloudflare.com/1.1.1.1/encrypted-dns/dns-over-tls
- DoH
  - DNS messages sent as HTTP's MIME type: application/dns-message
  - HTTP/2
  - https://developers.cloudflare.com/1.1.1.1/encrypted-dns/dns-over-https/make-api-requests/dns-wireformat
- Integrity about query answers? DNSSec

Deployment – split DNS



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