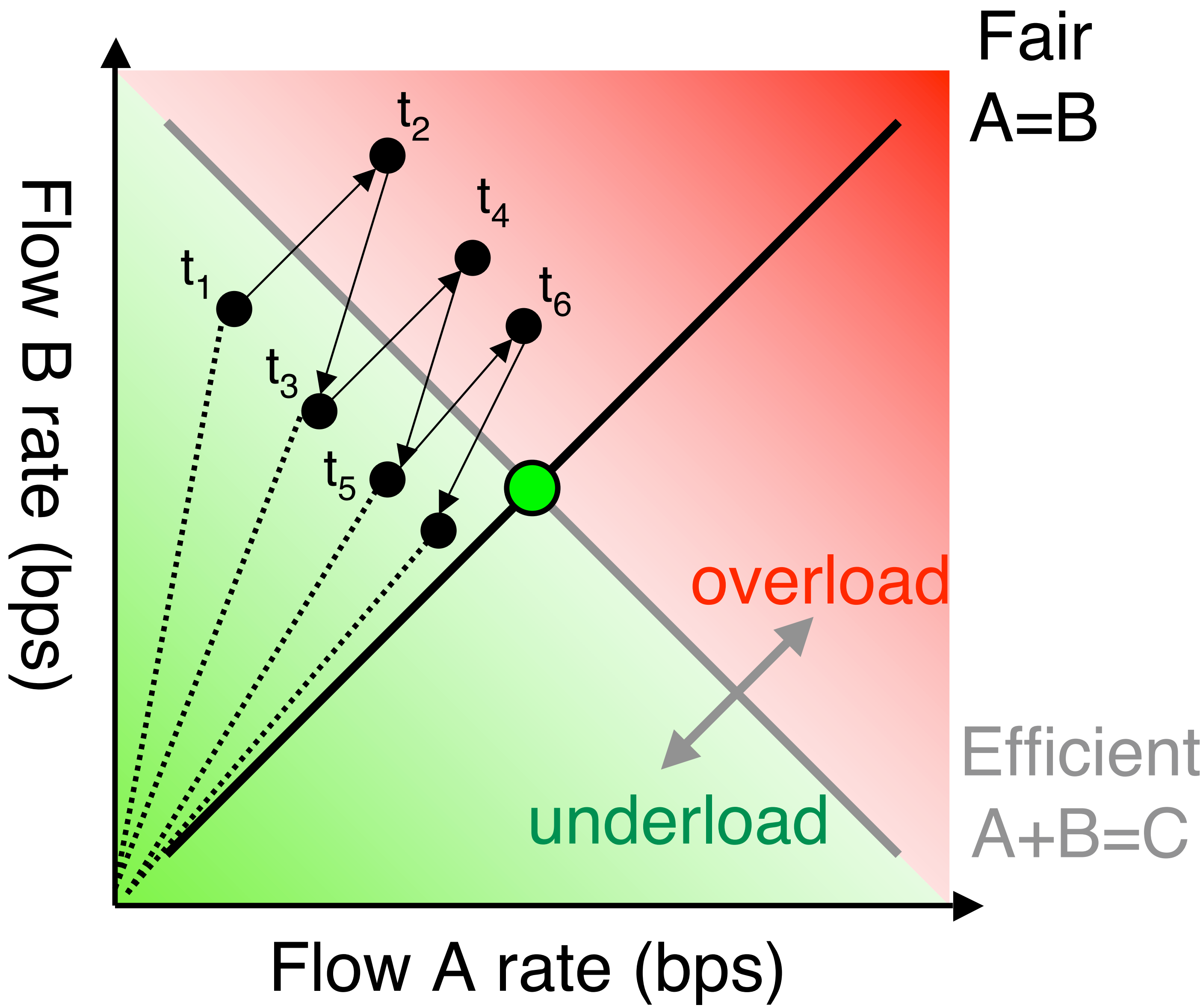
Lecture 8: TCP Friendliness, DCCP, NATs, and STUN

Congestion Control

- TCP dynamically adapts its rate in response to congestion
- AIMD causes flows to converge to fair goodput
- But how do losses (e.g., bit errors) affect goodput?
- What about UDP?

Chiu Jain Phase Plots



Responding to Loss

- **Set threshold to $\frac{cwnd}{2}$**
- **On timeout**
  - Set cwnd to 1
  - Causes TCP to enter slow start
- **On triple duplicate ACK (Reno)**
  - Set cwnd to $\frac{cwnd}{2}$
  - Retransmit missing segment
  - Causes TCP to stay in congestion avoidance

Analyzing TCP Simply

- **Assume all segments are MSS long**
- **Assume a packet loss rate p**
- **Assume a constant RTT**
- **Assume p is small (no timeouts)**

Analysis

- **Window size** W **cuts to** $\frac{W}{2}$ **after a loss**
- **Grows to** W **after** $\frac{W}{2}$ **RTTs**
- **Goodput =** $\frac{3}{4} \cdot W \cdot MTU \cdot \frac{1}{RTT}$

Window Size

- $p = \frac{1}{(\frac{W}{2}+(\frac{W}{2}+1)+...+W)}$
- $p \approx \frac{1}{\frac{3}{8}W^2}$
- $W \approx \sqrt{\frac{8}{3 \cdot p}}$
- **Goodput =** $\frac{3}{4} \cdot \sqrt{\frac{8}{3 \cdot p}} \cdot MTU \cdot \frac{1}{RTT}$
- **Goodput =** $\frac{1.22 \cdot MTU}{RTT \cdot \sqrt{p}}$
- **Constant factor changes based on delayed acks, etc.**

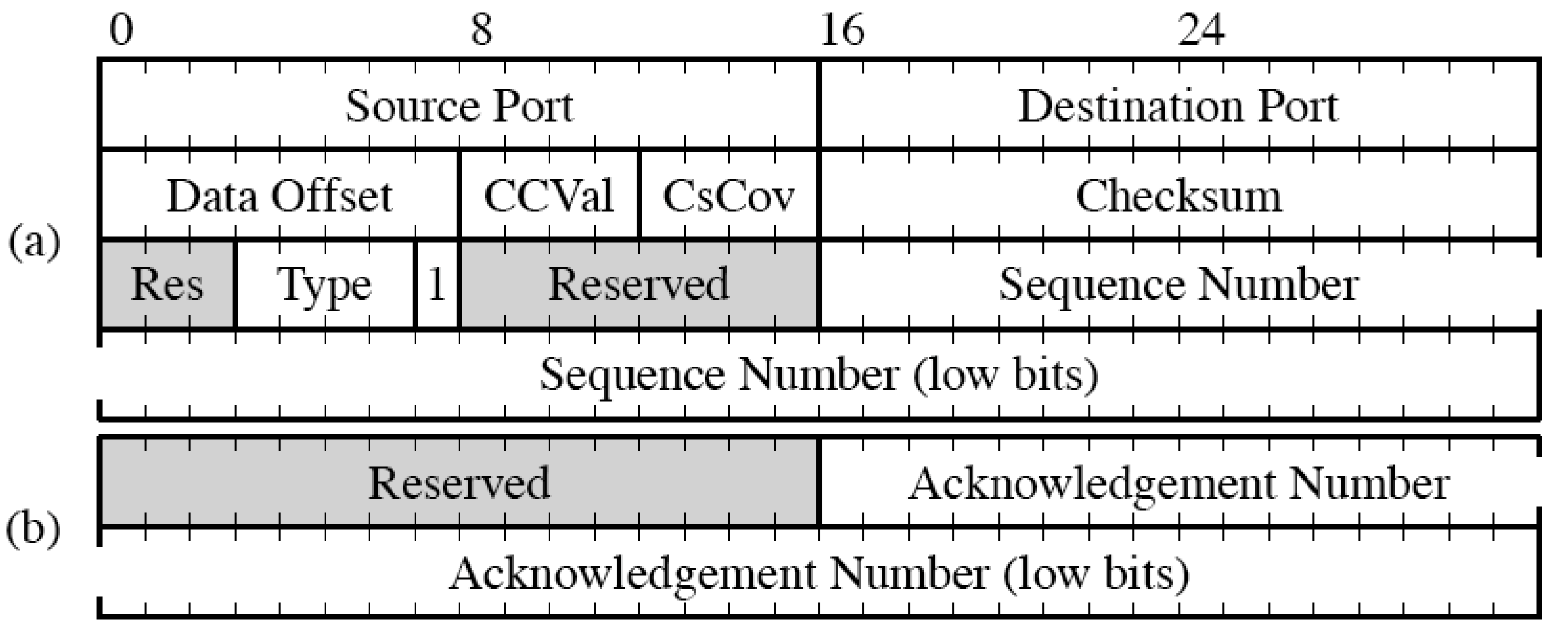
TCP Friendliness

- **Don’t want other protocols to disrupt TCP**
- **UDP happily shuts down TCP flows**
- **“TCP friendliness:” obeying TCP congestion control as per prior goodput equation**
  - Does not imply acting like TCP
  - E.g., does not require abrupt window changes

DCCP

- **Datagram Congestion Control Protocol (DCCP) provides congestion control for unreliable datagrams (RFC 4340)**
- **Connection-oriented protocol**
  - Request-response-ack establishment
  - Close-reset or CloseReq-Close-reset teardown
- **Counts packets, not bytes**

DCCP Segment



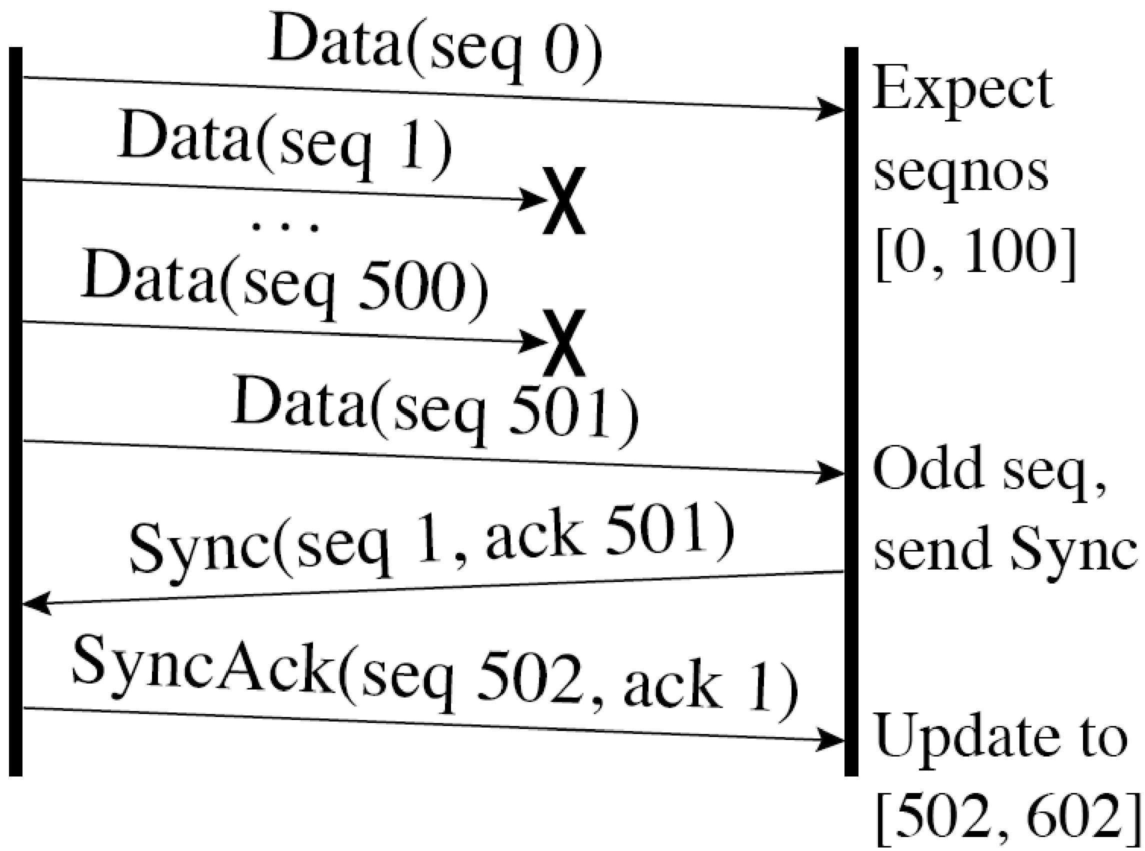
Sequence Numbers

- **Every DCCP packet uses a new sequence number**
  - Data
  - Acknowledgements
  - Control traffic
- **Acknowledgements are for *last packet received***
  - Not cumulative acknowledgements
  - Does not succinctly describe connection history
  - Options can give packet vectors

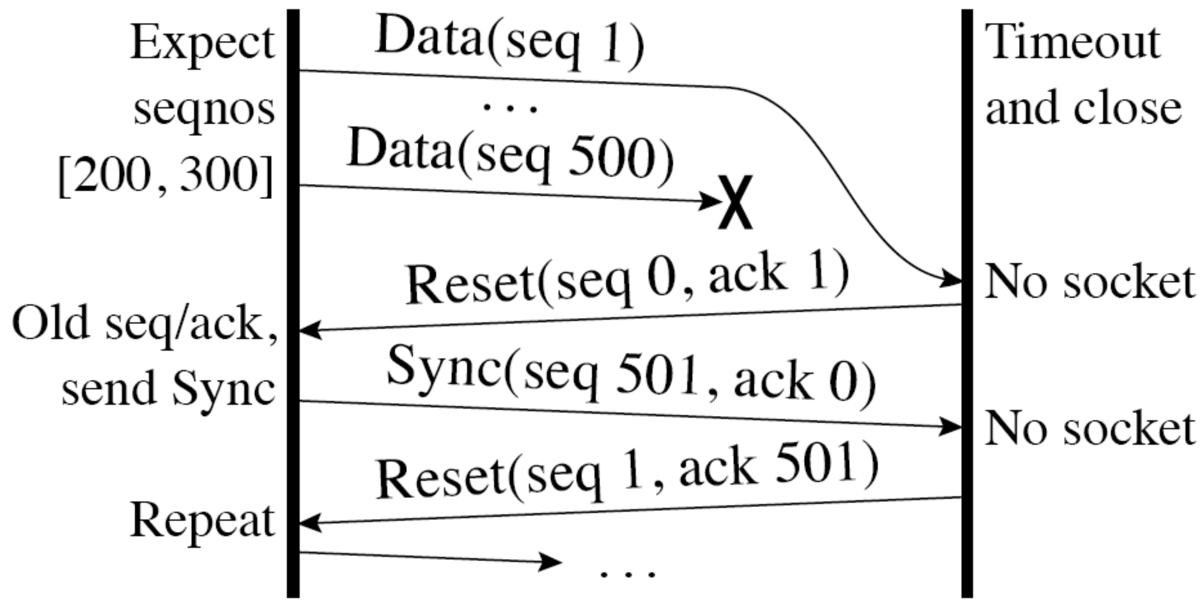
Synchronization

- DCCP uses sequence number windows to protect from attacks
- Large bursts of losses cause packets to fall past windows
- Need to resynchronize

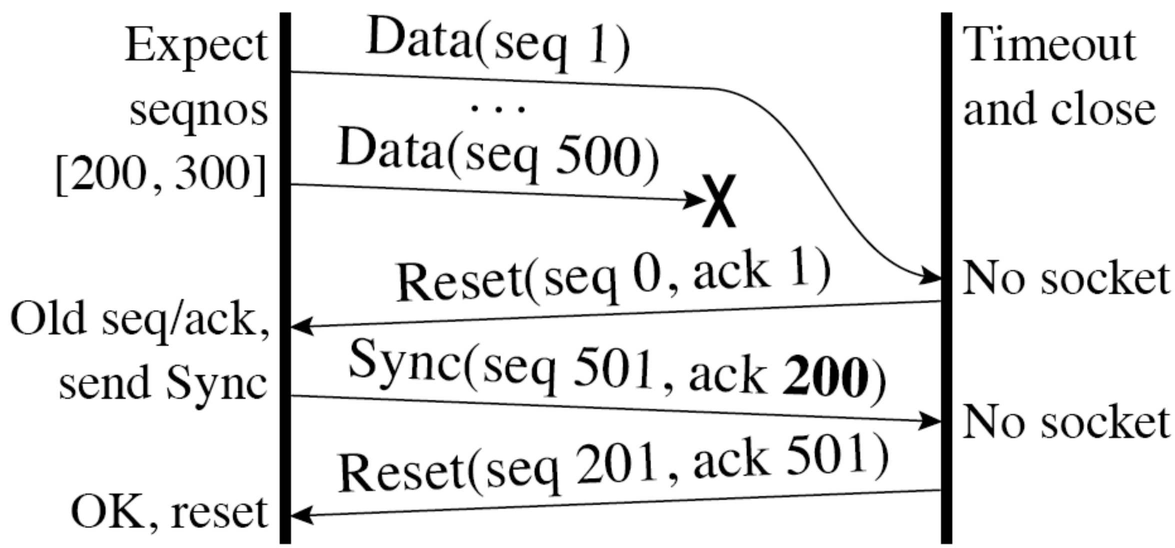
Synchronization Exchange



Synchronization on Reset Problem



Synchronization on Reset Solution



DCCP options

- **Data offset field $\geq$ generic header size**
- **Optional header fields**
  - Padding (`0x00`)
  - Mandatory (`0x01`), reset if not possible
  - Change/Confirm L/R (`0x20, 0x21, 0x22, 0x23`)
  - Ack Vector

Congestion Control

- **Defines Congestion Control IDs (CCIDs)**
- **Negotiated with change/confirm L/R options**
- **Each half-connection can have different congestion control**
- **CCID 2: TCP congestion control (AIMD) (RFC 4941)**
- **CCID 3: TCP-friendly congestion control (RFC 4942)**

Ack Vector

- **0: Received, 1: Received ECN, 2: Reserved, 3: Not yet received**

```
+--------+--------+--------+--------+--------+--------
|0010011?| Length |SSLLLLLL|SSLLLLLL|SSLLLLLL|  ...
+--------+--------+--------+--------+--------+--------
Type=38/39         \___________ Vector ___________...

0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|Sta| Run Length|
+-+-+-+-+-+-+-+-+
```

CCID 2

- **Uses TCP congestion control**
  - Maintains a `cwnd`, slow-start, etc.
- **Adds congestion control to acks**
  - Sender specifies an *AckRatio*, R
  - Ratio of data to ack packets (TCP with delayed ACKs is 2)
  - On detecting ack losses, double R
  - After $\frac{cwnd}{R^2-R}$ lossless congestion windows, decrement R

CCID 3

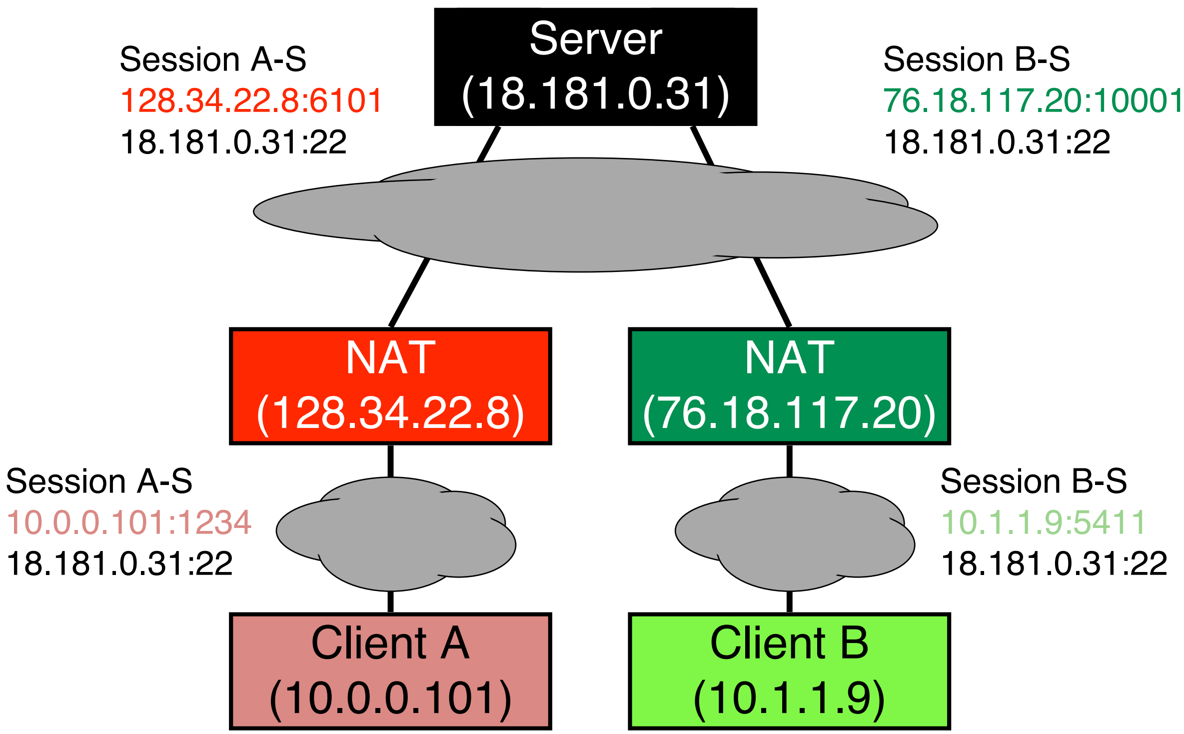
- **Uses TCP-friendly congestion control**
- **Uses a sending rate, rather than a congestion window**
- **Receiver sends feedback once per RTT, reporting loss rate**
- **If sender hears no feedback, halves sending rate**
- **Security issue with loss rate reporting: report *loss intervals*, rather than just a loss rate, verifiable with ECN nonces**

DCCP Today

- **Numerous implementations**
- **IETF Standards Track**
- **Well suited to VoIP, Internet Gaming, etc.**
- **Sees very little use**

NAT

- **Network Address Translator**



Motivations and Complications

- There are only 2^{32} IP addresses
- Firewalls for security
- Breaks end-to-end (node does not know its external IP)
- Node might not even know if it's behind a NAT
- NAT needs to be able to dynamically assign mappings

Types of NAT (RFC 3849)

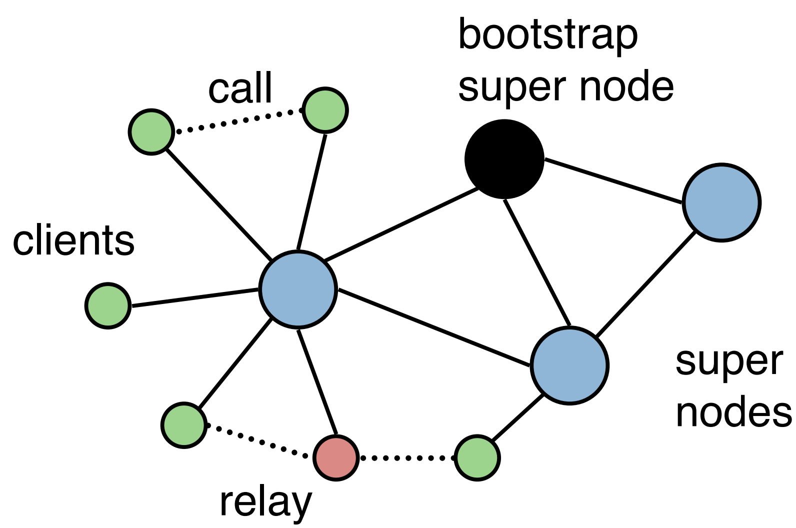
- Full Cone: no ingress filter (single local-external mapping)
- Restricted Cone: ingress filter on address
- Port Restricted: ingress filter on address/port
- Symmetric: different mappings for different external destinations
- Teminology is imperfect (static port mappings, etc.)

How a NAT Works

- **Maps between global and local (IP,port) pairs**
- **Requires knowledge of transport packet format**
- **UDP datagram, TCP SYN**
  - Can shut down TCP mapping on FIN+ACK
  - UDP requires timeouts ($>$ 2 minutes, unless IANA says otherwise)
- **RFC 4787/BCP 127 defines recommended behaviors**

NAT Problems

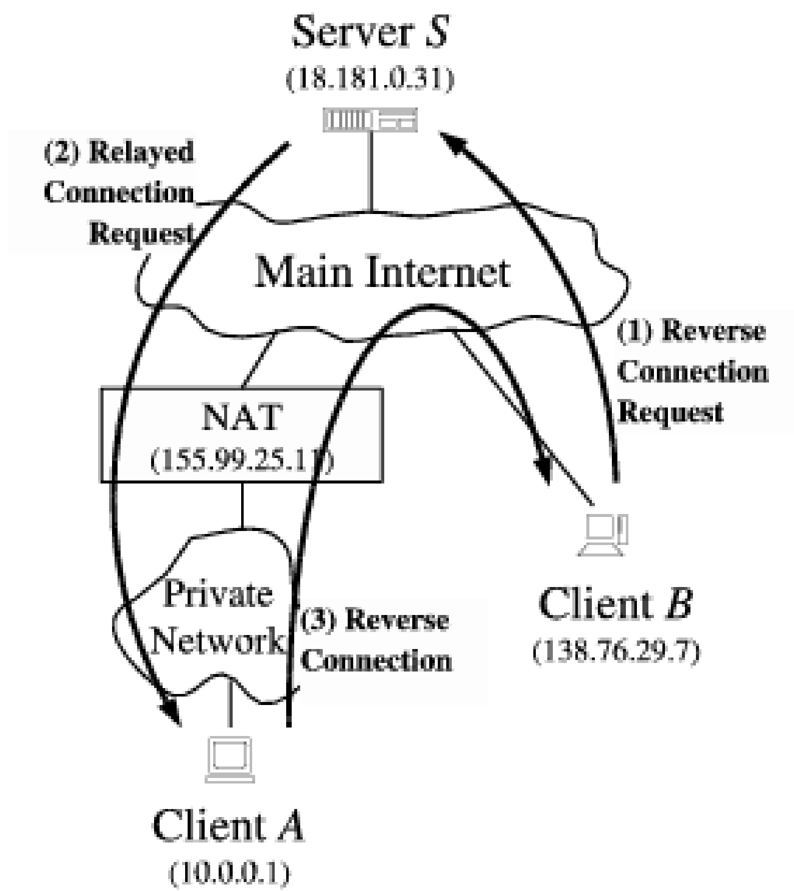
- **Incoming TCP connections**
- **E.g., Skype**



TCP Through NATs

- Server socket doesn't initiate traffic: NAT can't set up mapping
- Rendezvous servers (as in Skype)
- Connection reversal through rendezvous if only one is behind a NAT (rendezvous server asks un-NAT node to open a port so NAT node can connect)

TCP Reversal



More NAT Problems

- Port mapping: 0-1023 should map to 0-1023
- Port parity: even port → even port, odd port → odd port (RFC 3550: RTP uses even, RTCP uses odd))
- Hairpinning: two nodes behind a NAT communicate with external IPs

STUN (RFC 3849)

- **"Simple Traversal of User Datagram Protocol (UDP) Through Network Address Translators (NATs)"**
- **Enables a node to**
  - Determine if it is behind a NAT, and if so, what kind
  - Obtain a public IP address/port pair
- **Client-server protocol, requires no changes to NATs**
- **STUN server coordinates**

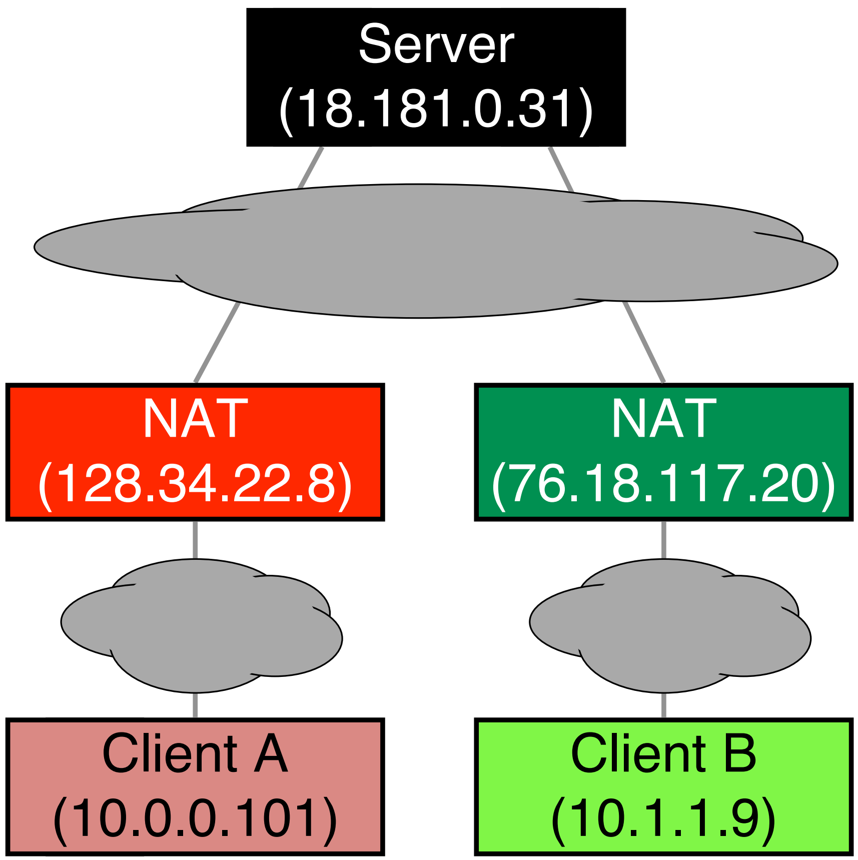
STUN Binding Requests

- **Node sends BR to STUN server**
- **STUN sends a response that has the address and port it sees**
  - If different than node's local address and port, it's behind a NAT
- **Node can probe to see what kind of NAT**
  - Ask STUN server to respond from different address: no response, address restricted; different response, symmetric
  - Ask STUN server to respond from different port: no response, port restricted
- **When does STUN not work?**

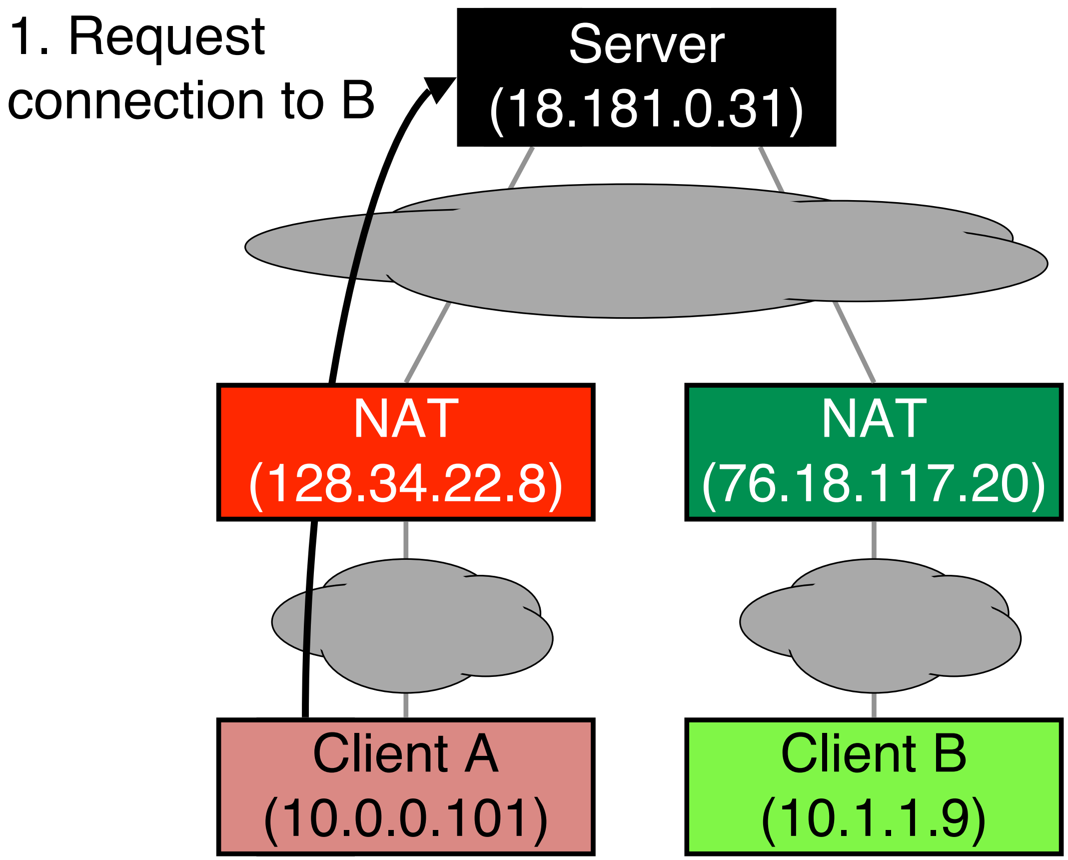
NAT Hole-Punching

- **Problem with STUN: doesn't work when two nodes are behind same NAT**
- **Two nodes A, B communicate with server S**
- **A and B report their local IP address to server**
- **Server tells the other the address/port pair** (L, G)
- **A tries to send UDP packets to** (L_B, G_B) **using** L_A
- **B tries to send UDP packets to** (L_A, G_A) **using** L_B

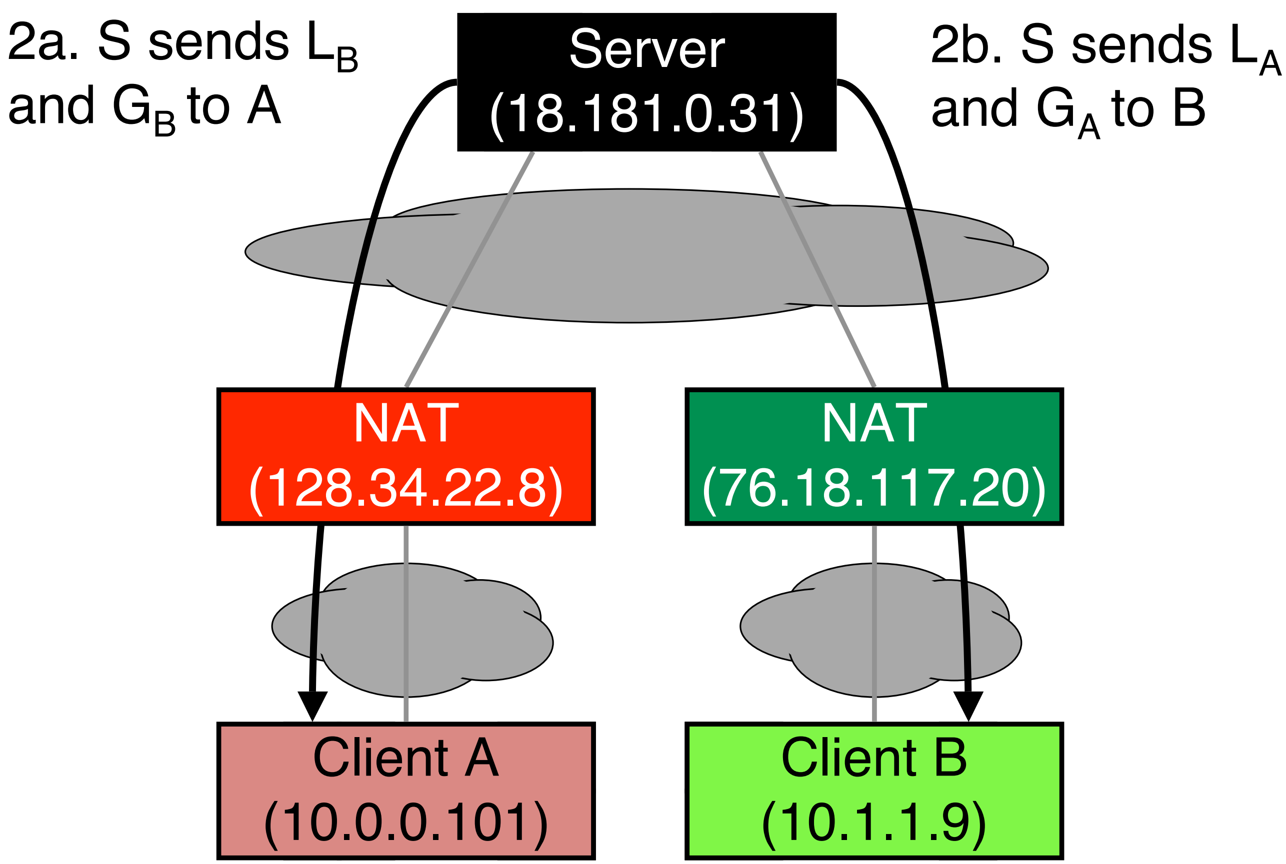
NAT Hole-Punching Example



NAT Hole-Punching Example



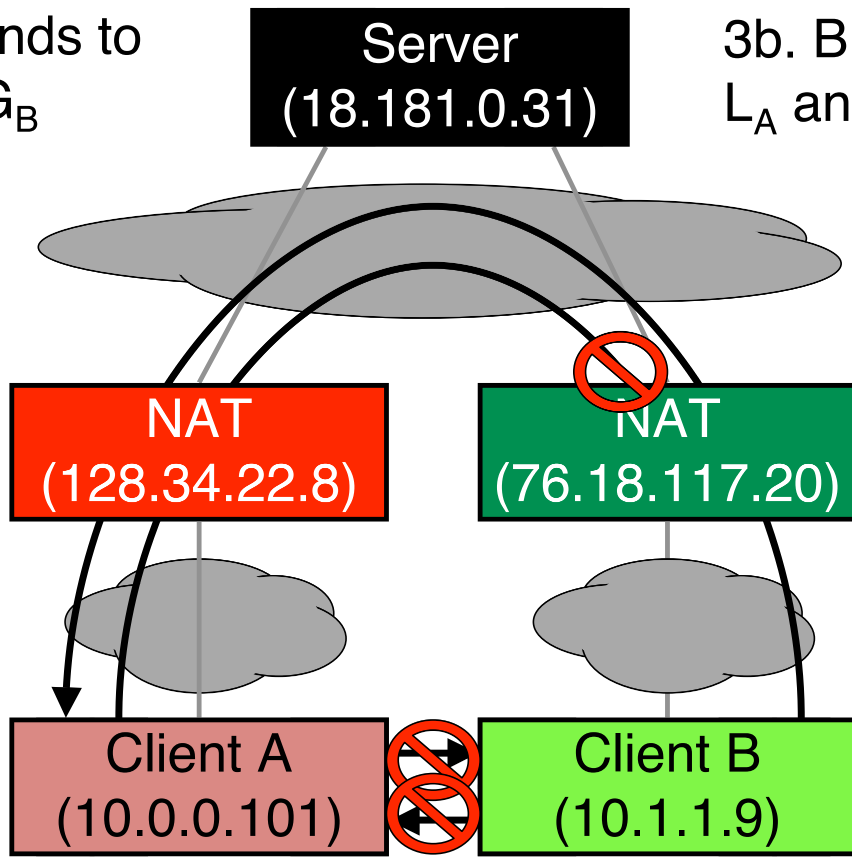
NAT Hole-Punching Example



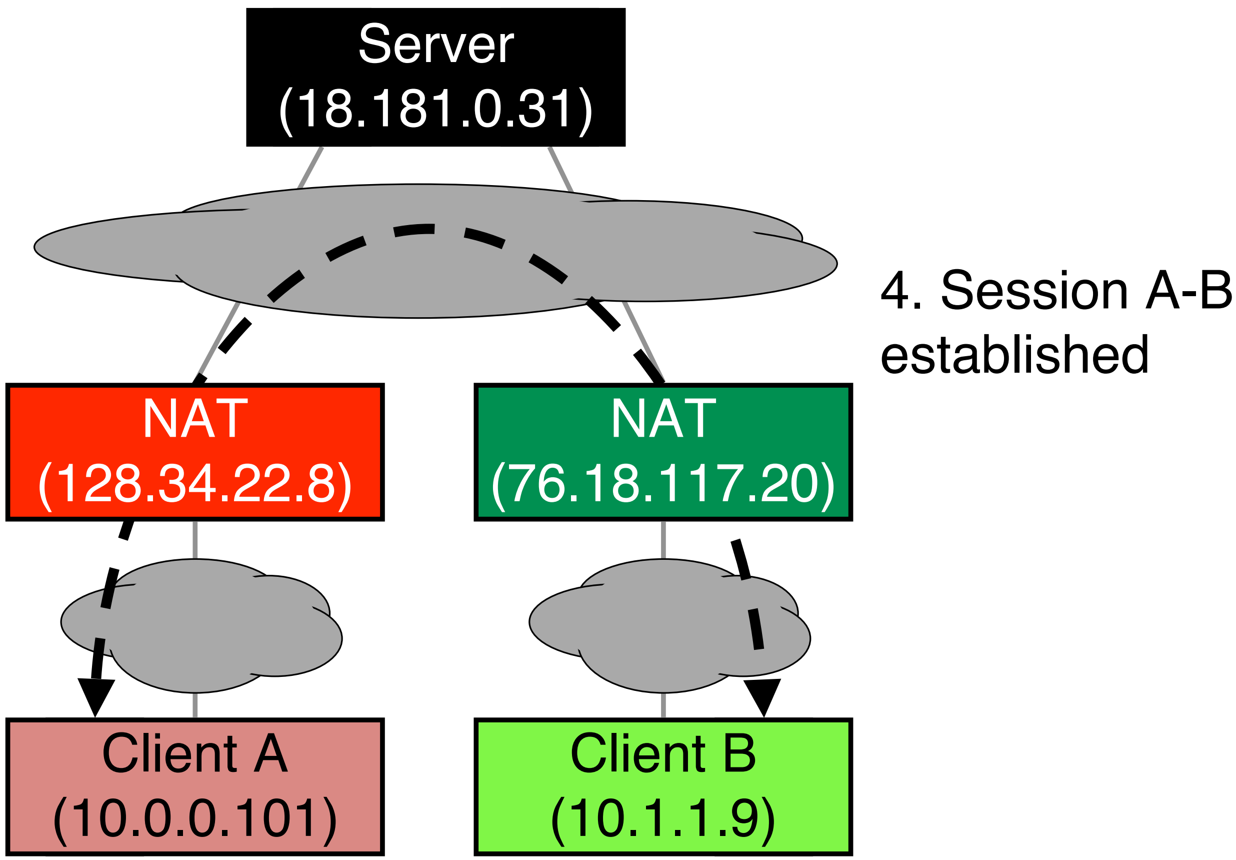
NAT Hole-Punching Example

3a. A sends to L_B and G_B

3b. B sends to L_A and G_A

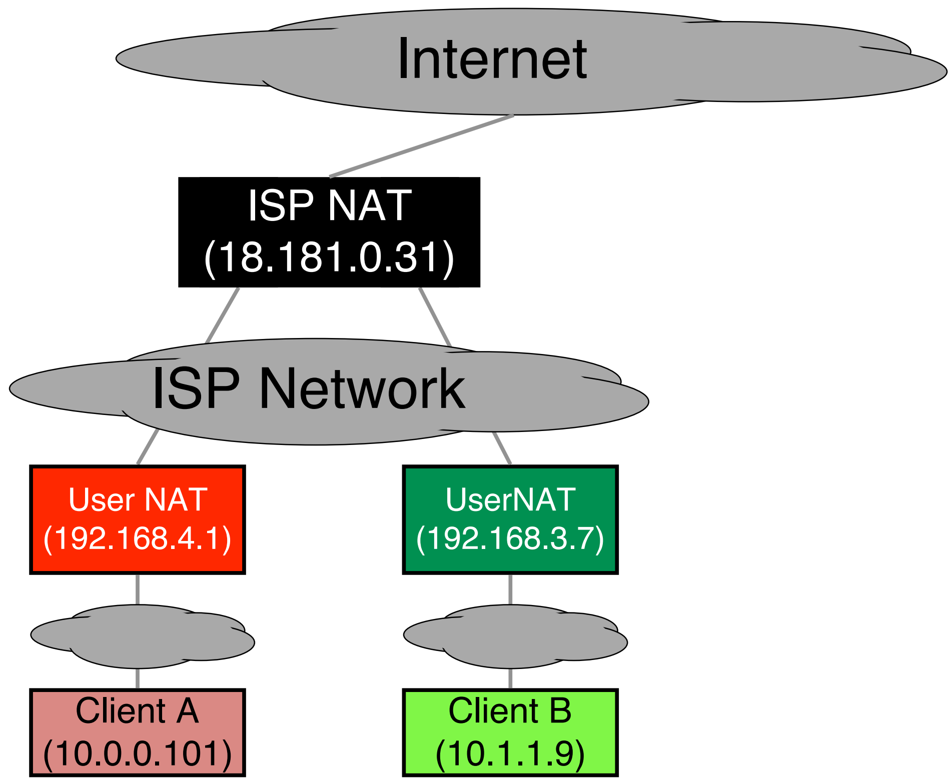


NAT Hole-Punching Example



Multiple NAT Layers

- **Common for consumer Internet: ISP has internal NAT, end user places another NAT**
- **Requires hairpinning at ISP NAT**



The New Hourglass