Lecture 21: Routing again

COMP 332, Spring 2023

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Acknowledgements: materials adapted from Computer Networking: A Top Down Approach 7th edition: ©1996-2016, J.F Kurose and K.W. Ross, All Rights Reserved as well as from slides by Abraham Matta at Boston University, and some material from Computer Networks by Tannenbaum and Wetherall.

Today

1. Announcements
   - Homework 7 coding due Wednesday, April 26 at 11:59p
   - Homework 8 due Wednesday, April 3 at 11:59p (no coding)
   - Homework 9 due Wednesday, May 10 at 11:59p (no written)

2. Internet addressing (again)
   - IPv6 addresses
   - Dynamic Host Configuration Protocol (DHCP)
   - Network Address Translation (NAT)

Takeaways from last time

Internet is divided into autonomous systems (AS)

- routing is done between (inter) and within (intra) autonomous systems: hierarchical routing
- one AS contains many subnets and many routers

Traffic is still routed to subnets

- but how those routes are set depend on intra-AS and inter-AS routing protocols.

Intra-AS routing

- performance focused
- RIP (Distance-Vector), OSPF (Link-State)

Inter-AS routing

- policy focused
- BGP (Path-Vector)

Internet Addressing

IPV6 ADDRESSES

IPv6 motivation

Initial motivation

- 32-bit address space soon to be completely allocated
- 128-bit IPv6 address

Additional motivation

- header format helps speed processing/forwarding
- header changes to facilitate QoS

IPv6 packet format

- fixed-length 40 byte header
- no fragmentation allowed

Dig www.google.com ANY

```
> dig ANY www.google.com

; <<>> DiG 9.8.3-P1 <<>> ANY www.google.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 31338
;; flags: qr rd ra; QUERY: 1, ANSWER: 7, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;www.google.com.                IN      ANY

;; ANSWER SECTION:
www.google.com.         240     IN      A       173.194.66.147
www.google.com.         240     IN      A       173.194.66.105
www.google.com.         240     IN      A       173.194.66.104
www.google.com.         240     IN      A       173.194.66.99
www.google.com.         240     IN      A       173.194.66.103
www.google.com.         240     IN      A       173.194.66.106
www.google.com.         208     IN      AAAA    2607:f8b0:400d:c01::68

;; Query time: 4 msec
;; SERVER: 129.133.52.12#53(129.133.52.12)
;; WHEN: Mon Apr  9 13:15:11 2018
;; MSG SIZE  rcvd: 156
```

AAAA is an IPv6 record

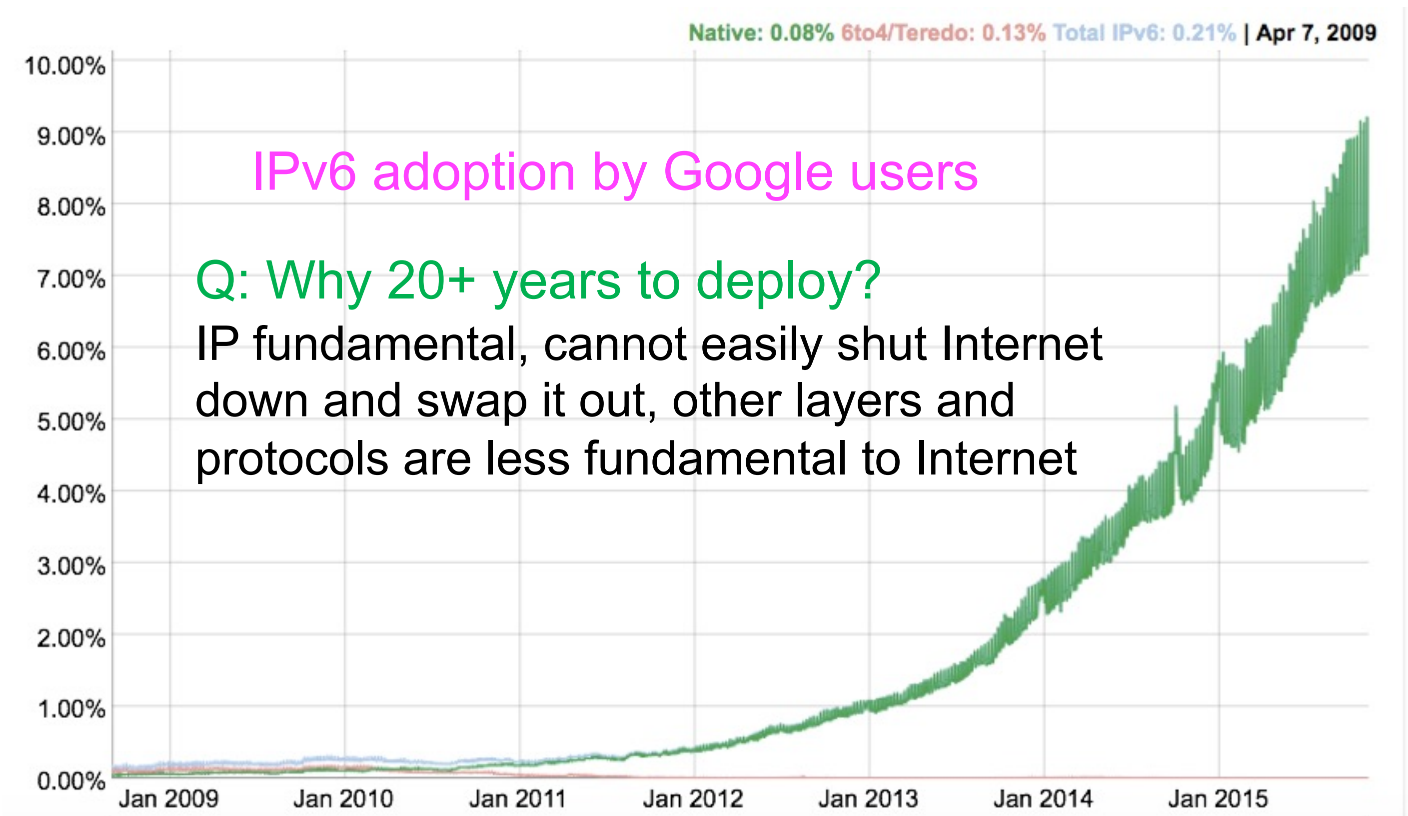
Ifconfig example

```
> ifconfig
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 16384
        options=1203<RXCSUM,TXCSUM,TXSTATUS,SW_TIMESTAMP>
        inet 127.0.0.1 netmask 0xff000000
        inet6 ::1 prefixlen 128
        inet6 fe80::1%lo0 prefixlen 64 scopeid 0x1
        nd6 options=201<PERFORMNUD,DAD>
gif0: flags=8010<POINTOPOINT,MULTICAST> mtu 1280
stf0: flags=0<> mtu 1280
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether 78:4f:43:73:43:26
        inet6 fe80::1c8d:4bcb:b52d:9d1d%en0 prefixlen 64 secured scopeid 0x5
        inet 10.66.104.246 netmask 0xfffffc00 broadcast 10.66.107.255
        nd6 options=201<PERFORMNUD,DAD>
        media: autoselect
        status: active
```

IPv6 deployment

Standardized ~1998

- 2008: IPv6 < 1% of Internet traffic
- 2011: IPv6 increasingly implemented in OS, mandated by governments and cell providers for new network devices, ….
- as recently as last year, Wesleyan did not support IPv6



IPv6 adoption by Google users

Q: Why 20+ years to deploy?

IP fundamental, cannot easily shut Internet down and swap it out, other layers and protocols are less fundamental to Internet

Addressing

DYNAMIC HOST CONFIGURATION PROTOCOL

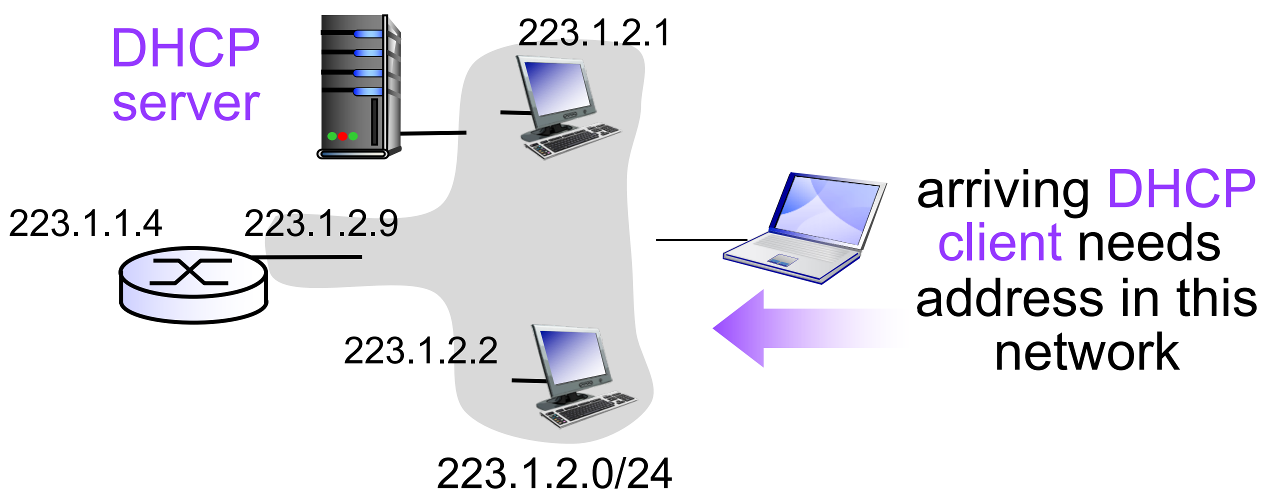
DHCP: Dynamic Host Configuration Protocol

Goal

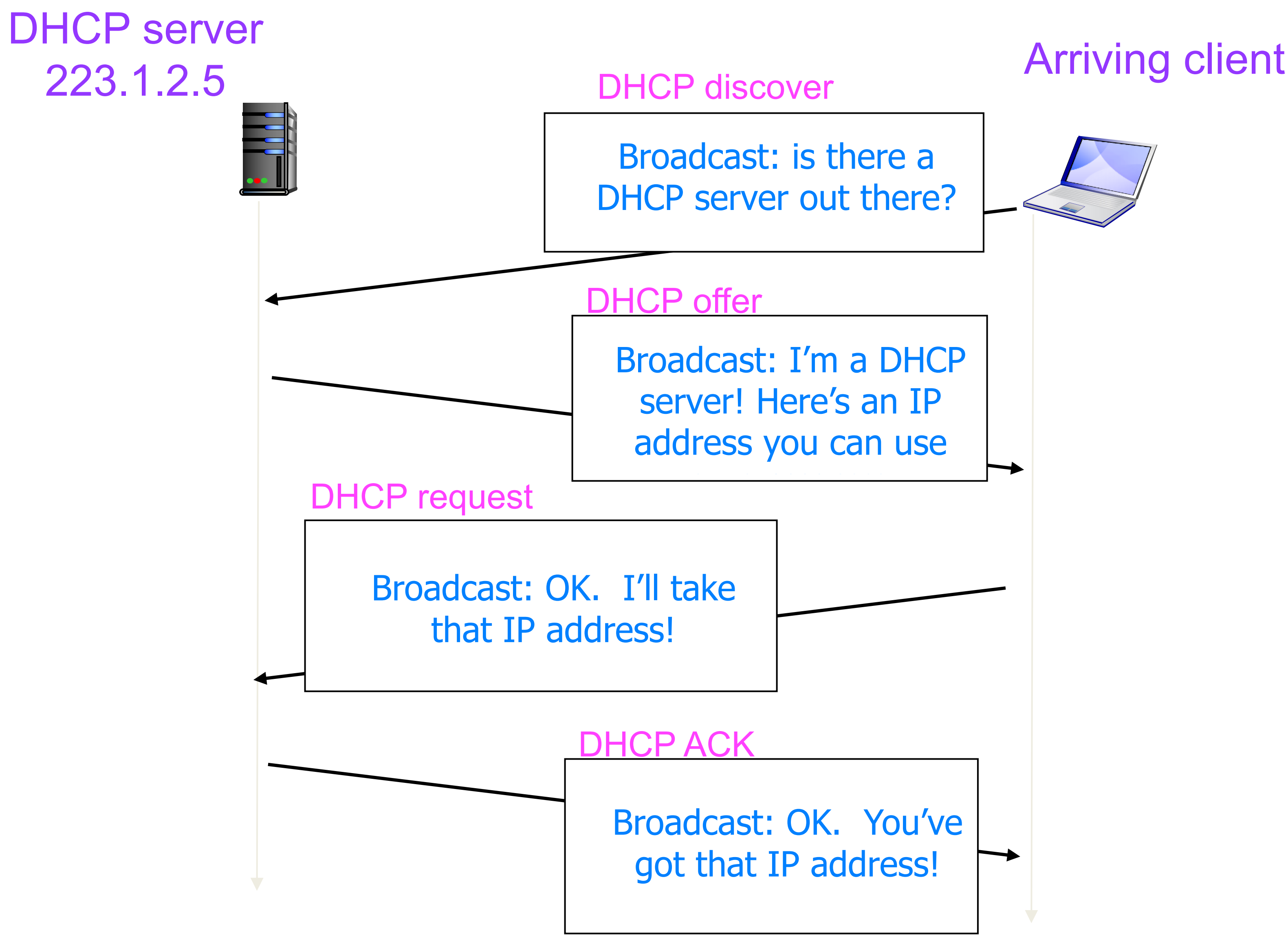
- let host dynamically obtain IP addr from server when it joins network

Benefits

- reuse of addresses by different hosts
  - only hold address while connected to network
  - host can renew its lease on address in use
- support for mobile users who want to join network



Client-server scenario



Q: What layer is DHCP in?

Q: What transport layer protocol does DHCP run over?

No.	Time	Source	Destination	Protocol	Length	Info
1163	6.261619	0.0.0.0	255.255.255.255	DHCP	342	DHCP Discover – Transaction ID 0xecc8a20d
1199	6.565966	0.0.0.0	255.255.255.255	DHCP	342	DHCP Discover – Transaction ID 0xecc8a20e
1201	6.570664	129.133.176.5	vmanfredismbp2.wi…	DHCP	342	DHCP Offer – Transaction ID 0xecc8a20e
1205	7.573840	0.0.0.0	255.255.255.255	DHCP	342	DHCP Request – Transaction ID 0xecc8a20e
1206	7.581751	129.133.176.6	vmanfredismbp2.wi…	DHCP	342	DHCP ACK – Transaction ID 0xecc8a20e
1208	7.597775	129.133.176.5	vmanfredismbp2.wi…	DHCP	342	DHCP ACK – Transaction ID 0xecc8a20e

```
▶ Frame 1205: 342 bytes on wire (2736 bits), 342 bytes captured (2736 bits) on interface 0
▶ Ethernet II, Src: 78:4f:43:73:43:26 (78:4f:43:73:43:26), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
▶ Internet Protocol Version 4, Src: 0.0.0.0 (0.0.0.0), Dst: 255.255.255.255 (255.255.255.255)
▶ User Datagram Protocol, Src Port: 68 (68), Dst Port: 67 (67)
▼ Bootstrap Protocol (Request)
    Message type: Boot Request (1)
    Hardware type: Ethernet (0x01)
    Hardware address length: 6
    Hops: 0
    Transaction ID: 0xecc8a20e
    Seconds elapsed: 1
  ▶ Bootp flags: 0x0000 (Unicast)
    Client IP address: 0.0.0.0 (0.0.0.0)
    Your (client) IP address: 0.0.0.0 (0.0.0.0)
    Next server IP address: 0.0.0.0 (0.0.0.0)
    Relay agent IP address: 0.0.0.0 (0.0.0.0)
    Client MAC address: 78:4f:43:73:43:26 (78:4f:43:73:43:26)
    Client hardware address padding: 00000000000000000000
    Server host name not given
    Boot file name not given
    Magic cookie: DHCP
  ▶ Option: (53) DHCP Message Type (Request)
  ▶ Option: (55) Parameter Request List
  ▶ Option: (57) Maximum DHCP Message Size
  ▶ Option: (61) Client identifier
  ▶ Option: (50) Requested IP Address
  ▶ Option: (54) DHCP Server Identifier
  ▶ Option: (12) Host Name
  ▶ Option: (255) End
    Padding: 000000
```

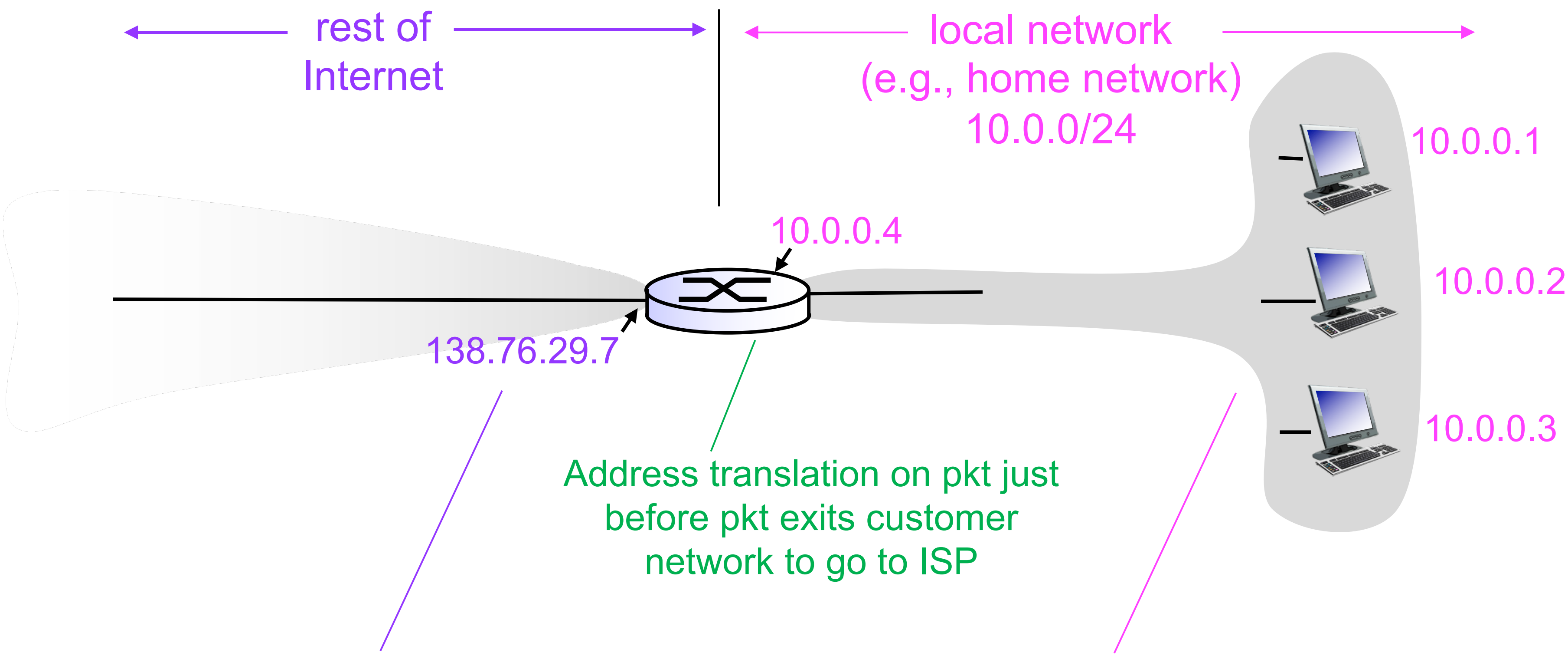
Addressing

NETWORK ADDRESS TRANSLATION

Network Address Translation (NAT)

Motivation

– local network uses 1 IP address as far as outside world is concerned



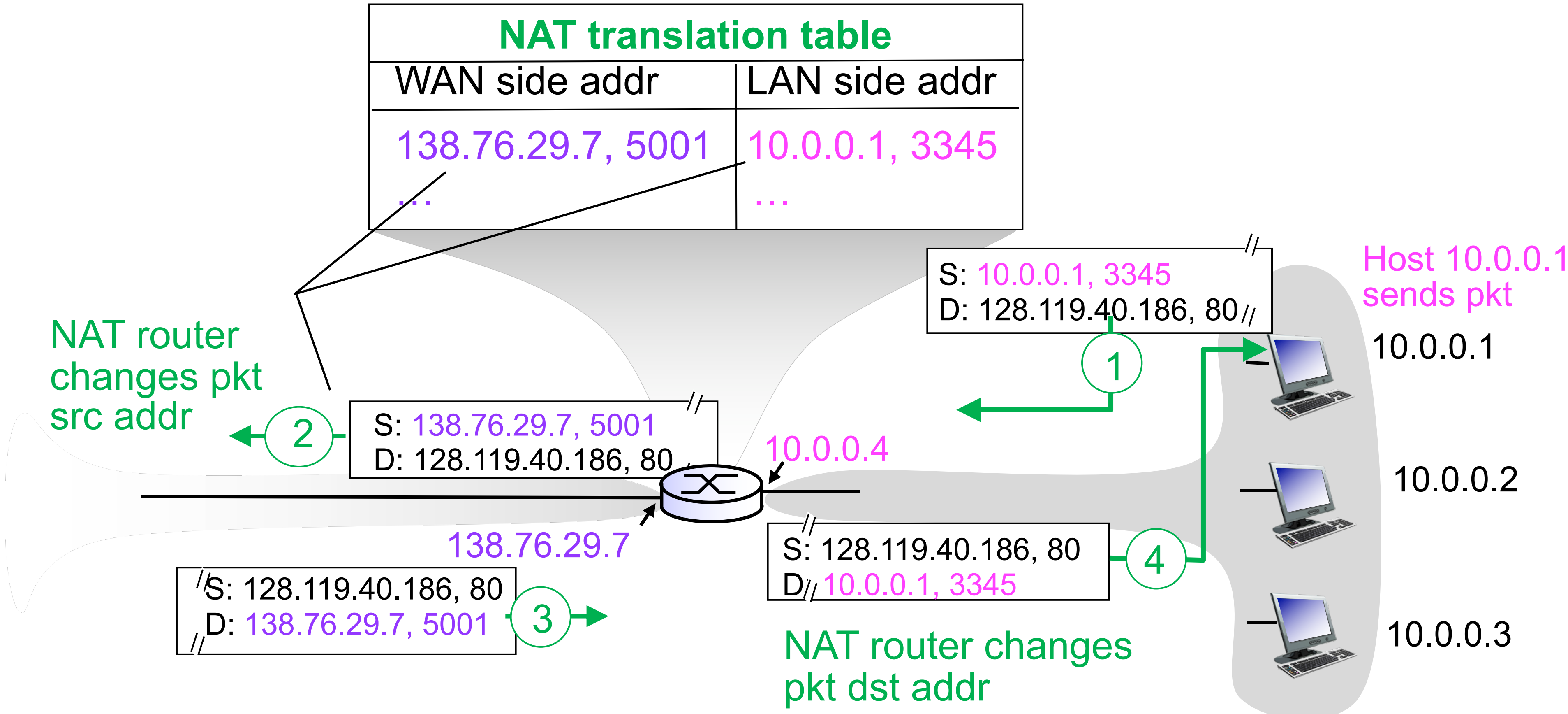
Externally: all packets leaving local network have same single source NAT IP address: 138.76.29.7, different source port #s

Internally: each host gets unique address from set of private subnet addresses, 10.0.0/24

NAT implementation on router

Outgoing packets

Replace (src IP addr, port #) to (NAT IP addr, new port #)



Incoming packets

Replace (NAT IP addr, new port #) in dst fields with corresponding (src IP addr, port #) in NAT table

Q: # of connections supported with 16-bit port #?

Q: Why was NAT was designed this way? Can ICMP traffic reach host behind NAT router?

Most traffic is TCP or UDP

NAT pros and cons

Pros

- don’t need range of addresses from ISP
  - just one public IP address for all devices
- change private addresses of devices
  - without notifying outside world
- change ISP
  - without changing addresses of devices in local network
- security
  - devices inside local network not explicitly addressable or visible

Cons: NAT is controversial!

- routers should only process up to network layer
- address shortage should be solved by IPv6
- violates e2e argument
  - app designers (e.g., p2p) must account for NAT usage
- creates a strange kind of connection-oriented network
- NAT traversal
  - how to connect to server behind NAT? Problems for VOIP, FTP, …

Recall RFC 1958 architectural principles

1. Make sure it works: don't finalize standard before implementing
2. Keep it simple: Occam's razor
3. Make clear choices: choose one way to do it
4. Exploit modularity: e.g., protocol stack
5. Expect heterogeneity: different hardware, links, applications
6. Avoid static options and parameters: better to negotiate
7. Look for a good not necessarily perfect design: onus is on the designers with the outliers to work around design
8. Be strict when sending and tolerant when receiving
9. Think about scalability: no centralized databases, load evenly spread over resources
10. Consider performance and cost: if bad, no one will use network