

CSCE 463/612

Networks and Distributed Processing
Fall 2025

Application Layer V

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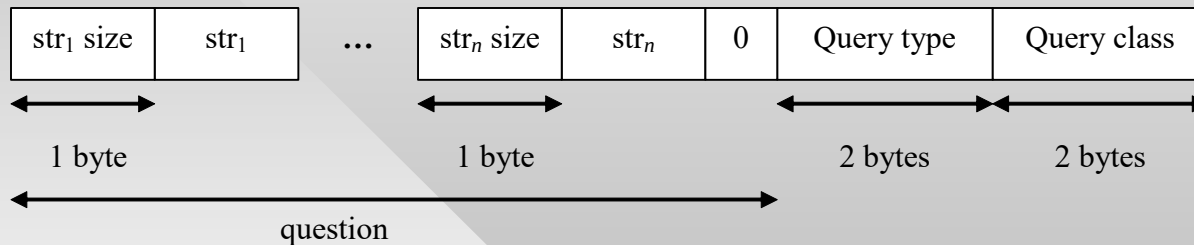
September 30, 2025

Homework #2

TX ID	flags
nQuestions	nAnswers
nAuthority	nAdditional

- Unlike HTTP, all fields are binary
 - Make sure to refresh pointer usage
- Question format:

questions (variable size)
answers (variable size)
authority (variable size)
additional (variable size)



- Create structs for fixed headers
 - Fill in the values (flags: DNS_QUERY and DNS_RD, nQuestions = 1)
 - Allocate memory for the packet
 - Write question into buffer

```
class QueryHeader {  
    u_short type;  
    u_short class;  
};
```

```
class FixedDNSheader {  
    u_short ID;  
    u_short flags;  
    u_short questions;  
    ...  
};
```

Homework #2

- High-level operation for DNS questions:

```
char packet [MAX_DNS_LEN];           // 512 bytes is max
char host[] = "www.google.com";
int pkt_size = strlen(host) + 2 + sizeof(FixedDNSHeader) + sizeof(QueryHeader);

// fixed field initialization
FixedDNSHeader *fdh = (FixedDNSHeader *) packet;
QueryHeader *qh = (QueryHeader*) (packet + pkt_size - sizeof(QueryHeader));
fdh->ID = ...
fdh->flags = ...
...
qh->type = ...
qh->class = ...

// fill in the question
MakeDNSQuestion (fdh + 1, host);
// transmit to Winsock
sendto (sock, packet, ...);
```

- If packet is incorrectly formatted, you will usually get no response; use Wireshark to check outgoing packets

Homework #2

```
class DNSAnswerHdr {  
    u_short type;  
    u_short class;  
    u_int ttl;  
    u_short len;  
};
```

- Formation of questions:

```
makeDNSquestion (char* buf, char *host) {  
    while(words left to copy){  
        buf[i++] = size_of_next_word;  
        memcpy (buf+i, next_word, size_of_next_word);  
        i += size_of_next_word;  
    }  
    buf[i] = 0;    // last word NULL-terminated  
}
```

- All answers start with an RR name, followed by a fixed *DNS answer header*, followed by the answer itself

- Uncompressed answer (not common)

```
0x3 "irl" 0x2 "cs" 0x4 "tamu" 0x3 "edu" 0x00  
<DNSAnswerHdr> <ANSWER>
```

- Compressed (2 upper bits 11, next 14 bits jump offset)

```
0xC0 0x0C <DNSAnswerHdr> <ANSWER>
```

- For type-A questions, the answer is a 4-byte IP

Homework #2

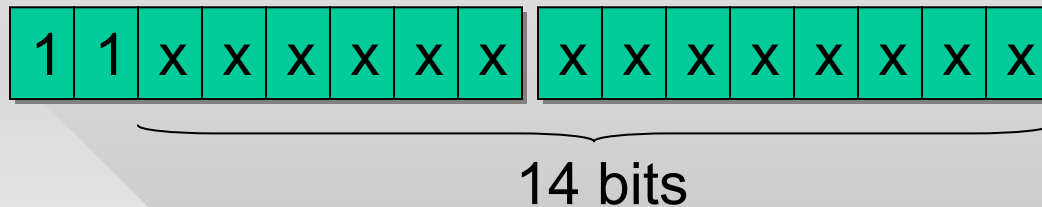
- To check the header
 - Hex printout on screen
 - Wireshark
- What is `sizeof(DNSAnswerHdr)`?
 - The actual size is 10 bytes, but the compiler will align/pad it to 4-byte boundary (so 12)
- Remember to change struct packing of all classes that define binary headers to 1 byte
- Caveats (must be properly handled):
 - Exceeding array boundaries on jumps
 - Infinite looping on compressed answers

```
class DNSAnswerHdr {  
    u_short type;  
    u_short class;  
    u_int ttl;  
    u_short len;  
};
```

```
#pragma pack(push,1)  
// define headers here  
#pragma pack(pop)
```

Homework #2

- How to check if compressed and read 14-bit offset?
 - Suppose array `char *ans` contains the reply packet
 - The answer begins within this array at position `curPos`



```
char *ans; // points to reply buffer
if (ans[curPos] >= 0xC0)
    // compressed; so jump
else
    // uncompressed, read next word
```

```
char *ans; // points to reply buffer
if ( (ans[curPos] >> 6) == 3)
    // compressed; so jump
else
    // uncompressed, read next word
```

```
// computing the jump offset
int off = ( (ans[curPos] & 0x3F) << 8) + ans[curPos + 1];
```

- The first two checks will generally **fail**
 - Use only **unsigned** chars when reading buffer!

Homework #2

- Note that jumps may appear **mid-answer**
0x3 "irl" 0xC0 0x22 <DNSAnswerHdr> <ANSWER>
- Jumps may be nested, but must eventually end with a 0-length word
 - Need to remember the position **following the very first jump** so that you can come back to read DNSAnswerHdr
- Replies may be malicious or malformed
 - Homework must avoid crashing
- If AAAA (IPv6) answers are present, skip
 - Use DNSAnswerHdr::len to jump over unknown types
- **Caution with TAMU VPN**
 - Malformed packets are filtered out

Chapter 2: Roadmap

2.1 Principles of network applications

2.2 Web and HTTP

2.3 FTP

2.4 Electronic Mail

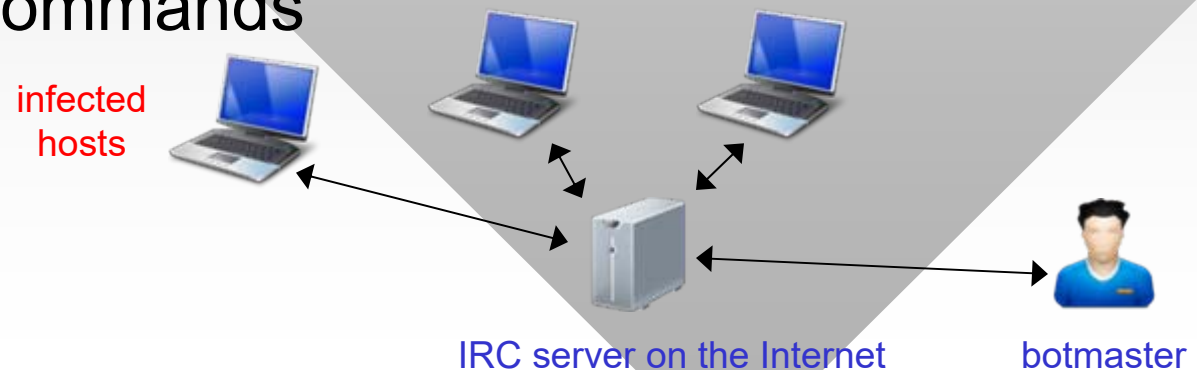
- SMTP, POP3, IMAP

2.5 DNS (extras)

2.6 P2P file sharing

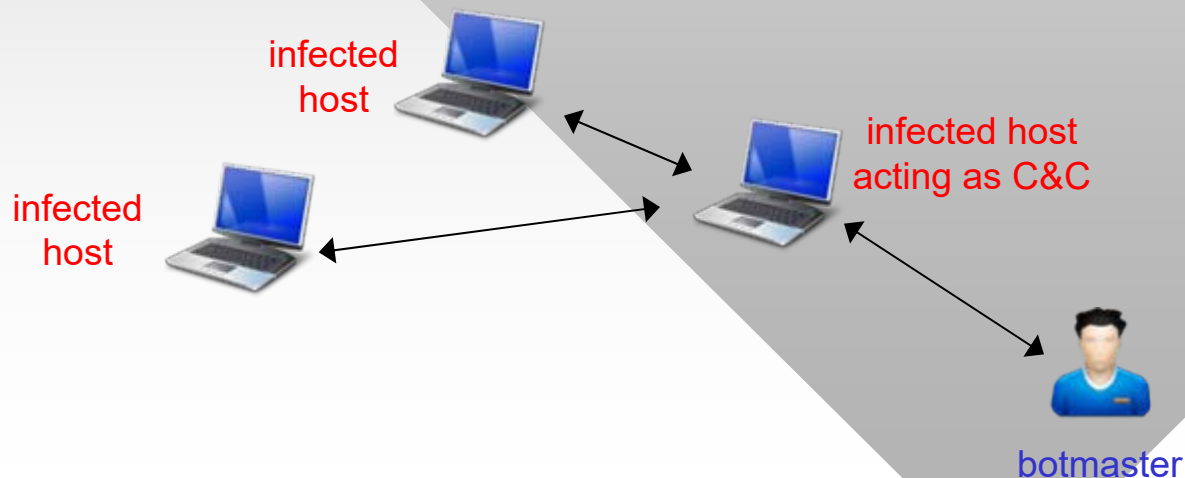
Botnets

- Viruses, trojan horses, rootkits, and various malware affect millions of computers today
- Years ago, viruses mostly performed pranks or corrupted data, but this has changed
 - Modern attacks are often driven by financial gains
- Infected hosts are organized into **botnets**
 - Large collection of computers under control of a **botmaster**
- Early botnets used IRC (Internet Relay Chat) to send and receive commands



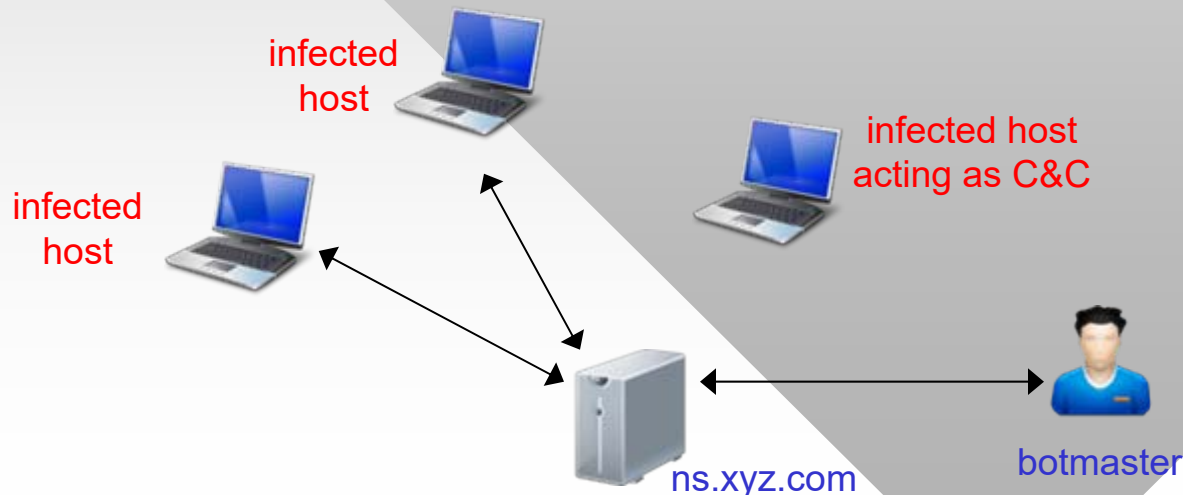
Botnets 2

- Eventually, ISPs started blocking IRC traffic
 - Also, IRC servers were easy targets for shutdown and filtering (e.g., detection of encrypted commands and botnet channels)
- Modern P2P botnets use dynamically changing rendezvous points called **C&C** (command & control)
 - Stealthy because C&C's IP can change over time
 - Main problem: how does the botnet find the current C&C?



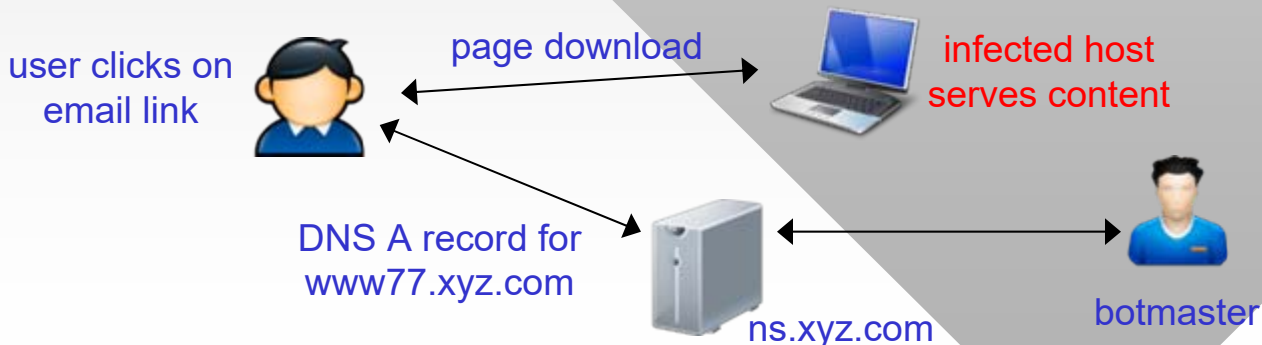
Botnets 3

- **Fast flux** is a method for discovering the IP address of the C&C and other resources the botnet may need
 - Botmaster registers a domain (say xyz.com) and controls the DNS server ns.xyz.com
- Botnet contacts nameserver ns.xyz.com and obtains the current IP of the C&C (or multiple ones)
 - Performs a type-A lookup inside xyz.com



Botnets 4

- Main defense against botnet traffic is blocking communication with the C&C
 - Fast Flux makes it harder since the C&C changes over time and is load-balanced across several hosts
 - When C&C is blocked, botnet learns other locations quickly
- Fast flux can also be used to serve phishing content
 - Suppose email arrives to user with a link to www77.xyz.com
 - Botnet can use DNS to serve this request from a variety of compromised hosts



Botnets 5

Nowadays, TLD servers auto-detect fastflux and block suspected domains in conjunction with the registrar

- Benefits to serving HTTP content using fast flux
 - Difficult to trace IPs hosting content or block malicious URLs
 - Botnet is failure resilient -- if hosts are cleaned or go offline, there is automatic fail-over to other live hosts
 - Cheap in terms of bandwidth, simple to implement
- However, there is a problem
 - Suppose ISP, email filter (e.g., SpamAssassin), or the registrar block all references to xyz.com?
 - If xyz.com is taken down, the botnet freezes
- **Domain flux** aims to solve this issue
 - If current domain is blocked, botnet generates replacement domain names and tries to resolve them to find the C&C
 - More difficult to trace and block

Botnets 6

- Toy example:
 - Suppose botnet computers generate names using this sequence: 1.com, 2.com, 3.com, 5.com, 8.com, 13.com, etc.
 - Current domain name stays in effect until it is blocked
 - Initially, botmaster registers 1.com and 34.com
 - When 1.com gets blocked, the botnet automatically switches to 34.com, while botmaster registers 144.com, and so on
- In reality, the botnet goes through thousands of failed lookup attempts until it finds an active domain
 - Can be detected from a huge number of failed DNS queries
- Domains may be too random to be human-produced
 - If so, machine-learning algorithms can be used to detect infected hosts that are attempting domain flux

Botnets 7

- In some cases, reverse engineering the random generator allows one to predict future domain names
 - By registering these domains, botnets can be hijacked
 - Researchers have shown this is possible in B. Stone-Gross et al., “Your botnet is my botnet: Analysis of a botnet takeover,” ACM CCS, 2009.
- How large are botnets? Some examples:
 - BredoLab (2009): 30M hosts, 3.6B emails/day
 - Conficker (2008): 10.5M hosts, 10B emails/day
 - Cutwail (2007): 1.5M hosts, 74B emails/day
 - Torpig (paper above): 180K hosts (theft of 500K bank accounts, credit cards)
 - Avalanche (2008-2016): phishing botnet w/500K hosts

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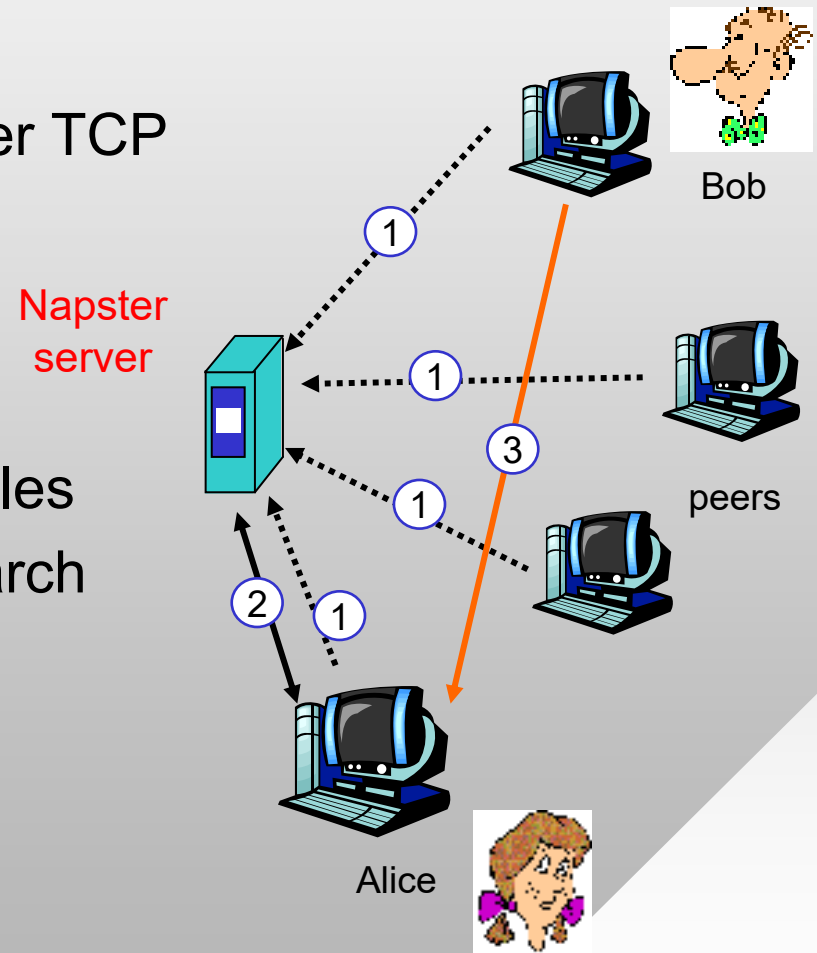
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2.5 DNS

2.6 P2P file sharing

Hybrid P2P

- Napster (1999)
 - Application-layer protocol over TCP
 - Centralized directory server
- Sequence of steps
 - Connect to server, login
 - Upload your IP/port + list of files
 - Give server keywords for search
 - Select “best” answer (ping)
 - Download from peer
- Single point of failure
- Performance bottleneck
- Target for litigation due to copyright infringement

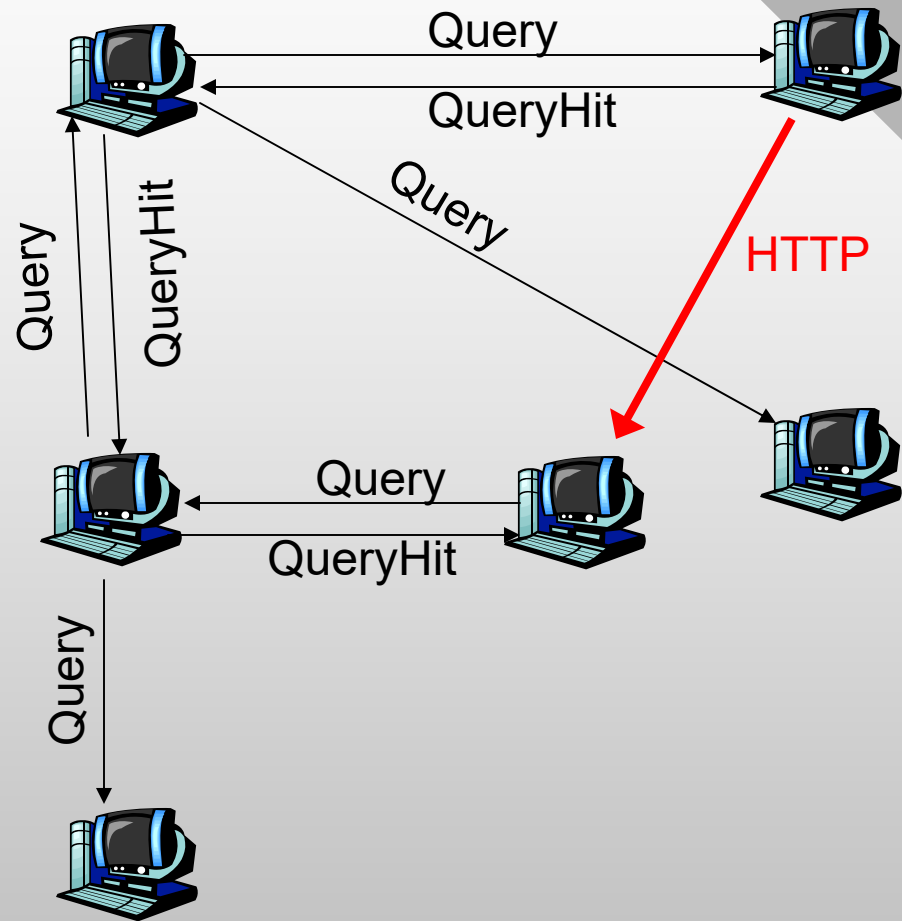


Decentralized P2P

- Napster folded in 2002
 - Other P2P systems took over (Gnutella, KaZaA, BitTorrent, eDonkey)
- Gnutella/0.4 (2001)
 - Public-domain protocol
 - Fully distributed design
- Many Gnutella clients implementing protocol
 - Limewire, Morpheus, BearShare
- How to find content?
- Idea: construct a graph
 - Edge between peer X and Y if there's a TCP connection between them
- All active peers and edges are called an **overlay network**
 - Peer typically connected to < 30 neighbors
- Search proceeds by flooding up to some depth
 - **Limited-scope flooding**

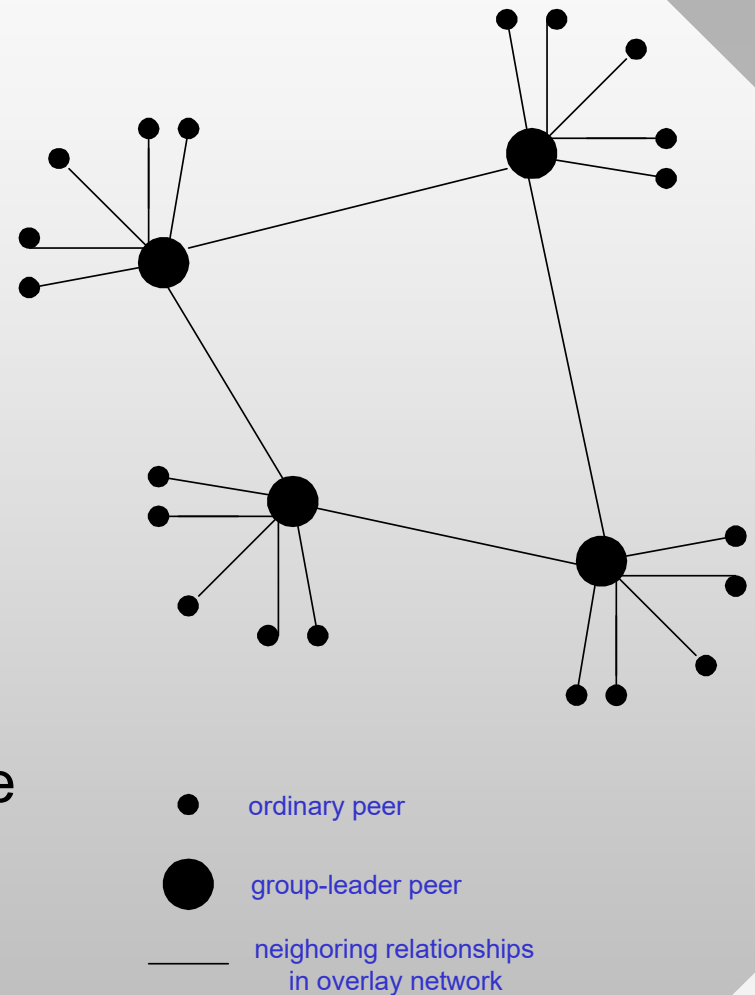
Decentralized P2P

- Queries are P2P
 - Inefficient due to huge volumes of traffic
 - Average degree k , depth of flood d , overhead $(k-1)^d$
- Downloads are P2P from a **single** user
 - Unreliable (peer departure or failure kills transfer)
 - Inefficient (asymmetry of upstream/downstream bandwidth)
- Join protocol (bootstrapping)
 - Find an entry peer X , flood its neighbors to obtain more candidates, establish connections to those who accept



Hierarchical P2P

- Gnutella/0.4 scaled to about 25K users and then choked
- Alternative construction proposed by KaZaA (2002)
 - Peer is either a group leader (supernode) or assigned to one
- Group leader tracks the content of all its children, acting like a mini-Napster
 - Peers query their group leaders, which flood the supernode graph until some number of matches found
 - Query-hits not routed, but sent directly to original supernode



Hierarchical P2P

- With 150 neighbors, this architecture is 150x more efficient than Gnutella/0.4 in message overhead
 - With 389M downloads as of 2008, KaZaA was more popular than Napster ever was, accounting for 50% of ISP bandwidth in some regions and running 3M concurrent users
- Gnutella/0.6 soon adopted the same structure
 - Scaled to 6.5M online users, 60M unique visitors per week
- Additional features
 - Hashed file contents to identify exact version of files
 - Upload and request queuing at each user, rate-limiting
 - Parallel downloads from multiple peers
 - Support for crawl requests that reveal neighbors

Other P2P

- Terminology: user holding a complete file is a **seed**
 - Traditional systems download only from seeds
 - Seed departs, transfer fails
- Idea: let non-seeds grab chunks from each other
 - Peers organize into a group (torrent) based on the file they're downloading
- Traditional systems download files **sequentially**
 - Starvation for final blocks
- Idea: maximize availability
 - Participants forced to serve chunks they have to others
 - **Rarest** chunk in torrent is always replicated first
- Known as **BitTorrent** (2001)
 - Protocol with many implementations
 - Requires **trackers** to keep torrent membership
 - Had more concurrent users than YouTube and Facebook combined
- Built-in incentives to share
 - Rate-limiting (**choking**) based on upload activity

Other P2P

- **Tor (Onion Router)**
 - Anonymity network of peers
- Each packet sent through a random chain of P2P nodes
 - Final user relays packet towards destination
 - Return packets processed similarly along reverse path
- Tor can be run thru an API
 - Extremely slow
 - Many exit points are known and blocked by Google
- Roughly 36M users
- **Freenet**
 - Anonymous information exchange, hiding identities of communicating parties
- Legacy **Skype** chat
 - Video streaming services either directly between users or relayed through non-firewalled peers
- **Distributed Hash Tables**
 - General class of P2P systems that map information into high-dimensional search space with guaranteed $\log(N)$ bounds on delay to find content