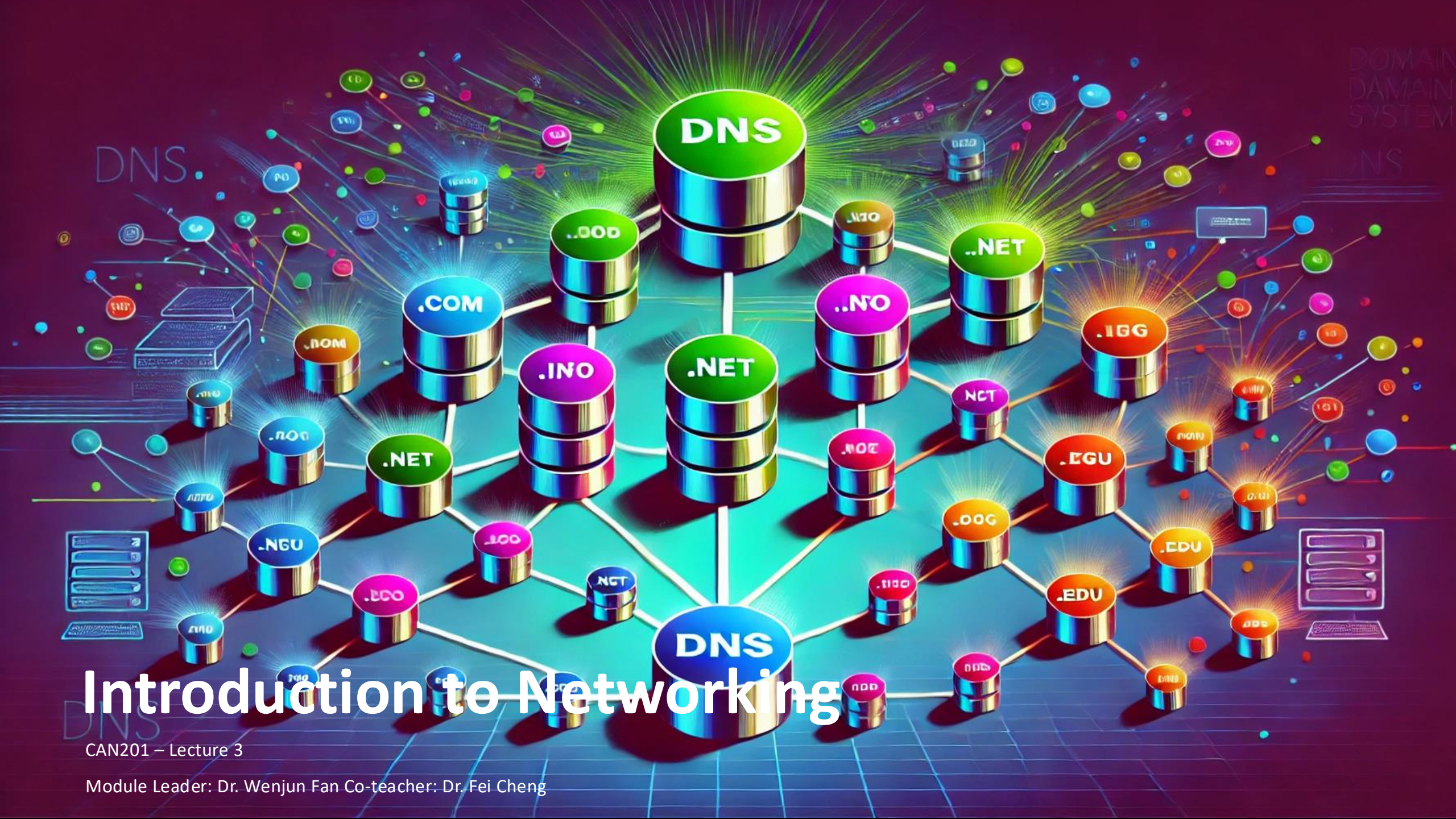


Introduction to Networking

CAN201 – Lecture 3

Module Leader: Dr. Wenjun Fan Co-teacher: Dr. Fei Cheng

HTTP = WEBPAGE?

Application Programming Interface

RESTful API

- Representational State Transfer API
- A set of recommended styles/rules for API design
  - Use of standard HTTP methods (GET, POST, PUT, DELETE, etc.) to operate on resources.
  - Resources are identified via URIs, where each URI represents a resource.
  - Statelessness, meaning the server does not store any client session information between requests.
  - Use of standard HTTP status codes to represent the outcome of requests.
- **Over 93% of developers using RESTful API in their projects**

Examples of RESTful

- **Yes:**
  - **Retrieving User Information**
  - Request: GET /users/123
  - Description: Retrieves information about the user with ID 123

  - **Creating a New User**
  - Request: POST /users
  - Request Body: json
    - { "name": "Alice", "email": "alice@example.com" }
  - Description: Creates a new user on the server.

Examples of RESTful

- **Yes:**
  - **Updating User Information**
  - Request: PUT /users/123
  - Request Body:json
    - { "email": "newemail@example.com" }
  - Description: Updates the email of the user with ID 123.

  - **Deleting a User**
  - Request: DELETE /users/123
  - Description: Deletes the user with ID 123.

Examples of RESTful

- **No:**
  - Request: GET /getUser?id=123
  - Description: Retrieves information about the user with ID 123.
  - Reason: Using Verbs in the URI

  - Request: POST /users/getUserInfo
  - Request Body: json
    - { "id": 123 }
  - Description: Retrieves information about the user with ID 123.
  - Reason: Using POST for Retrieval

Examples of RESTful

- **No:**
  - Request: GET /users/updateEmail?id=123&email=newemail@example.com
  - Description: Updates the email of a user.
  - Reason: Including Actions in the URI

Lecture III – Application Layer (2)

1. Domain Name System (DNS)
2. P2P Applications
3. Socket Programming

Identification

- **You and me:**
  - Uni-ID, CNID / Passport, Name, Nickname
- **Internet hosts:**
  - IP address (32 bit for IPv4) - used for addressing datagrams
  - "Name", eg. www.xjtlu.edu.cn - used by humans
- **Q: How to map between IP address and name?**

L To Z

Auckland 2004

Yellow Pages®

Telecom

A To K

Auckland 2004

Yellow Pages®

Telecom

DNS: domain name system

- **Application-layer protocol:**
  - C/S architecture
  - UDP (port 53)
  - hosts, name servers communicate to resolve names (name / address translation)
- **Distributed database implemented in hierarchy of many name servers**

DNS: services, structure

- **DNS services**
  - Hostname to IP address translation(A)
  - Host aliasing (cname)
    - canonical, alias names
  - Mail server aliasing(mx)
  - Load distribution
    - Replicated Web servers: many IP addresses correspond to one name

Why not centralize DNS?

- Single point of failure
- Traffic volume
- Distant centralized database
- Maintenance

Thinking about the DNS

humongous distributed database:

- ~ billion records, each simple

handles many *trillions* of queries/day:

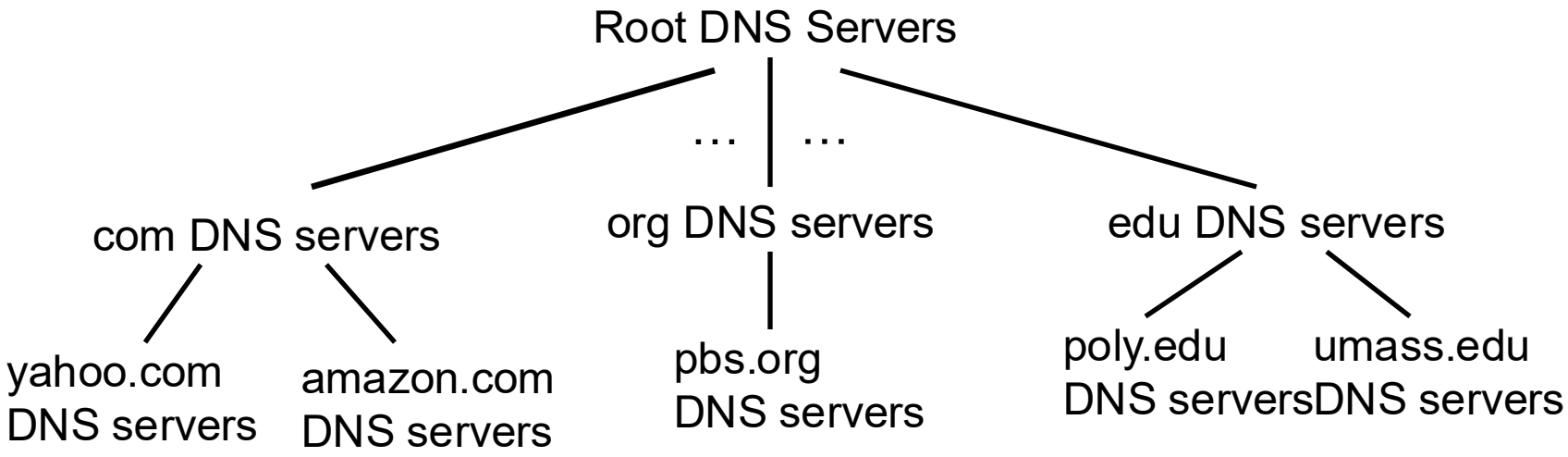
- *many* more reads than writes
- *performance matters:* almost every Internet transaction interacts with DNS - msecs count!

organizationally, physically decentralized:

- millions of different organizations responsible for their records

"bulletproof": reliability, security

DNS: a distributed, hierarchical database



Root

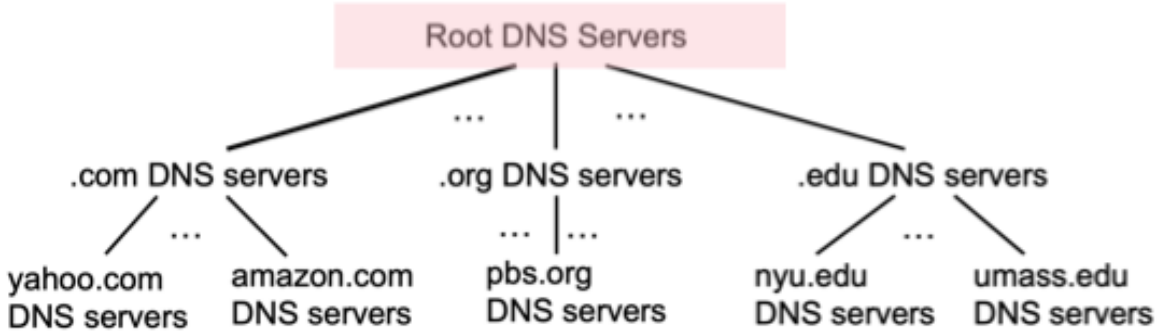
Top Level Domain

Authoritative

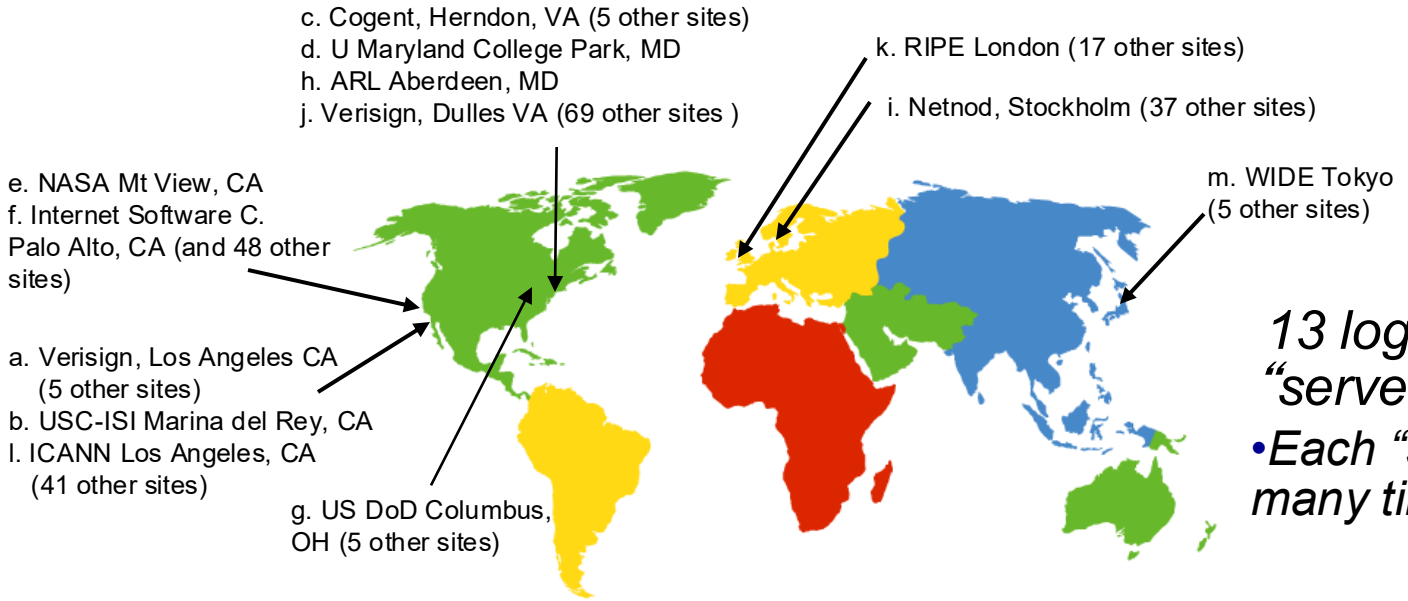
Client wants IP for www.amazon.com:

- **Client queries root server to find com DNS server**
- **Client queries .com DNS server to get amazon.com DNS server**
- **Client queries amazon.com DNS server to get IP address for www.amazon.com**

DNS: root name servers



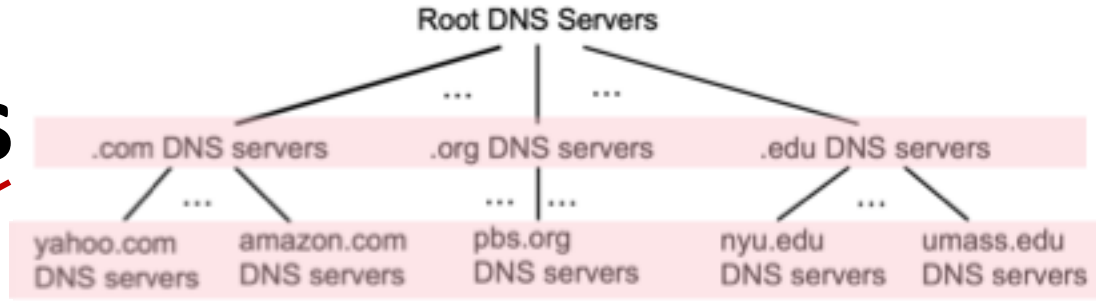
- **Contacted by local name server that can not resolve name**
- **Root name server:**
  - Contacts authoritative name server if name mapping not known
  - Gets mapping
  - Returns mapping to local name server



13 logical root name "servers" worldwide

- *Each "server" replicated many times*

TLD, authoritative servers



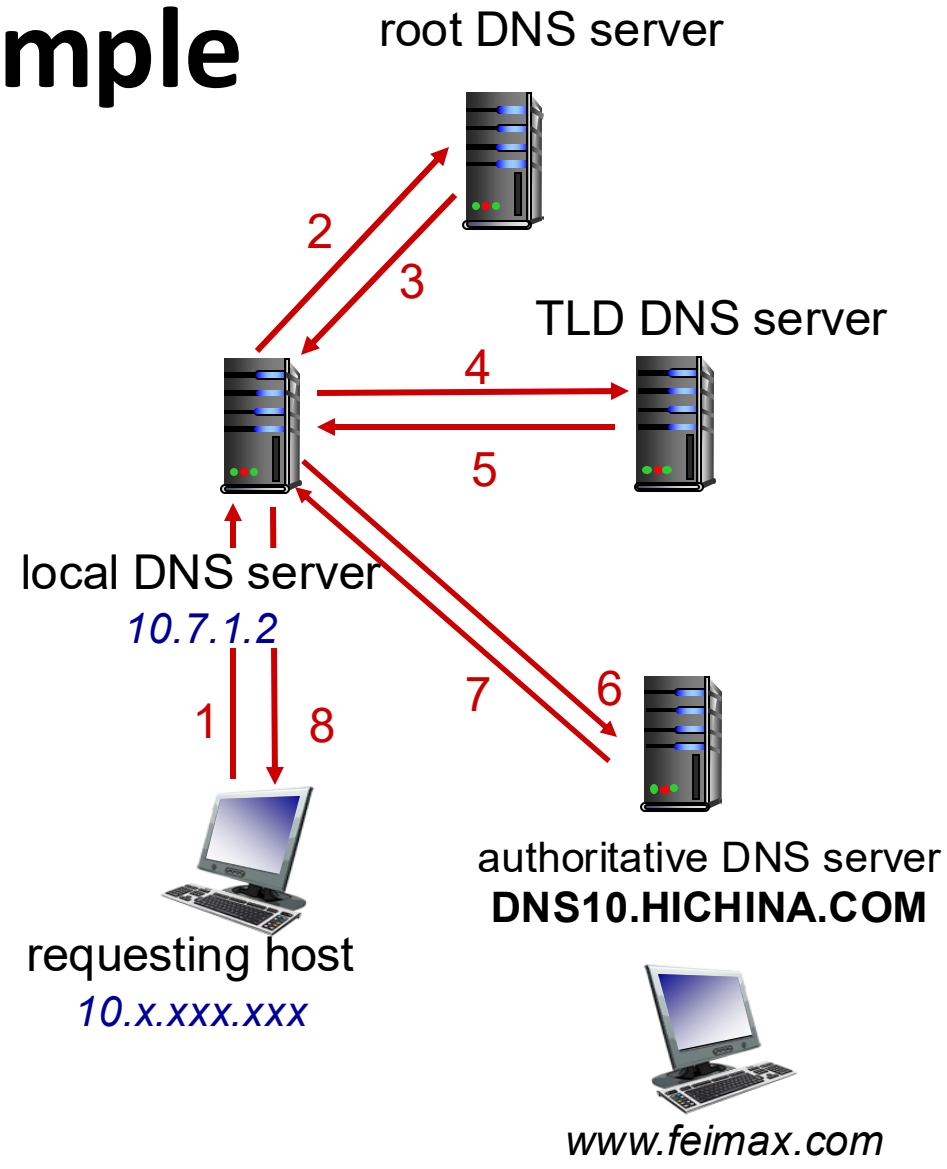
- **Top-level domain (TLD) servers:**
  - Responsible for com, org, net, edu, aero, jobs, museums, and all Top-level country domains, e.g.: cn, uk, fr, ca, jp
  - *Eg.:*
    - *Network Solutions* maintains servers for .com TLD
    - *Educause* for .edu TLD (https://net.educause.edu/)
- **Authoritative DNS servers:**
  - Organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
  - Can be maintained by organization or service provider

Local DNS name server

- **Does not strictly belong to hierarchy**
- **Each ISP (residential ISP, company, university) has one**
  - Also called "default name server"
  - to find yours:
    - MacOS: `% scutil --dns`
    - Windows: `>ipconfig /all`
- **When host makes DNS query, query is sent to its local DNS server**
  - Has local cache of recent name-to-address translation pairs (but may be out of date!)
  - Acts as proxy, forwards query into hierarchy

DNS name resolution example

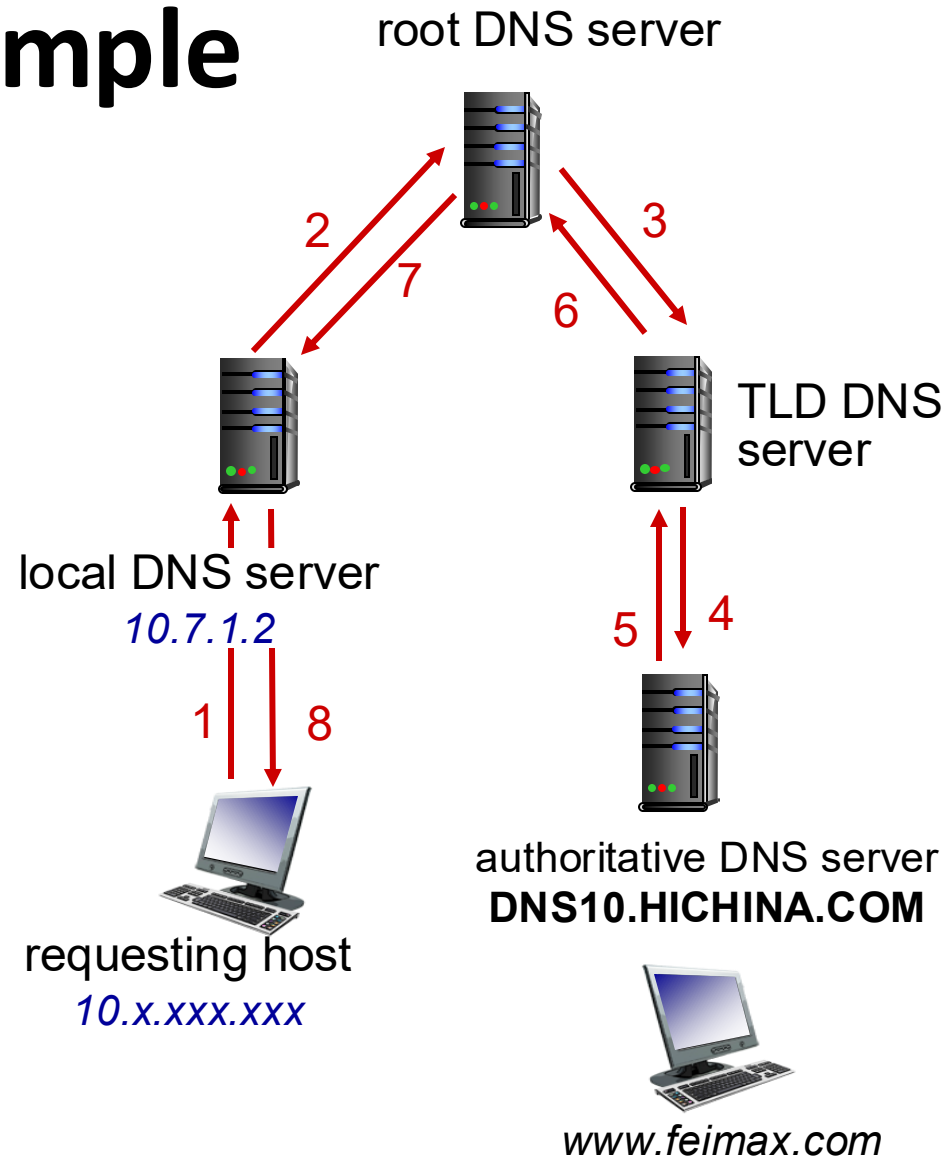
- **Host at XJTLU wants IP address for www.feimax.com**
- **Iterated query:**
  - contacted server replies with name of server to contact
  - "I don't know this name, but ask this server"



DNS name resolution example

- **Recursive query:**
  - Puts burden of name resolution on contacted name server
  - Heavy load at upper levels of hierarchy

dig +trace



DNS: caching, updating records

- **Once (any) name server learns mapping, it *caches* mapping**
  - Cache entries timeout (disappear) after some time (TTL)
  - TLD servers typically cached in local name servers
    - thus root name servers not often visited
- **Cached entries may be *out-of-date***
  - If name host changes IP address, may not be known Internet-wide until all TTLs expire
- **Update/notify mechanisms proposed IETF standard**
  - RFC 2136

DNS records

DNS: **distributed database storing resource records (RR)**

RR format: `(name, value, type, ttl)`

type=A

- **name** is hostname
- **value** is IP address

type=NS

- **name** is domain (e.g., foo.com)
- **value** is hostname of authoritative name server for this domain

type=CNAME

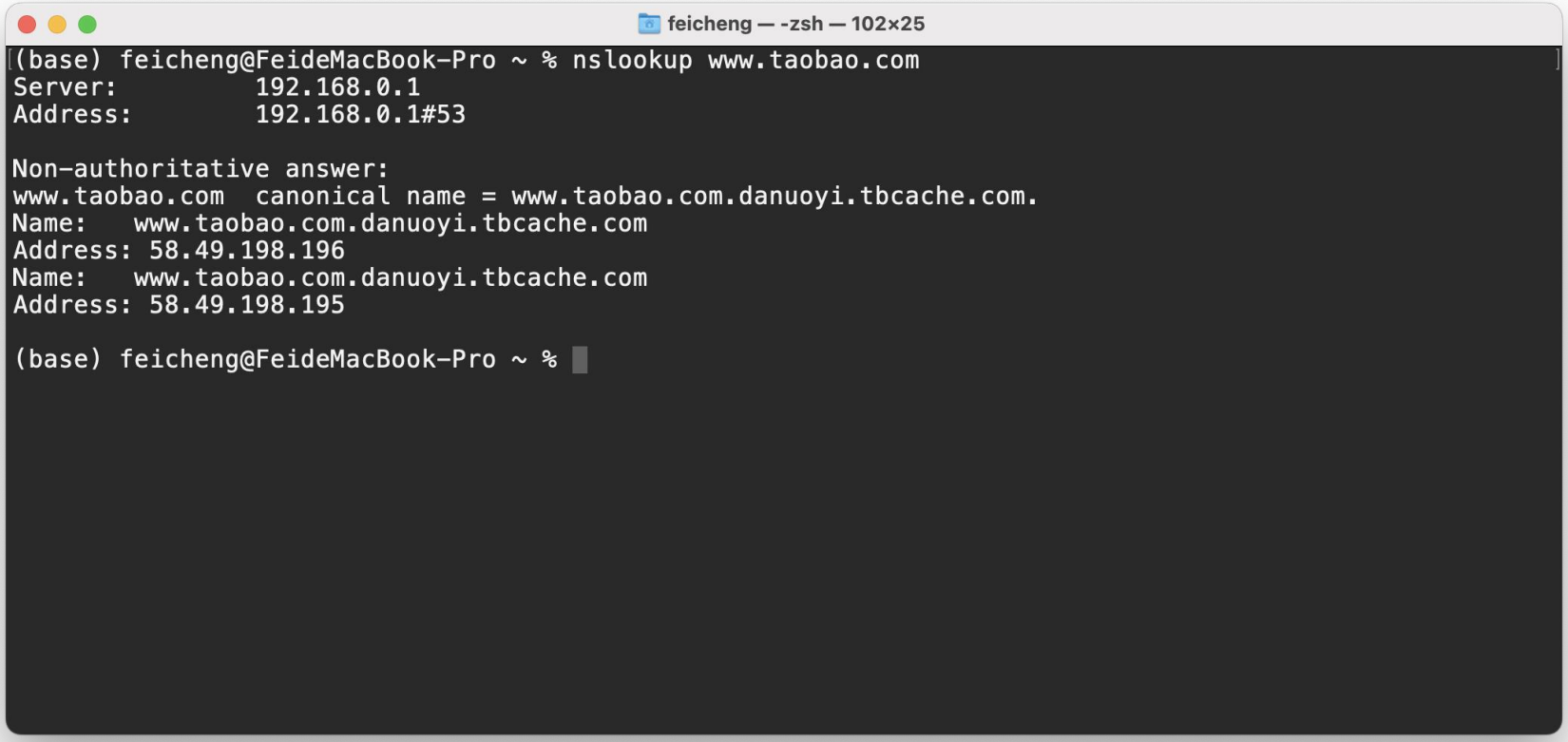
- **name** is alias name for some "canonical" (the real) name
- **www.taobao.com** is really www.taobao.com.danuoyi.tbcache.com
- **value** is canonical name

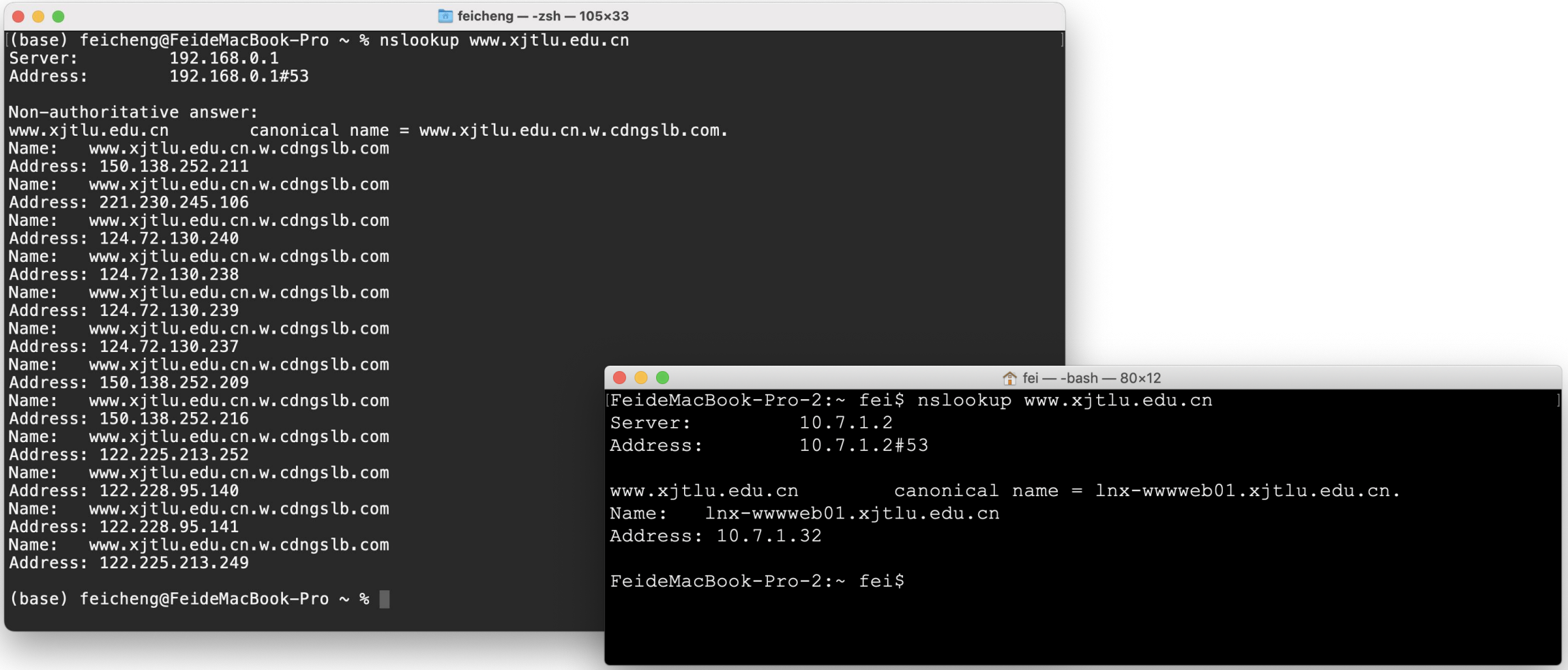
type=MX

- **value** is name of mailserver associated with **name**

Loop up a domain name

- Use *nslookup* command:





When the internet access point changes, the IP address from DNS may change

Try it at home, or at XJTLU

Get information of a domain name

- **Use *whois* command:**
  - whois feimax.com

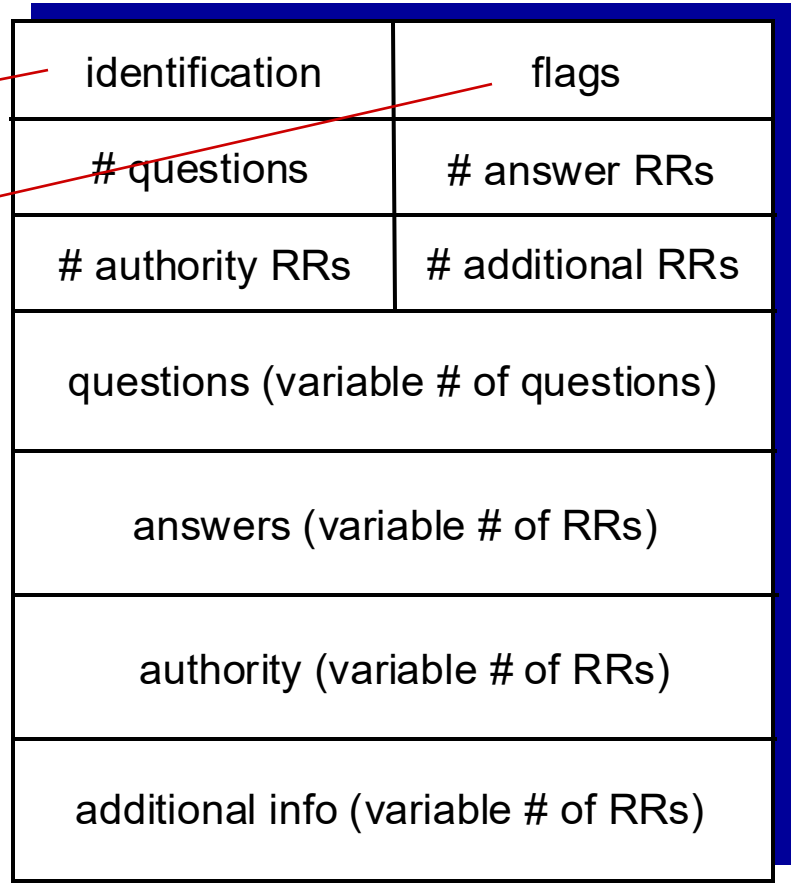
```
Domain Name: FEIMAX.COM
Registry Domain ID: 1957417764_DOMAIN_COM-VRSN
Registrar WHOIS Server: grs-whois.hichina.com
Registrar URL: http://www.net.cn
Updated Date: 2025-09-02T07:15:33Z
Creation Date: 2015-09-04T05:56:45Z
Registry Expiry Date: 2026-09-04T05:56:45Z
Registrar: Alibaba Cloud Computing (Beijing) Co., Ltd.
Registrar IANA ID: 420
Registrar Abuse Contact Email: DomainAbuse@service.aliyun.com
Registrar Abuse Contact Phone: +86.95187
Domain Status: ok https://icann.org/epp#ok
Name Server: DNS10.HICHINA.COM
Name Server: DNS9.HICHINA.COM
DNSSEC: unsigned
URL of the ICANN Whois Inaccuracy Complaint Form: https://www.icann.org/wicf/
```

DNS protocol, messages

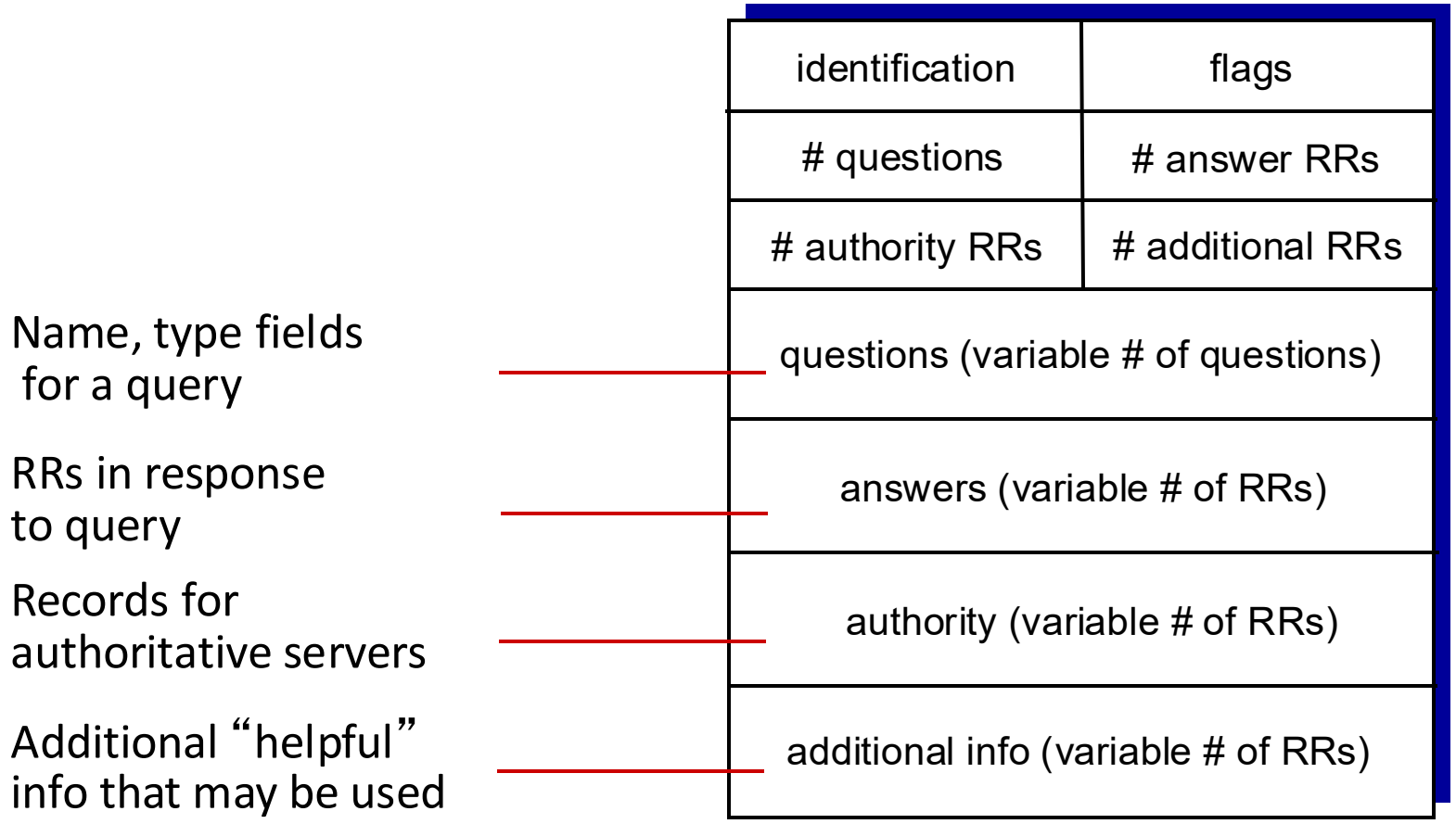
- ***Query*** **and** ***reply*** **messages, both with same** ***message format***

Message header

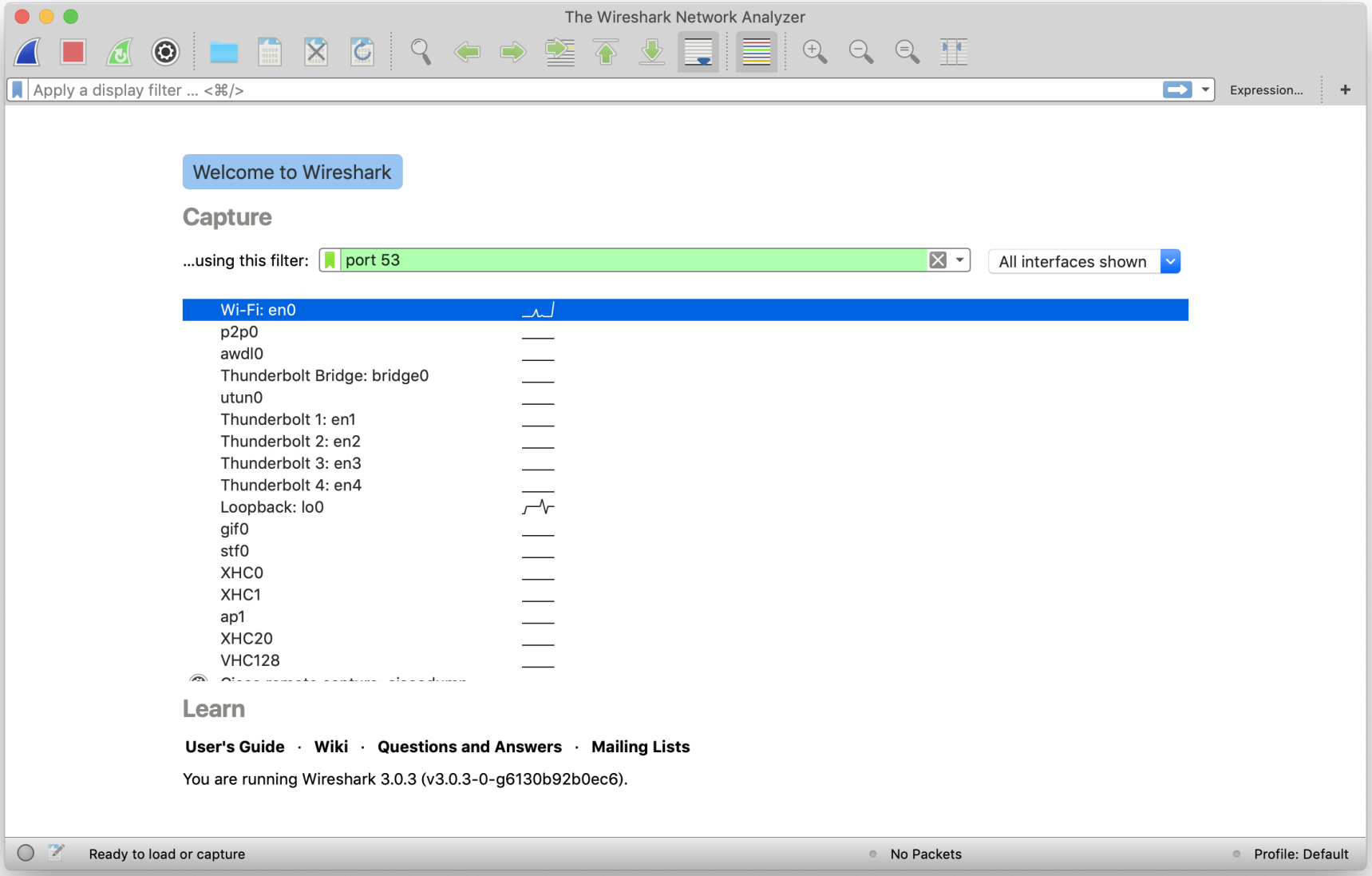
- identification: 16 bit # for query, reply to query uses same #
- flags:
  - query or reply
  - recursion desired
  - recursion available
  - reply is authoritative

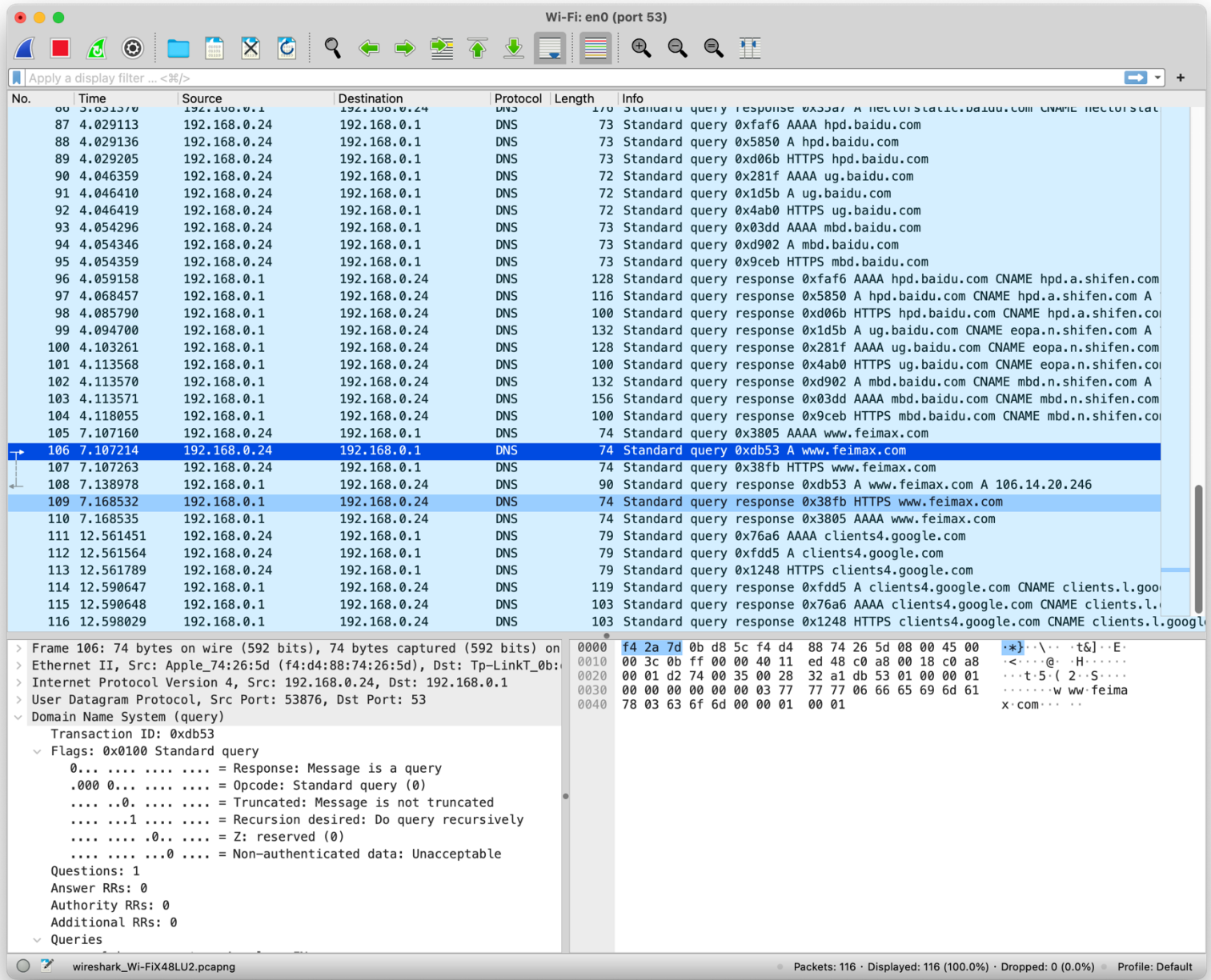


DNS protocol, messages

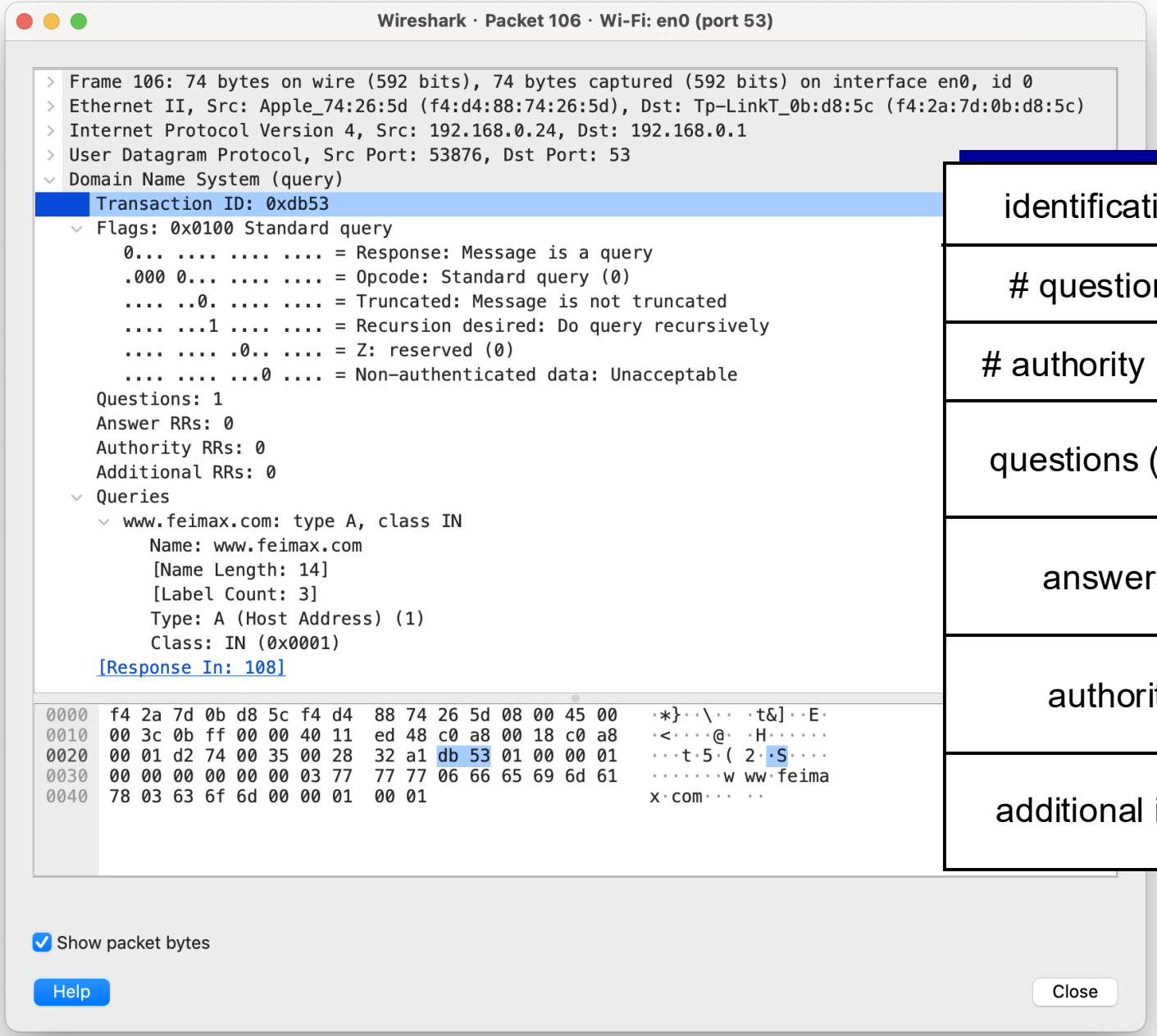


Wireshark examples



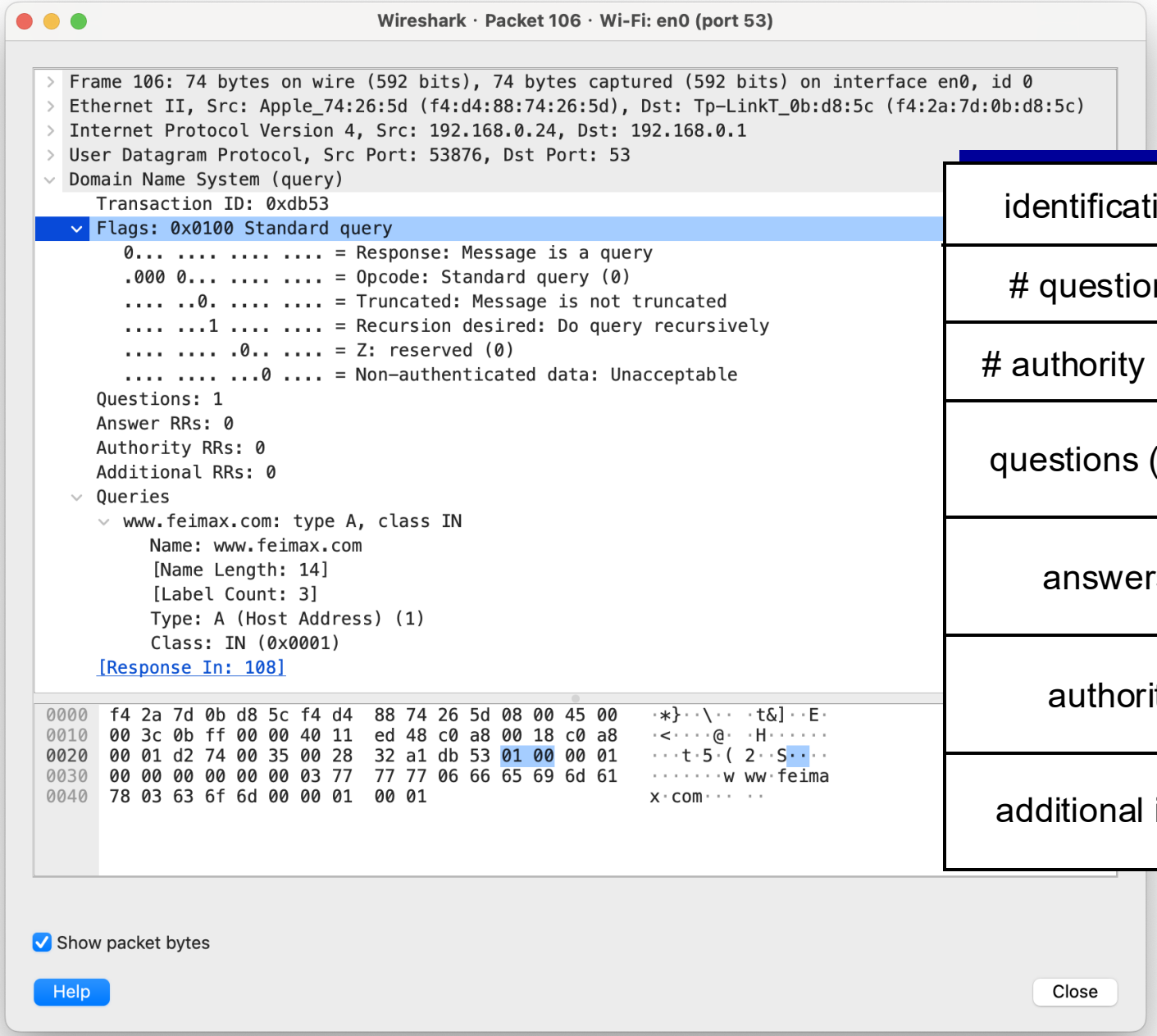

Wi-Fi: en0 (port 53)
Apply a display filter ... <⌘/>
No. Time Source Destination Protocol Length Info
87 4.029113 192.168.0.24 192.168.0.1 DNS 73 Standard query 0xfaf6 AAAA hpd.baidu.com
88 4.029136 192.168.0.24 192.168.0.1 DNS 73 Standard query 0x5850 A hpd.baidu.com
89 4.029205 192.168.0.24 192.168.0.1 DNS 73 Standard query 0xd06b HTTPS hpd.baidu.com
90 4.046359 192.168.0.24 192.168.0.1 DNS 72 Standard query 0x281f AAAA ug.baidu.com
91 4.046410 192.168.0.24 192.168.0.1 DNS 72 Standard query 0x1d5b A ug.baidu.com
92 4.046419 192.168.0.24 192.168.0.1 DNS 72 Standard query 0x4ab0 HTTPS ug.baidu.com
93 4.054296 192.168.0.24 192.168.0.1 DNS 73 Standard query 0x03dd AAAA mbd.baidu.com
94 4.054346 192.168.0.24 192.168.0.1 DNS 73 Standard query 0xd902 A mbd.baidu.com
95 4.054359 192.168.0.24 192.168.0.1 DNS 73 Standard query 0x9ceb HTTPS mbd.baidu.com
96 4.059158 192.168.0.1 192.168.0.24 DNS 128 Standard query response 0xfaf6 AAAA hpd.baidu.com CNAME hpd.a.shifen.com
97 4.068457 192.168.0.1 192.168.0.24 DNS 116 Standard query response 0x5850 A hpd.baidu.com CNAME hpd.a.shifen.com A
98 4.085790 192.168.0.1 192.168.0.24 DNS 100 Standard query response 0xd06b HTTPS hpd.baidu.com CNAME hpd.a.shifen.co
99 4.094700 192.168.0.1 192.168.0.24 DNS 132 Standard query response 0x1d5b A ug.baidu.com CNAME eopa.n.shifen.com A
100 4.103261 192.168.0.1 192.168.0.24 DNS 128 Standard query response 0x281f AAAA ug.baidu.com CNAME eopa.n.shifen.com
101 4.113568 192.168.0.1 192.168.0.24 DNS 100 Standard query response 0x4ab0 HTTPS ug.baidu.com CNAME eopa.n.shifen.co
102 4.113570 192.168.0.1 192.168.0.24 DNS 132 Standard query response 0xd902 A mbd.baidu.com CNAME mbd.n.shifen.com A
103 4.113571 192.168.0.1 192.168.0.24 DNS 156 Standard query response 0x03dd AAAA mbd.baidu.com CNAME mbd.n.shifen.com
104 4.118055 192.168.0.1 192.168.0.24 DNS 100 Standard query response 0x9ceb HTTPS mbd.baidu.com CNAME mbd.n.shifen.co
105 7.107160 192.168.0.24 192.168.0.1 DNS 74 Standard query 0x3805 AAAA www.feimax.com
106 7.107214 192.168.0.24 192.168.0.1 DNS 74 Standard query 0xdb53 A www.feimax.com
107 7.107263 192.168.0.24 192.168.0.1 DNS 74 Standard query 0x38fb HTTPS www.feimax.com
108 7.138978 192.168.0.1 192.168.0.24 DNS 90 Standard query response 0xdb53 A www.feimax.com A 106.14.20.246
109 7.168532 192.168.0.1 192.168.0.24 DNS 74 Standard query response 0x38fb HTTPS www.feimax.com
110 7.168535 192.168.0.1 192.168.0.24 DNS 74 Standard query response 0x3805 AAAA www.feimax.com
111 12.561451 192.168.0.24 192.168.0.1 DNS 79 Standard query 0x76a6 AAAA clients4.google.com
112 12.561564 192.168.0.24 192.168.0.1 DNS 79 Standard query 0xfdd5 A clients4.google.com
113 12.561789 192.168.0.24 192.168.0.1 DNS 79 Standard query 0x1248 HTTPS clients4.google.com
114 12.590647 192.168.0.1 192.168.0.24 DNS 119 Standard query response 0xfdd5 A clients4.google.com CNAME clients.l.goo
115 12.590648 192.168.0.1 192.168.0.24 DNS 103 Standard query response 0x76a6 AAAA clients4.google.com CNAME clients.l.
116 12.598029 192.168.0.1 192.168.0.24 DNS 103 Standard query response 0x1248 HTTPS clients4.google.com CNAME clients.l.googl
Frame 106: 74 bytes on wire (592 bits), 74 bytes captured (592 bits) on
Ethernet II, Src: Apple_74:26:5d (f4:d4:88:74:26:5d), Dst: Tp-LinkT_0b:
Internet Protocol Version 4, Src: 192.168.0.24, Dst: 192.168.0.1
User Datagram Protocol, Src Port: 53876, Dst Port: 53
Domain Name System (query)
Transaction ID: 0xdb53
Flags: 0x0100 Standard query
0... .... = Response: Message is a query
.000 0... .... = Opcode: Standard query (0)
.... ..0. .... = Truncated: Message is not truncated
....1 .... = Recursion desired: Do query recursively
.... .0.. .... = Z: reserved (0)
....0 .... = Non-authenticated data: Unacceptable
Questions: 1
Answer RRs: 0
Authority RRs: 0
Additional RRs: 0
Queries
0000 f4 2a 7d 0b d8 5c f4 d4 88 74 26 5d 08 00 45 00
0010 00 3c 0b ff 00 00 40 11 ed 48 c0 a8 00 18 c0 a8
0020 00 01 d2 74 00 35 00 28 32 a1 db 53 01 00 00 01
0030 00 00 00 00 00 00 03 77 77 77 06 66 65 69 6d 61
0040 78 03 63 6f 6d 00 00 01 00 01
wireshark_Wi-FiX48LU2.pcapng
Packets: 116 · Displayed: 116 (100.0%) · Dropped: 0 (0.0%)
Profile: Default

Request



identification	flags
# questions	# answer RRs
# authority RRs	# additional RRs
questions (variable # of questions)	
answers (variable # of RRs)	
authority (variable # of RRs)	
additional info (variable # of RRs)	

Request



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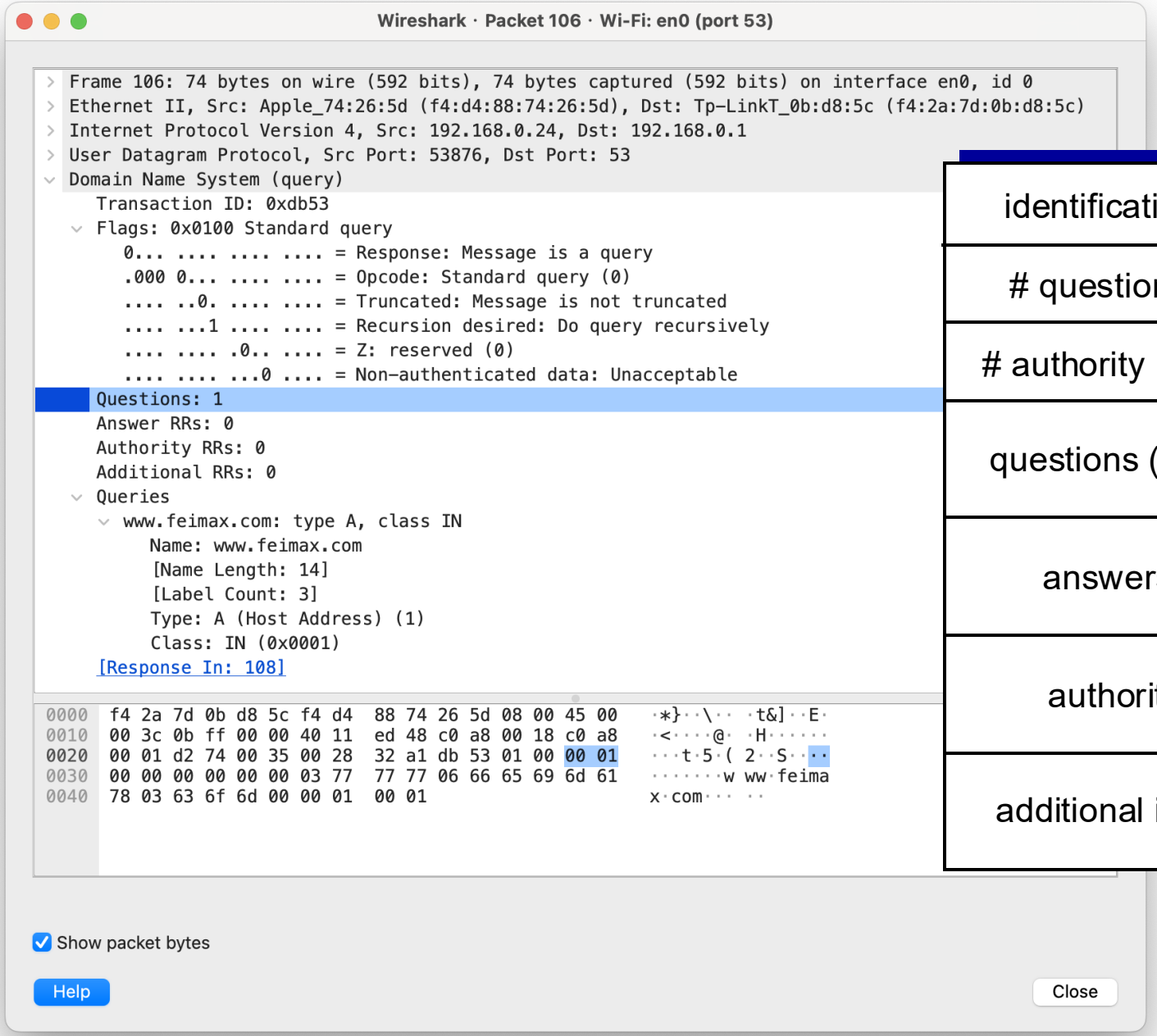

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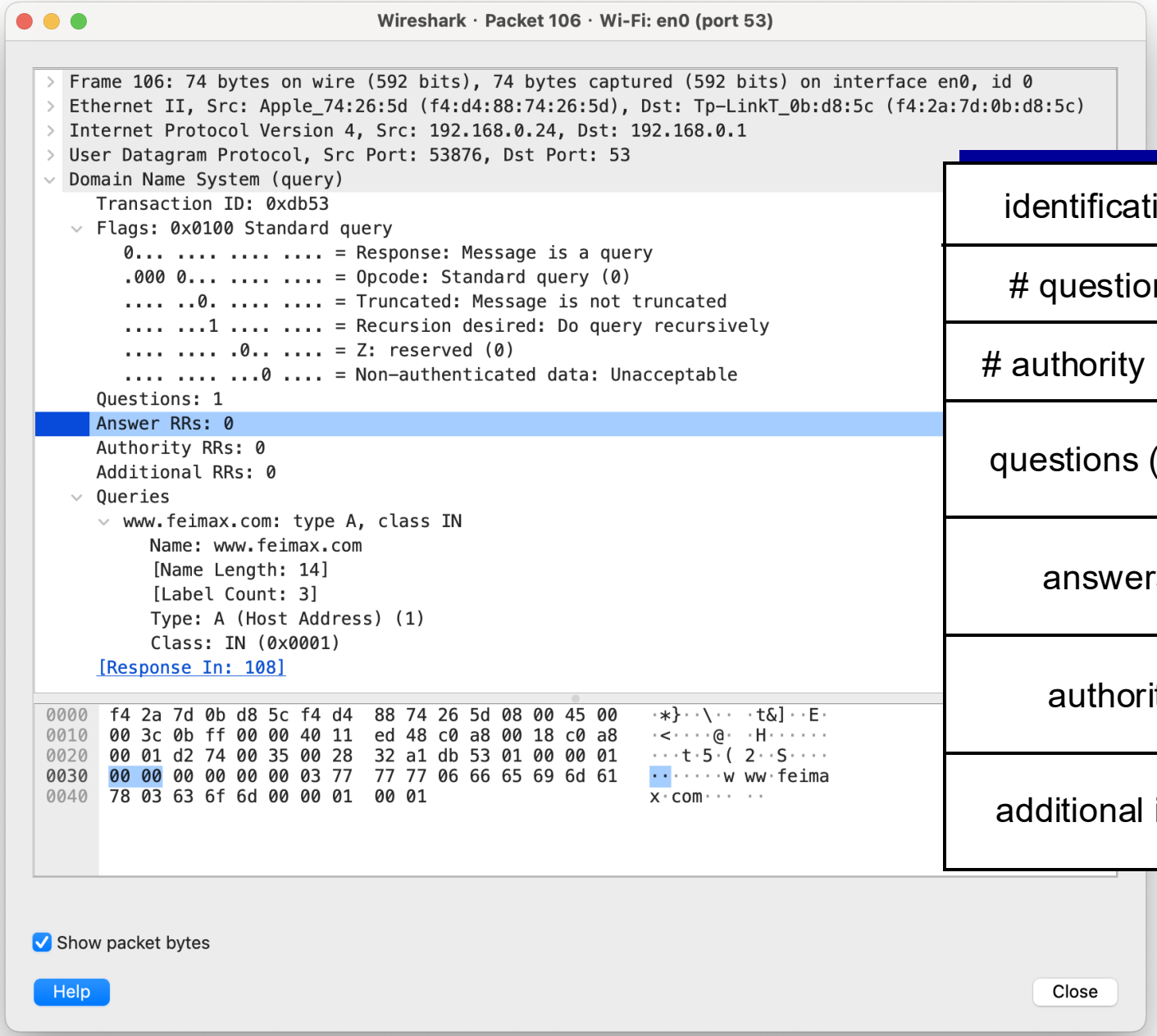

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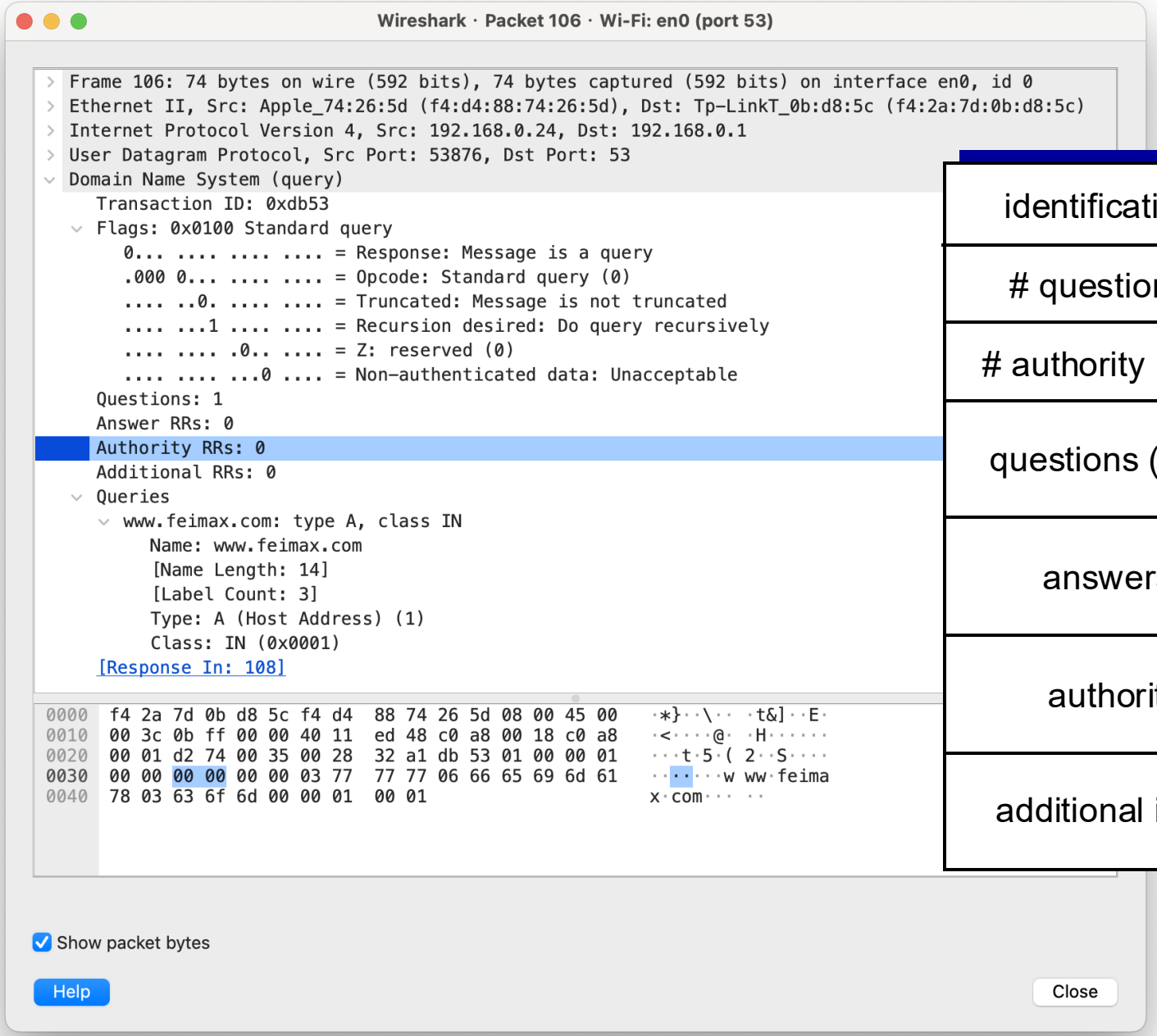

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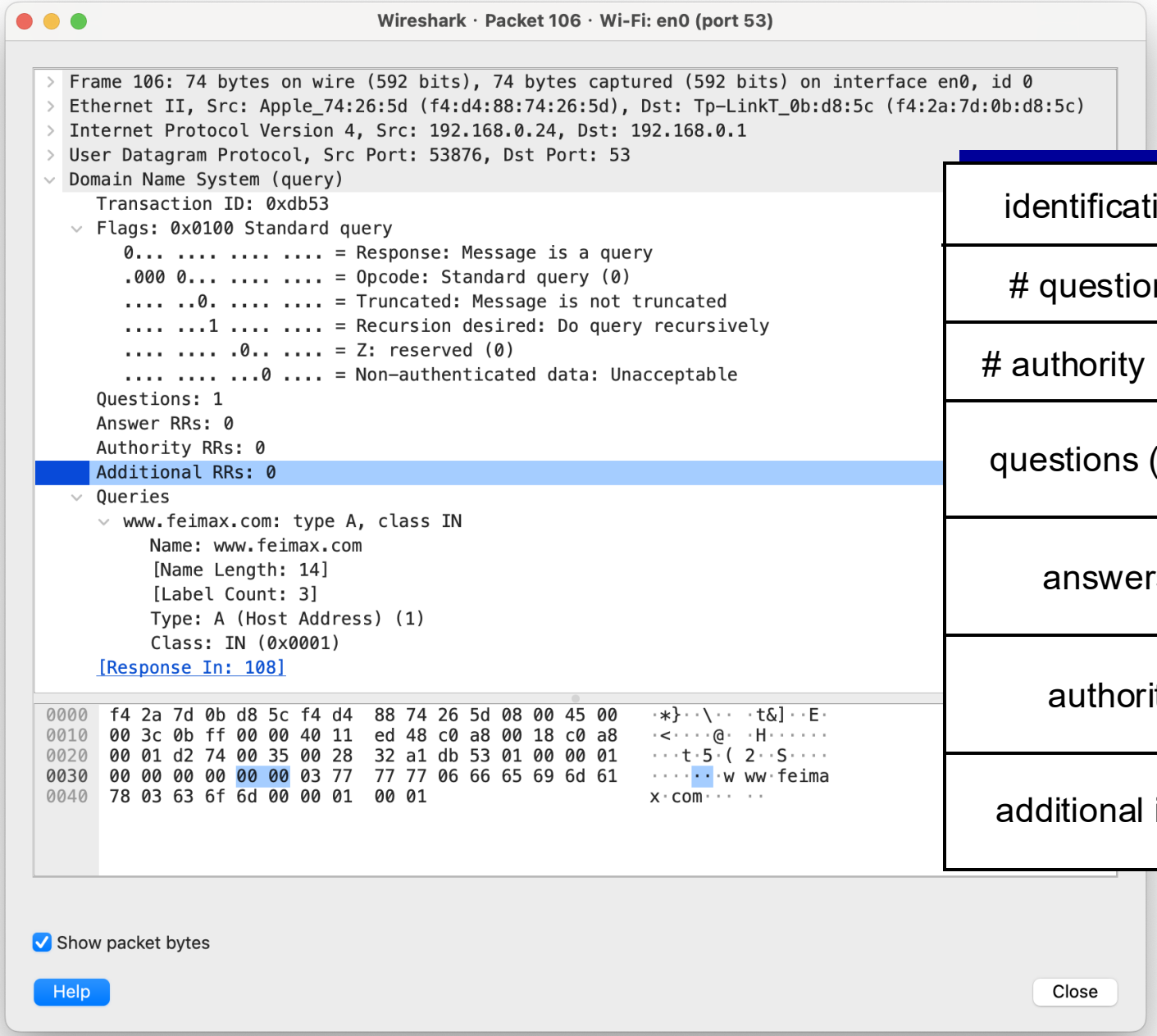

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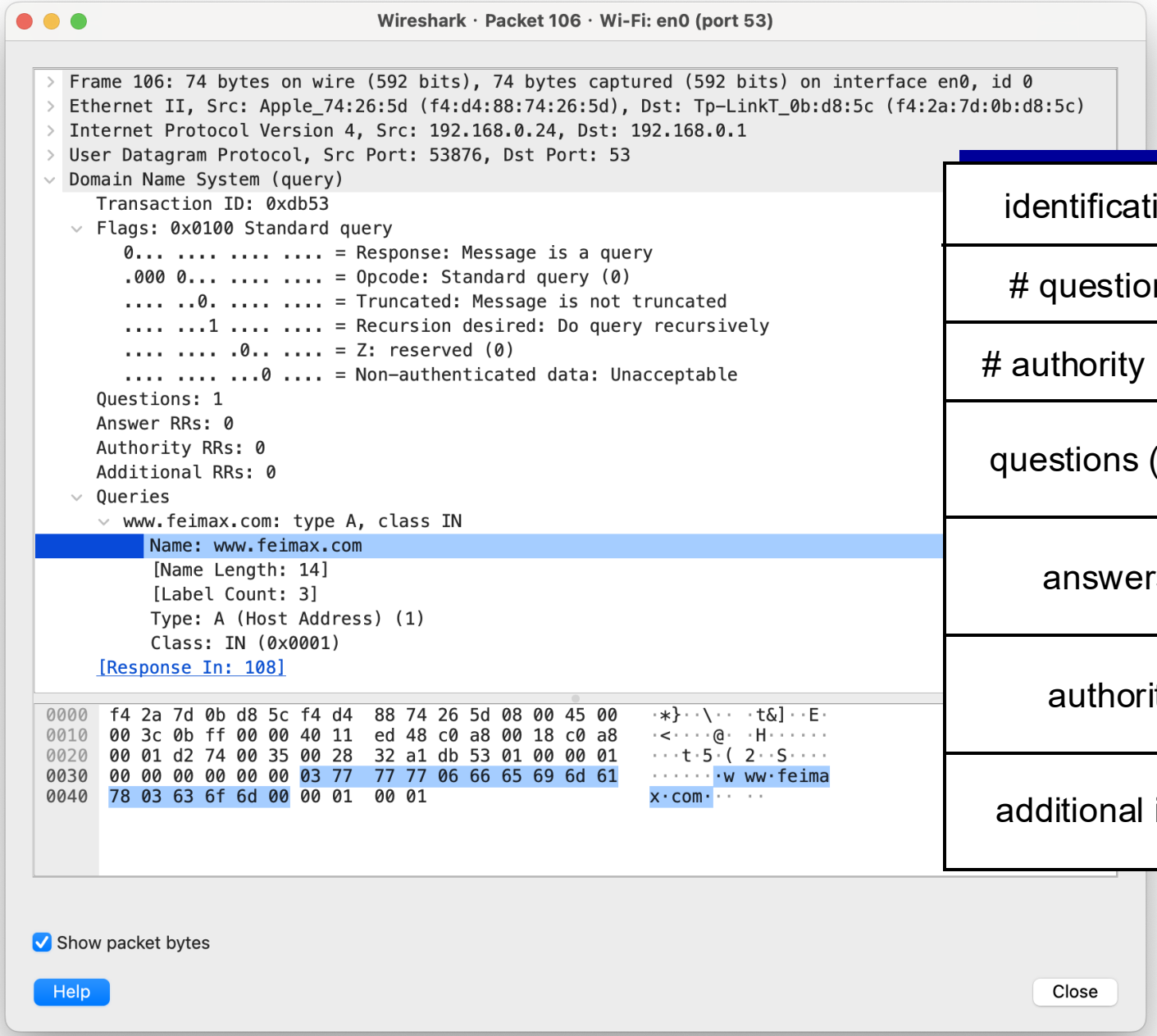

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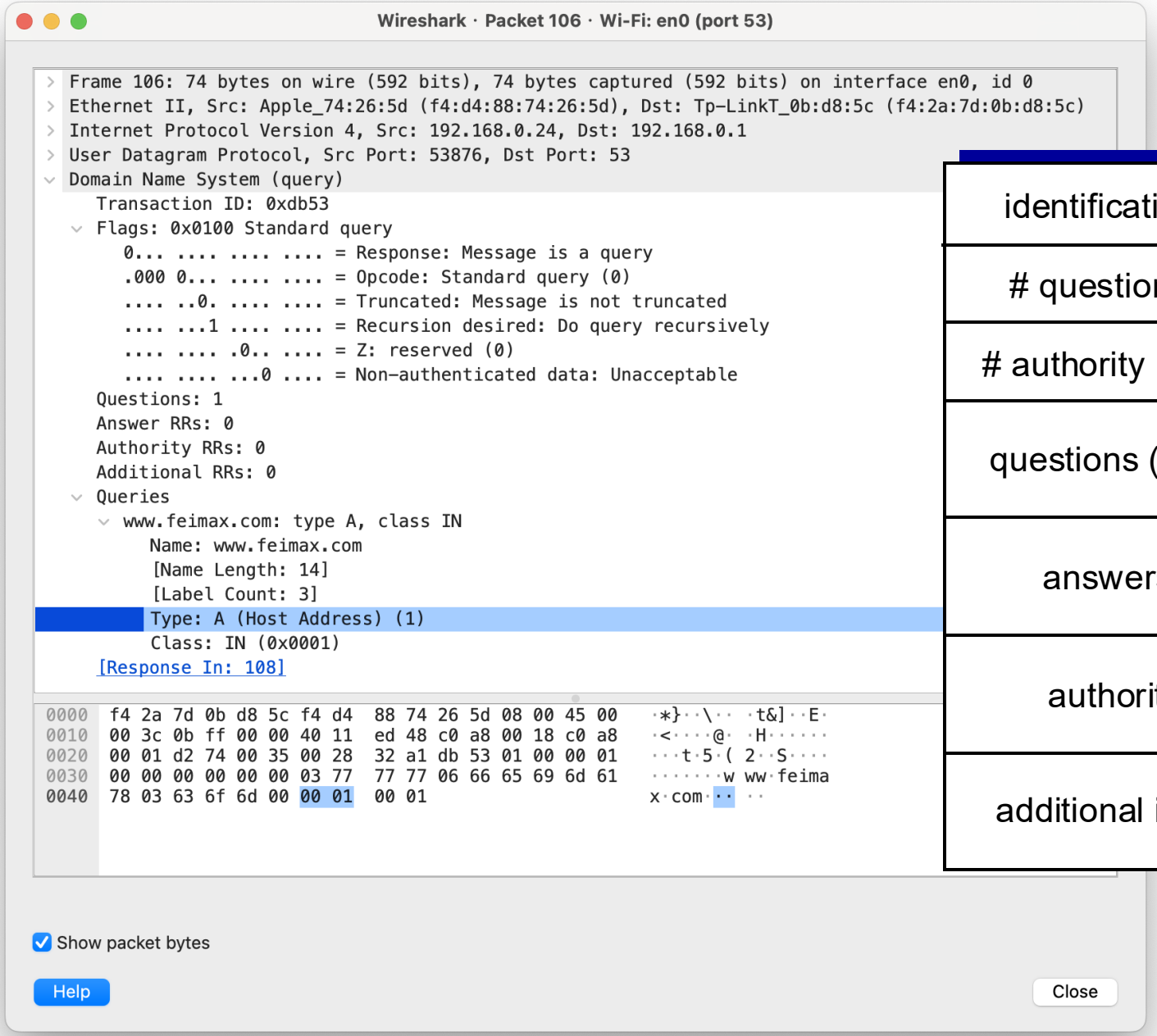

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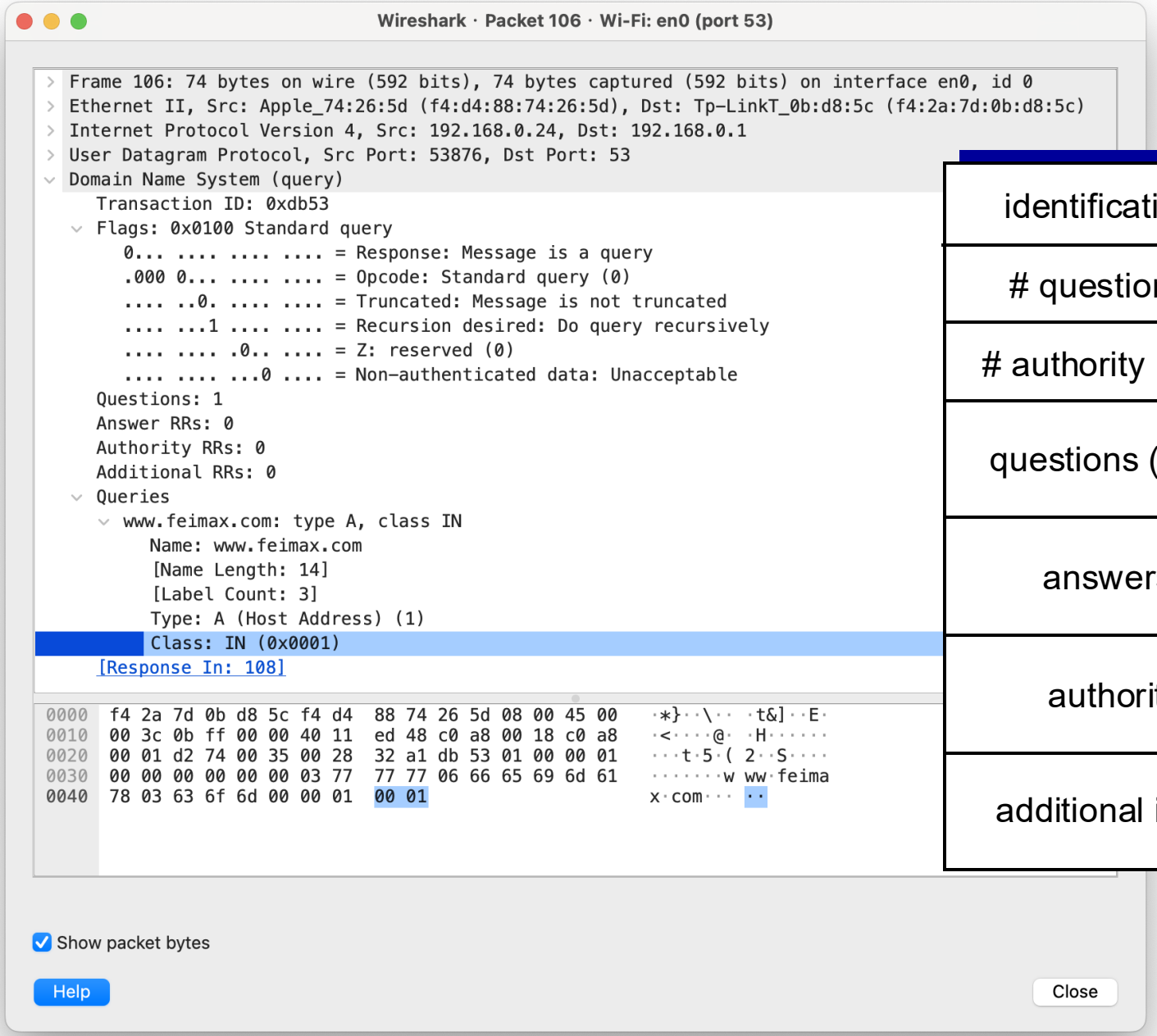
Request



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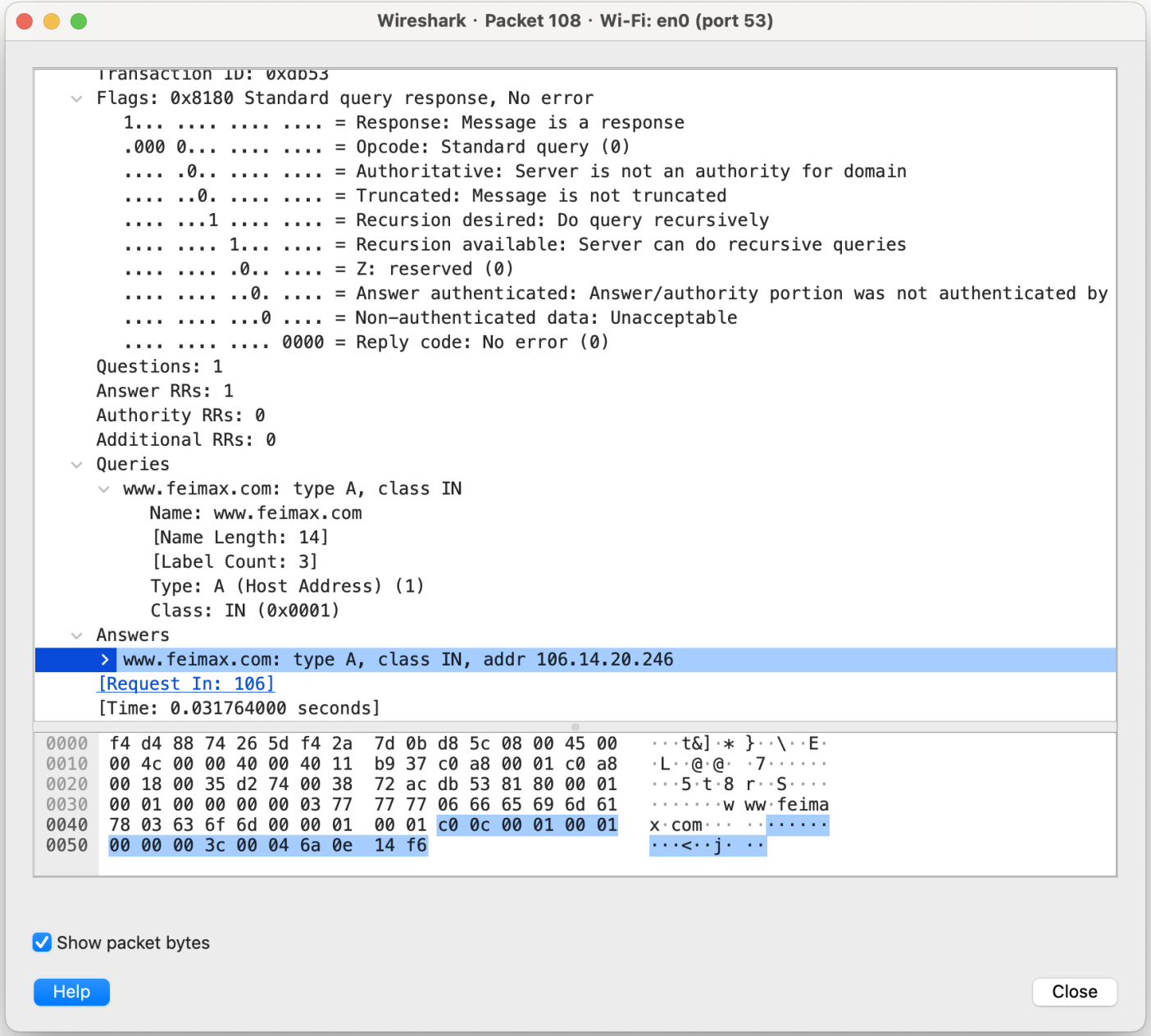
additional info (variable # of RRs)	

Response


Wireshark · Packet 108 · Wi-Fi: en0 (port 53)
Transaction ID: 0xdb53
Flags: 0x8180 Standard query response, No error
1... .... = Response: Message is a response
.000 0... .... = Opcode: Standard query (0)
.... .0.. .... = Authoritative: Server is not an authority for domain
.... ..0. .... = Truncated: Message is not truncated
....1 .... = Recursion desired: Do query recursively
.... 1... .... = Recursion available: Server can do recursive queries
.... .0.. .... = Z: reserved (0)
....0. .... = Answer authenticated: Answer/authority portion was not authenticated by
....0 .... = Non-authenticated data: Unacceptable
.... 0000 = Reply code: No error (0)
Questions: 1
Answer RRs: 1
Authority RRs: 0
Additional RRs: 0
Queries
www.feimax.com: type A, class IN
Name: www.feimax.com
[Name Length: 14]
[Label Count: 3]
Type: A (Host Address) (1)
Class: IN (0x0001)
Answers
www.feimax.com: type A, class IN, addr 106.14.20.246
[Request In: 106]
[Time: 0.031764000 seconds]
0000 f4 d4 88 74 26 5d f4 2a 7d 0b d8 5c 08 00 45 00
0010 00 4c 00 00 40 00 40 11 b9 37 c0 a8 00 01 c0 a8
0020 00 18 00 35 d2 74 00 38 72 ac db 53 81 80 00 01
0030 00 01 00 00 00 00 03 77 77 77 06 66 65 69 6d 61
0040 78 03 63 6f 6d 00 00 01 00 01 c0 0c 00 01 00 01
0050 00 00 00 3c 00 04 6a 0e 14 f6
Show packet bytes
Help
Close

Inserting records into DNS

- **Example: new startup "feimax.com"**
- **Register name feimax.com at DNS registrar (e.g., net.cn)**
  - Normally, you don't need to set up the NS record
  - Insert A record for the IP address of your host
  - Insert MX record for email
  - …

Name Type RR TTL

主机记录	记录类型	解析请求来源(isp)	记录值	TTL
group	CNAME	默认	plugin.vsais.com	10 分钟
nas	显性URL	默认	https://feimax.cn6.quickconnect.cn/	10 分钟
www	A	默认	106.14.20.246	10 分钟
@	显性URL	默认	http://www.feimax.com	10 分钟
@	TXT	默认	v=spf1 include:spf.mxhichina.com -all	10 分钟
mail	CNAME	默认	mail.mxhichina.com	10 分钟
@	MX	默认	mxw.mxhichina.com. | 10	10 分钟
@	MX	默认	mxn.mxhichina.com | 5	10 分钟

Aliyun Domain Name Settings

Domain name is a scarce resource.

Lecture III – Application Layer (2)

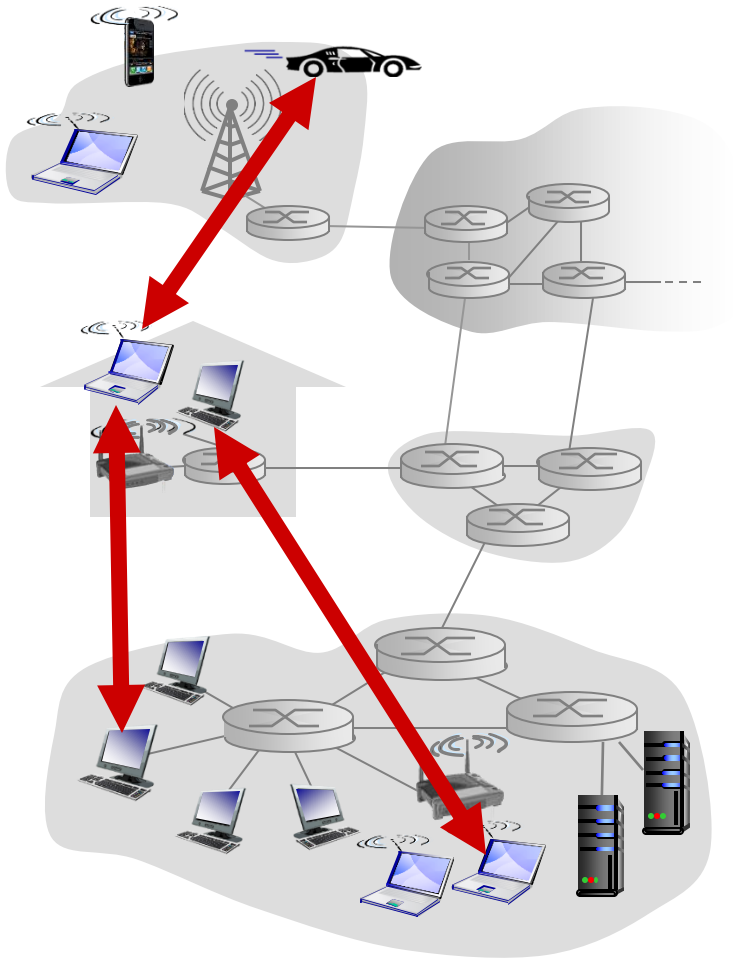
1. Domain Name System (DNS)
2. P2P Applications
3. Socket Programming

Pure P2P architecture

- *No* always-on server
- Arbitrary end systems directly communicate
- Peers change IP addresses

Examples:

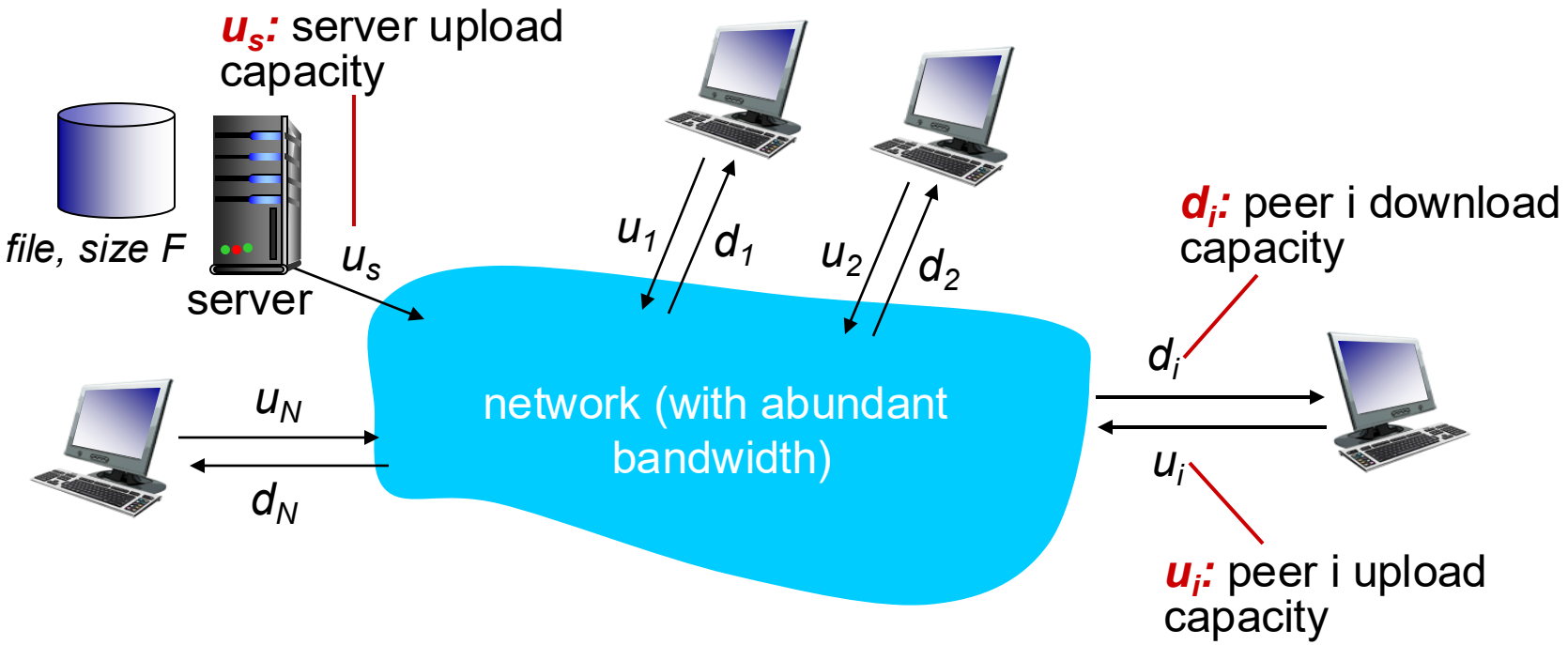
- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)



File distribution: client-server vs P2P

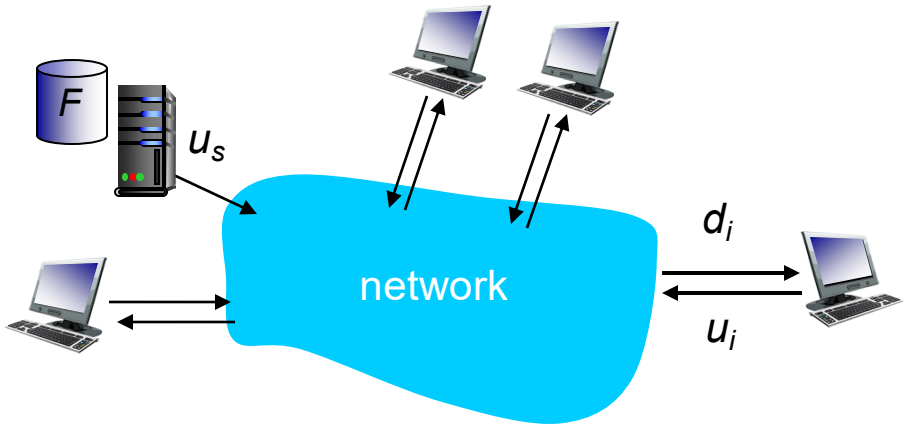
Q: how much time to distribute file (size *F*) from one server to *N* *peers*?

- peer upload/download capacity is limited resource



File distribution time: client-server

- **server transmission:** must sequentially send (upload) N file copies:
  - time to send one copy: F/u_s
  - time to send N copies: NF/u_s
- **client:** each client must download file copy
  - d_{min} = min client download rate
  - max client download time: F/d_{min}



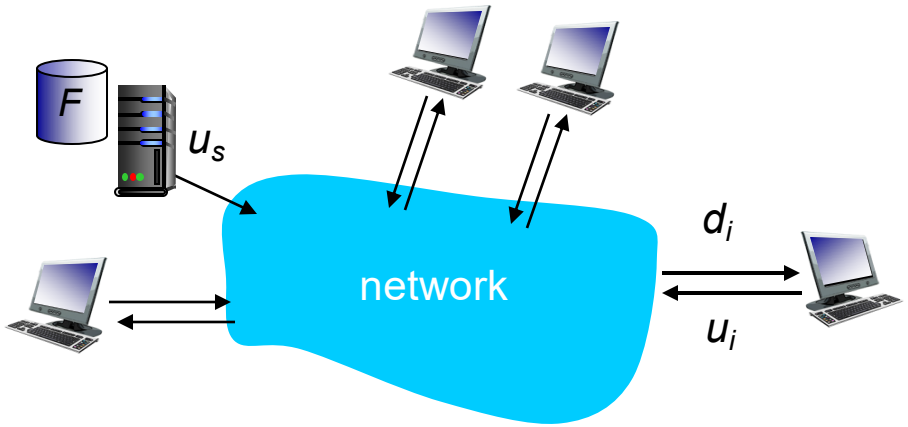
time to distribute F to N clients using client-server approach

$$D_{c\text{-}s} > max\{NF/u_s, F/d_{min}\}$$

increases linearly in N

File distribution time: P2P

- **server transmission:** must sequentially send (upload) at least one file copies:
  - time to send one copy: F/u_s
- **client:** each client must download file copy
  - min client download time: F/d_{min}
- **clients:** as total must download NF bits
  - max upload rate (limiting max download rate) is $u_s + \Sigma u_i$



time to distribute F to N clients using P2P approach

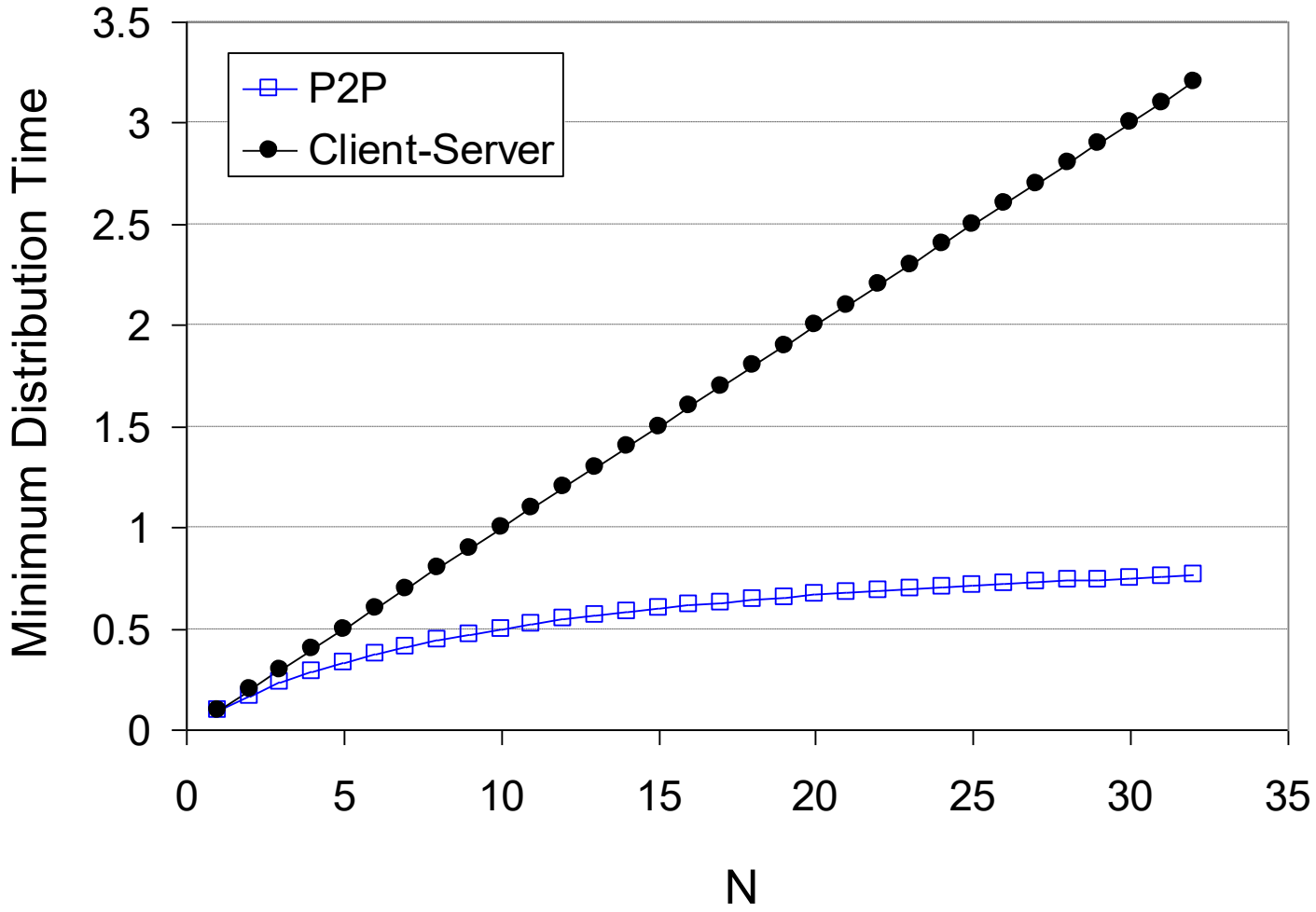
$$D_{P2P} > max\{F/u_s, F/d_{min}, NF/(u_s + \Sigma u_i)\}$$

increases linearly in *N* …

… but so does this, as each peer brings service capacity

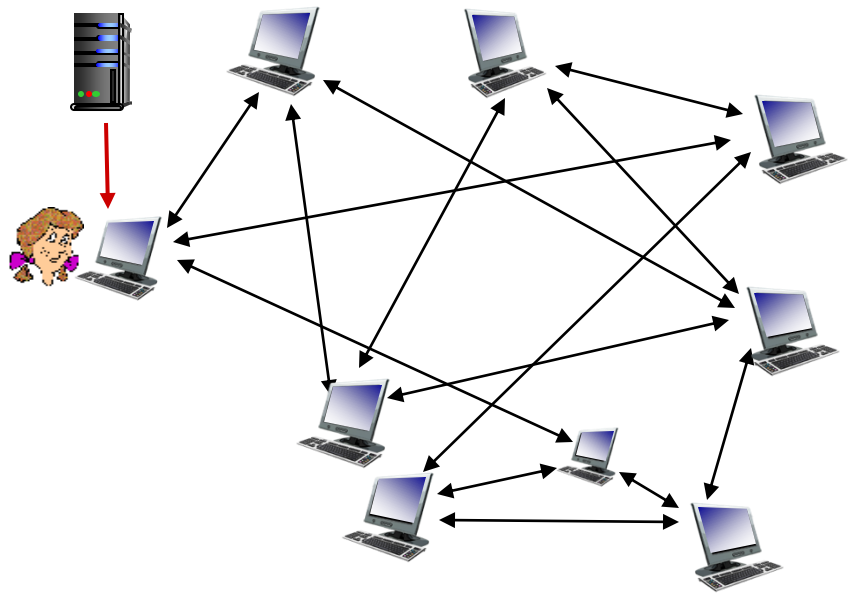
Client-server vs. P2P: example

client upload rate = u, F/u = 1 hour, $u_s = 10u$, $d_{min} \geq u_s$



BitTorrent

- Efficient content distribution system using file swarming.
- The throughput increases with the number of downloaders via the efficient use of network bandwidth.

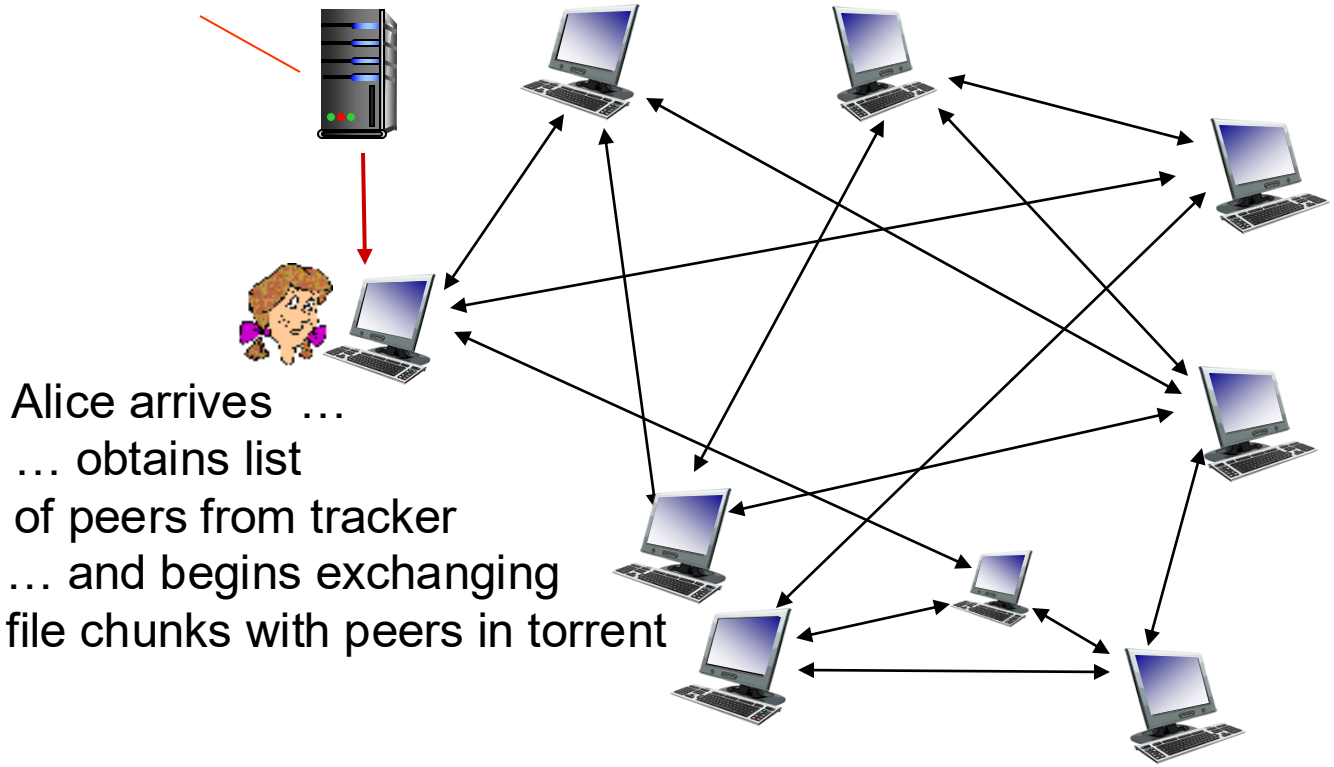


BitTorrent

- **Peers in torrent send/receive file pieces(chunks)**

Tracker: a central server keeping a list of all peers tracks peers participating in torrent

Torrent/Swarm: group of peers exchanging chunks of a file



BitTorrent

- **To share a file or group of files, the initiator first creates a .torrent file, a small file that contains:**
  - **Metadata** about the files to be shared
  - Information about the **tracker**, the computer that coordinates the file distribution
- **Downloaders first obtain a .torrent file, and then connect to the specified tracker, which tells them from which other peers to download the pieces of the file.**

Metadata of .torrent

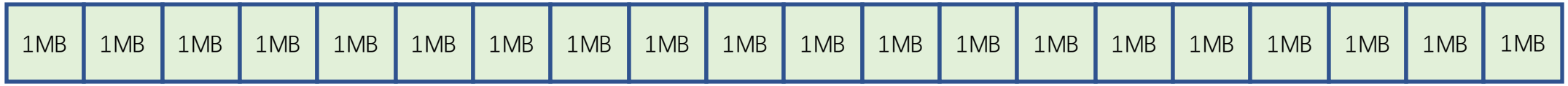
- SHA-1 hashes of all pieces
- A mapping of the pieces to files
- Piece size
- Length of the file
- A tracker reference

Pieces of the file

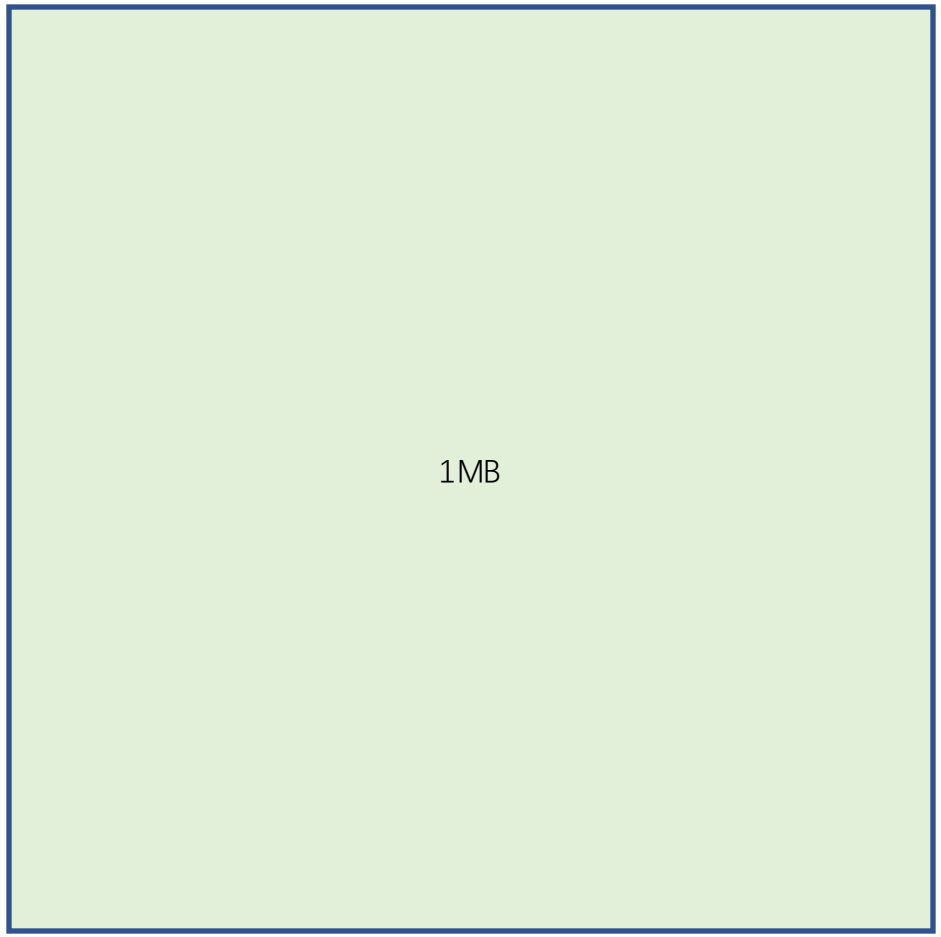
A 20MB File

Pieces of the file

A 20MB File



Pieces of the file

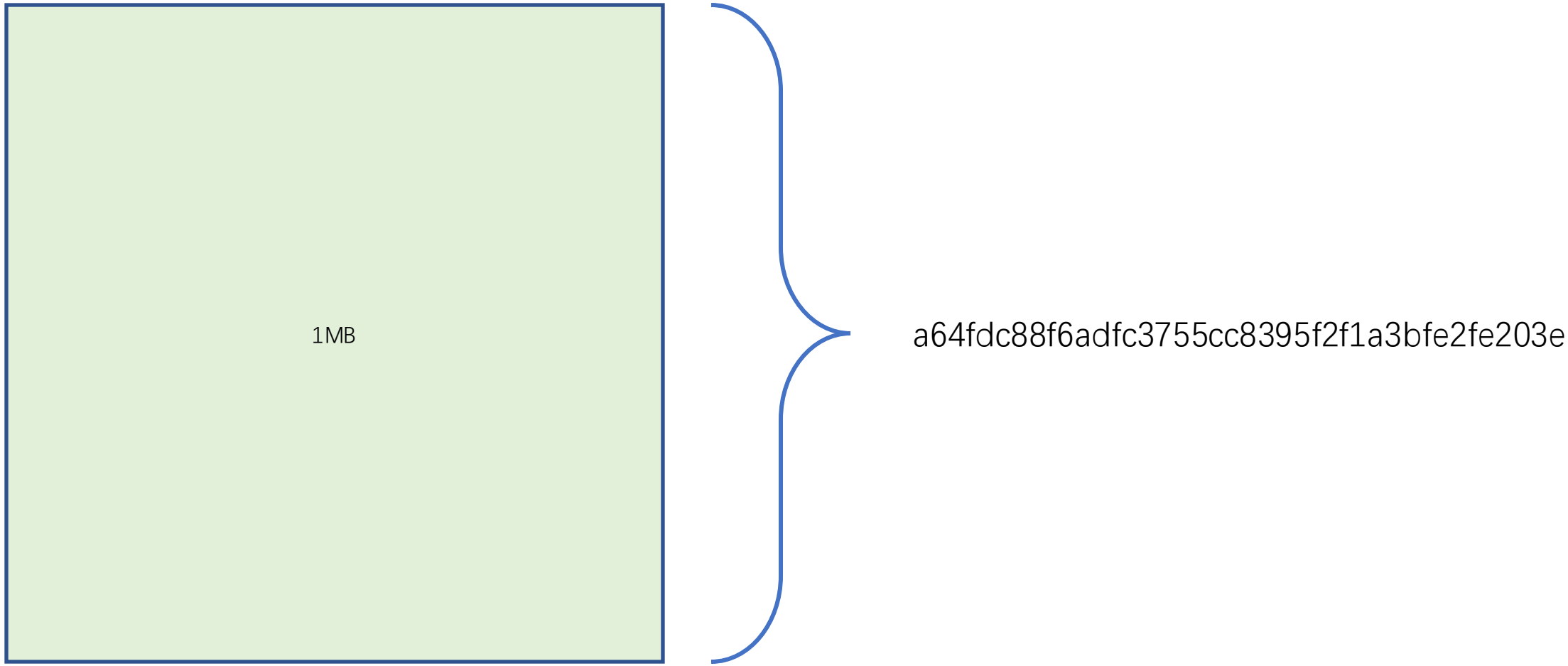


Pieces of the file

000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
000010100101010100101010011111001001010
……

a64fdc88f6adfc3755cc8395f2f1a3bfe2fe203e

Pieces of the file



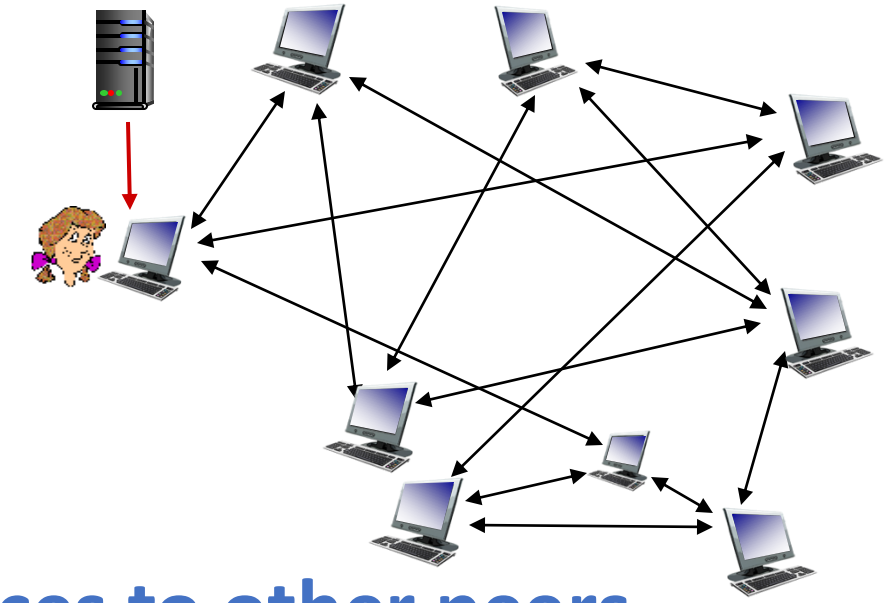
Pieces of the file – SHA1 List

A 20MB File

d01b701843e3fe7866aaa33458504d4d72c2d2b7
e6d9e8325c4dd58f75924b6b0a4d914df4dc2d2d
a0c60e0ac1adee5908b923db2d91c94e56802c62
4bb19bd734729d831d16e8a756fc85919712f779
51f8bc061e66c297b9655902b4a432ae1d68bdf6
fdfdcfef8be54a1a0aa2492d99f038d29309c71c
8bfb3ea7fd6f0f28bcafac1bb978342d3897dcc9
f00c928c5084b42dc9256ea6a708c8f2e580957d
3be062723dd90986594e542fab731750f40f1ae2
71e1dc348aaeb13f65b6c2e46d6ccd358a5000d4
……

BitTorrent

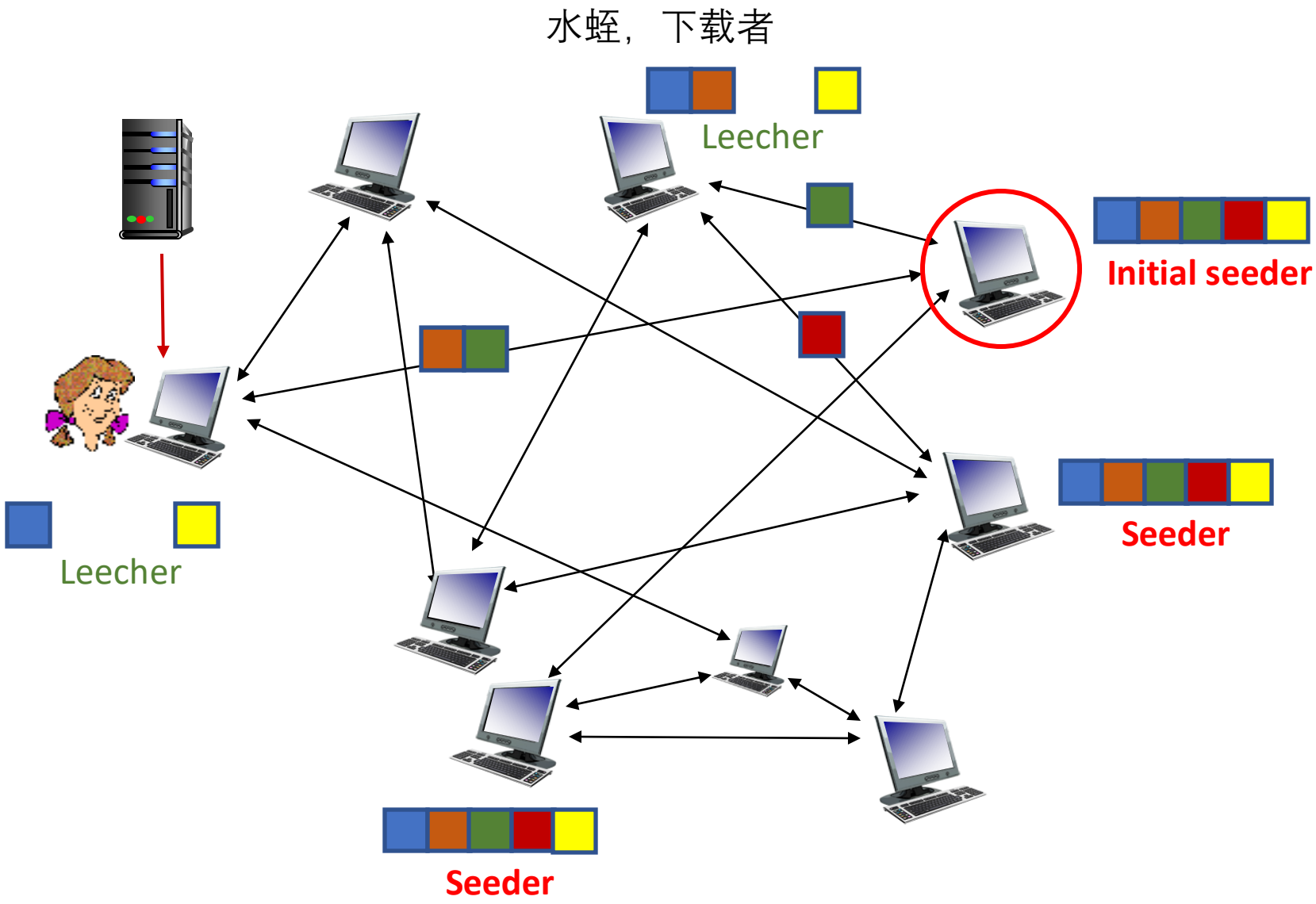
- **Peer joining torrent:**
  - has no pieces, but will accumulate them over time from other peers
  - registers with tracker to get list of peers, connects to subset of peers ("neighbors")



- **While downloading, peer uploads pieces to other peers**
- **Peer may change peers with whom it exchanges pieces**
- **Peers may come and go**
- **Once peer has entire file, it may (selfishly) leave or remain in torrent**

Seeder = a peer that provides the complete file.

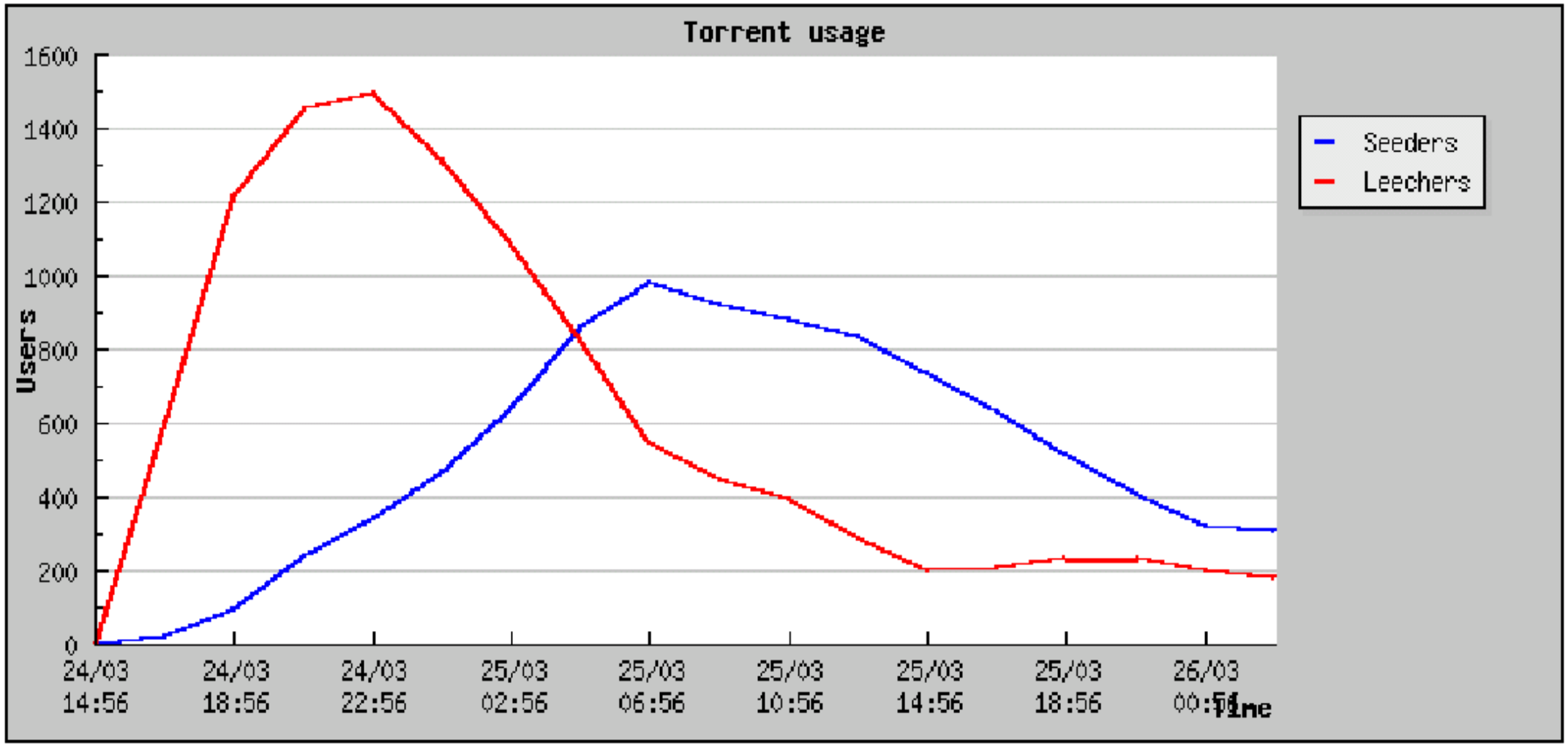
Initial seeder = a peer that provides the initial copy.



Leecher -> Seeder

- As soon as a leecher has a complete piece, it can potentially share it with other downloaders.
- Eventually each leecher becomes a seeder by obtaining all the pieces, and assembles the file. Verifies the “checksum” of the file.

Leecher -> Seeder



Piece selection policy

- The order in which pieces are selected by different peers is critical for good performance.
- If an inefficient policy is used, then peers may end up in a situation where each has all identical set of easily available pieces, and none of the missing ones.
- If the original seed is prematurely taken down, then the file cannot be completely downloaded!

Piece selection - Macro view

Piece selection - Micro view

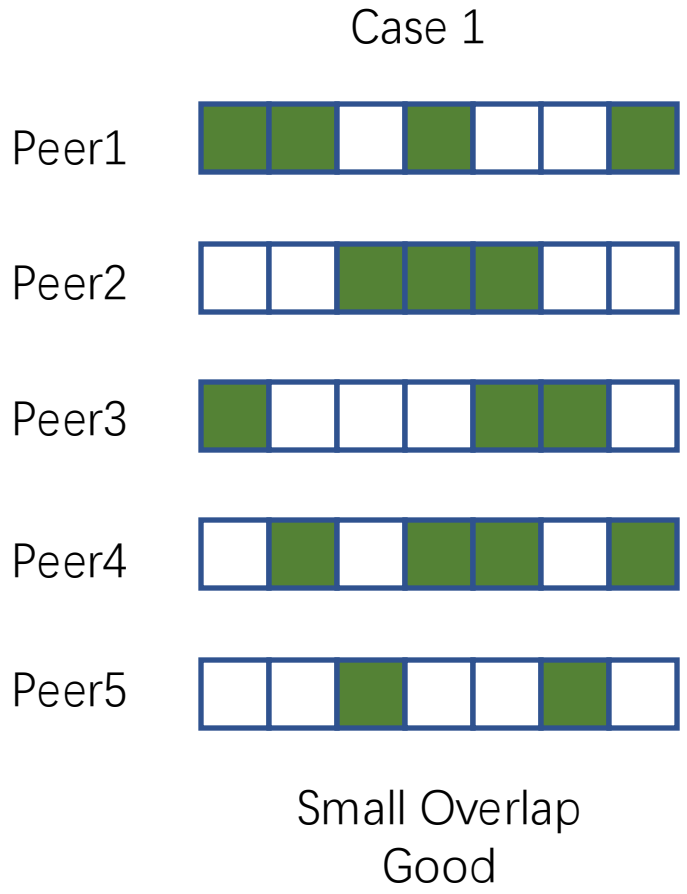
- **Rarest First**
  - General rule
- **Random First Piece**
  - Special case, at the beginning
- **Endgame Mode**
  - Special case

Random First Piece

- Initially, a peer has nothing to trade
- Important to get a complete piece ASAP
- Select a random piece of the file and download it

Rarest First

- Determine the pieces that are most rare among your peers, and download those first.
- This ensures that the most commonly available pieces are left till the end to download.



Endgame Mode

- Near the end, missing pieces are requested from every peer containing them.
- This ensures that a download is not prevented from completion due to a single peer with a slow transfer rate.
- Some bandwidth is wasted, but in practice, this is not too much.

BitTorrent – Internal Mechanism

- **Built-in incentive mechanism (where all the magic happens):**
  - Choking Algorithm
  - Optimistic Unchoking

Choking

- **Choking is a *temporary refusal* to upload. It is one of BT's most powerful idea to deal with free riders (those who only download but never upload).**
  - For avoiding free riders and avoiding network congestion
- ***Tit-for-tat strategy* is based on game-theoretic concepts.**

  以牙还牙

Optimistic unchoking

- A peer sends pieces to those four peers currently sending her chunks at highest rate
  - other peers are choked by Alice (do not receive chunks from her)
  - re-evaluate top 4 every10 secs
- Every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

- Reasons:
  - To discover currently unused connections that are better than the ones being used
  - To provide minimal service to new peers

Upload-Only mode

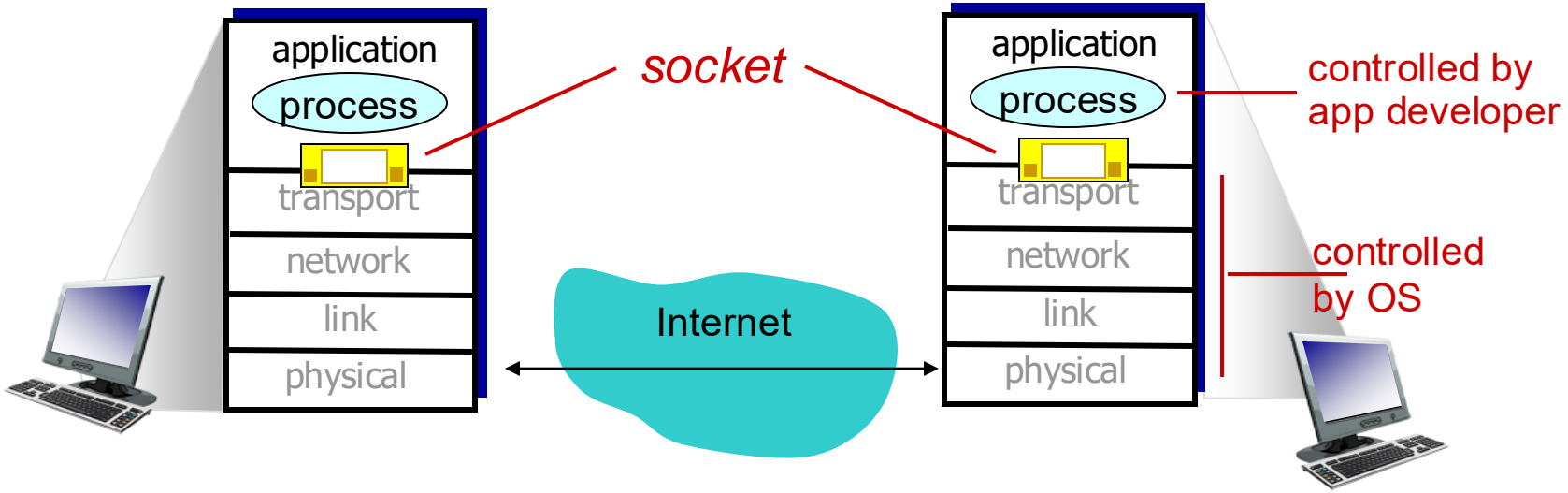
- Once download is complete, a peer can **only upload**. The question is, which nodes to upload to?
- Policy: Upload to those with the best upload rate. This ensures that pieces get replicated faster, and new seeders are created fast

Lecture III – Application Layer (2)

1. Domain Name System (DNS)
2. P2P Applications
3. Socket Programming

Socket programming

- **Goal:** learn how to build client/server applications that communicate using sockets
- **Socket:** door between application process and end-end-transport protocol



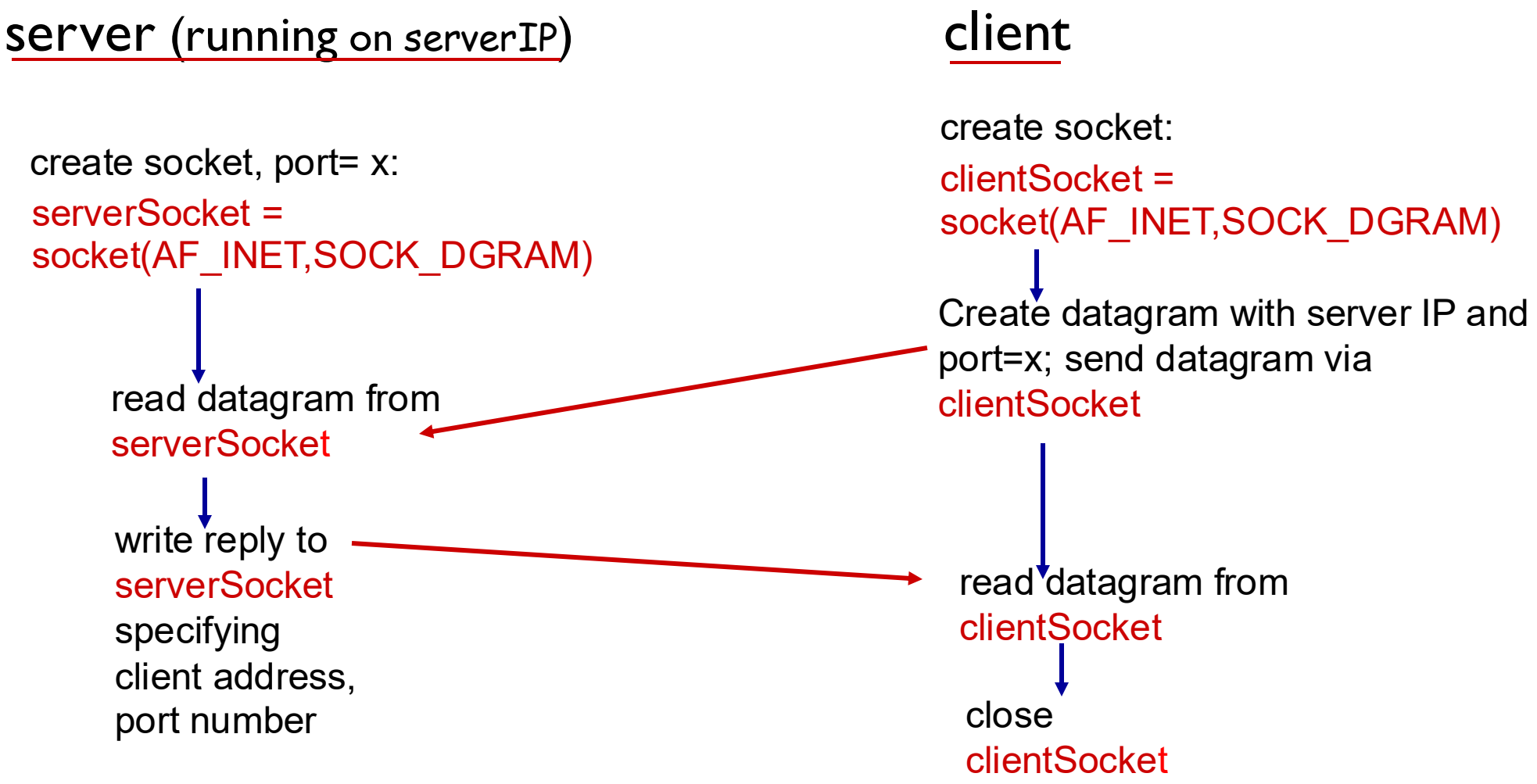
Socket programming

- **Two socket types for two transport services:**
  - UDP: unreliable datagram
  - TCP: reliable, byte stream-oriented
- **Application Example:**
  1. client reads a line of characters (data) from its keyboard and sends data to server
  2. server receives the data and converts characters to uppercase
  3. server sends modified data to client
  4. client receives modified data and displays line on its screen

Socket programming with UDP

- **UDP: no "connection" between client & server**
  - No handshaking before sending data
  - Sender explicitly attaches IP destination address and port # to each packet
  - Receiver extracts sender IP address and port# from received packet
- **UDP: transmitted data may be lost or received out-of-order**
- **Application viewpoint:**
  - UDP provides unreliable transfer of groups of bytes ("datagrams") between client and server

Client/server socket interaction: UDP



Example app: UDP server

Python UDPServer

include Python's socket library

create UDP socket

bind socket to local port number 12000

loop forever

Read from UDP socket into message, getting client's address (client IP and port)

send upper case string back to this client

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET, SOCK_DGRAM)
serverSocket.bind(('', serverPort))
print ('The server is ready to receive')
while True:
    message, clientAddress = serverSocket.recvfrom(2048)
    modifiedMessage = message.decode().upper()
    serverSocket.sendto(modifiedMessage.encode(),
                        clientAddress)
```

Example app: UDP client

Python UDPClient

include Python's socket library

create UDP socket for server

get user keyboard input

Attach server name, port to message; send into socket

print out received string and close socket

```
from socket import *
serverName = 'hostname'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_DGRAM)

message = input('Input lowercase sentence:')
clientSocket.sendto(message.encode(),
                    (serverName, serverPort))
modifiedMessage, serverAddress = clientSocket.recvfrom(2048)
print(modifiedMessage.decode())
clientSocket.close()
```

Socket programming with TCP

Client must contact server

- Server process must first be running
- Server must have created socket (door) that welcomes client's contact

client contacts server by:

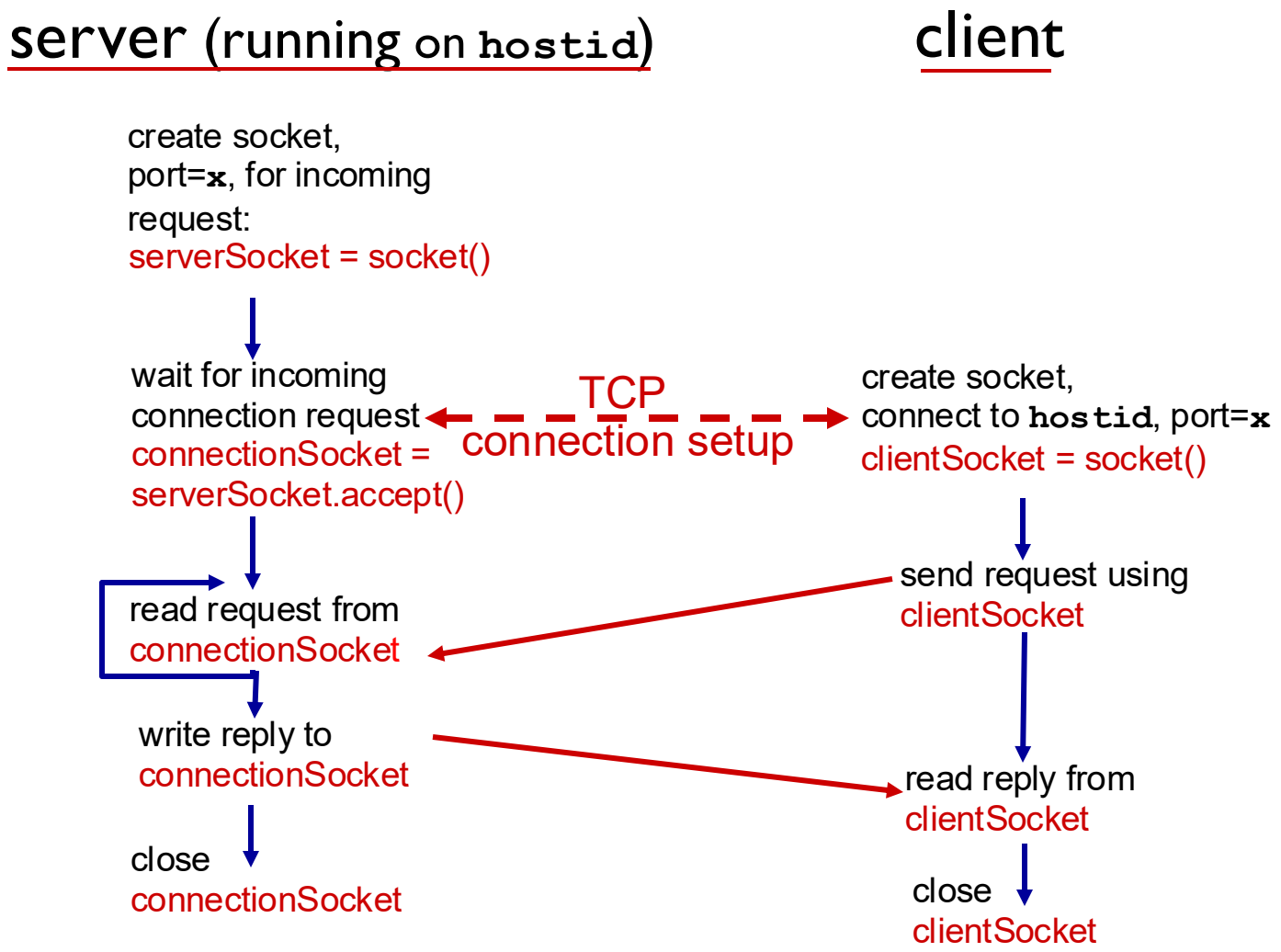
- Creating TCP socket, specifying IP address, port number of server process
- ***When client creates socket:*** client TCP establishes connection to server TCP

- When contacted by client, server TCP creates new socket for server process to communicate with that particular client
  - **Allows server to talk with multiple clients**
  - **Source port numbers used to distinguish clients (more in Chap 3)**

Application viewpoint:

TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server

Client/server socket interaction: TCP



Example app: TCP server

Python TCPServer

```
from socket import *

serverPort = 12000
serverSocket = socket(AF_INET, SOCK_STREAM)
serverSocket.bind(('', serverPort))
serverSocket.listen(1)
print('The server is ready to receive')
while True:
    connectionSocket, addr = serverSocket.accept()

    sentence = connectionSocket.recv(1024).decode()
    capitalizedSentence = sentence.upper()
    connectionSocket.send(capitalizedSentence.
                          encode())
    connectionSocket.close()
```

create TCP welcoming socket

server begins listening for incoming TCP requests

loop forever

server waits on accept() for incoming requests, new socket created on return

read bytes from socket (but not address as in UDP)

close connection to this client (but *not* welcoming socket)

Example app: TCP client

Python TCPClient

create TCP socket for server, remote port 12000

No need to attach server name, port

```
from socket import *
serverName = 'servername'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName,serverPort))
sentence = input('Input lowercase sentence:')
clientSocket.send(sentence.encode())
modifiedSentence = clientSocket.recv(1024)
print('From Server:', modifiedSentence.decode())
clientSocket.close()
```

Application Layer - Summary

- **Application architectures**
  - client-server
  - P2P
- **Application service requirements**
  - reliability, bandwidth, delay
- **Internet transport service model**
  - connection-oriented, reliable: TCP
  - unreliable, datagrams: UDP
- **Specific protocols:**
  - HTTP
  - DNS
  - P2P: BitTorrent
- **Socket programming:**
  - TCP, UDP sockets

Thanks.