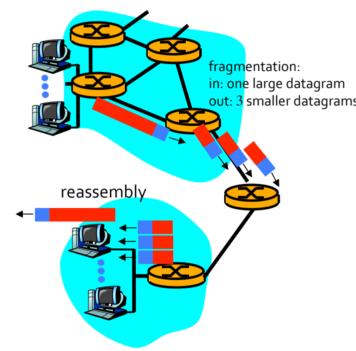
eecs489 COMPUTER NETWORKS

Lecture 7: IP Fragmentation, IPv6, NAT

IP Fragmentation & Reassembly

Network links have MTU (maximum transmission unit) – the largest possible link-level frame

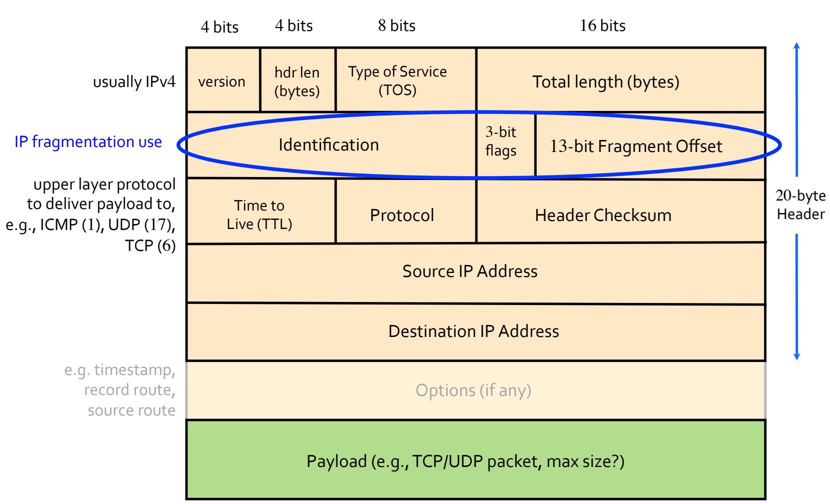
- different link types, different MTUs
- not including frame header/trailer
- but including any and all headers above the link layer



Large IP datagrams are split up ("fragmented") in the network

- each with its own IP header
- fragments are "reassembled" only at final destination (why?)
- IP header bits used to identify and order related fragments

IPv4 Packet Header Format

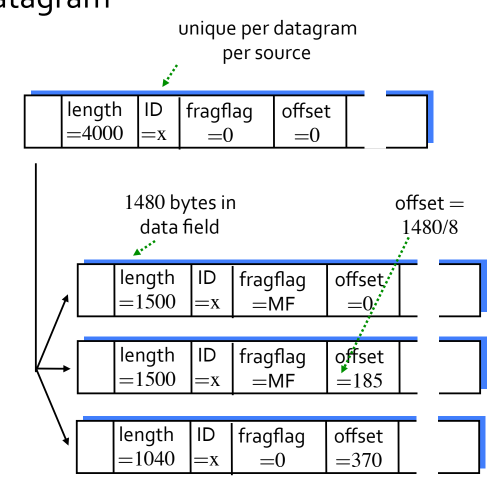


IP Fragmentation and Reassembly

Example: 4000-byte datagram
MTU = 1500 bytes

One large datagram becomes several smaller datagrams

- all but the last fragments must be in multiple of 8 bytes
- offsets are specified in unit of 8-byte chunks
- IP header = 20 bytes (1 header becomes 3 in this example)



Fragmentation Considered Harmful

Reason 1: lose 1 fragment, lose whole packet:

- kernel has limited buffer space
- but IP doesn't know number of fragments per packet

For example:

- sender sends two packets, L and S
  - L is fragmented into 8 fragments
  - S is fragmented into 2 fragments
- receiver has 8 buffer slots
- suppose fragments arrive in the following order:
  L1, L2, L3, L4, L5, L6, L7, S1, L8, S2
- receiver's buffer fills up after S1, both packets thrown away when reassembly timer times out

Fragmentation Considered Harmful

Reason 2: inefficient transmission

Example:

- 10 KB of data
- sent as 1024 byte TCP segments
- uses 10 IP packets, each 1064 bytes (TCP/IP headers, each 20 bytes)
- suppose MTU is 1006 bytes
- each TCP segment is fragmented into 2 IP packets, of 1,004 bytes and 80 bytes respectively
- ends up sending 20 packets
- If TCP had sent 960-byte segments, only need to send 11 packets

Fragmentation Considered Harmful

Analysis:

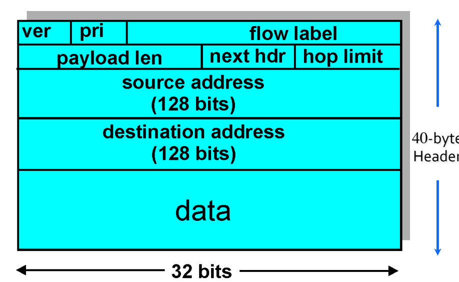
- IP doesn't have control over number of fragments
- TCP can do buffer management better because it has more information

Alternatives to fragmentation:

- send only small datagrams (why not?)
- do path MTU discovery and let TCP send the appropriate segment sizes
  - set DF flag
  - router returns ICMP error message (type 3, code 4) if fragmentation becomes necessary
- IPv6 enforces minimum MTU of 1280 bytes (576 bytes for IPv4), fragmentation requires fragmentation header

IPv6

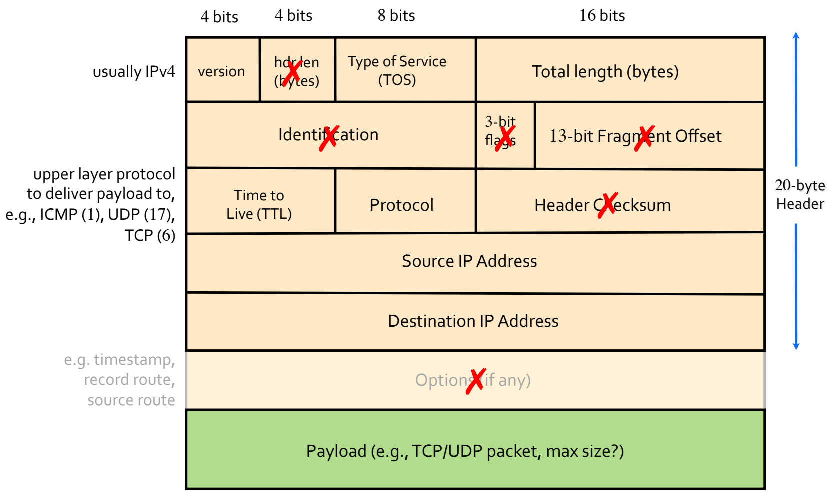
Initial motivation:
32-bit address space exhaustion, increases address size



Additional motivation:

- efficient header format helps speed processing/forwarding
  - header length: removed, use fixed-length 40-byte header (0.07% overhead even for 576-byte packets)
  - header checksum: removed to reduce processing time at each hop
  - options: allowed, but outside of header, indicated by "next header" field

IPv4 Packet Header Format



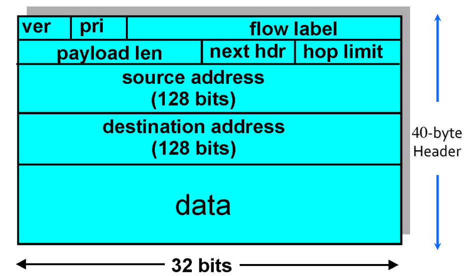
IPv6

Additional motivation:

- header changes to facilitate Quality of Service (QoS)
  - priority: set priority amongst datagrams in flow (ToS bit)
  - flow label: identify datagrams in the same "flow" (concept of "flow" not well defined, originally these were "reserved" bits)

Next header identifies "upper layer" protocol or IPv6 options:

- hop-by-hop option, destination option, routing, fragmentation, authentication, encryption



IPv6 Address

What does an IPv6 address look like?

- 128 bits written as 8 16-bit integers separated by ':'
- each 16-bit integer is represented by 4 hex digits

Example:
`FEDC:BA98:7654:3210:FEDC:BA98:7654:3210`

Abbreviations:

actual - `1080:0000:0000:0000:0008:0800:200C:417A`

skip leading 0's - `1080:0:0:0:8:800:200C:417A`

double '::' - `1080::8:800:200C:417A`

but not `::BA98:7654::`

IPv6 Address Format

`FEDC:BA98:7654:3210:FEDC:BA98:7654:3210`

Subnet prefix (64 bits) | Interface identifier (64 bits)

Interface identifier: MAC address (globally unique!)

- MAC addresses are 48 bits: add `FFFE` between the 2 halves
- loopback: `::1/128` (only 1 address, not a whole class A block (`127/8`) as in IPv4)

Subnet prefix: automatically obtained from router

- `/32` assigned to Internet Registries (ARIN/RIPE/APNIC), which then dish out smaller address blocks

IPv6 Special Subnet Prefixes

Link-local prefix: `FE80::/10` (flush left), not forwarded by router

Unique Local Addresses (ULA): `FC00::/7` routed within a set of cooperating subnets (e.g., networks of the same organization)

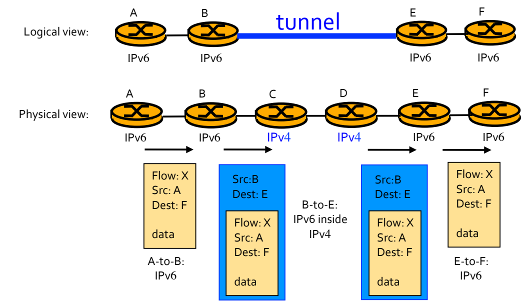
Multicast addresses: `FF00::/8`

IPv4 addresses: `::/96`, e.g., IPv4's `10.0.0.1` can be written as `0:0:0:0:0:0:A00:1` or `::10.0.0.1`

Tunneling

Not all routers can be upgraded simultaneous

- no "flag days"
- how will the network operate with mixed IPv4 and IPv6 routers?

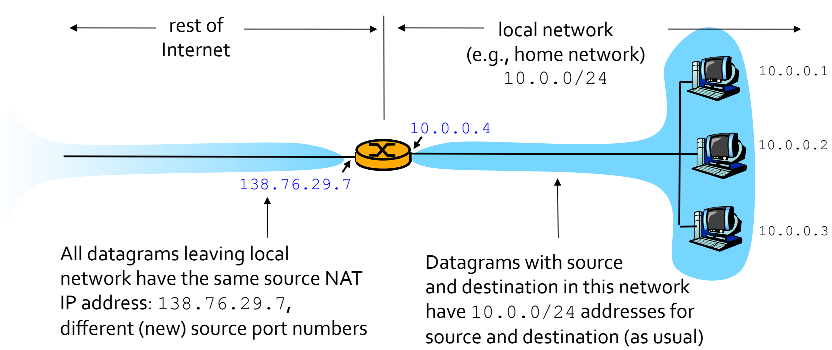


Tunneling:
IPv6 packets carried as payload in IPv4 datagrams among IPv4 routers

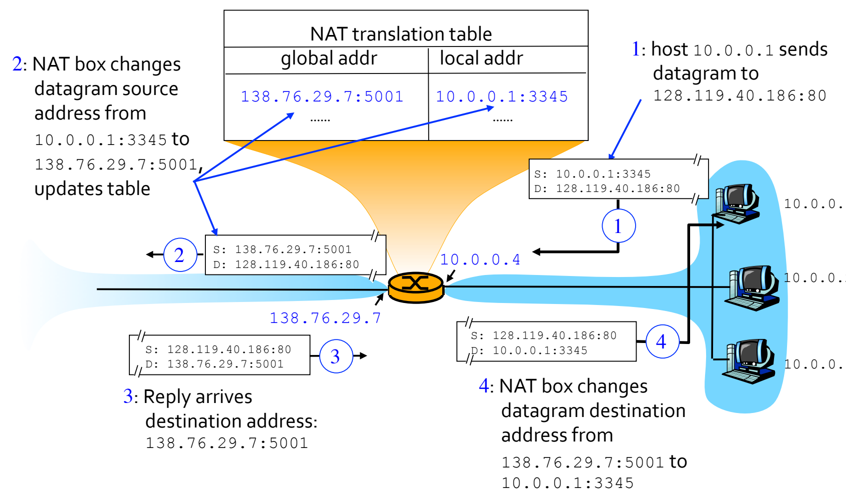
NAT: Network Address Translation

Motivation: a stop-gap measure to handle the IPv4 address exhaustion problem

- share a limited number (≥ 1) of global, static addresses among a number of local hosts
- local to global address binding done per connection, on-demand



NAT: Example



A NAT Box's Functions

Why new port#?

Why not simply use the original source port#?

1. Replaces `<sourceIP, port#>` of every outgoing datagram to `<NATIP, newport#>`
   - update header checksum
   - remote hosts use `<NATIP, newport#>` as destination address
2. In NAT translation table, record every mapping of `<sourceIP, port#>` to `<NATIP, newport#>`
3. Replaces `<NATIP, newport#>` in destination field of every incoming datagram with corresponding `<sourceIP, port#>` stored in the NAT table
   - update header checksum
4. Forwards modified datagrams into the local network

IP Address Space for Private Internets

Three blocks of the IP address space have been reserved for private internets [RFC 1981]:

```
10.0.0.0 - 10.255.255.255 (10/8 prefix)
172.16.0.0 - 172.31.255.255 (172.16/12)
192.168.0.0 - 192.168.255.255 (192.168/16)
```

Why must private Internets use reserved address spaces?

Types of NAT

NAT table maps `iAddr+iPort` of a local host to its `eAddr+ePort`

1. Full-cone NAT:
   - any remote host can send packets intended for `iAddr+iPort` to `eAddr+ePort`
2. IP-restricted NAT:
   - a remote host (`rAddr`) can send packets to `eAddr+ePort` only if `iAddr+iPort` has contacted `rAddr` (at any remote port, `rPort`)
3. Port-restricted NAT:
   - a remote host can send packets to `eAddr+ePort` only using an `rPort` that `iAddr+iPort` has contacted at `rAddr`

Symmetric NAT: `eAddr+ePort` can only be used by a pre-specified connection, `iAddr+iPort+rAddr+rPort`

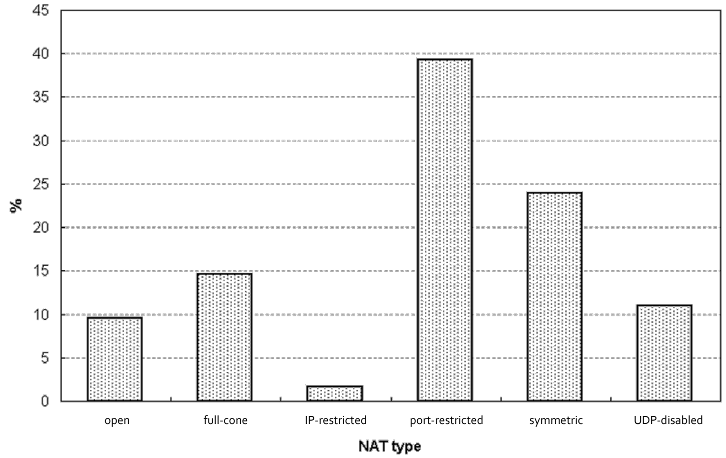
NAT Type Connectivity

	open	full-cone	IP-restricted	port-restricted	symmetric	UDP-disabled
open	✔	✔	✔	✔	✔	✔
full-cone		✔	✔	✔	✔	✗
IP-restricted			✔	✔	✔	✗
port-restricted				✔	✗	✗
symmetric					✗	✗
UDP-disabled						✗

table is symmetric along the diagonal

[Shami '09]

NAT Type Distribution



[Shami '09]

NAT Traversal

STUN (Session Traversal Utilities for NAT):

- an open server that returns to NATted host the `eAddr+ePort` used by its NAT box
- also returns the type of the NAT box

UPnP (Universal Plug and Play):

- allows internal hosts to add static entries into a UPnP-speaking NAT box's mapping table
- used to traverse full-cone NAT
- NAT box returns `eAddr+ePort` that internal host can advertise publicly, e.g., when registering with BitTorrent Tracker

NAT Traversal

TURN (Traversal Using Relays around NAT):

- an open server that serves as a relay for a host behind a symmetric NAT to accept connection (from a single host only, i.e., not for NATted host to act as server)
- also useful to traverse traffic-restrictive firewalls

NAT: Pros

Can change address of devices in local network without notifying outside world

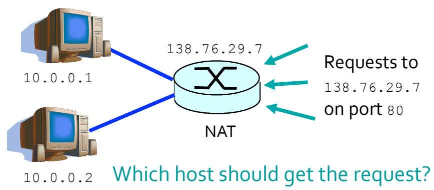
Devices inside local network not explicitly addressable by or visible to the outside world (security through obscurity)

NAT: Cons

Devices inside local network not explicitly addressable by or visible to the outside world, making peer-to-peer networking that much harder

- routers should only process up to layer 3 (port#'s are application layer objects!)
- port#'s are meant to identify sockets, not end hosts!

Address shortage should be solved by IPv6, instead NAT hinders the adoption of IPv6!



NAT: Lesson

Be careful what you propose as a "temporary" patch

"Temporary" solutions have a tendency to stay around beyond expiration date