CS 356: Computer Network Architectures

Lecture 15: DHCP, NAT, IPv6, and IP tunnels

[PD] chapter 3.2.7, 3.2.9, 4.1.3, 4.3.3

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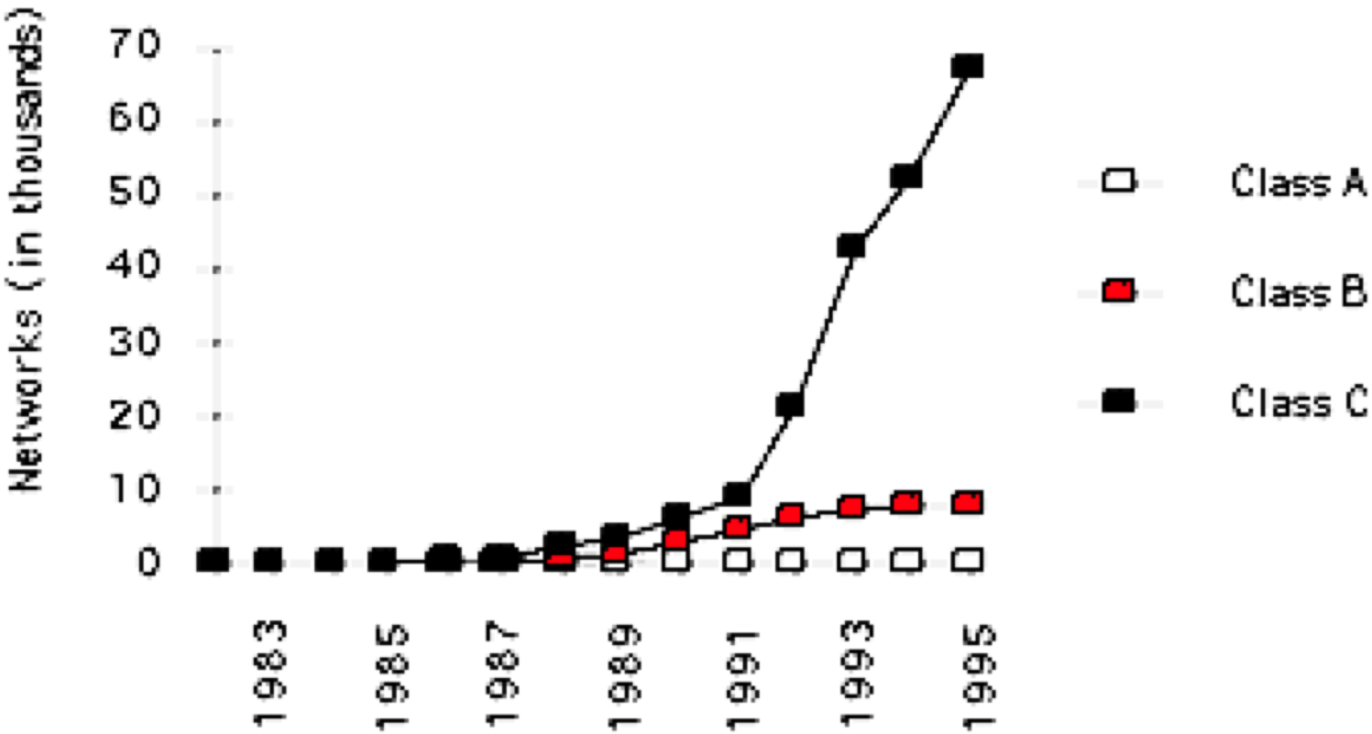
Overview

- Miscellaneous topics

- Sample midterm released

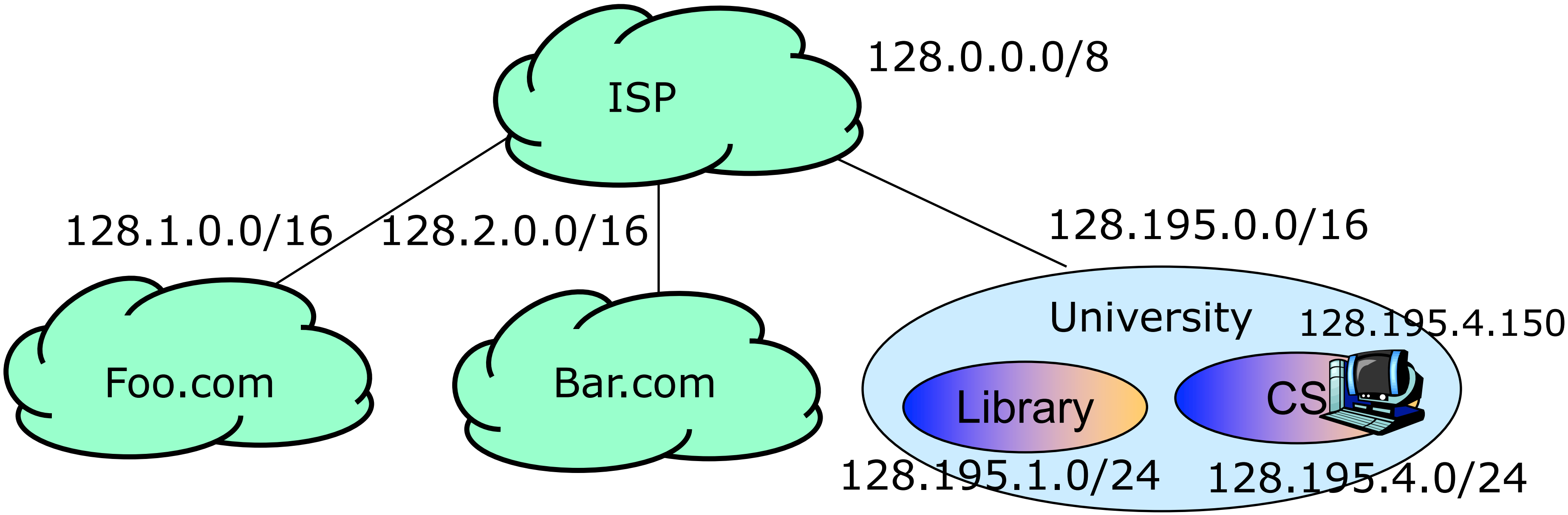
BGP Scalability

Routing table scalability with Classful IP Addresses



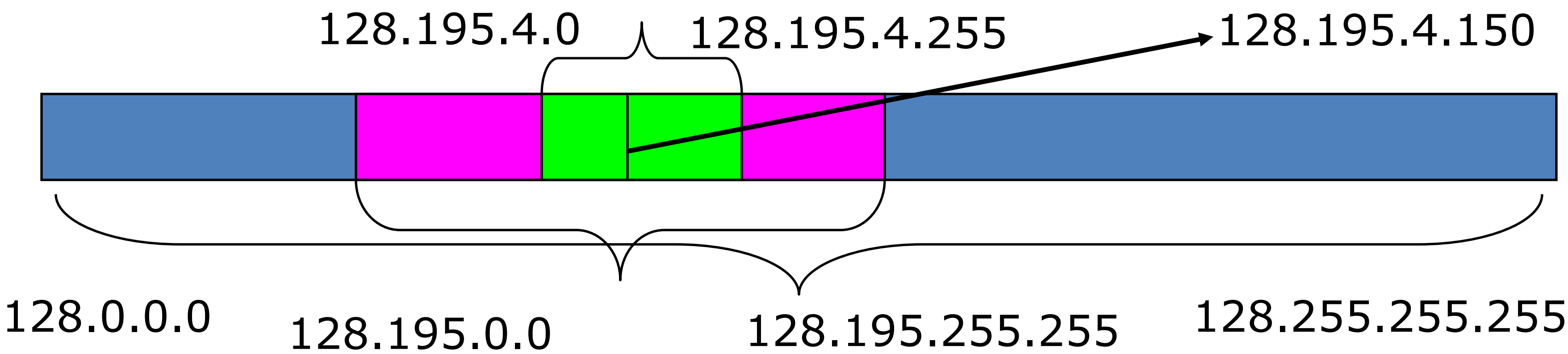
- Fast growing routing table size
- Classless inter-domain routing aims to address this issue

CIDR hierarchical address allocation



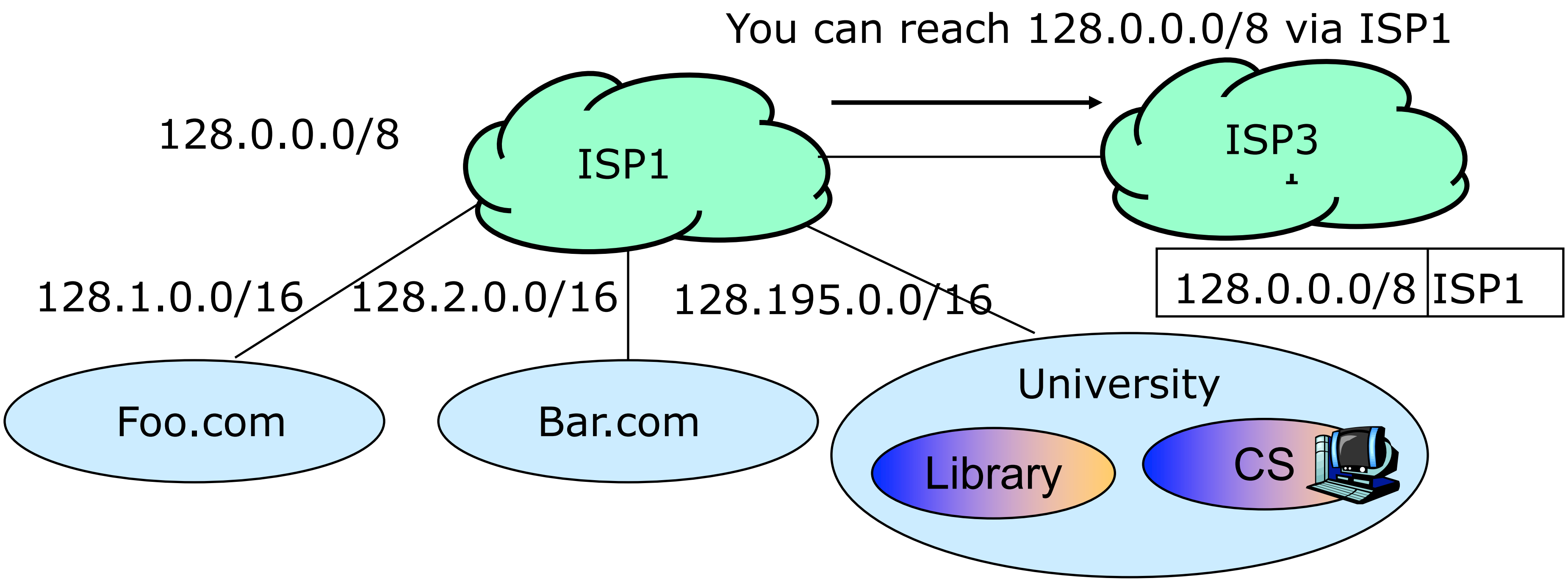
- IP addresses are hierarchically allocated.
- An ISP obtains an address block from a Regional Internet Registry
- An ISP allocates a subdivision of the address block to an organization
- An organization recursively allocates subdivision of its address block to its networks
- A host in a network obtains an address within the address block assigned to the network

Hierarchical address allocation



- ISP obtains an address block 128.0.0.0/8 → [128.0.0.0, 128.255.255.255]
- ISP allocates 128.195.0.0/16 ([128.195.0.0, 128.195.255.255]) to the university.
- University allocates 128.195.4.0/24 ([128.195.4.0, 128.195.4.255]) to the CS department's network
- A host on the CS department's network gets one IP address 128.195.4.150

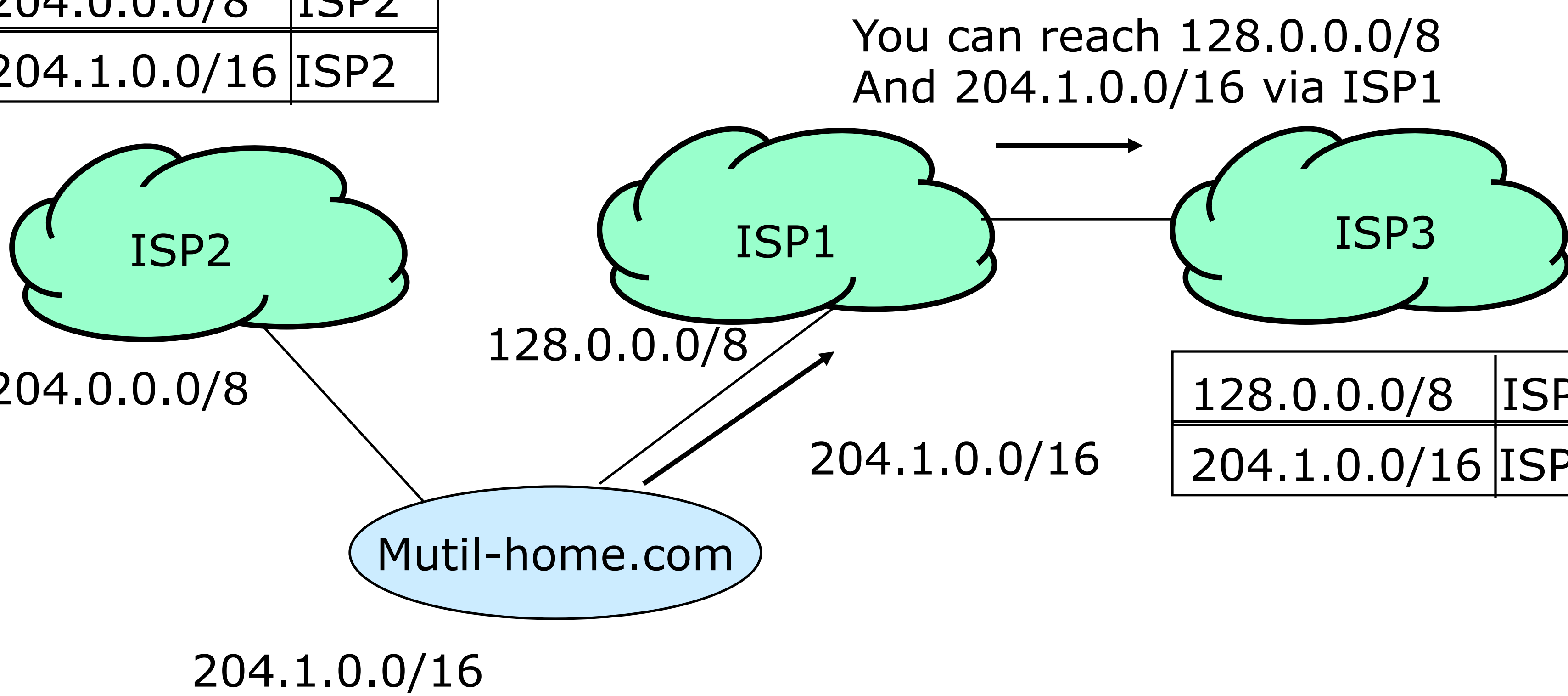
CIDR allows route aggregation



- ISP1 announces one address prefix 128.0.0.0./8 to ISP2
- ISP2 can use one routing entry to reach all networks connected to ISP1

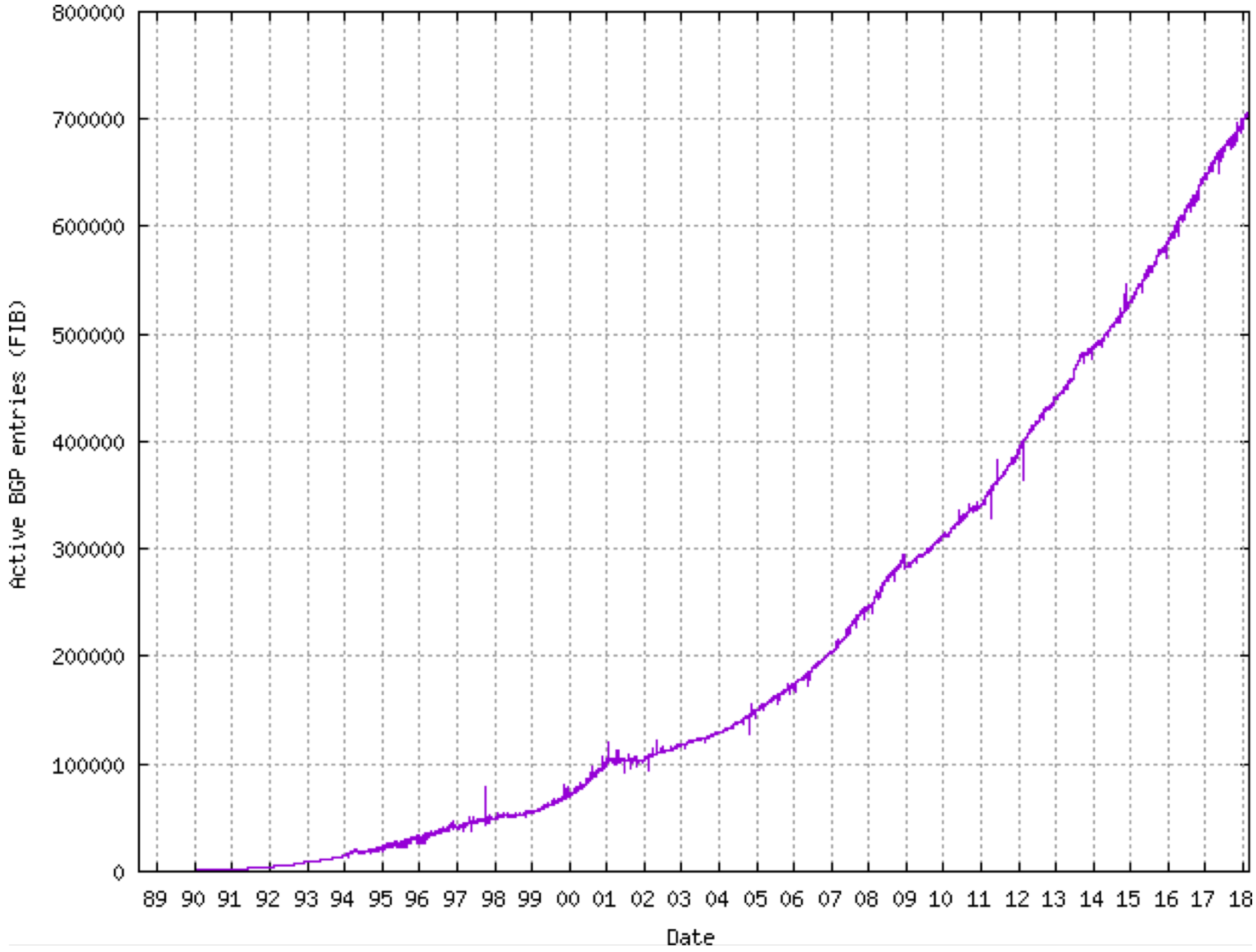
Multi-homing increases routing table size

204.0.0.0/8	ISP2
204.1.0.0/16	ISP2



128.0.0.0/8	ISP1
204.1.0.0/16	ISP1

Global routing tables continue to grow (1989-now)



Source: https://www.cidr-report.org

A policy routing example

4. (10 pts) Figure 3 shows an AS-level topology. Assume all ASes use the common BGP policies to select forwarding paths. Answer the following questions.

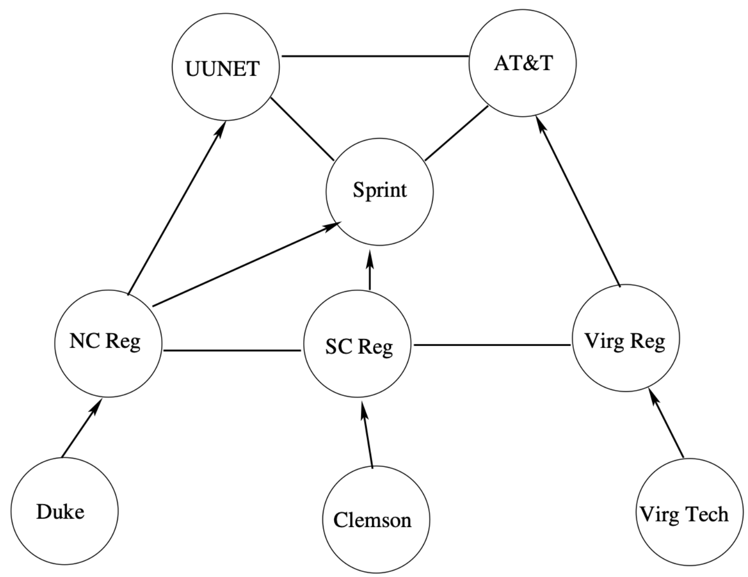


Figure 3: **An AS-level network topology. Each circle represents an AS. A solid line represents a peering relationship between two ASes, and an arrowed line represents a customer-provider relationship with the arrow pointing to the provider.**

(a) (5 pts) What are the policy-allowed AS paths for packets sent from Duke to Virginia Tech? List all such paths. For each path, specify each AS on the path.

Dynamic Host Configuration Protocol (DHCP)

Dynamic Assignment of IP addresses

- Dynamic assignment of IP addresses is desirable
  - IP addresses are assigned on-demand
  - Avoid manual IP configuration
    - Inconvenient, error prone
    - ifconfig
  - Support mobile devices

DHCP

- **Dynamic Host Configuration Protocol (DHCP)**
  - Designed in 1993
  - Supports temporary allocation (“leases”) of IP addresses
  - DHCP client can acquire all IP configuration parameters
    - Default router, network mask, DNS resolver

- Sent as UDP packets

- A client-server protocol
  - Server port: 67
  - Client port: 68
    - Most client-server protocols do not have unique client ports

DHCP Message Format

<table>
<tr><td>OpCode</td><td>Hardware Type</td><td>Hardware Address Length</td><td>Hop Count</td></tr>
<tr><td colspan="2">Number of Seconds</td><td colspan="2">Unused (in BOOTP)
Flags (in DHCP)</td></tr>
<tr><td colspan="4">Transaction ID</td></tr>
<tr><td colspan="4">Client IP address</td></tr>
<tr><td colspan="4">Your IP address</td></tr>
<tr><td colspan="4">Server IP address</td></tr>
<tr><td colspan="4">Gateway IP address</td></tr>
<tr><td colspan="4">Client hardware address (16 bytes)</td></tr>
<tr><td colspan="4">Server host name (64 bytes)</td></tr>
<tr><td colspan="4">Boot file name (128 bytes)</td></tr>
<tr><td colspan="4">Options</td></tr>
</table>

(There are >100 different options)

DHCP

- **OpCode**: *1 (Request), 2(Reply)*

  Note: DHCP message type is sent in an option

- **Hardware Type**: *1 (for Ethernet)*
- **Hardware address length**: *6 (for Ethernet)*
- **Hop count**: *set to 0 by client*
- **Transaction ID**: *Integer (used to match reply to response)*
- **Seconds:** *number of seconds since the client started to boot*

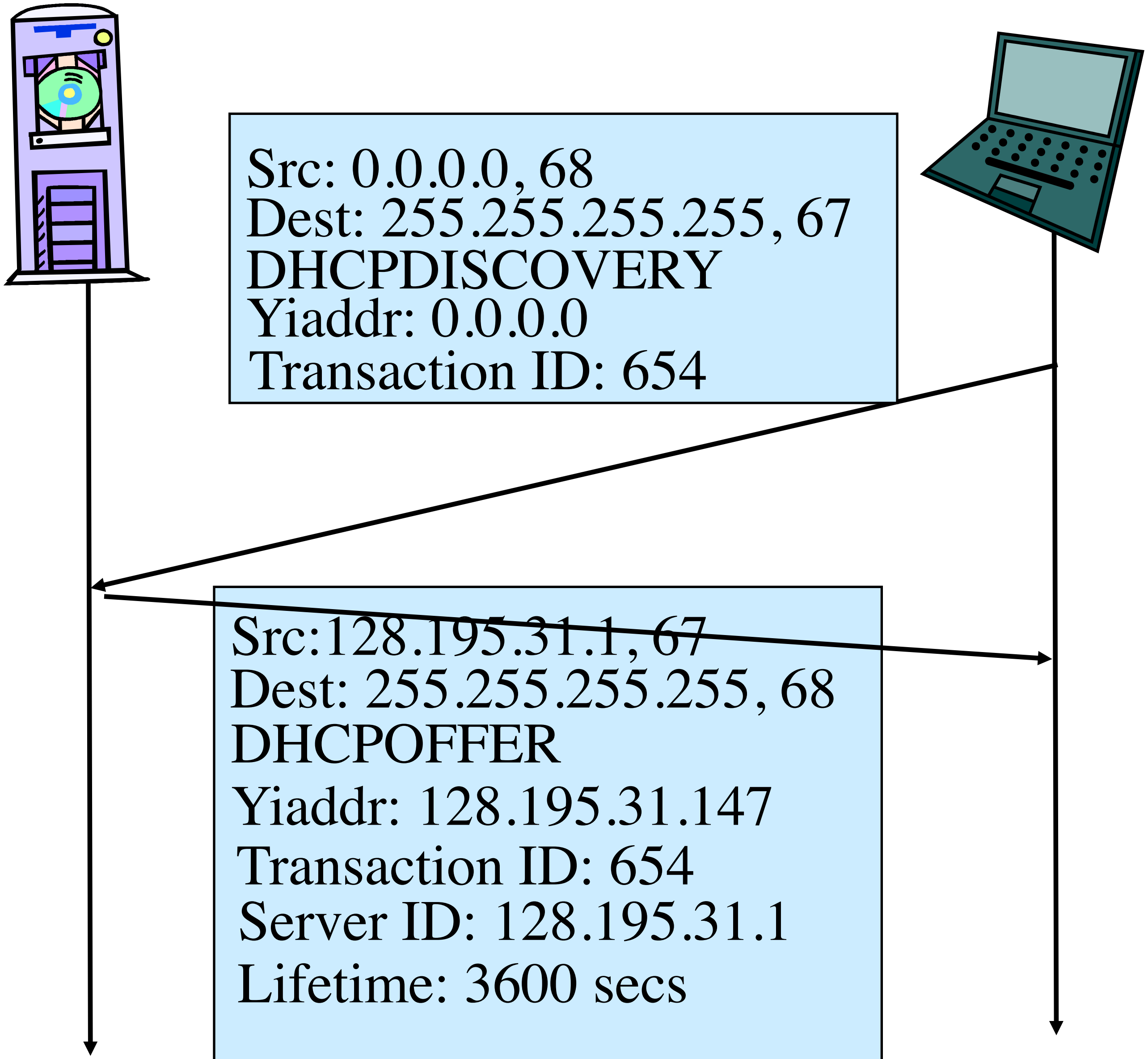
- **Client IP address, Your IP address, server IP address, Gateway IP address, client hardware address, server host name, boot file name:**
  client fills in the information that it has, leaves rest blank

DHCP Message Type

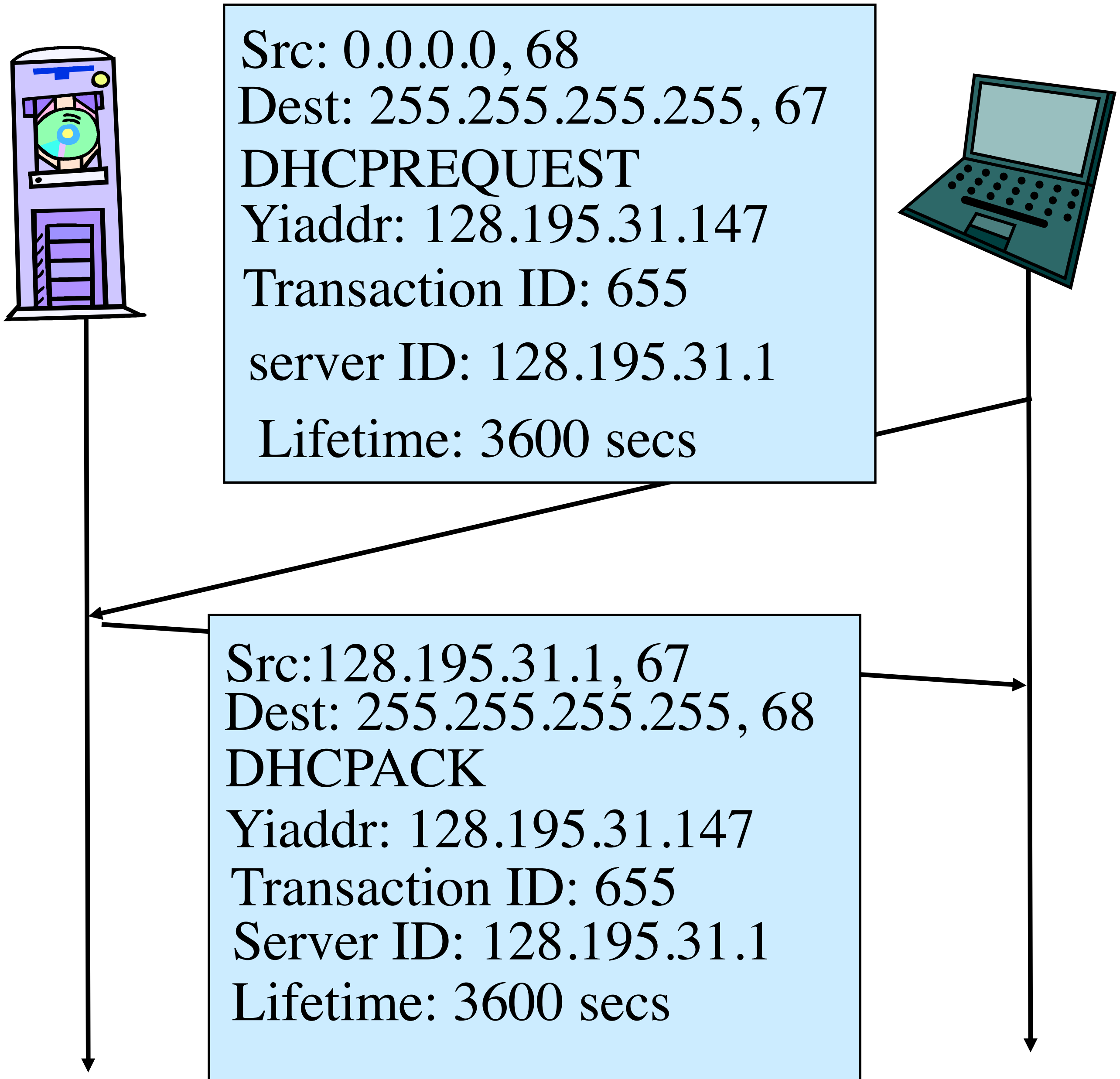
- Message type is sent as an option.

Value	Message Type
1	DHCPDISCOVER
2	DHCPOFFER
3	DHCPREQUEST
4	DHCPDECLINE
5	DHCPACK
6	DHCPNAK
7	DHCPRELEASE
8	DHCPINFORM

DHCP operations



DHCP operations



More on DHCP operations

- A client may receive DCHP offers from multiple servers
- The DHCPREQUEST message accepts offers from one server
- Other servers who receive this message considers it as a decline
- A client can use its address after receiving DHCPACK
- DHCP replies can be unicast, depending on implementation
  - Client hardware address as MAC destination
  - Yiaddr as IP destination

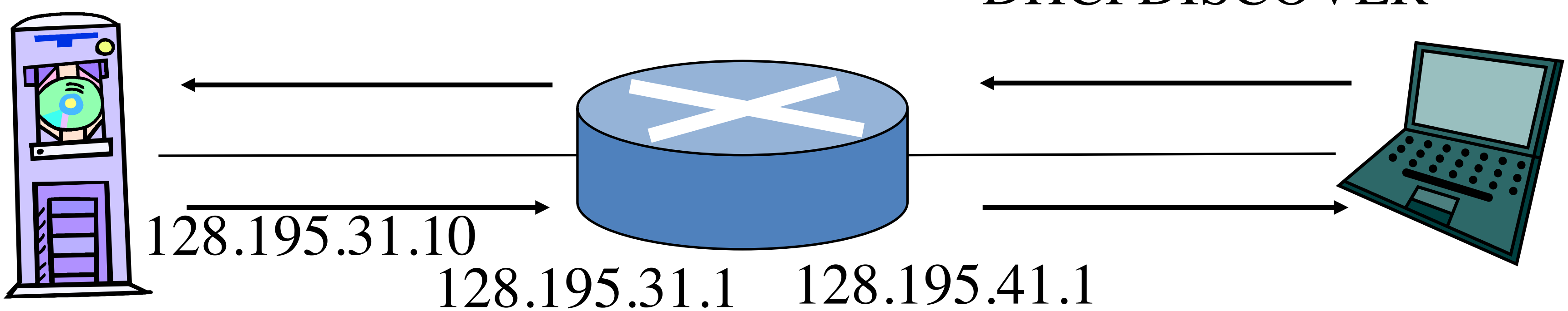
Scalability

- How many DHCP servers do we need?
  - Routers do not forward broadcast IP addresses
  - One per subnetwork! Too many
- Solution: relay agent
  - Configured with the DHCP server's IP address
  - One relay agent per subnetwork
  - Unicast to the DHCP server

DHCP relay agent

Src: 0.0.0.0., 68
Dest: 128.195.31.10, 67
Giaddr: 128.195.41.1
DHCPDISCOVER

Src: 0.0.0.0., 68
Dest: 255.255.255.255, 67
Giaddr: 0
DHCPDISCOVER



Src: 128.195.31.10, 67
Dest: 128.195.41.1, 67
Giaddr: 128.195.41.1
DHCPOFFER

……

Src: 128.195.41.1, 67
Dest: 255.255.255.255, 68
Giaddr: 128.195.41.1
DHCPOFFER

……

Well-known client port

- Why does DHCP choose a well-known client port?
- A: For relay purpose. Otherwise, the relay agent has to remember the port of the original DHCP discovery message.

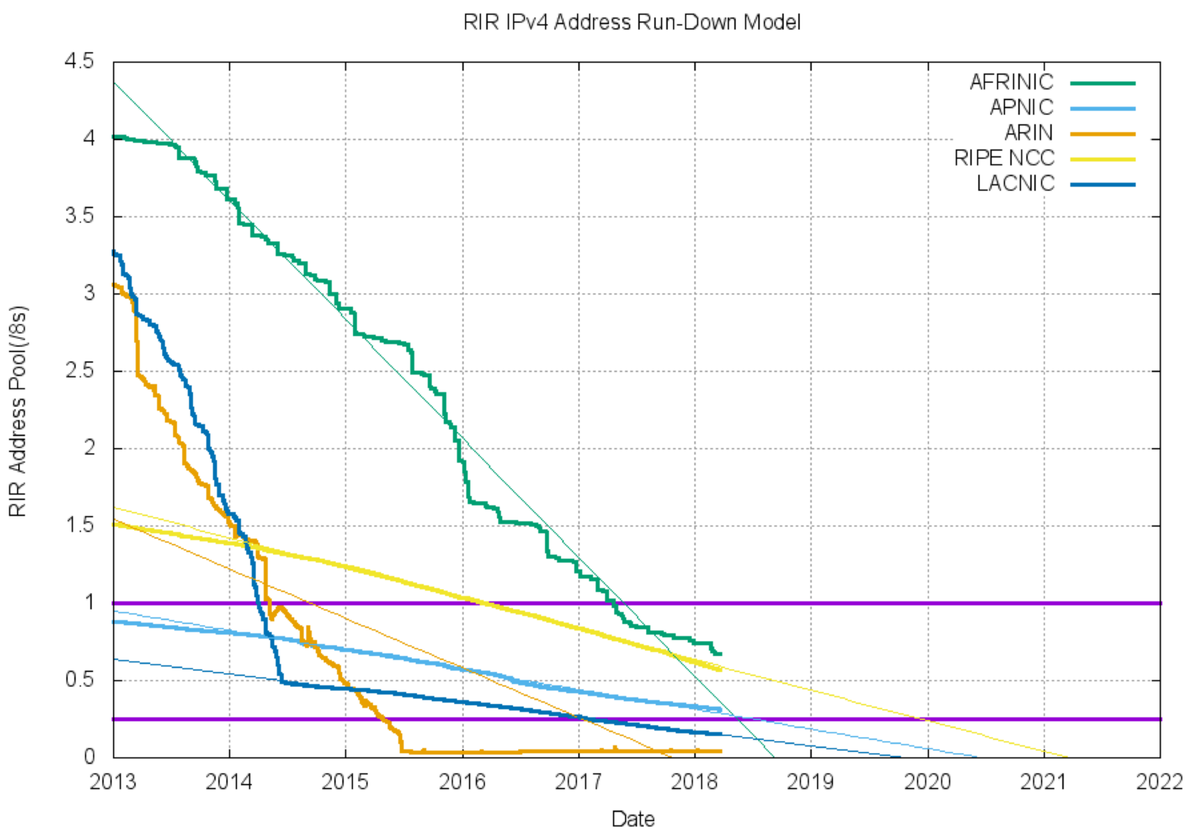
History of DHCP

- Three Protocols:
  - RARP (until 1985, no longer used)
  - BOOTP (1985-1993)
  - DHCP (since 1993)

- Only DHCP is widely used today

Network Address Translation

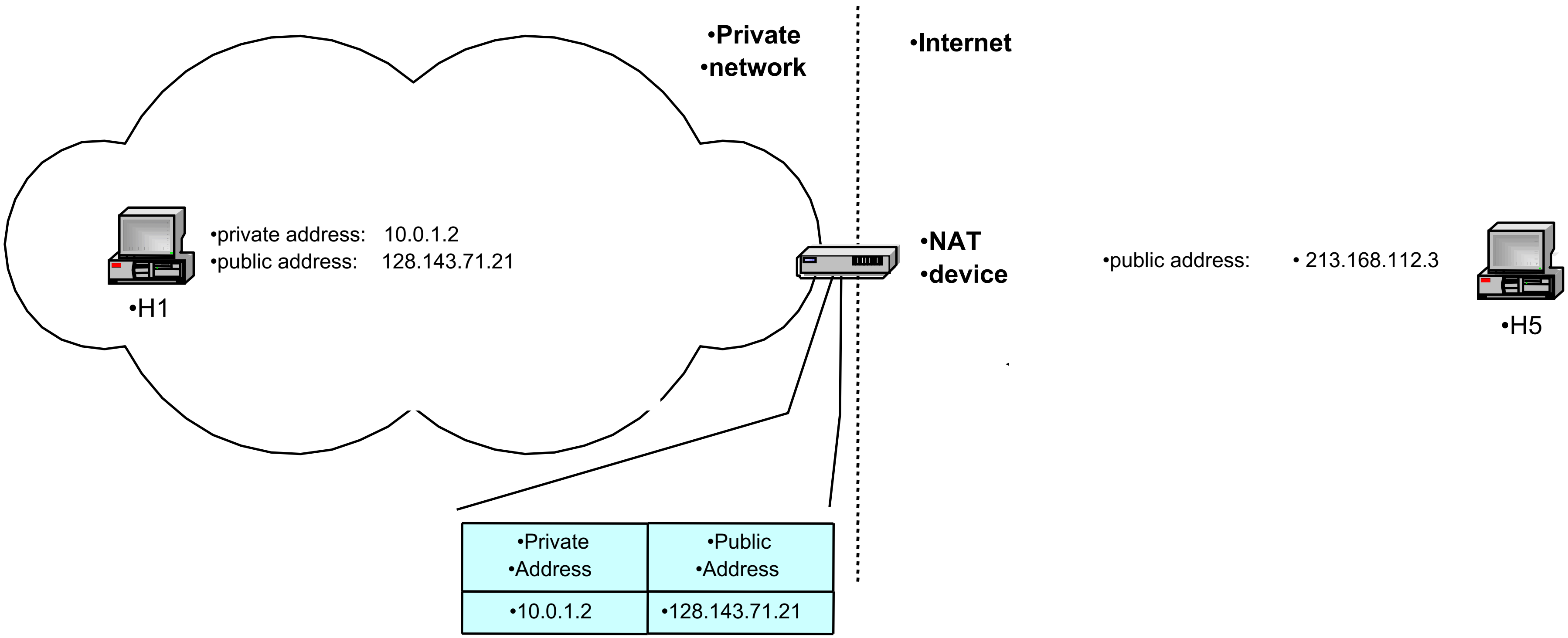
Network address translation



- A fix to the IP address depletion problem.
  - NAT is a router function where IP addresses (and possibly port numbers) of IP datagrams are replaced at the boundary of a private network
- We'll discuss another solution: IPv6

http://www.potaroo.net/tools/ipv4/index.html

Basic operation of NAT



- NAT device has address translation table

Private Network

- *Private IP* network is an IP network that is not directly connected to the Internet

- IP addresses in a private network can be assigned arbitrarily.
  - Not registered and not guaranteed to be globally unique
  - Public IP address are assigned via Internet registries

- Generally, private networks use addresses from the following experimental address ranges (*non-routable addresses*):
  - 10.0.0.0 – 10.255.255.255
  - 172.16.0.0 – 172.31.255.255
  - 192.168.0.0 – 192.168.255.255

Main uses of NAT

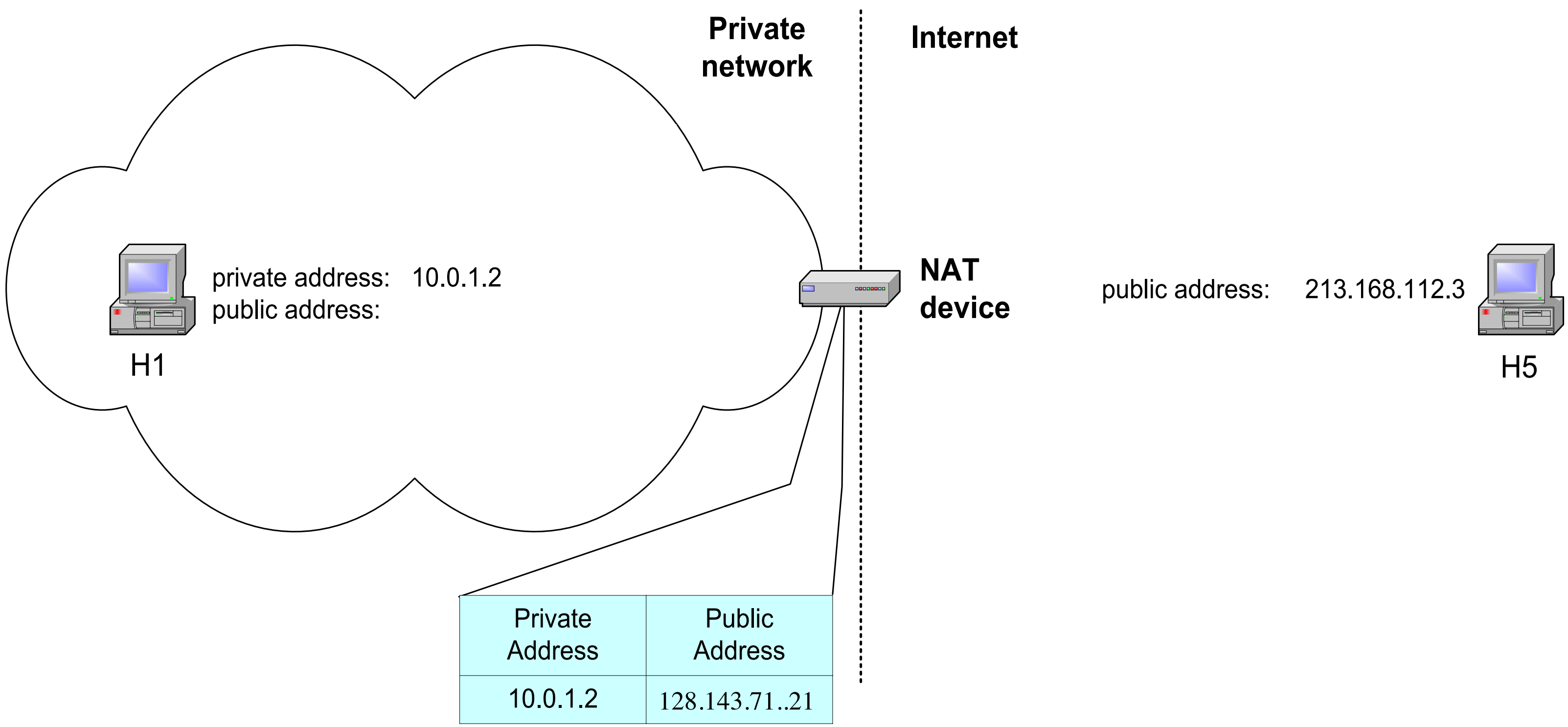
- Pooling of IP addresses
- Supporting migration between network service providers
- IP masquerading
- Load balancing of servers

Pooling of IP addresses

- **Scenario:** Corporate network has many hosts but only a small number of public IP addresses

- **NAT solution:**
  - Corporate network is managed with a private address space
  - NAT device manages a pool of public IP addresses

Pooling of IP addresses



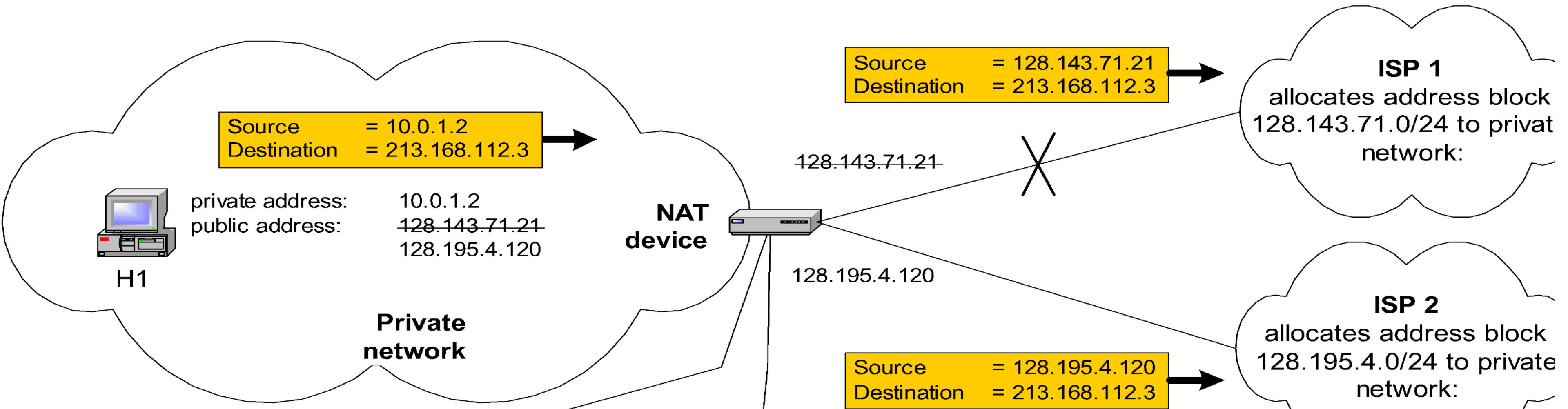
Pool of addresses: 128.143.71.0-128.143.71.30

Supporting migration between network service providers

- **Scenario:** a corporate network changes its ISP
  - change all IP addresses in the network?

- **NAT solution:**
  - Assign private addresses to the hosts of the corporate network
  - NAT device has address translation entries which bind the private address of a host to the public address.
  - Migration to a new network service provider merely requires an update of the NAT device. The migration is not noticeable to the hosts on the network.

Supporting migration between network service providers

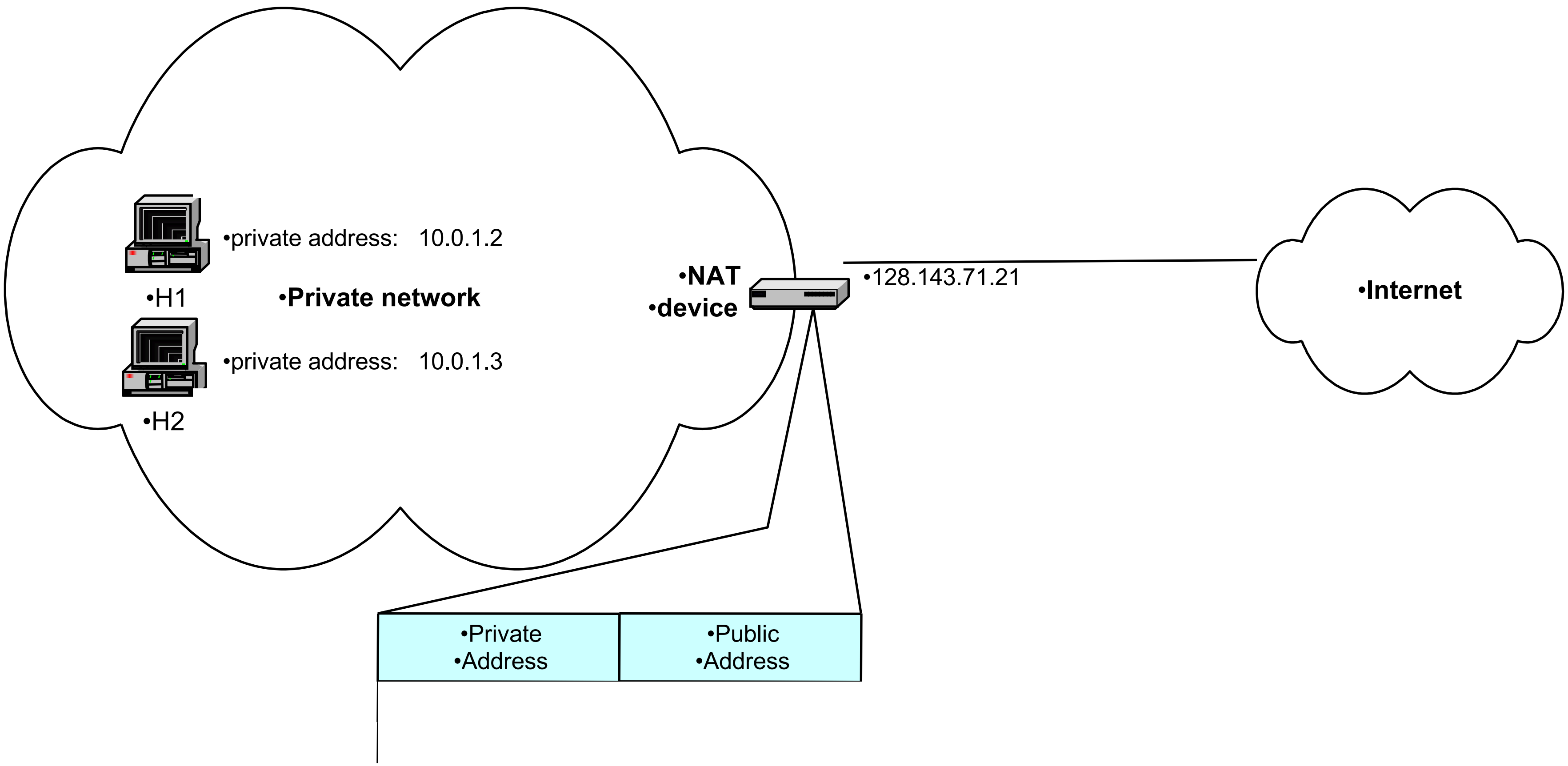


Private Address	Public Address
10.0.1.2	~~128.143.71.21~~ 128.195.4.120

IP masquerading

- **Also called: Network address and port translation (NAPT), port address translation (PAT).**
- **Scenario:** Single public IP address is mapped to multiple hosts in a private network.
- **NAT solution:**
  - Assign private addresses to the hosts of the corporate network
  - NAT device modifies the port numbers for outgoing traffic

IP masquerading

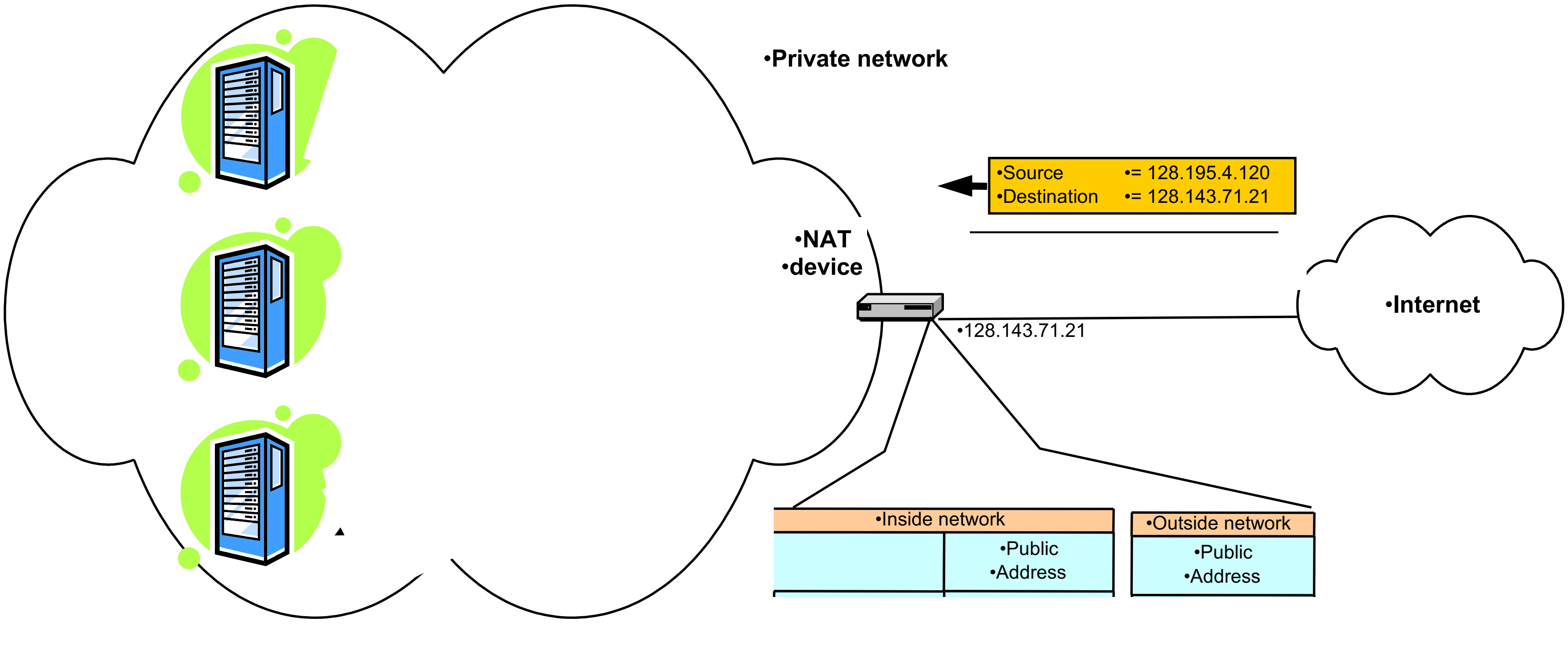


Load balancing of servers

- **Scenario:** Balance the load on a set of identical servers, which are accessible from a single IP address
  - Used by many distributed service providers such as Google

- **NAT solution:**
  - Here, the servers are assigned private addresses
  - NAT device acts as a proxy for requests to the server from the public network
  - The NAT device changes the destination IP address of arriving packets to one of the private addresses for a server
  - A sensible strategy for balancing the load of the servers is to assign the addresses of the servers in a round-robin fashion.
    - Or hashing

Load balancing of servers



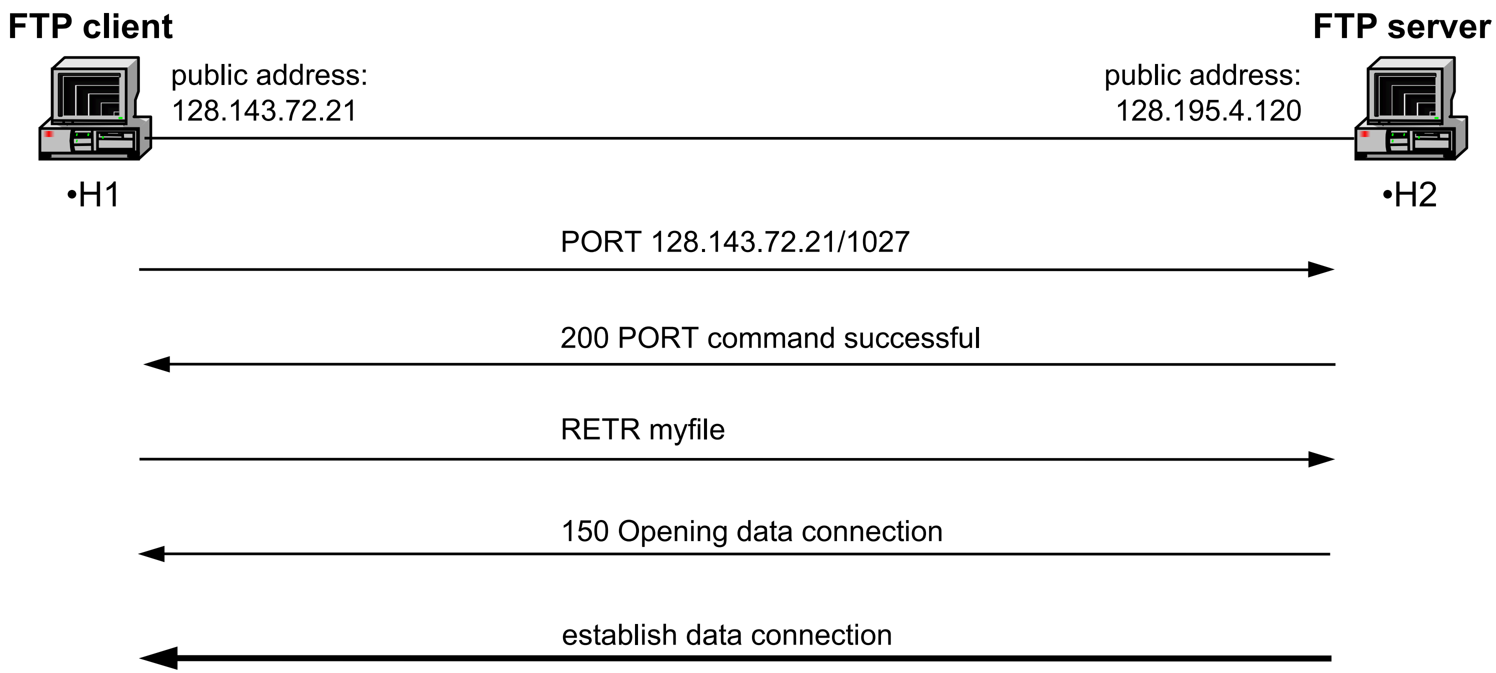
Concerns about NAT

- **Performance:**
  - Modifying the IP header by changing the IP address requires that NAT boxes recalculate the IP header checksum
  - Modifying port number requires that NAT boxes recalculate TCP checksum
- **Fragmentation**
  - Care must be taken not to assign a fragment different IP or port number

Concerns about NAT

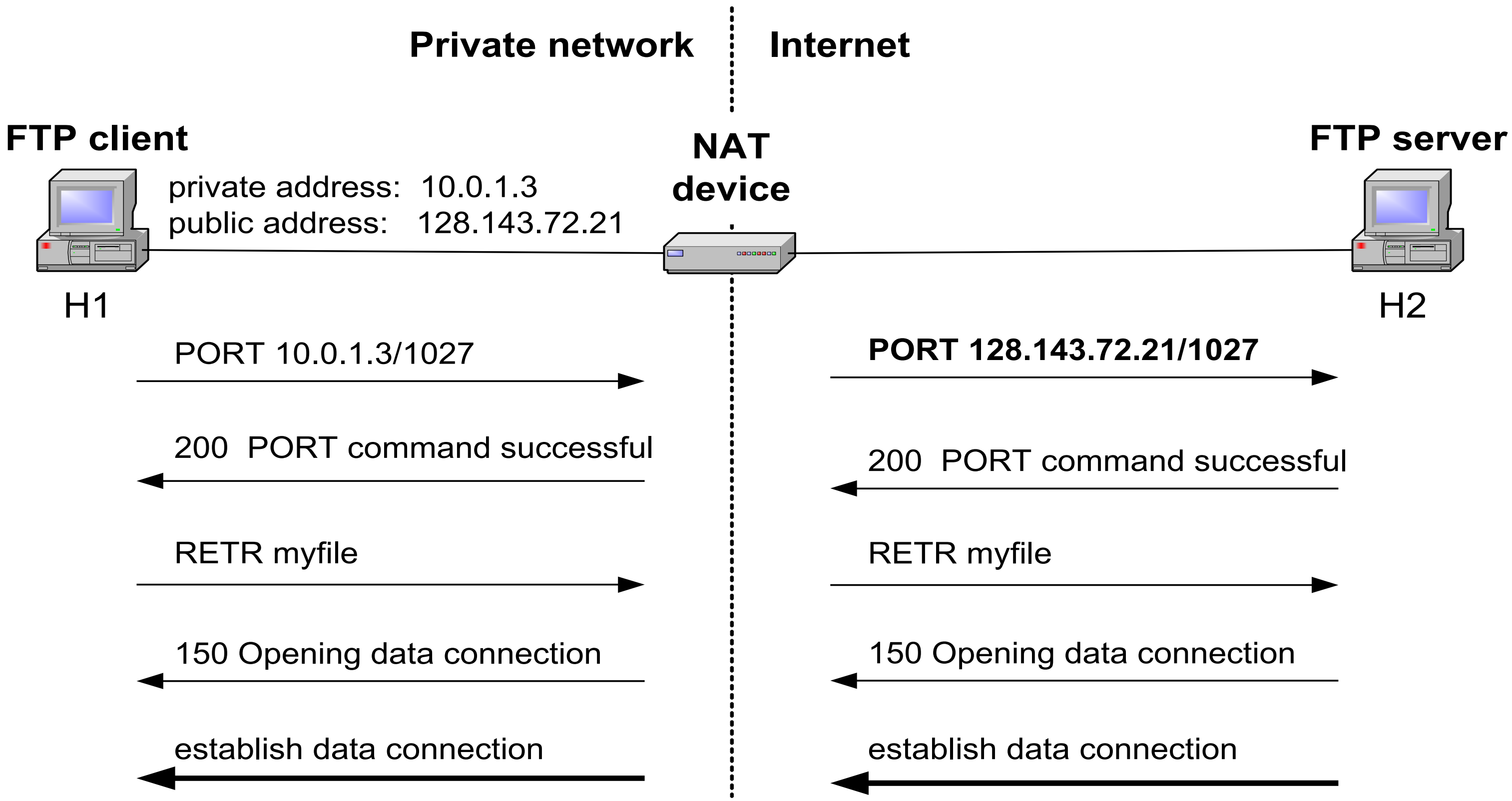
- **End-to-end connectivity:**
  - NAT destroys universal end-to-end reachability of hosts on the Internet.
  - A host in the public Internet often cannot initiate communication to a host in a private network.
  - The problem is worse, when two hosts that are in a private network need to communicate with each other.
    - Difficult to deploy peer-to-peer applications such as Skype

NAT and FTP



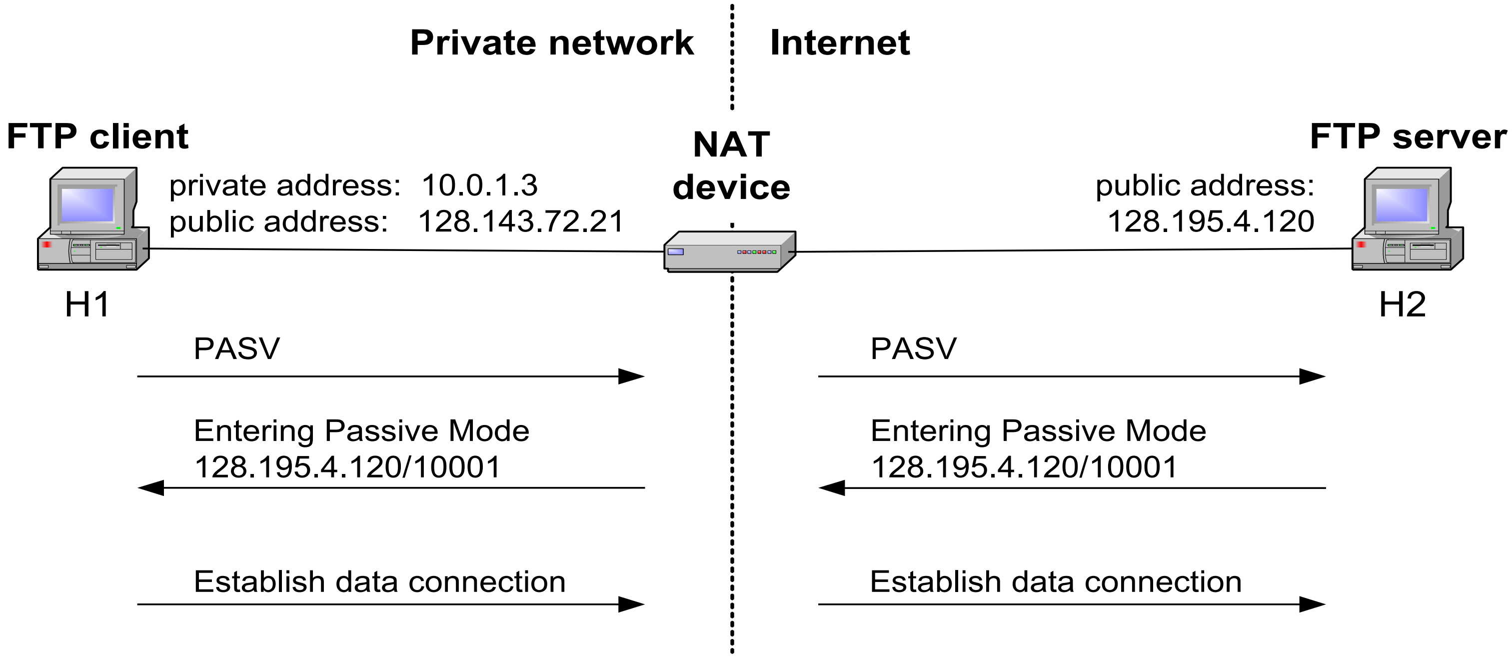
- Normal FTP operation
- What problem will FTP run into if using unmodified NAT?

NAT and FTP



- NAT device with FTP support

NAT and FTP



- FTP in passive mode and NAT.

Next Generation IP (IPv6)

Addressing

- 128-bit addresses
  - 2^{128}
- "if the earth were made entirely out of 1 cubic millimetre grains of sand, then you could give a unique [IPv6] address to each grain in 300 million planets the size of the earth"
- http://en.wikipedia.org/wiki/IP_address
- Or, using a more earthly analogy:
- "The optimistic estimate would allow for 3,911,873,538,269,506,102 addresses per square meter of the surface of the planet Earth." "IP Next Generation Overview"
- R. Hinden, Communications of the ACM, Vol. 39, No. 6 (June 1996) pp 61 - 71, ISSN:0001-0782 http://portal.acm.org/citation.cfm?coll=GUIDE&dl=GUIDE&id=228517

IPv6 Addresses

- Classless addressing/routing (similar to CIDR)
- Notation: x:x:x:x:x:x:x:x (x = 16-bit hex number)
  - contiguous 0s are compressed: 47CD::A456:0124
  - IPv6 compatible IPv4 address:

    ::FFFF:128.42.1.87

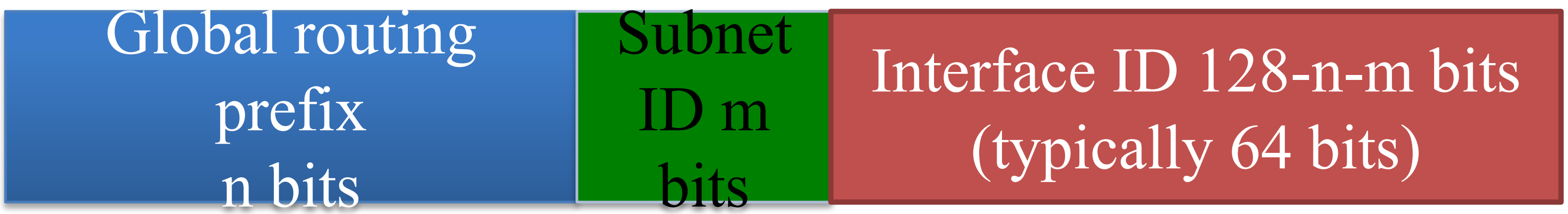
IPv6 addressing architecture

- RFC 4291
- All addresses are assigned to interfaces, not nodes

Types of IPv6 addresses

Address type	Binary prefix	IPv6 notation
Unspecified	00...0 (128 bits)	::/128
Loopback	00...1 (128 bits)	::1/128
Multicast	11111111	FF00::/8
Link-local unicast	1111111010	FE80::/10
Global unicast	Everything else	
Anycast	Allocated from unicast space	

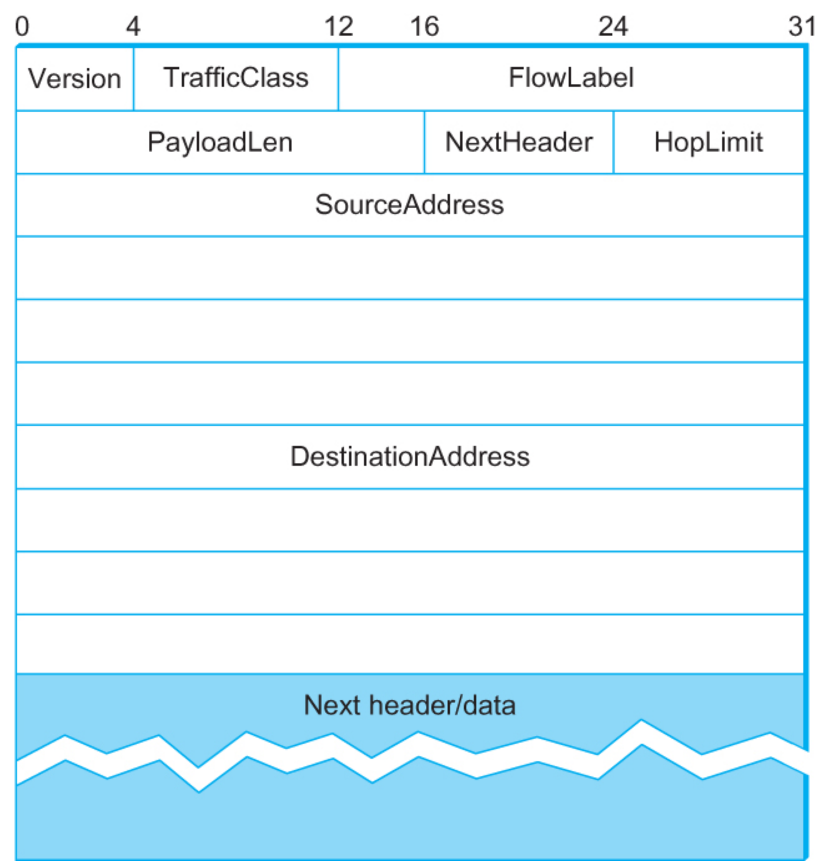
Global Unicast Addresses



- For all unicast addresses, except those that start with the binary value 000, Interface IDs are required to be 64 bits long
  - Can be derived from 48-bit Ethernet address

IPv6 Header

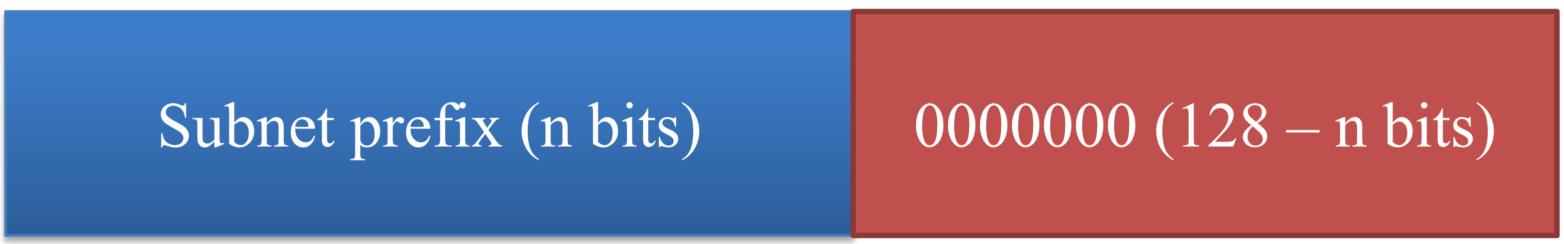
- 40-byte "base" header
- Extension headers (fixed order, mostly fixed length)
  - fragmentation
  - source routing
  - authentication and security
  - other options



Autoconfiguration

- Link-local prefix + interface ID
- Routers advertise global prefixes

IPv6 Anycast Addresses



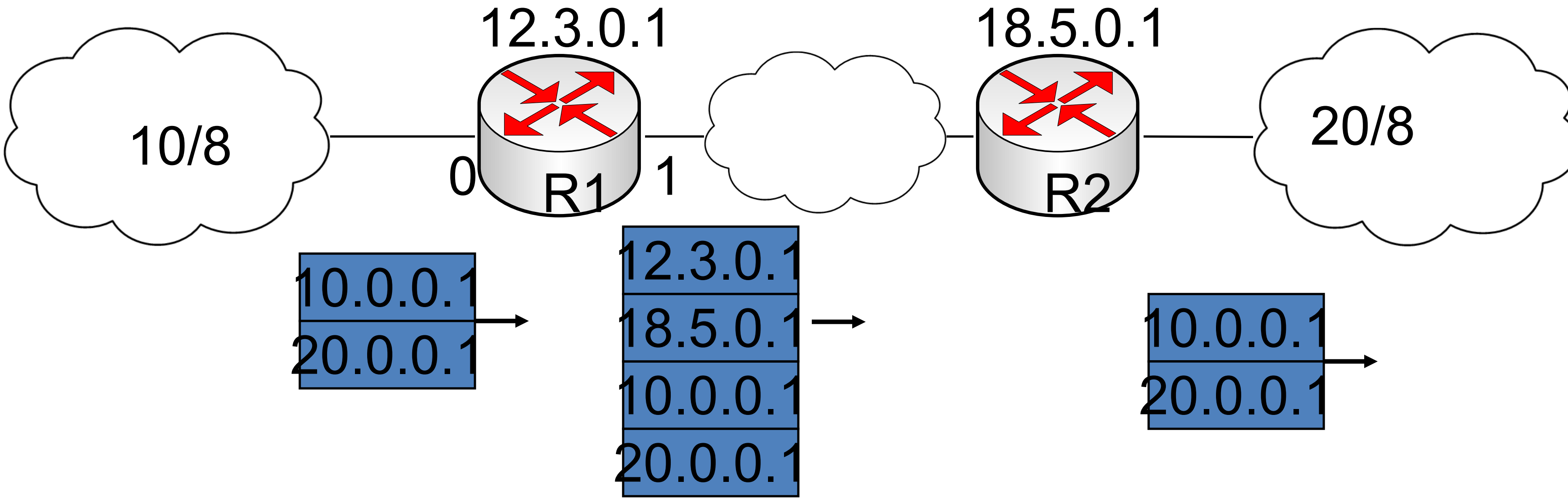
- Assigned to more than one interface
- All zero interface address
- Allocated from the unicast address space
- Ex: all root DNS servers

IP Tunnels

IP tunnels

- Tunnels
  - A technique used in many scenarios
    - VPN, IPv4-v6 transition, Mobile IP, Multicast, Non-IP forwarding, IPsec

What is a tunnel



- A "pseudowire", or a virtual point-to-point link
- The head router encapsulates a packet in an outer header destined to the tail router

Virtual interface

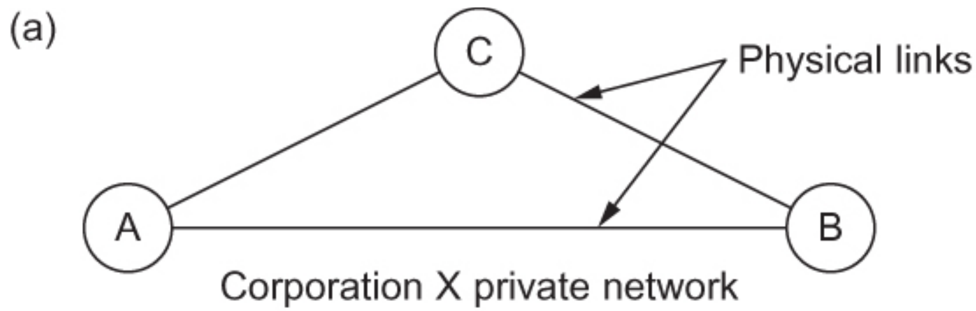
- A router adds a tunnel header for packets sent to a virtual interface

NetworkNum	nextHop
10/8	ether0
20/8	tun0
0/0	ether1

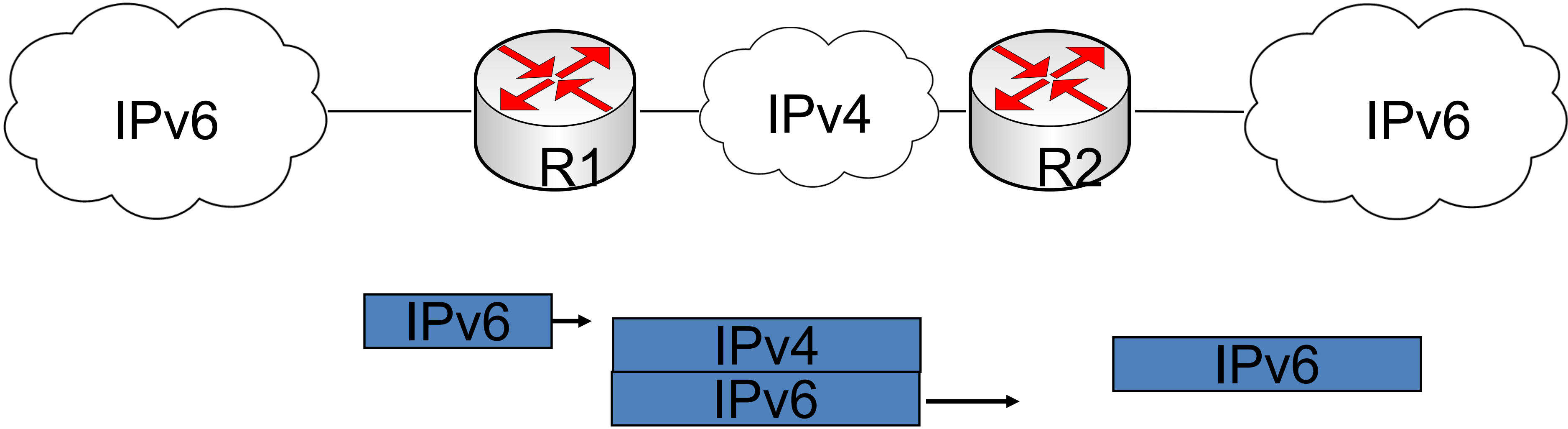
Tunnel applications

- Traversing a region of network with a different addressing format or with insufficient routing knowledge
- Building virtual private networks

FIGURE 3.26 An example of virtual private networks: (a) two separate private networks; (b) two virtual private networks sharing common switches.



IPv4-v6 transition



Generic Routing Encapsulation (GRE)

- Defined in [RFC 2784] and updated by [RFC 2890]