Peer-to-Peer Networks
16 Hole Punching

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Peer-to-Peer Networks

NAT, PAT & Firewalls

Network Address Translation

- Problem
  - too few (e.g. one) IP addresses for too many hosts in a local network
  - hide hosts IP addresses from the outer world
- Basic NAT (Static NAT)
  - replace internal IP by an external IP
- Hiding NAT
  - = PAT (Port Address Translation)
  - = NAPT (Network Address Port Translation)
  - Socket pair (IP address and port number) are transformed
  - to a single outside IP address
- Hosts in local network cannot be addressed from outside

DHCP Dynamic Host Configuration Protocol

- DHCP (Dynamic Host Configuration Protocol)
  - manual binding of MAC address
    - e.g. for servers
  - automatic mapping
    - fixed, yet not pre-configured
  - dynamic mapping
    - addresses may be reused
- Integration of new hosts without configuration
  - hosts fetches IP address from DHCP server
  - sever assigns address dynamically
  - when the hosts leaves the network the IP address may be reused by other hosts
  - for dynamic mapping addresses must be refreshed
  - if a hosts tries to reuse an outdated address the DHCP server denies this request
  - problem: stealing of IP addresses
- P2P
  - DHCP is good for anonymity
    - if the DHCP is safe
  - DHCP is bad for contacting peers in local networks

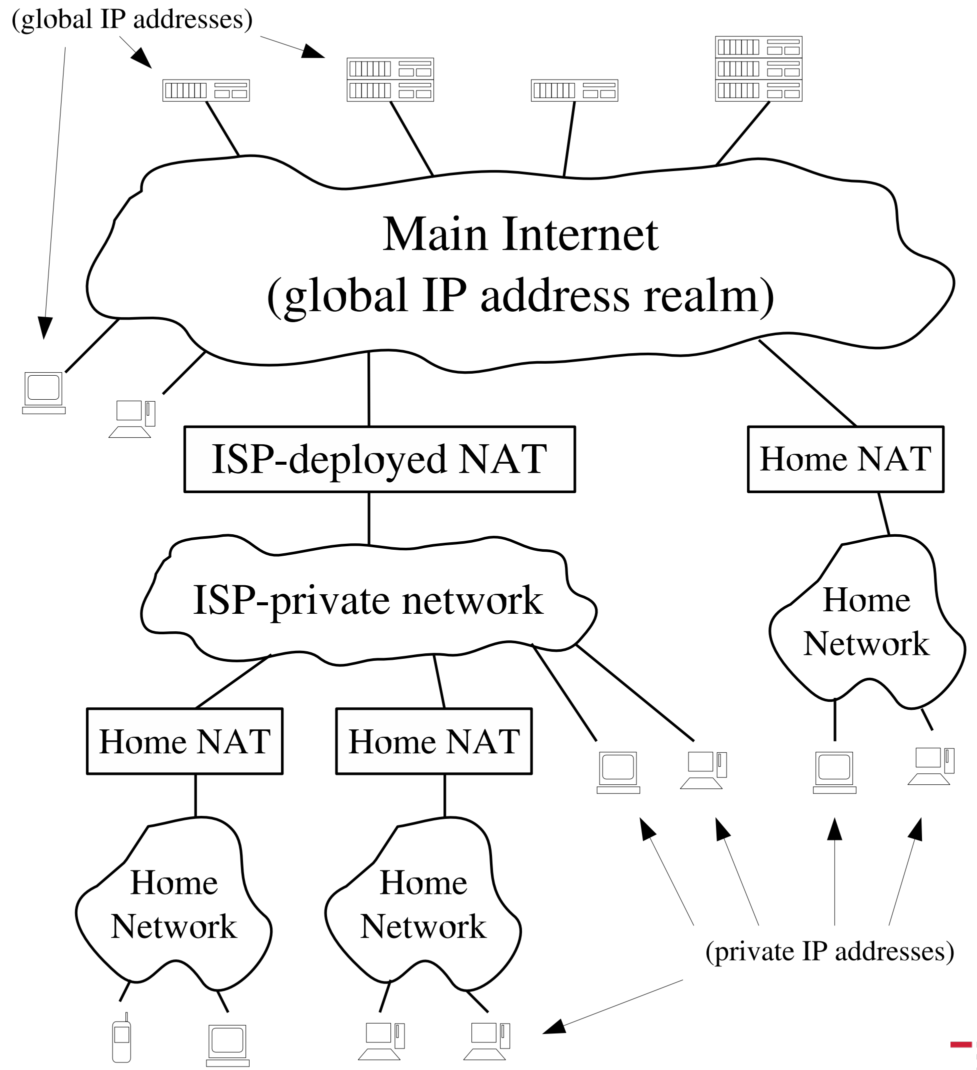
Firewalls

- Types of Firewalls
  - Host Firewall
  - Network Firewall
- Network Firewall
  - differentiates between
    - external net
      - Internet, hostile
    - internal net
      - LAN, trustworthy
    - demilitarized zone
      - servers reachable from the external net
- Host Firewall
  - e.g. personal firewall
  - controls the complete data traffic of a host
  - protection against attacks from outside and inside (trojans)
- Methods
  - Packet Filter
    - blocks ports and IP addresses
  - Content Filter
    - filters spam mails, viruses, ActiveX, JavaScript from html pages
  - Proxy
    - transparent (accessible and visible) hots
    - channels the communication and attacks to secured hosts
  - Stateful Inspection
    - observation of the state of a connection
- Firewalls can prevent Peer to Peer connections
  - on purpose or as a side effect
  - are treated here like NAT

Types of Firewalls & NATs (RFC 3489)

- Open Internet
  - addresses fully available
- Firewall that blocks UDP
  - no UDP traffic at all
  - hopeless, maybe TCP works?
- Symmetric UDP Firewall
  - allows UDP out
  - responses have to come back to the source of the request
  - like a symmetric NAT, but no translation
- Full-cone NAT
  - if an internal address is mapped to an external address all packets will be sent through this address
  - External hosts can send packets to the external address which are delivered to the local address
- Symmetric NAT
  - Each internal request is mapped to a new port
  - Only a contacted host can send a message inside
    - on the very same external port arriving on the internal port
- Restricted cone NAT
  - Internal address are statically mapped to external addresses
  - All such UDP packets of one internal port use this external port
  - All external hosts can use this port to sent a packet to this host if they have received a packet recently from the same internal port (to any external port)
- Port restricted cone NAT
  - All UDP packets from one internal address use the same external port
  - External hosts must use this port to sent a packet to this host if they have received a packet recently from the same internal port to the same external port

Combination of NATs

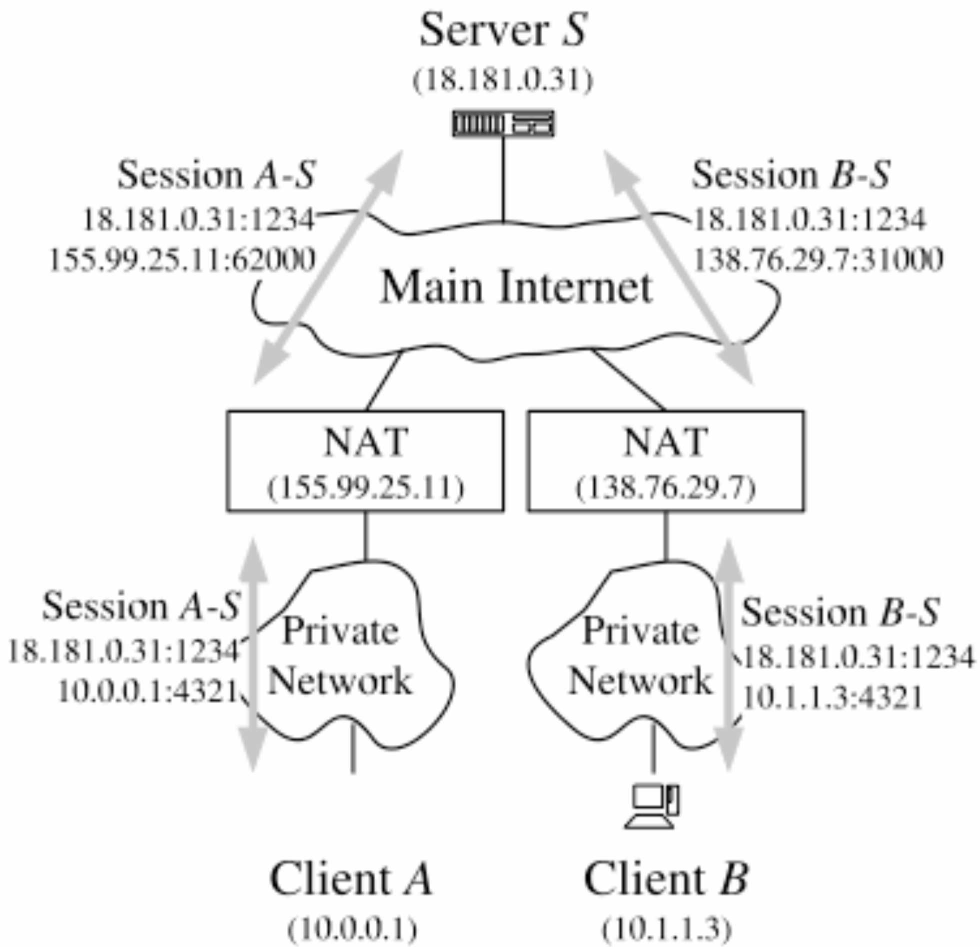


Peer-to-Peer Communication Accross Network Address Translators

Bryan Ford, Pyda Srisuresh, Dan Kegel

Overcoming NAT by Relaying

- Relaying
  - use a open (non-NATed) server to relay all UDP or TCP connections
  - first both partners connect to the server
  - then, the server relays all messages



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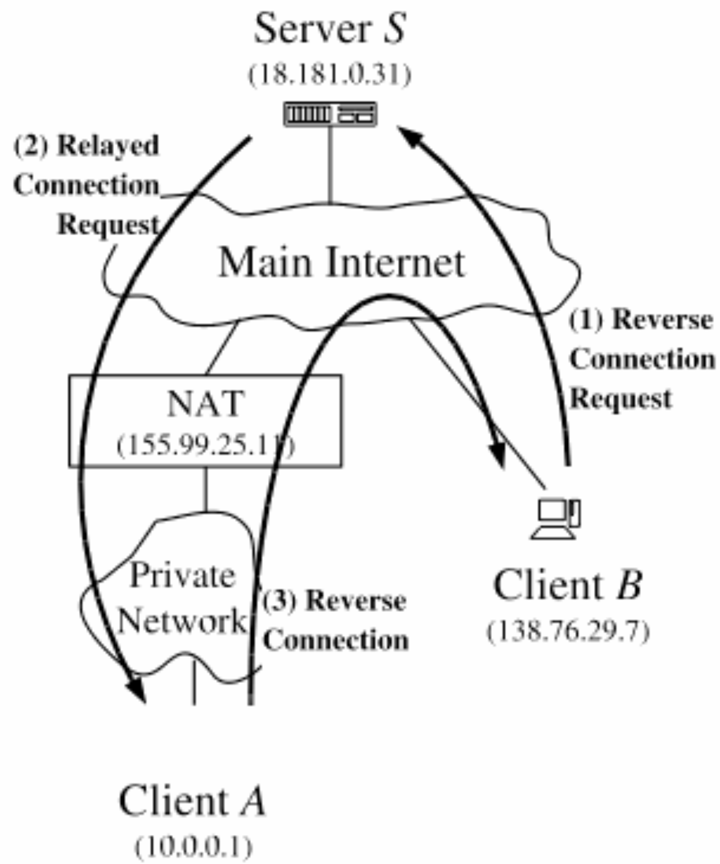
Connection Reversal

- If only one peer is behind NAT
  - then the peer behind NAT always starts connection
- Use a server to announce a request for connection reversal
  - periodic check for connection requests is necessary



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Peer-to-Peer Networks

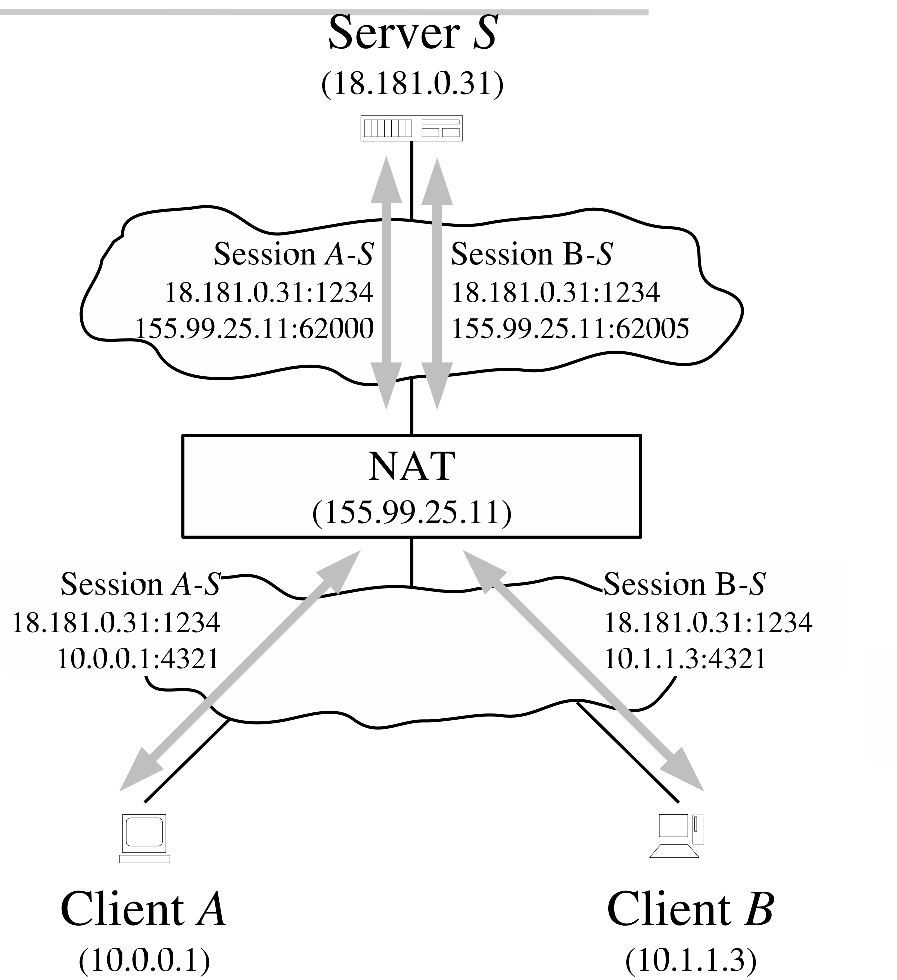
UDP Hole Punching

UDP Hole Punching

- Dan Kegel (1999), NAT and Peer-to-Peer Networking, Technical Report Caltech
- A does not know B‘s address
- Algorithm
  - A contacts rendezvous server S and tells his local IP address
  - S replies to A with a message containing
    - B‘s public and private socket pairs
  - A sends UDP packets to both of this addresses
    - and stays at the address which works

UDP Hole Punching

- Peers Behind a Common NAT
  - Rendezvous server is used to tell the local IP addresses
  - Test with local IP address establish the connections in the local net



Before Hole Punching

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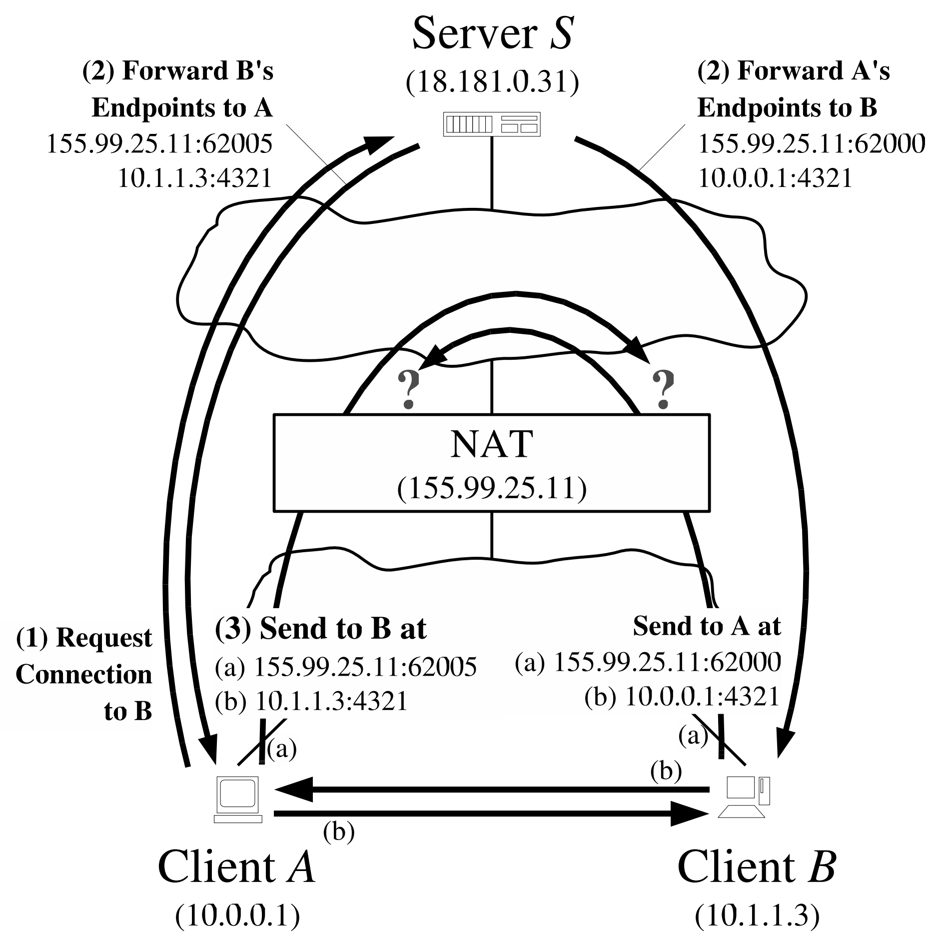

The Hole Punching Process

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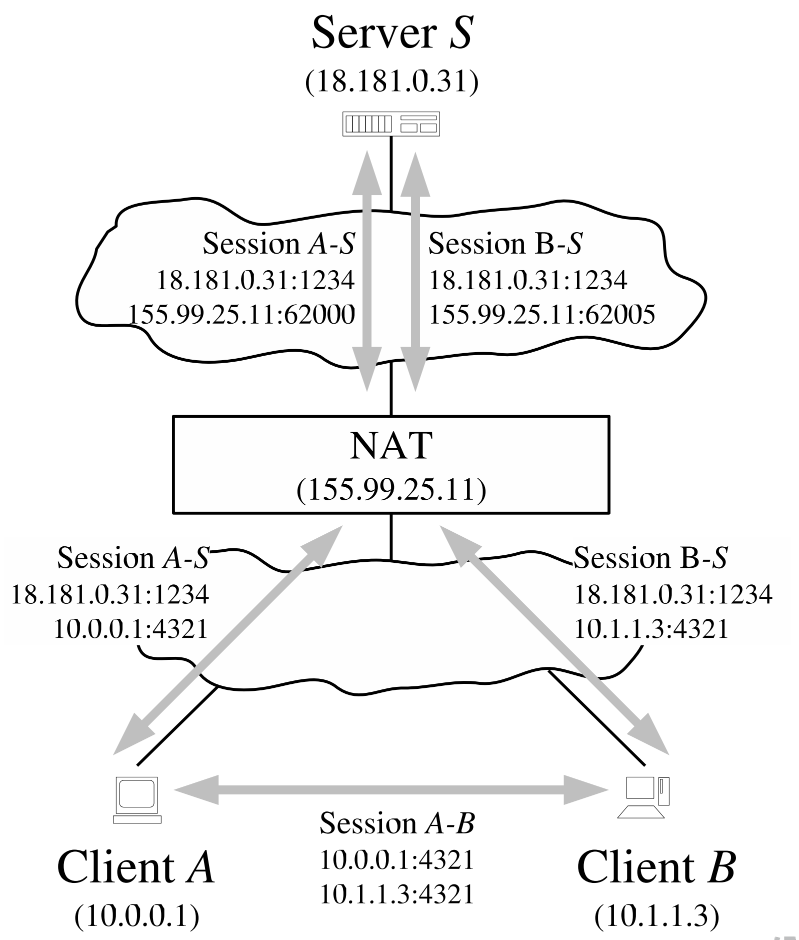

After Hole Punching

Peer-to-Peer Communication Accross Network Address Translators

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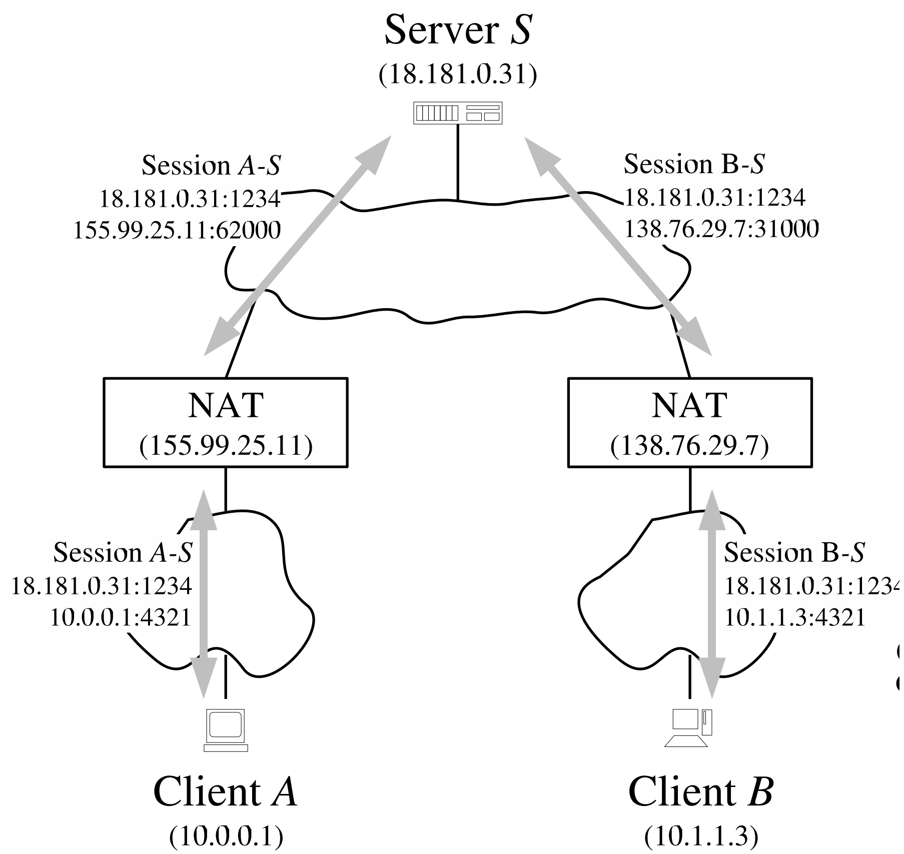
UDP Hole Punching

- Peers Behind Different NATs
  - Rendezvous server is used to tell the NAT IP addresses
  - Test with NAT IP address establishes the connections
  - Peers reuse the port from the Rendezvous server



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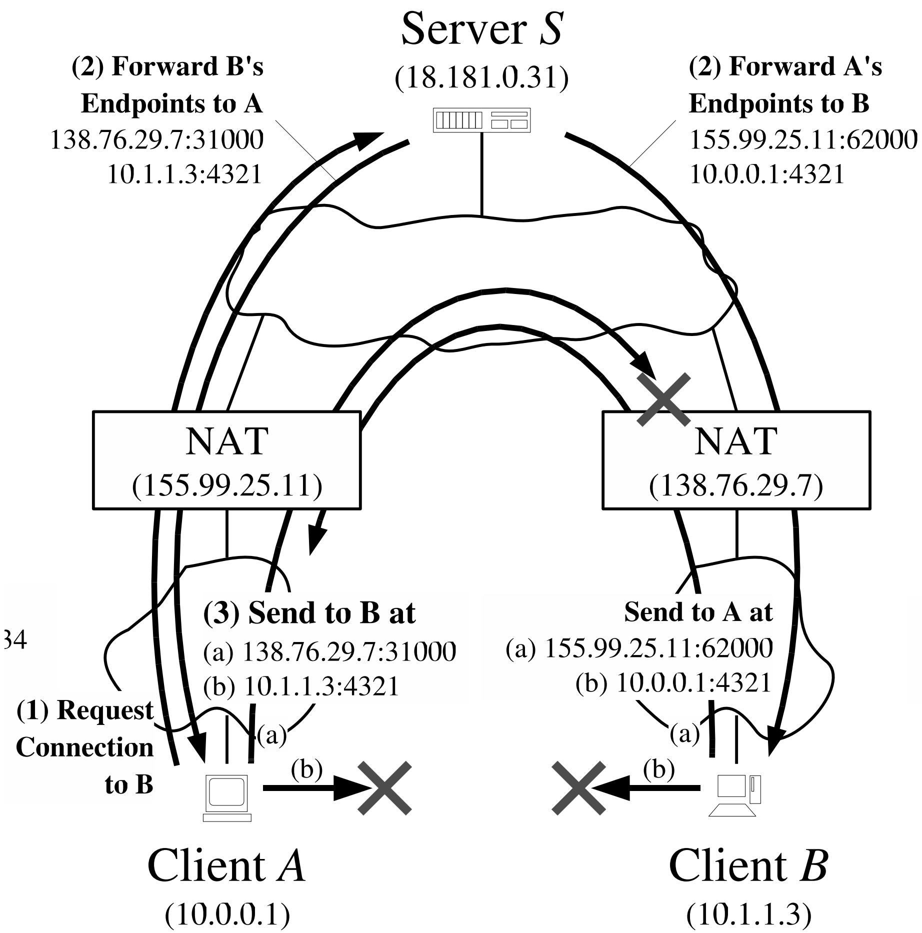

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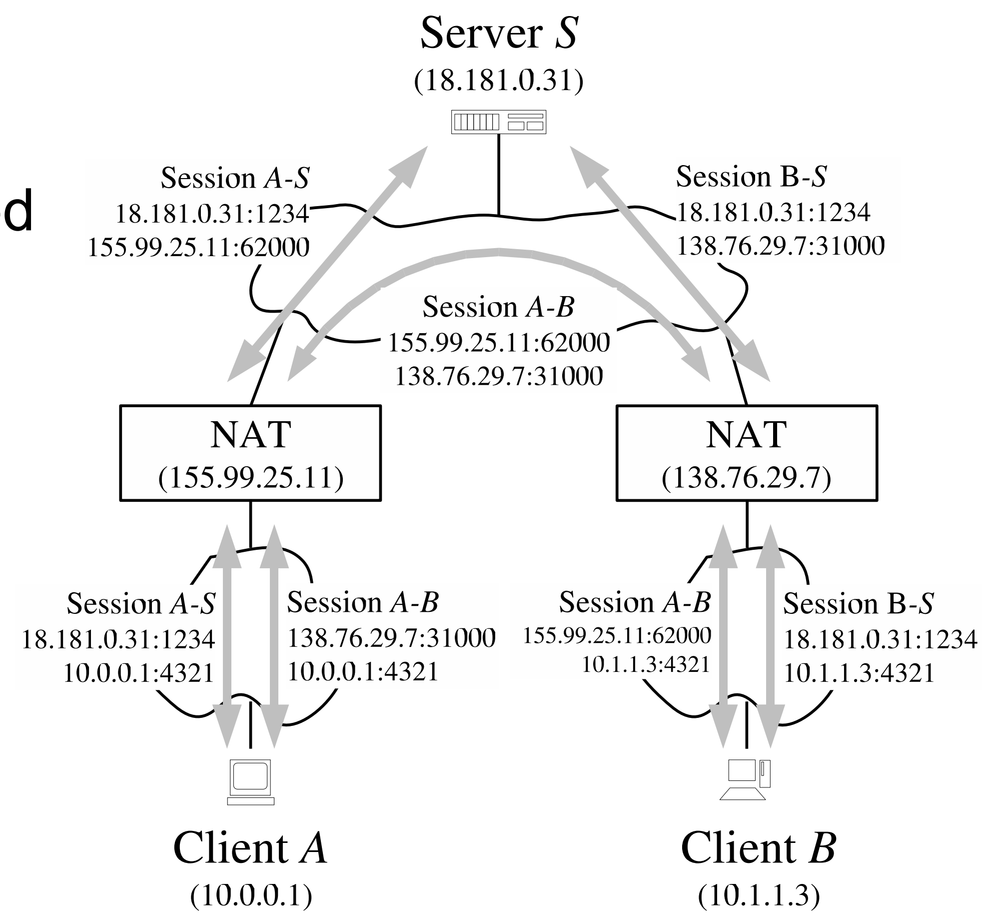

After Hole Punching

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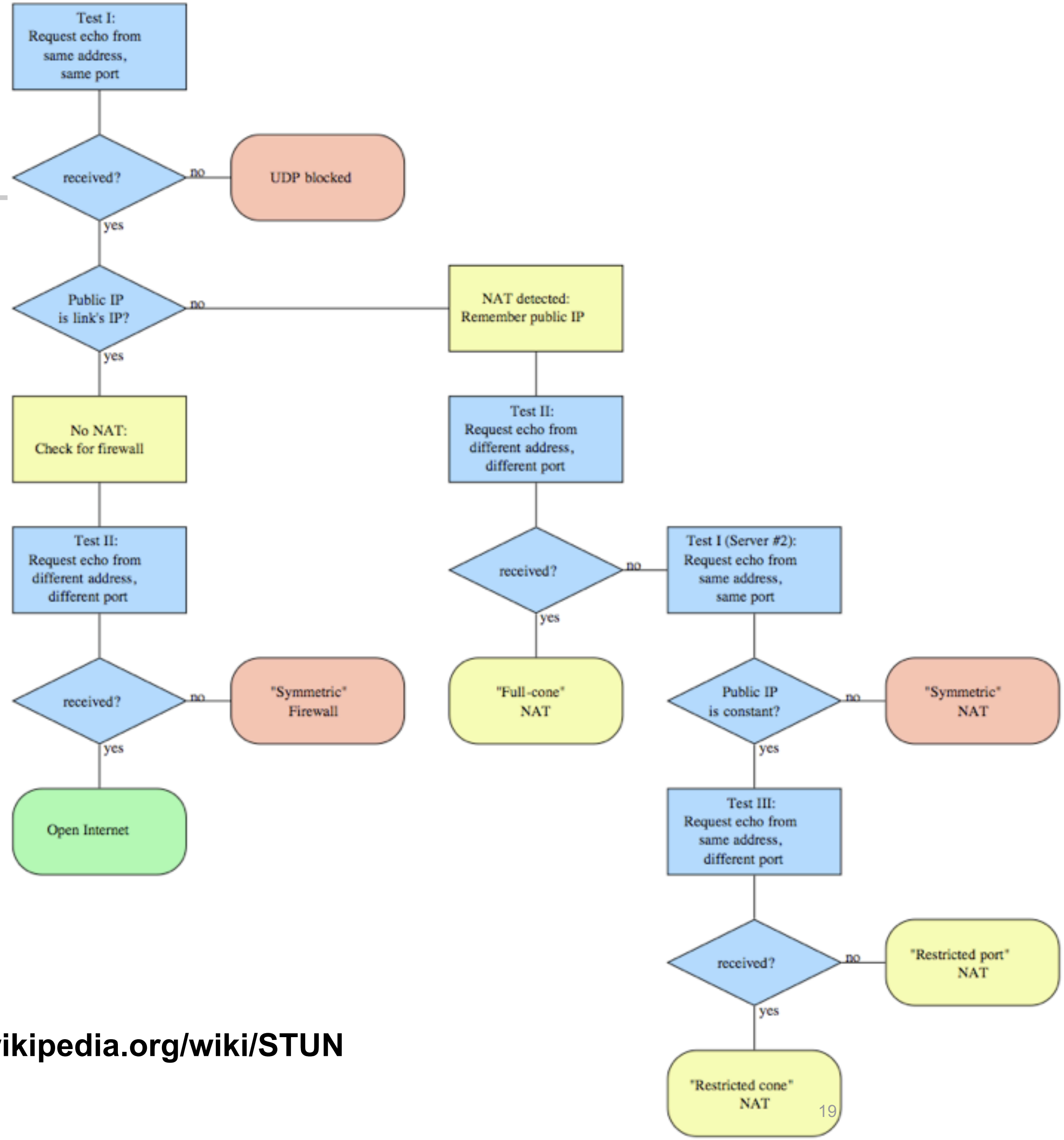
Simple traversal of UDP over NATs (STUN)

- RFC 3489, J. Rosenberg, C. Huitema, R. Mahy, STUN - Simple Traversal of User Datagram Protocol Through Network Address Translators (NATs), 2003
- Client-Server Protocol
  - Uses open client to categorize the NAT router
- UDP connection can be established with open client
  - Tells both clients the external ports and one partner establishes the connection
- Works for Full Cone, Restricted Cone and Port Restricted Cone
  - Both clients behind NAT router can initialize the connection
  - The Rendezvous server has to transmit the external addresses
- Does not work for Symmetric NATs

STUN

- Client communicates to at least two open STUN server



NAT types

from: http://en.wikipedia.org/wiki/STUN

Peer-to-Peer Networks

TCP Hole Punching

TCP versus UDP Hole Punching

Category	UDP	TCP
Connection?	no	yes
Symmetry	yes	no client uses „connect“, server uses „accept“ or „listen“
Acknowledgments	no	yes must have the correct sequence numbers

P2P-NAT

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- Prerequisite
  - change kernel to allow to listen and connect TCP connections at the same time
  - use a Rendezvous Server S
  - Client A and client B have TCP sessions with s
- P2P-NAT
  - Client A asks S about B's addresses
  - Server S tells client A and client B the public and private addresses (IP-address and port number) of A and B
  - From the same local TCP ports used to register with S
    - A and B synchronously make outgoing connection attempts to the others' public and private endpoints
  - A and B
    - wait for outgoing attempts to succeed
    - wait for incoming connections to appear
    - if one outgoing connection attempt fails („connection reset", „host unreachable") then the host retries after a short delay
  - Use the first established connection
  - When a TCP connection is made the hosts authenticate themselves

P2P-NAT

- Peer-to-Peer Communication Accross Network Address Translators
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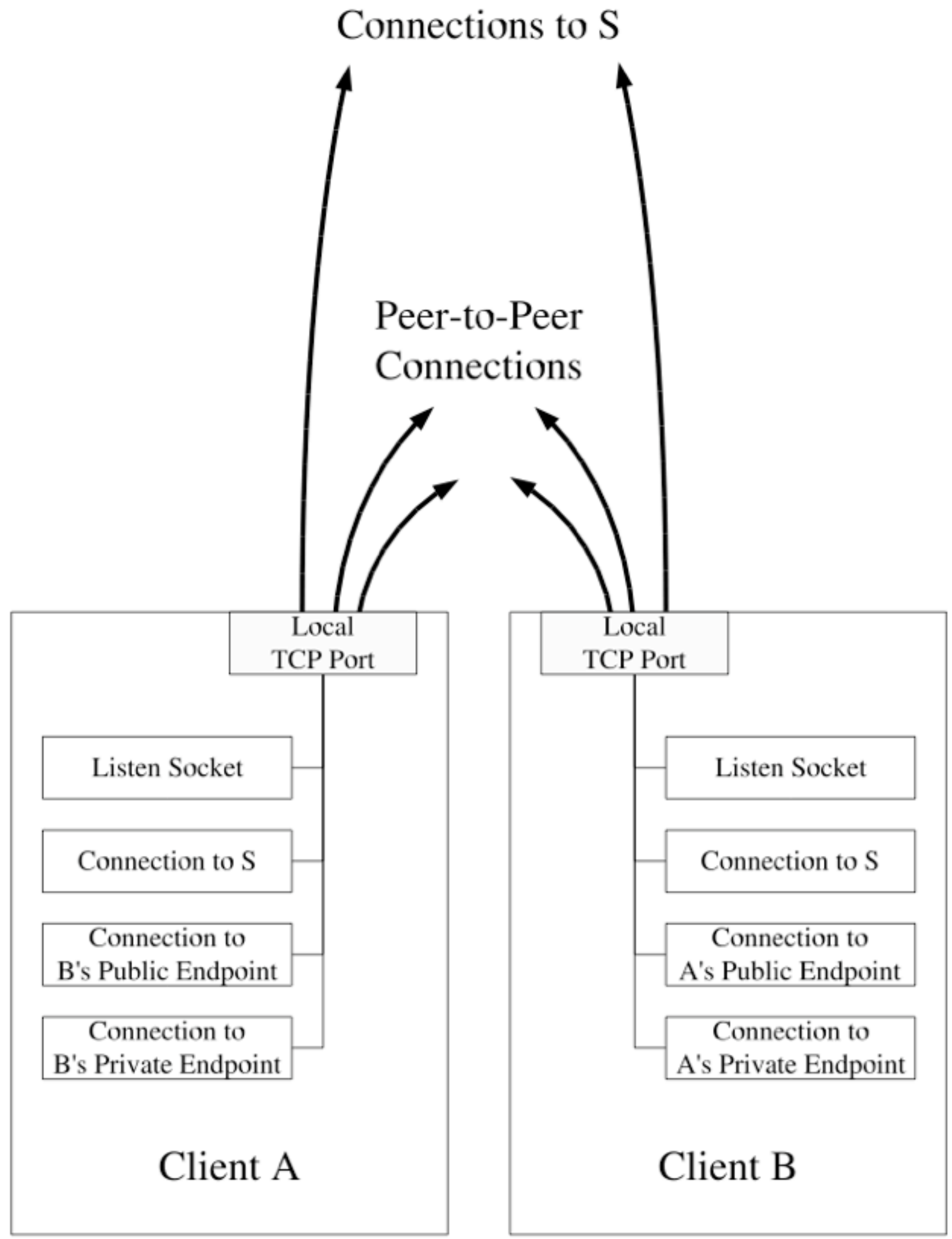


Figure 7: Sockets versus Ports for TCP Hole Punching

P2P-NAT

- Behavior for *nice* NAT-routers of A
  - The NAT router of A learns of outgoing TCP-connection when A contacts B using the public address
    - A has punched a hole in its NAT
  - A‘s first attempts may bounce from B‘s NAT router
  - B‘s connection attempt through A‘s NAT hole is successful
  - A is answering to B‘s connection attempt
  - B‘s NAT router thinks that the connection is a standard client server
- Some packets will be dropped by the NAT routers in any case
- This connection attempt may also work if B has punched a hole in his NAT router before A
  - The client with the weaker NAT router is the server in the TCP connection

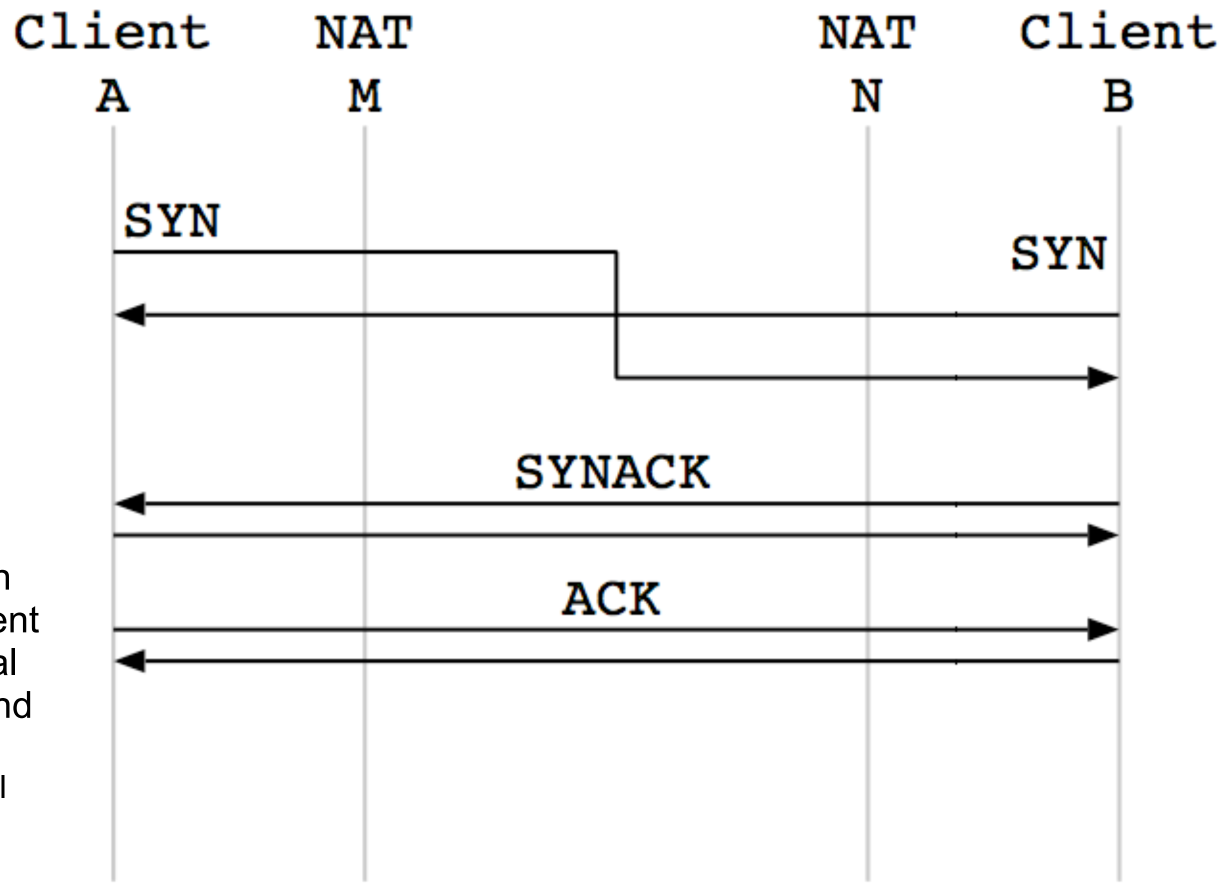
P2P-Nat
Problems with Acks?

- Suppose A has punched the hole in his router
- A sends SYN-packet
- but receives a SYN packet from B without Ack
  - so the first SYN from A must be ignored
- A replies with SYN-ACK to B
- B replies with ACK to A
  - all is fine then
- Alternatively:
  - A might create a new stream socket associated with B‘s incoming connection start
    - a different stream socket from the socket that A hole punching TCP SYN message
    - this is regarded as a failed connection attempt
  - Also results in a working connection

P2P-NAT
The Lucky (?) Case

- What if both clients A and B succeed synchronously?
- When both clients answere to the SYN with a SYN-ACK
  - results in **simultaneous TCP open**
- Can result in the failure of the connection
  - depends on whether the TCP implementation accepts a simultaneous successful „accept()“ and „connect()“ operation
- Then, the TCP connection should work correctly
  - if the TCP implementation complies with RFC 793
- The TCP connection has been „magically“ created itself from the wire
  - out of nowhere two fitting SYN-ACKs have been created.

P2P-NAT Working Principle



(d) P2PNAT

Picture from
Characterization and Measurement of TCP Traversal through NATs and Firewalls
Saikat Guha, Paul Francis

Success Rate of UDP Hole Punching and P2P-NAT (2005)

	UDP				TCP			
	Hole Punching		Hairpin		Hole Punching		Hairpin	
NAT Hardware								
Linksys	45/46	(98%)	5/42	(12%)	33/38	(87%)	3/38	(8%)
Netgear	31/37	(84%)	3/35	(9%)	19/30	(63%)	0/30	(0%)
D-Link	16/21	(76%)	11/21	(52%)	9/19	(47%)	2/19	(11%)
Draytek	2/17	(12%)	3/12	(25%)	2/7	(29%)	0/7	(0%)
Belkin	14/14	(100%)	1/14	(7%)	11/11	(100%)	0/11	(0%)
Cisco	12/12	(100%)	3/9	(33%)	6/7	(86%)	2/7	(29%)
SMC	12/12	(100%)	3/10	(30%)	8/9	(89%)	2/9	(22%)
ZyXEL	7/9	(78%)	1/8	(13%)	0/7	(0%)	0/7	(0%)
3Com	7/7	(100%)	1/7	(14%)	5/6	(83%)	0/6	(0%)
OS-based NAT								
Windows	31/33	(94%)	11/32	(34%)	16/31	(52%)	28/31	(90%)
Linux	26/32	(81%)	3/25	(12%)	16/24	(67%)	2/24	(8%)
FreeBSD	7/9	(78%)	3/6	(50%)	2/3	(67%)	1/1	(100%)
All Vendors	310/380	(82%)	80/335	(24%)	184/286	(64%)	37/286	(13%)

Table 1: User Reports of NAT Support for UDP and TCP Hole Punching

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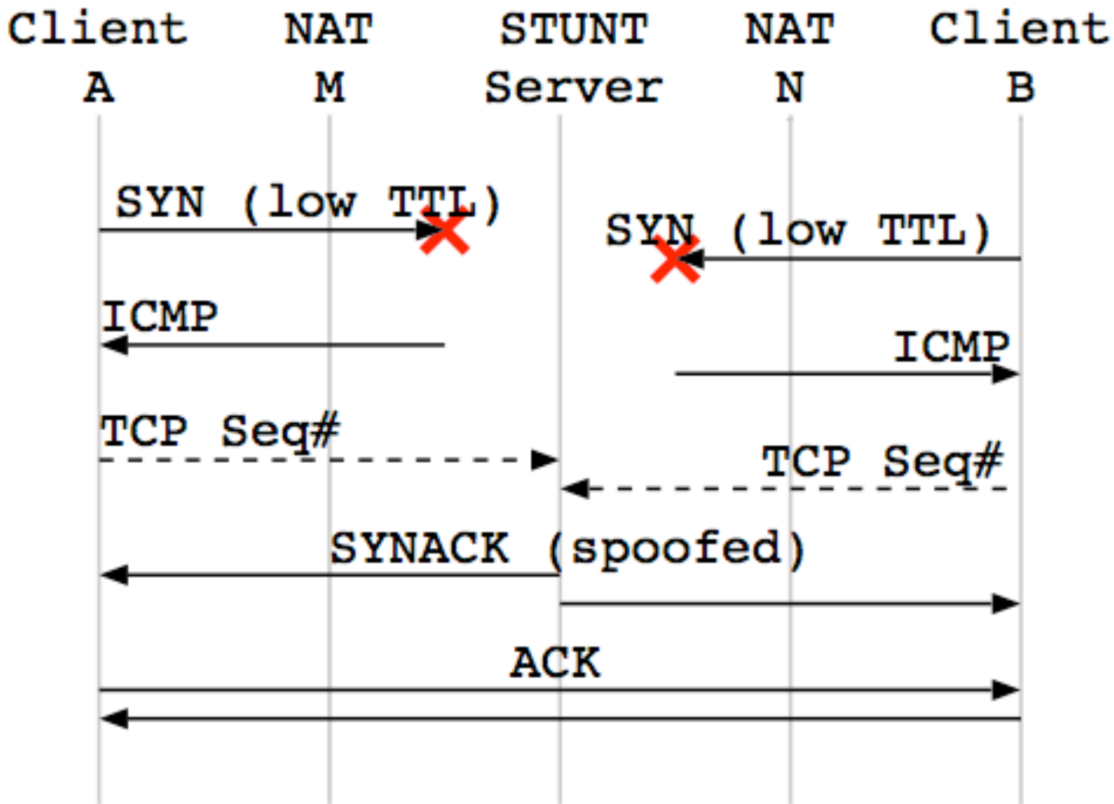
TCP Hole Punching with Small TTL

- NAT Servers can be punched with TCP Sync packets of small TTL
  - message passes NAT server
  - listening to outgoing messages helps to learn the Sequence Number
- Technique used by
  - STUNT#1, #2
  - NATBlaster

STUNT

Eppinger, TCP Connections for P2P Apps: A Software Approach to Solving the NAT Problem. Tech. Rep. CMU-ISRI-05-104, Carnegie Mellon University, Pittsburgh, PA, Jan. 2005.

- Both endpoints produce a SYN packet with small TTL
  - Packet passes NAT-router, yet does not reach target
- Both clients learn their own (!) sequence number
- STUNT (Rendezvous) server produces a spoofed SYNACK
  - with correct sequence number to both clients
- Both clients respond with ACK
- Hopefully, connection is established
- Problems:
  - Choice of TTL. Not possible if the two outermost NATs share an interface
  - ICMP-packet can be interpreted as fatal error
  - NAT may change the sequence number, spoofed SYNACK might be „out of window“
  - Third-party spoofer is necessary

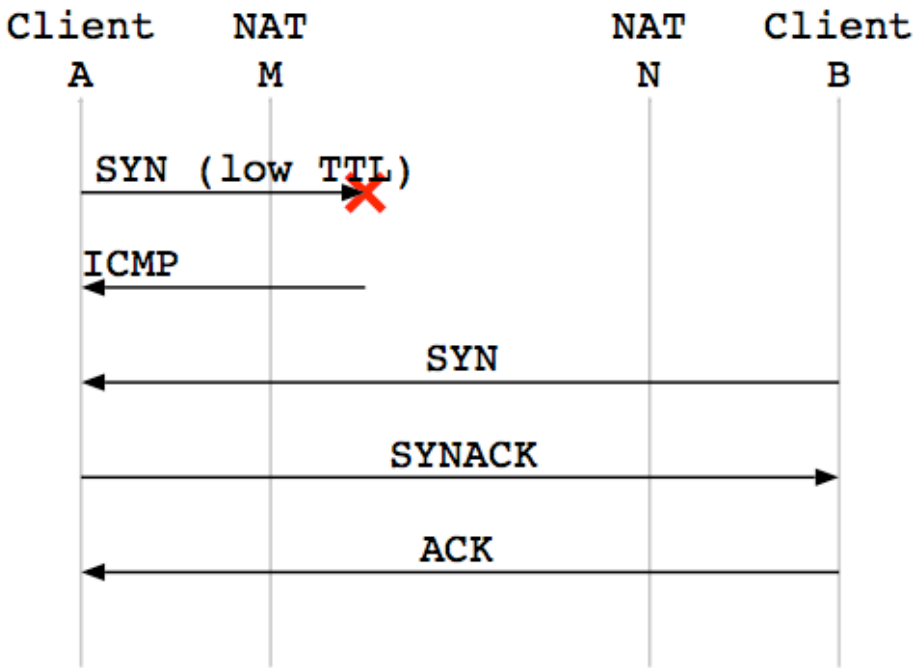


(a) STUNT #1

STUNT (version 2)

- Endpoints A produce a SYN packet with small TTL
  - Packet passes NAT-router, yet does not reach target
- Client A aborts attemption connect
  - accepts inbound connections
- Client B
  - learns address from Rendezvous server
  - initiates regular connection to A
- Client A answers with SYNACK
  - Hopefully, connection is established
- Problems:
  - Choice of TTL.
  - ICMP-packet must be interpreted as fatal error or
  - NAT must accept an inbound SYN following an outbound SYN
    - unusual situation

Guha, Takeda, Francis, NUTSS: A SIP-based Approach to UDP and TCP Network Connectivity. In Proceedings of SIGCOMM'04 Workshops (Portland, OR, Aug. 2004), pp. 43– 48.

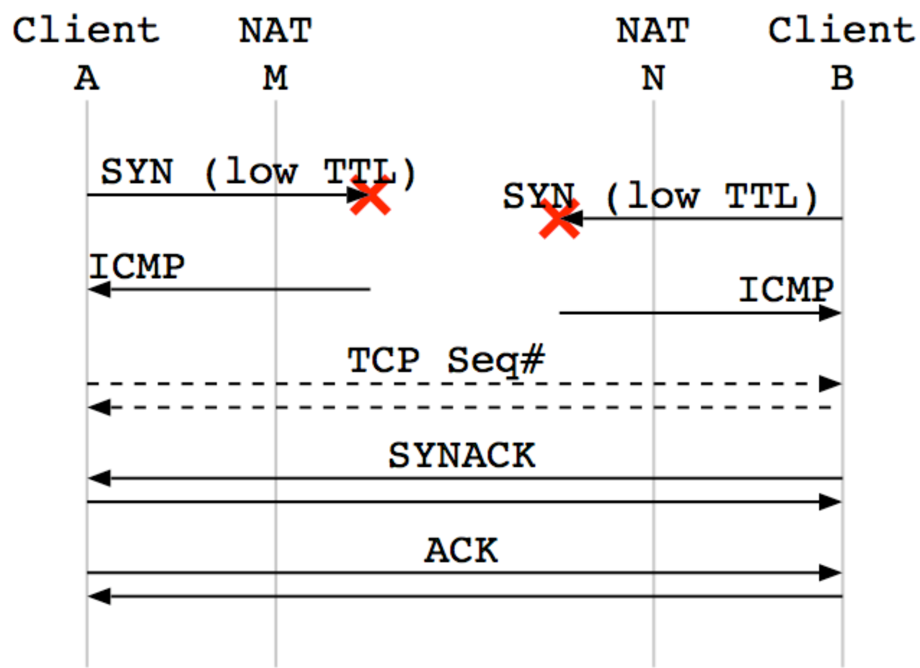


(b) STUNT #2

NATBlaster

Biggadie, Ferullo, Wilson, Perrig, NATBLASTER: Establishing TCP connections between hosts behind NATs. In Proceedings of ACM SIGCOMM, ASIA Workshop (Beijing, China, Apr. 2005).

- Both endpoints produce low TTL SYN-packets
  - passes NAT router, but does not reach other NAT router
- Learn sequence number for own connection
  - exchange this information using Rendezvous server
- Both endpoints produce SYN-ACK packets
  - Both endpoints answer with ACKs
  - Connection established
- Problems
  - Choice of TTL
  - NATs must ignore ICMP-packet
  - NAT may change sequence numbers
  - NAT must allow symmetric SYN-Acks after own SYN packet
    - unusual



(c) NATBlaster

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OS Issues of TCP Hole Punching

Approach	NAT/Network Issues	Linux Issues	Windows Issues
STUNT #1	• Determining TTL • ICMP error • TCP Seq# changes • IP Address Spoofi ng	• Superuser priv.	• Superuser priv. • Setting TTL
STUNT #2	• Determining TTL • ICMP error • SYN-out SYN-in		• Setting TTL
NATBlaster	• Determining TTL • ICMP error • TCP Seq# changes • SYN-out SYNACK-out	• Superuser priv.	• Superuser priv. • Setting TTL • RAW sockets (post WinXP SP2)
P2PNAT	• TCP simultaneous open • Packet fbod		• TCP simultaneous open (pre WinXP SP2)
STUNT #1 no-TTL	• RST error • TCP Seq# changes • Spoofi ng	• Superuser priv.	• Superuser priv. • TCP simultaneous open (pre WinXP SP2)
STUNT #2 no-TTL	• RST error • SYN-out SYN-in		
NATBlaster no-TTL	• RST error • TCP Seq# changes • SYN-out SYNACK-out	• Superuser priv.	• Superuser priv. • RAW sockets (post WinXP SP2) • TCP simultaneous open (pre WinXP SP2)

from Characterization and Measurement of TCP Traversal through NATs and Firewalls, Saikat Guha, Paul Francis

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Port Prediction

- NAT router changes port addresses for incoming connections
- A knows the type of NAT
  - learns the mapping from the Rendezvous (STUNT) server
  - predicts its mapping
- B also predicts his mapping
- Both clients send SYN packets to the predicted ports
- Usually, NAT servers can be very well predicted, e.g.
  - outgoing port is 4901.
  - then the incoming port is 4902
    - if 4902 is not used, then it is 4903
      - and so on....

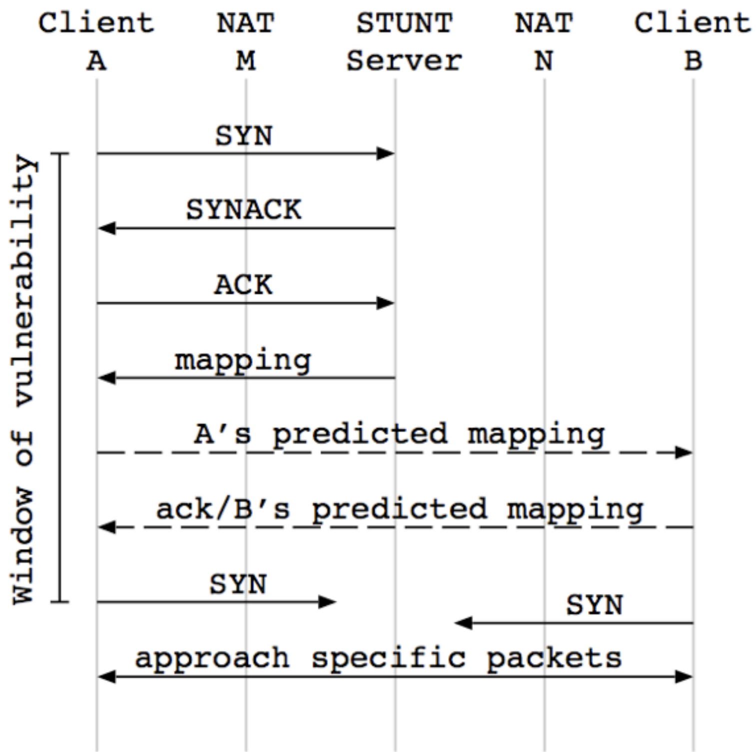

Figure 6: Port-prediction in TCP NAT-Traversal approaches.
from Characterization and Measurement of TCP Traversal through NATs and Firewalls, Saikat Guha, Paul Francis

How Skype Punches Holes

- An Experimental Study of the Skype Peer-to-Peer VoIP System, Saikat Guha, Neil Daswani, Ravi Jain
  - Skype does not publish its technique
  - Yet, behavior can be easily tracked
- Techniques
  - Rendezvous Server
  - UDP Hole Punching
  - Port scans/prediction
  - Fallback: UDP Relay Server
    - success rate of Skype very high, seldomly used

Universal Plug and Play

- The UPnP allows device-to-device networking
  - personal computers, networked home appliances, consumer electronics devices wireless devices
  - distributed, open architecture protocol based on established standards such as the Internet Protocol Suite (TCP/IP), HTTP, XML, and SOAP.
  - UPnP control points are devices which use UPnP protocols to control UPnP devices.
- Zero configuration networking.
  - UPnP compatible device can dynamically join a network
  - obtain an IP address
  - announce its name
  - convey its capabilities upon request
  - learn about the presence and capabilities of other devices
- DHCP, DNS are optional
- NAT traversal is implimented as **Internet Gateway Device Protocol (IGD Protocol)**

Internet Gateway Device Protocol

- Features
  - learns the public (external) IP address
  - request for a new public IP address
  - enumerate existing port mappings
  - add and remove port mappings
  - assign lease times to mappings
- NAT-routers
  - need to comply to UPnP to enable these features
  - some routers need to be configured to allow UPnP
- Risks
  - it is possible to attack a whole network
    - by a trojan
    - vulnerability of the router‘s implementation of IGD

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