Carrier-Grade NAT

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Agenda

CGN (Carrier-Grade NAT)

- Definition and purpose

NAT vs. Firewall

- Mapping/filtering, app traversal

Other CGN Behaviors

- Pooling, port limits, etc.

Session Logging

- Netflow/Syslog, formats, variations

CGN Design

- Performance, placement

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Network Address & Port Translation

Most of Broadband users are behind NAT today!

When say "NAT", they typically mean "NAPT"

- NAT
  - First described in 1991 (draft-tsuchiya-addrtrans), RFC1631
  - 1:1 translation: Does not conserve IPv4 addresses
  - Per-flow stateless
  - Today's primary use is inside of enterprise networks
    - Connect overlapping RFC1918 address space

  Note: NAT66 is stateful or stateless, but it is not NAPT

- NAPT
  - Described in 2001 (RFC3022)
  - 1:N translation
  - Conserves IPv4 addresses
  - Allows multiple hosts to share one IPv4 address
  - Only TCP, UDP, and ICMP
  - Connection has to be initiated from 'inside'
  - Per-flow stateful
  - Commonly used in home gateways and enterprise NAT

"NAT44" is used to differentiate IPv4-IPv4 NAPT from Address Family Translation, typically referred to as NAT64 and NAT46"

What is CGN?

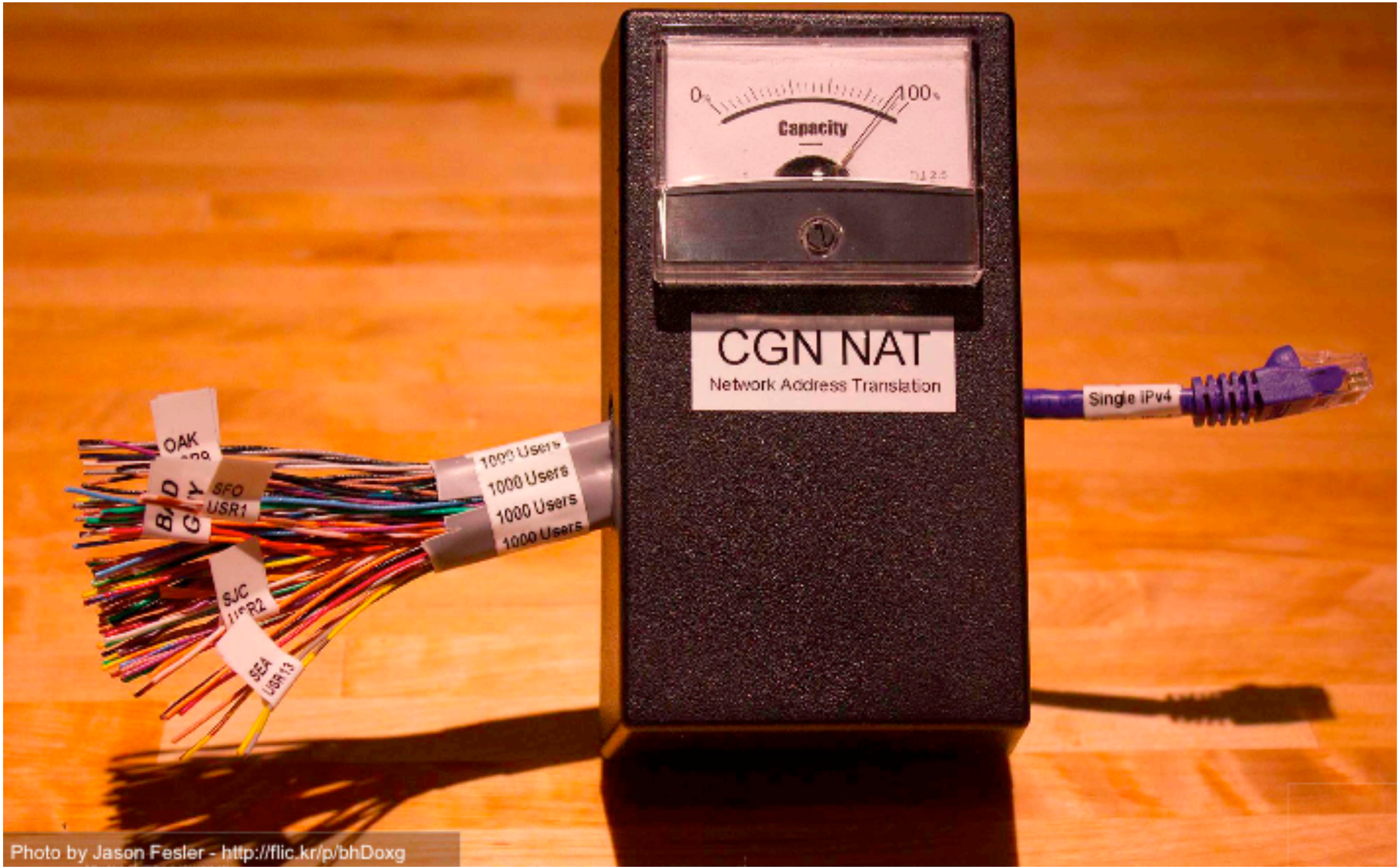

Photo by Jason Fesler - http://flic.kr/p/bhDoxg

Courtesy of Jason Fesler, Yahoo (V6 World Congress 2012)

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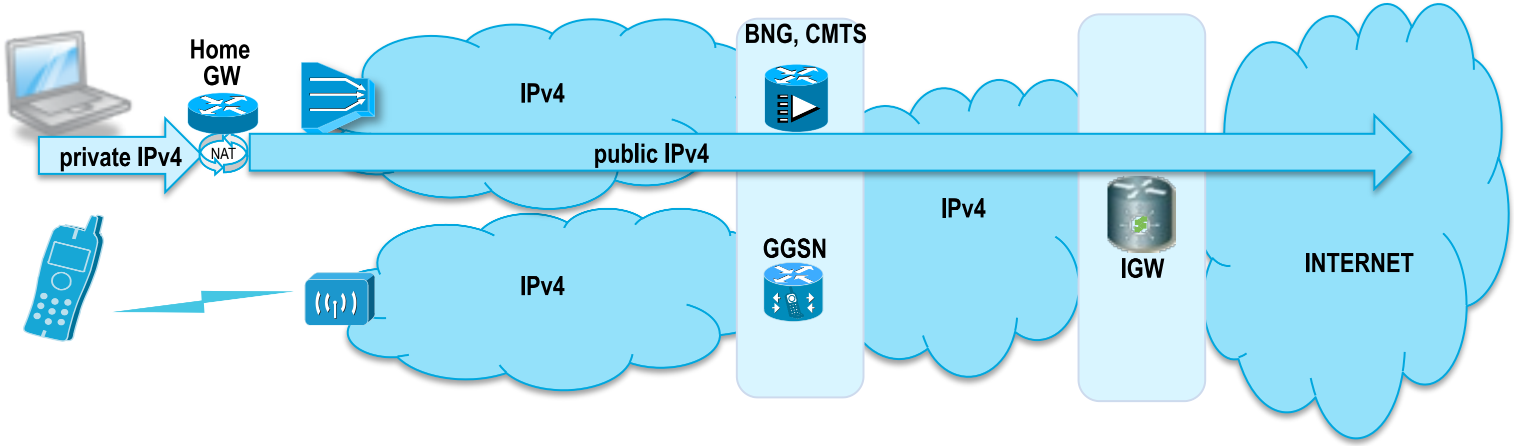
NAT in Internet Access

typical deployment today (wireline)



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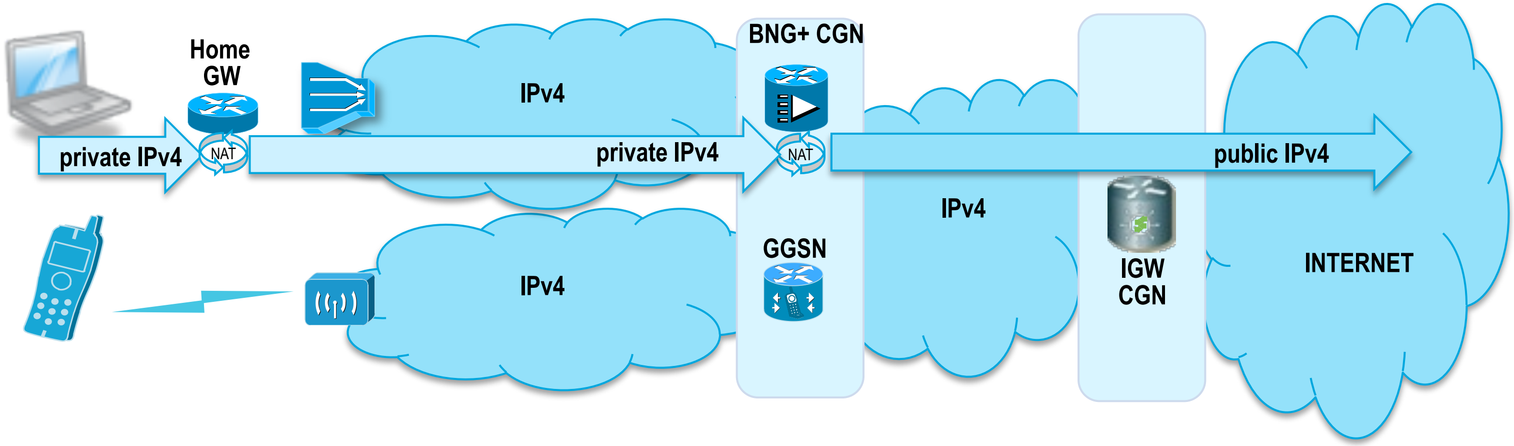
NAT in Internet Access

CGN – NAT444 (wireline)

RFC1918 or RFC6598 (100.64.0.0/10)



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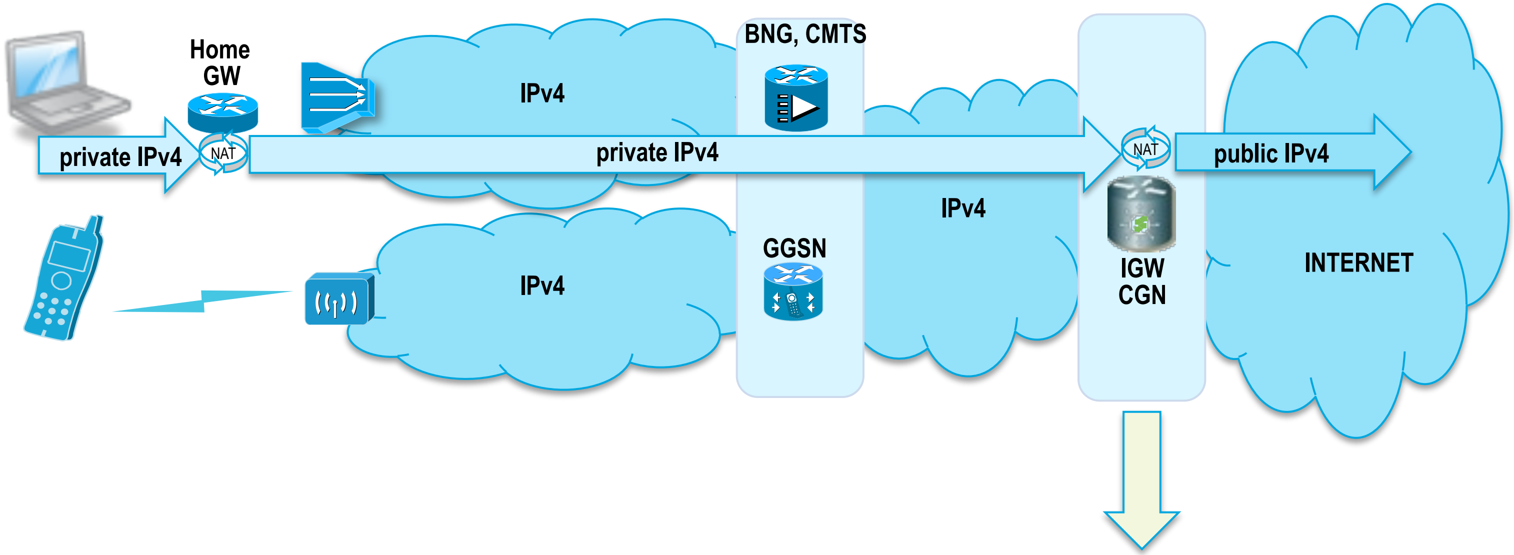
NAT in Internet Access

CGN – NAT444 (wireline)

RFC1918 or RFC6598 (100.64.0.0/10)



Large Scale

- 100G+ throughput
- 100M+ concurrent bidirectional sessions
- 1M+ sessions per second setup rate

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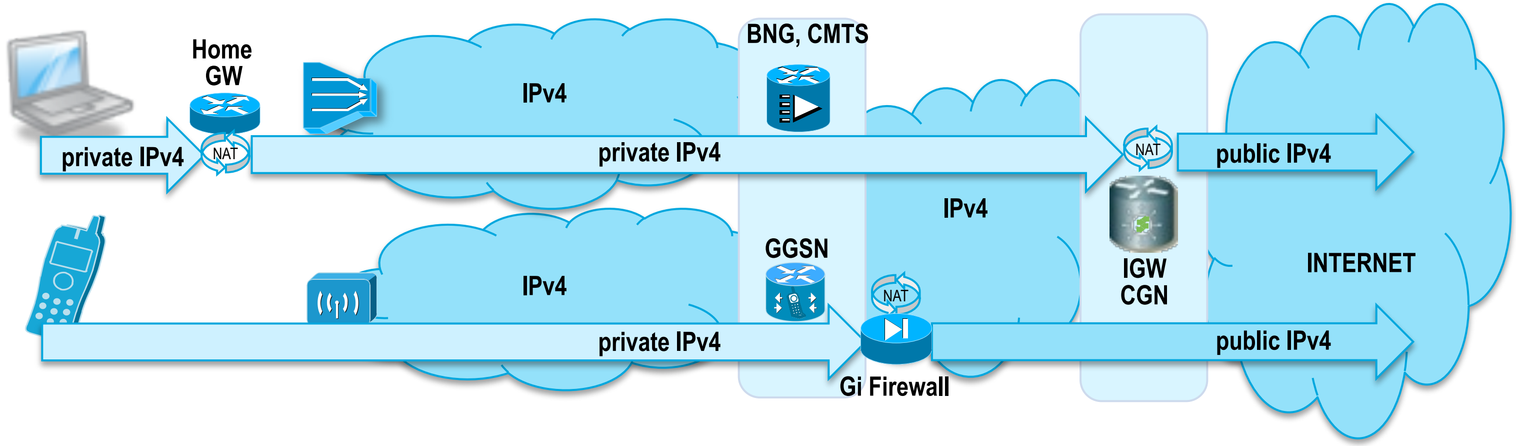
NAT in Internet Access

Mobile



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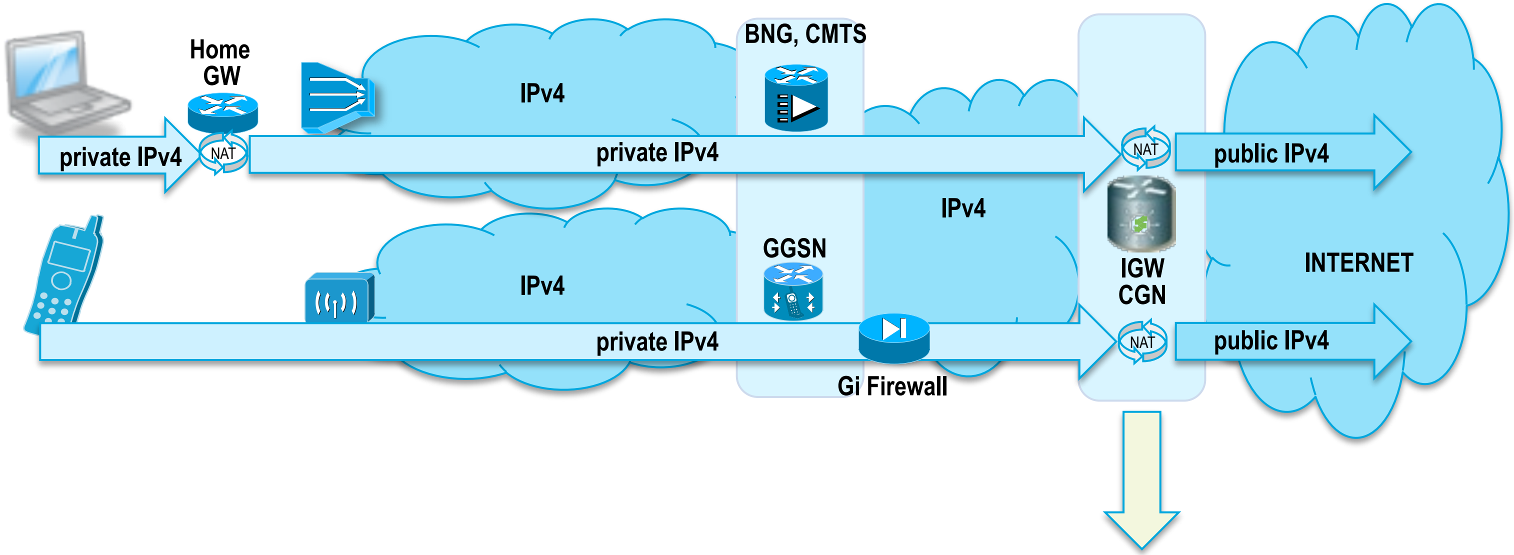
NAT in Internet Access

Mobile



Virtualization Support (VRF)

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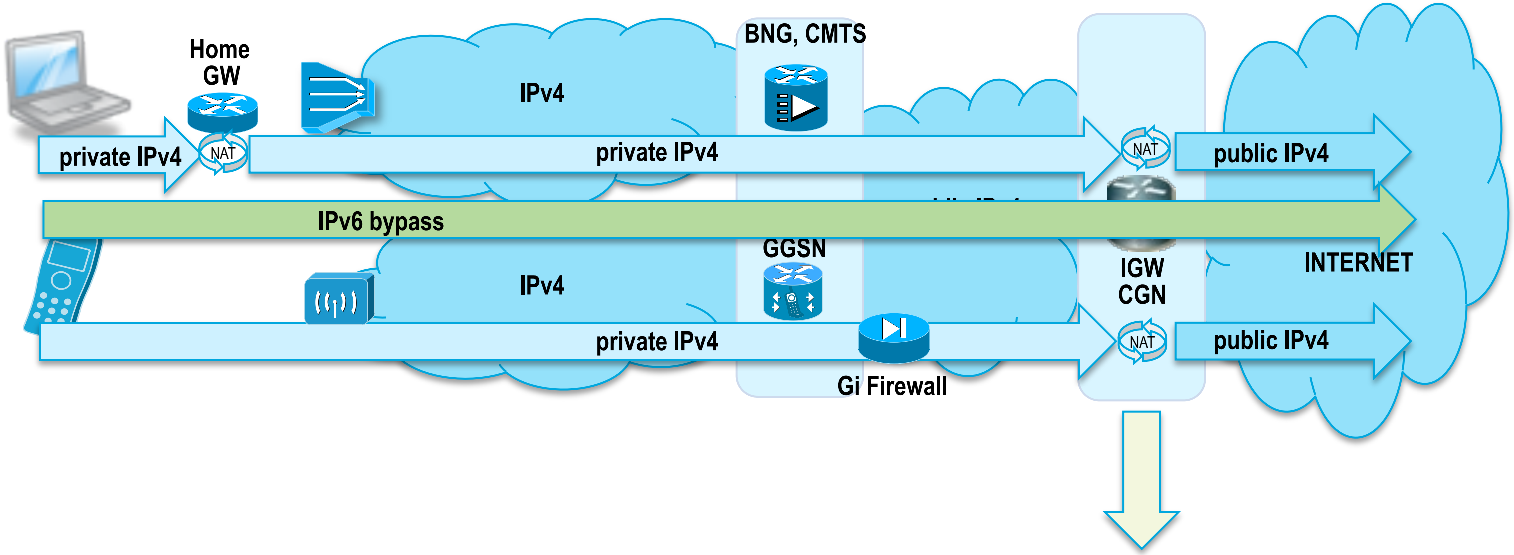
NAT in Internet Access

IPv6 ultimately bypasses CGN



Dual-Stack
6in4 tunneling – 6rd BR
4in6 tunneling – DS-Lite AFTR, MAP
NAT64 for v6-only hosts

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CGN = IP Address Sharing

IPv4 Exhaust workaround: move part of Internet from L3 to L4

- Adds capital and operations cost [$/Gbps] → decreases ARPU
  - CGN is here not to stay, but to be replaced (by IPv6)
- Inherent issues (general NAPT issues, mostly not NAT444 related)
  - draft-ford-shared-addressing-issues
- Servers must log also source port numbers
  - Shared IP address = shared suffering (blacklisting, spam,…)
  - Tracking and Law Enforcement, draft-ietf-intarea-server-logging-recommendations
  - Otherwise CGN must do log also Destination IP:port (privacy issue!)
- Requesting specific ports – “Not everyone can get port 80”
- Geo-Location issues (“get me the nearest ATM”)
- Complicates inbound access to media
- Keepalives → power consumption, mobile battery drain

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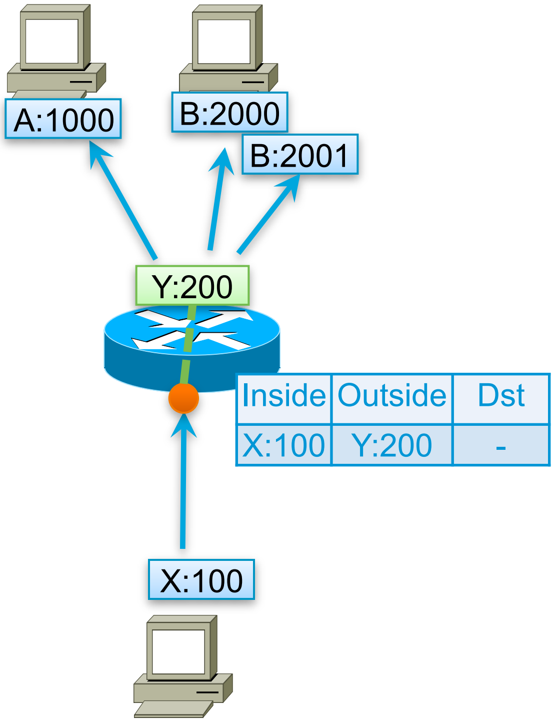
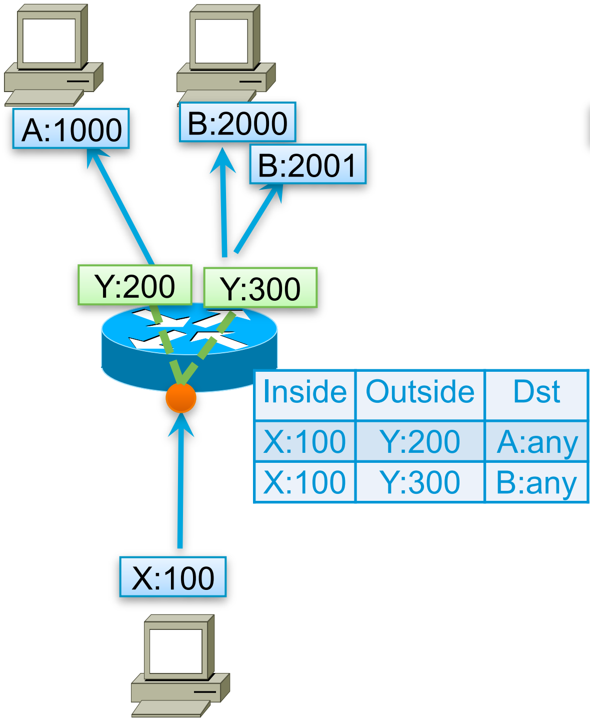
NAPT internals: Mapping

Endpoint Independent



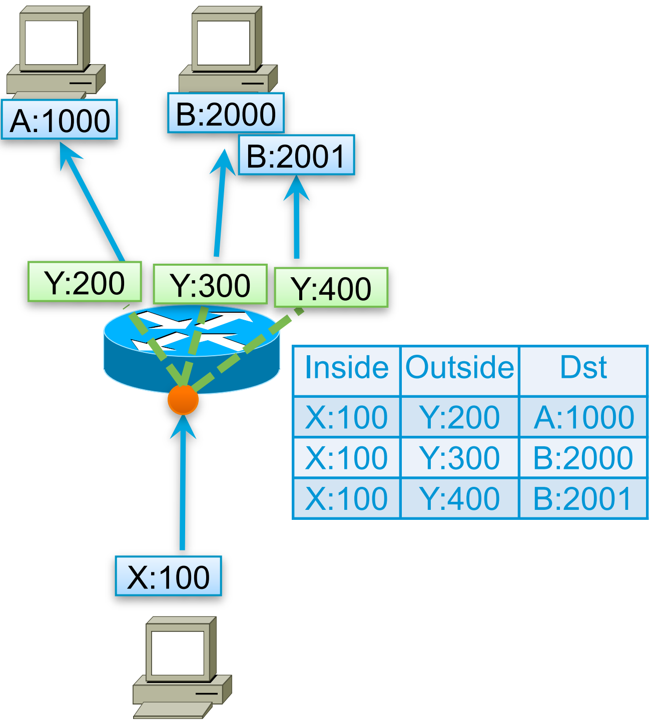
Inside	Outside	Dst
X:100	Y:200	-

Address Dependent



Inside	Outside	Dst
X:100	Y:200	A:any
X:100	Y:300	B:any

Address and port Dependent



Inside	Outside	Dst
X:100	Y:200	A:1000
X:100	Y:300	B:2000
X:100	Y:400	B:2001

IP Addres: Port Number

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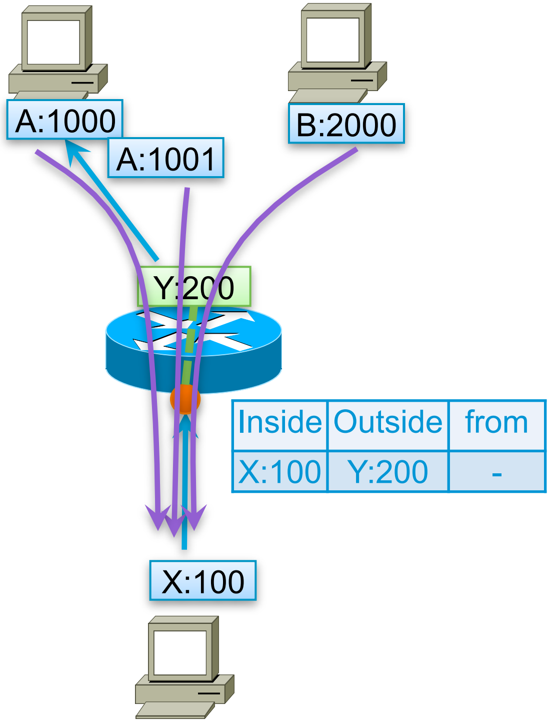
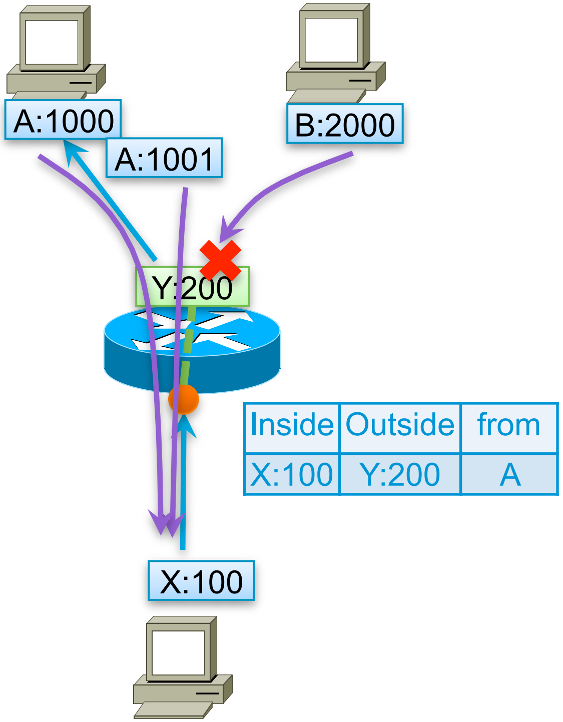
NAPT internals: Filtering

Endpoint Independent



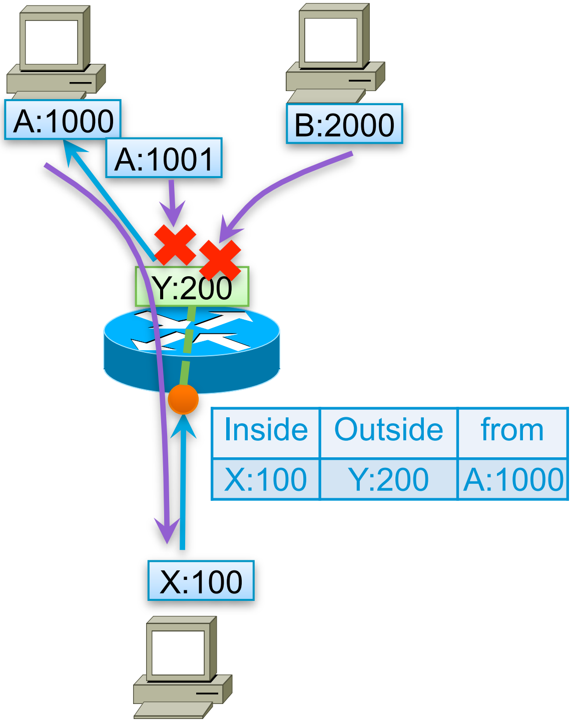
Inside	Outside	from
X:100	Y:200	-

Address Dependent



Inside	Outside	from
X:100	Y:200	A

Address and Port Dependent



Inside	Outside	from
X:100	Y:200	A:1000

IP Addres: Port Number

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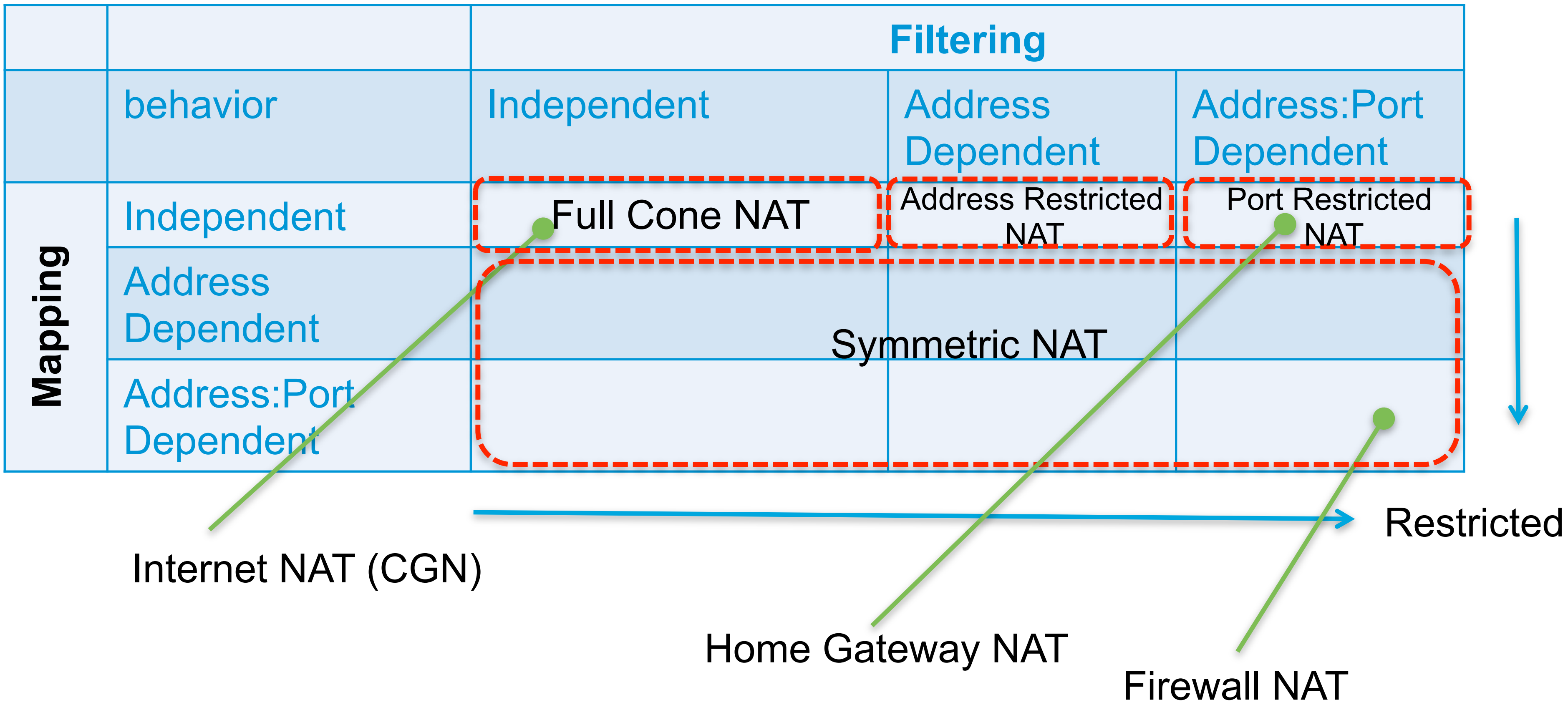
NAT mapping/filtering behavior



		Filtering		
	behavior	Independent	Address Dependent	Address:Port Dependent
Mapping	Independent	Full Cone NAT	Address Restricted NAT	Port Restricted NAT
	Address Dependent	Symmetric NAT		
	Address:Port Dependent			

STUN NAT Types

- Classic STUN : simple traversal of UDP through NAT(RFC3489)
- Now : Session Traversal Utilities for NAT(RFC5389)

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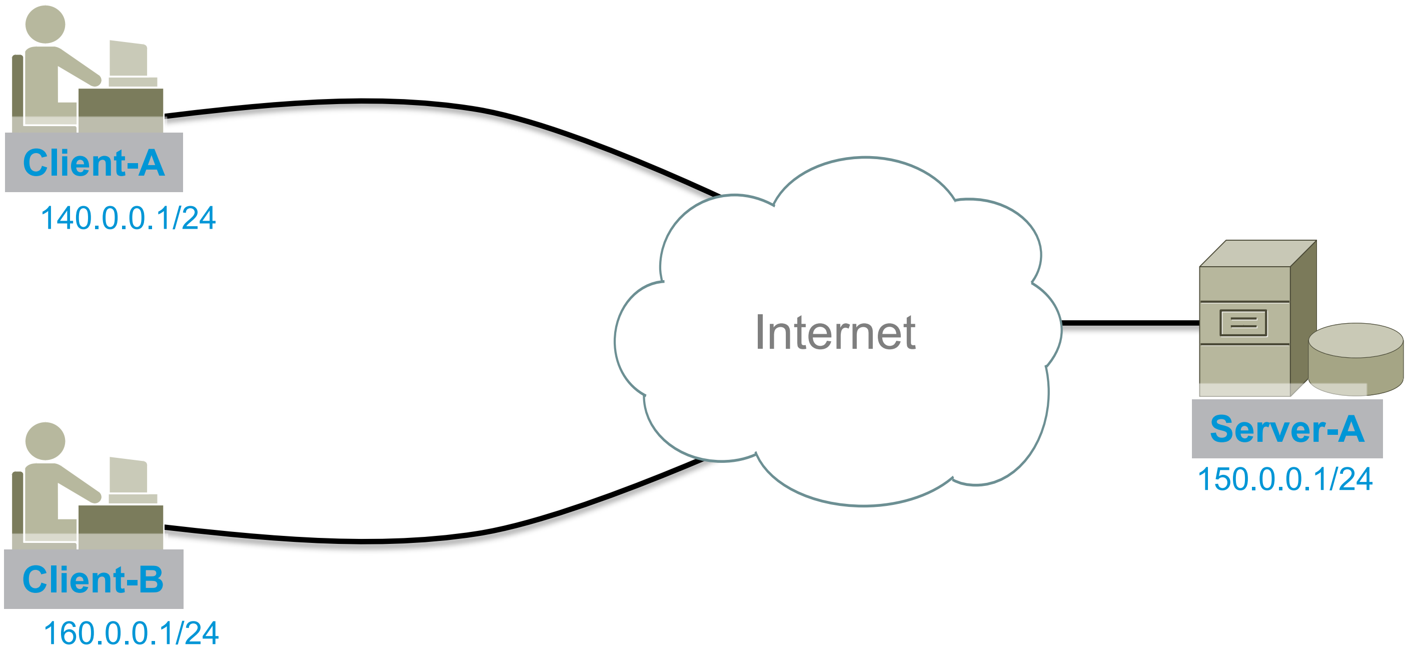
NAT != Firewall

Application transparency behaviors



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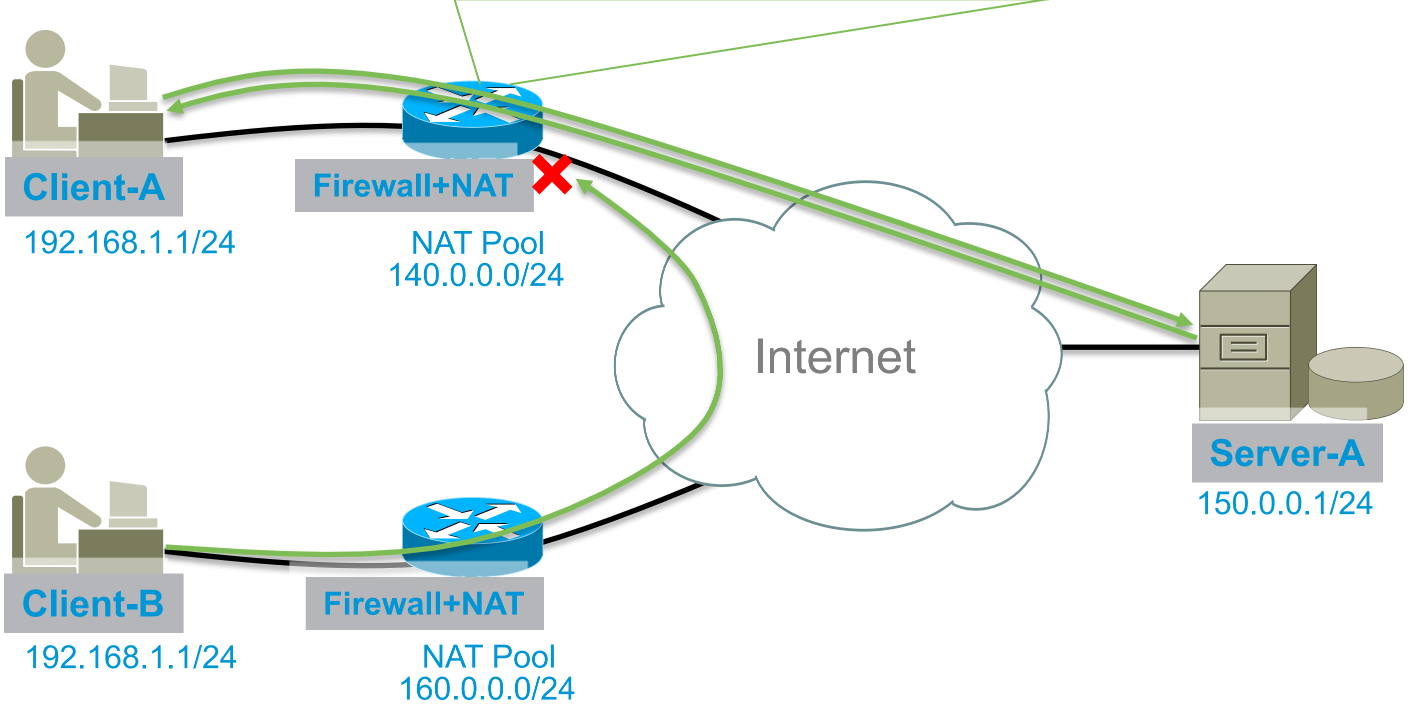
What is Symmetric NAT

Address:port restricted NAT = Firewalling behavior

NAT/PAT Entry:

Inside local	Inside global	Outside local	Outside global
192.168.1.1 :5000	140.0.0.1 :6000	150.0.0.1 :6000	150.0.0.1 :6000



Endpoint Dependent Mapping, Endpoint Dependent Filtering

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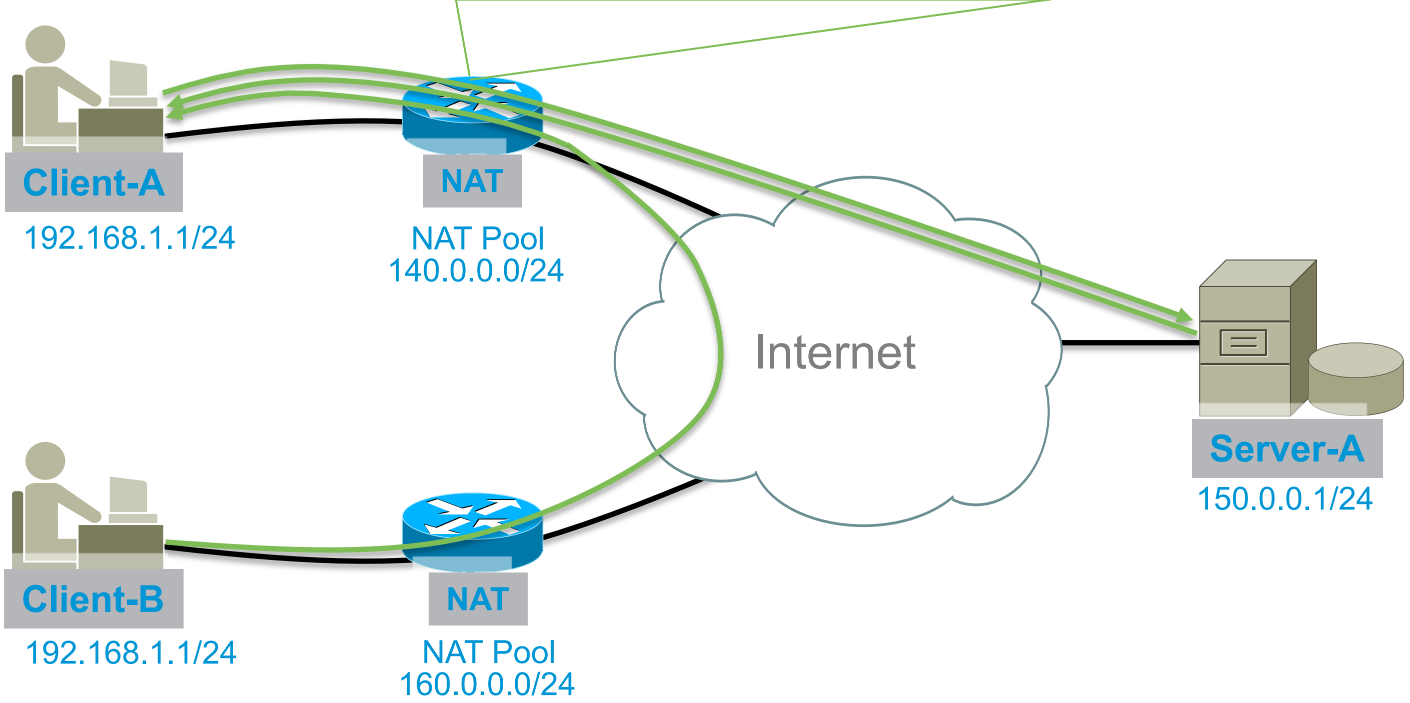
What is Full cone NAT

Pure NAT with no Firewalling behavior

NAT/PAT Entry:

Inside local	Inside global	Outside local	Outside global
192.168.1.1 :5000	140.0.0.1 :6000	any	any



Endpoint Independent Mapping, Endpoint Independent Filtering – EIM/EIF

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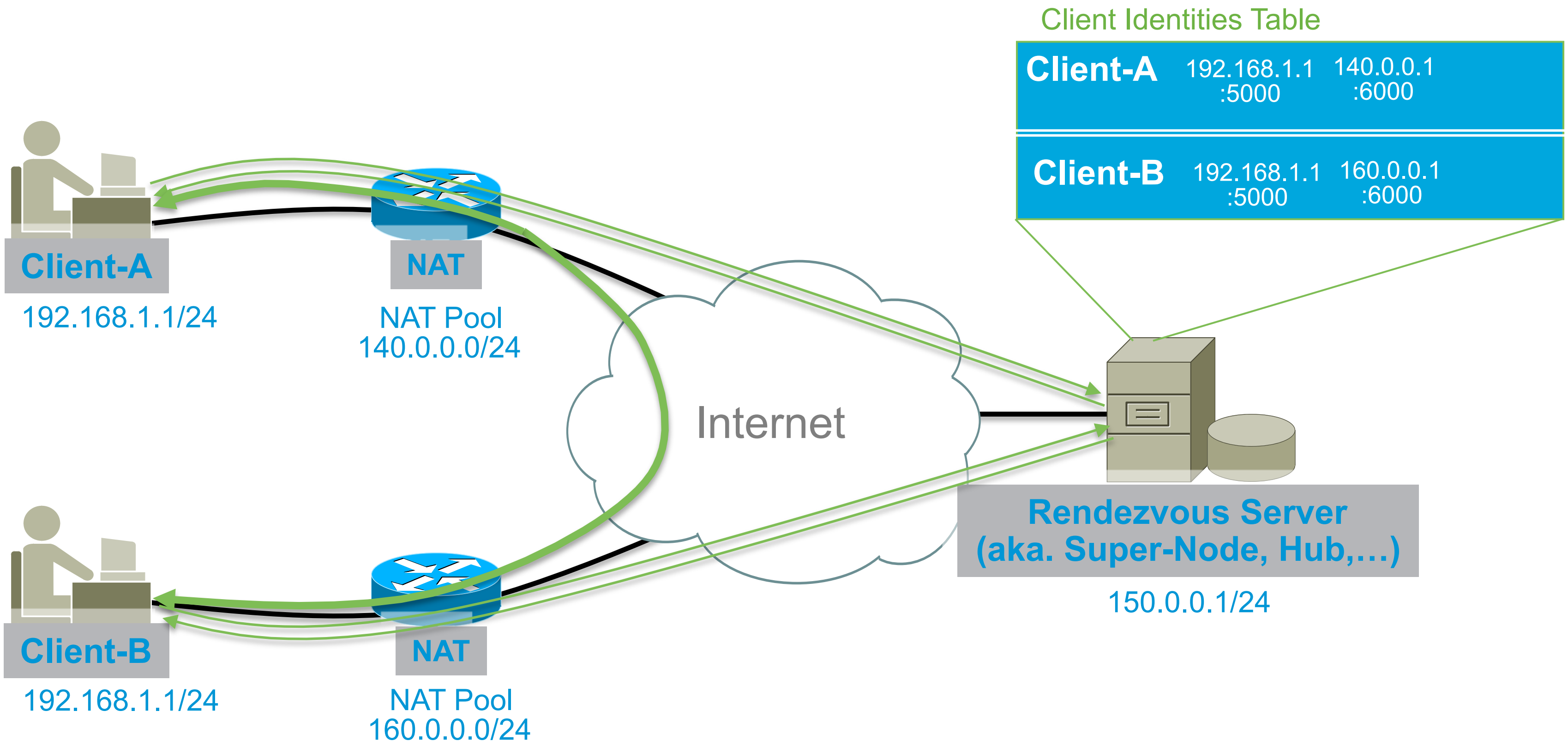
NAT Traversal with Full cone NAT

Peer-to-peer Applications Transparency



Client Identities Table

Client-A	192.168.1.1 :5000	140.0.0.1 :6000
Client-B	192.168.1.1 :5000	160.0.0.1 :6000

Client-A

192.168.1.1/24

NAT

NAT Pool
140.0.0.0/24

Internet

Client-B

192.168.1.1/24

NAT

NAT Pool
160.0.0.0/24

Rendezvous Server
(aka. Super-Node, Hub,…)

150.0.0.1/24

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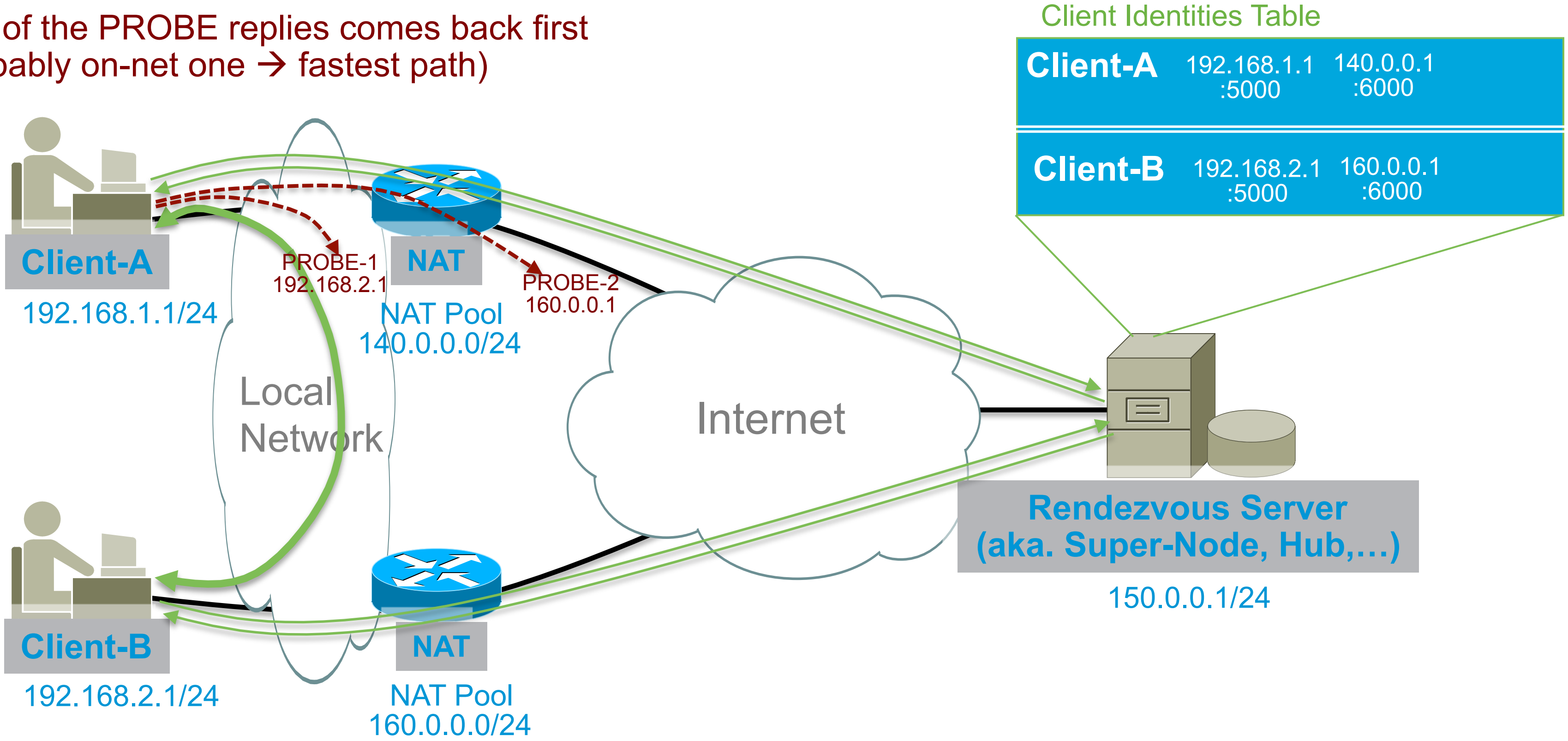
NAT Traversal with Full cone NAT

Connectivity Probes and the Shortest Path



One of the PROBE replies comes back first
(probably on-net one → fastest path)

Client Identities Table

Client-A	192.168.1.1 :5000	140.0.0.1 :6000
Client-B	192.168.2.1 :5000	160.0.0.1 :6000

Example: Skype Video call quality is good ☺

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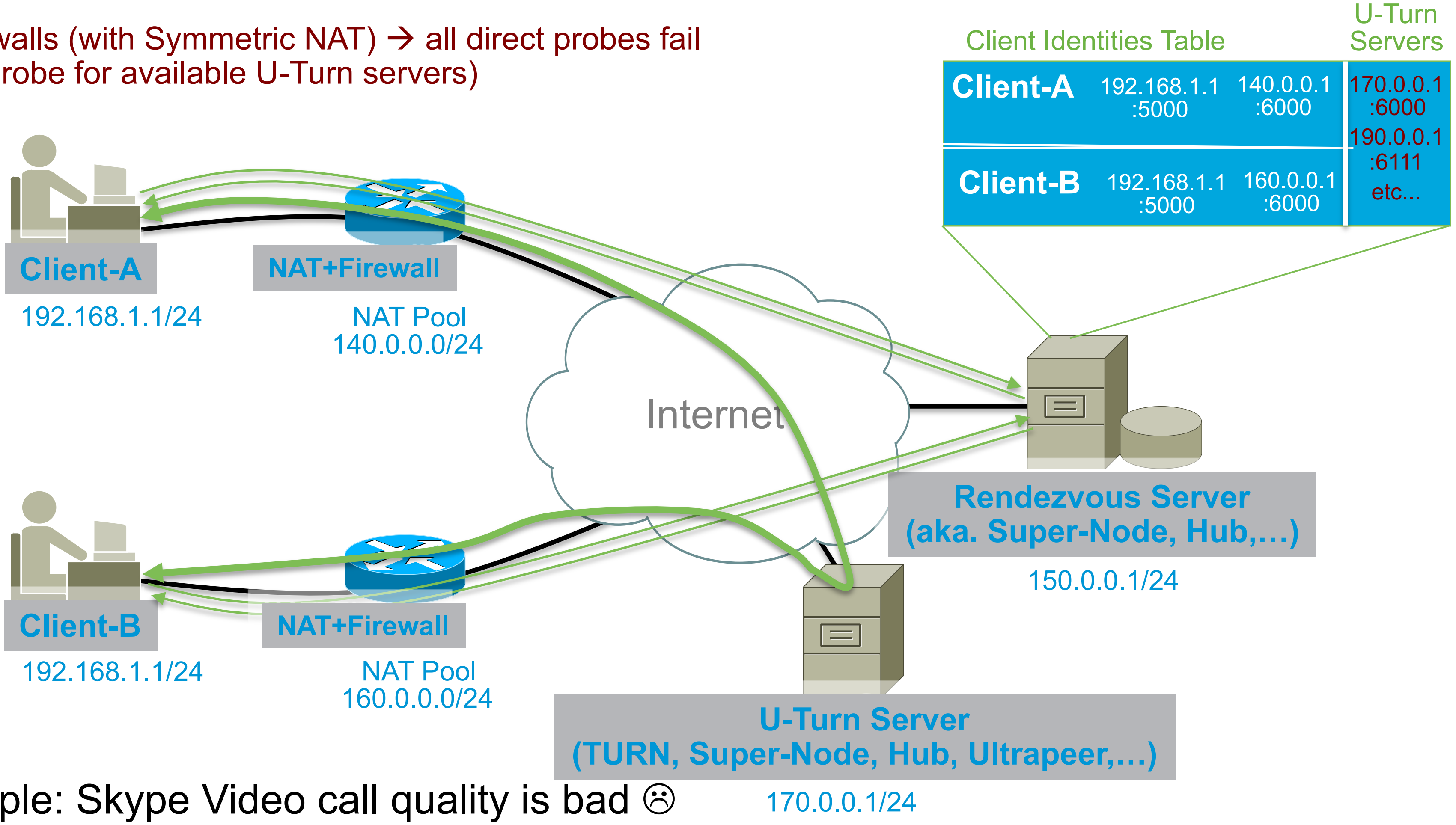
NAT Traversal with Firewalls

U-Turn server (Super-Node)

Firewalls (with Symmetric NAT) → all direct probes fail
(→ probe for available U-Turn servers)



Client Identities Table

			U-Turn Servers
Client-A	192.168.1.1 :5000	140.0.0.1 :6000	170.0.0.1 :6000 190.0.0.1 :6111 etc...
Client-B	192.168.1.1 :5000	160.0.0.1 :6000	

Example: Skype Video call quality is bad ☹

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Avoiding U-Turn Servers with Firewalls

Opening port holes in Firewall/NAT

- Application talks to the Firewall
  - UPnP-IGD (app to home router)
  - Common in Home Environment
  - Not applicable in Internet (scale, no suitable protocols defined)

- ALG's (Application Level Gateway) aka. Fixup
  - App proxy in the firewall – we jump from L4 to L6+
  - Common in Enterprise (closed environment – we know the list of supported apps)
  - Hardly applicable in Internet (open environment – we don't know all the apps)
    - How about encrypted and integrity-protected protocols?
    - How about URL with literals https://1.2.3.4

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Summary: CGN behavior best practices
draft-behave-lsn-requirements, RFC4787, RFC6145

- Internet way: keep it simple
  - EIM/EIF → Full Cone NAT → no ALG's (with well controlled exceptions)
  - CGN role is IPv4 exhaust solution, not security, LI, traffic monitoring, etc.
  - Respect OSI model – stay at L3, at L4 if you have to, not higher layers

- Firewall = ALG's = going above L4
  - Breaks Net Neutrality (OTT regulatory pushback)
  - ALG for Vendor-A breaks app from Vendor-B (same port, different traversal)
  - Undefined performance impact of ALG's → numerous DoS attack vectors
  - Bugs, ISP liable for 3rd party apps?

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Reality Check: Internet Apps work with NAT

iTunes

Google Maps

Playstation Network

iPhone App Store

Windows Live Messenger

Google Talk

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Reality Check: Apps and NAT Traversal

- STUN, ICE, TURN
  - NAT EIM/EIF – Intelligence in endpoint
  - Useful for offer/answer protocols (SIP, XMPP, probably more)
  - Standardized in MMUSIC and BEHAVE

ICE apps – exaples:

- **Google chat (XMPP)**
- **Microsoft MSN (SIP inside of XML)**
- **Yahoo (SIP)**
- **Counterpath softphone (SIP)**

STUN: "Session Traversal Utilities for NAT" – RFC 5389
ICE: "Interactive Connectivity Establishment" – RFC 5245
TURN: "Traversal Using Relays around NAT" – RFC 5766

- Other examples
  - IPSec over TCP/UDP
  - FTP PASV – data connection always to server
  - RTSPv1 → RSTPv2 (effectively replaced HTTP Video, ABR,…)
  - Skype – encrypted, does its own NAT traversal
  - Port 80/443 apps

Known Problems:
Active FTP (old browsers), RTSPv1 (old m.youtube.com), MS PPTP (old PC VPN)

CGN Behaviors

draft-ietf-behave-lsn-requirements

A CGN is defined by constrained behavior:

- NAT Behavior Compliance (RFC4787, RFC5382, RFC5508)
  - Endpoint Independent Mapping and Filtering (Full Cone NAT)
  - ALG’s (fixups) should not be used (exceptions like A-FTP)
  - Paired IP address pooling behavior
  - Port Parity preservation for UDP
  - Hairpinning behavior
  - Static Port Forwarding (PCP)
- Management
  - Port Limit per subscriber
  - Mapping Refresh
  - Very scalable NAT logging (binary Netflow)
- Redundancy – Intra-box Active/Standby, Inter-box Active/Active
- Scale – 10M’s concurrent sessions, 100K’s sessions per second, Virtualization (VRF-aware)
- IPv6 Transition Tool-set – dual-stack, NAT64, 6RD, DS-Lite, MAP-T…

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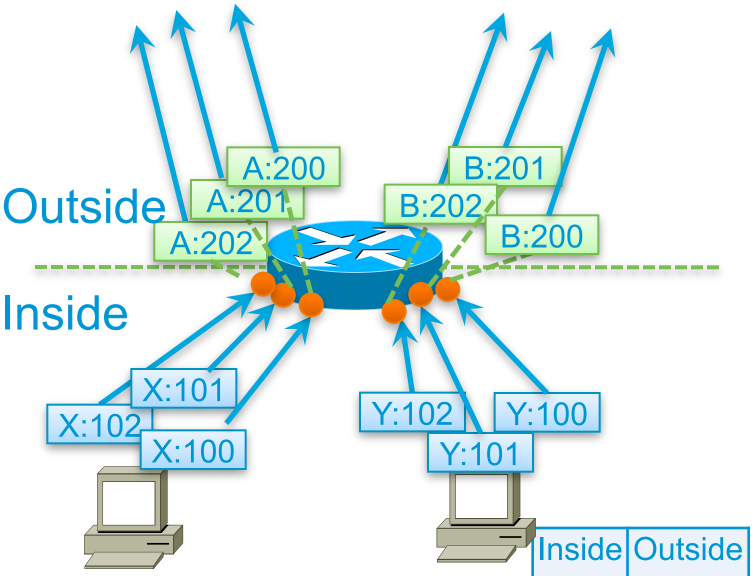
Paired IP Address Pooling Behavior



Inside	Outside
X:100	A:200
X:101	A:201
X:102	A:202
Y:100	B:200
Y:101	B:201
Y:102	B:202

- Paired (recommended) : use the same external IP address mapping for all sessions associated with the same internal IP address
- Some peer to peer applications don’t negotiate the IP address for multiple sessions (eg. apps that are not able to negotiate the IP address for RTP and RTCP separately)

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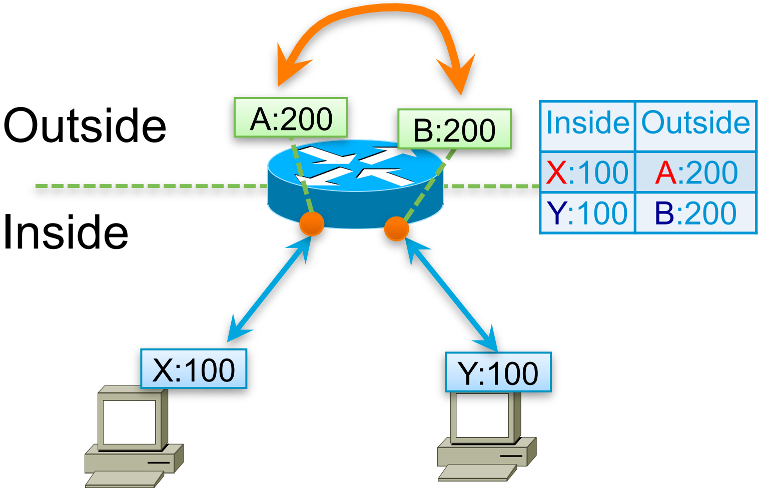
Hairpinning Behavior



Inside	Outside
X:100	A:200
Y:100	B:200

- Use Case: Allow communications between two endpoints behind the same NAT when they are trying each other's external IP addresses

Notation X:100 IPv4 address:Port *

* TCP/UDP port or Query ID for ICMP

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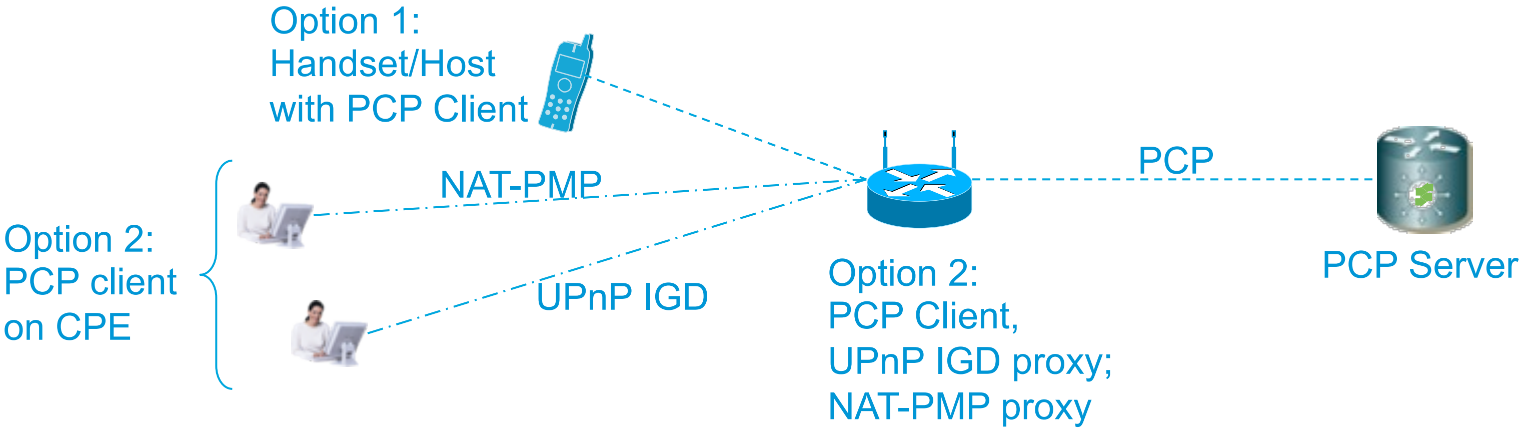
Static Port Forwarding

- Requirement: Ability to configure, a fixed private (internal) IP address:port associated with a particular subscriber while CGN allocates a free public IP address:port
- New protocol: PCP (Port Control Protocol)



- Delegate port numbers to requesting applications/hosts to avoid requirement for ALGs
- draft-ietf-pcp-base

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Other Port Behaviors

No Port Overloading

- A NAT must not have a "Port assignment" behavior of "Port overloading”(i.e. use port preservation even in the case of collision). Most applications will fail if this is used.

Port Parity Preservation

- An even port will be mapped to an even port, and an odd port will be mapped to an odd port. This behavior respects the [RFC3550] rule that RTP use even ports, and RTCP use odd ports.

Port Limit Per Subscriber

- Configurable port limit per subscriber for the system (includes TCP, UDP and ICMP). NAT Security – DoS attack/virus exhaust prevention.

* source: RFC4787, RFC5382

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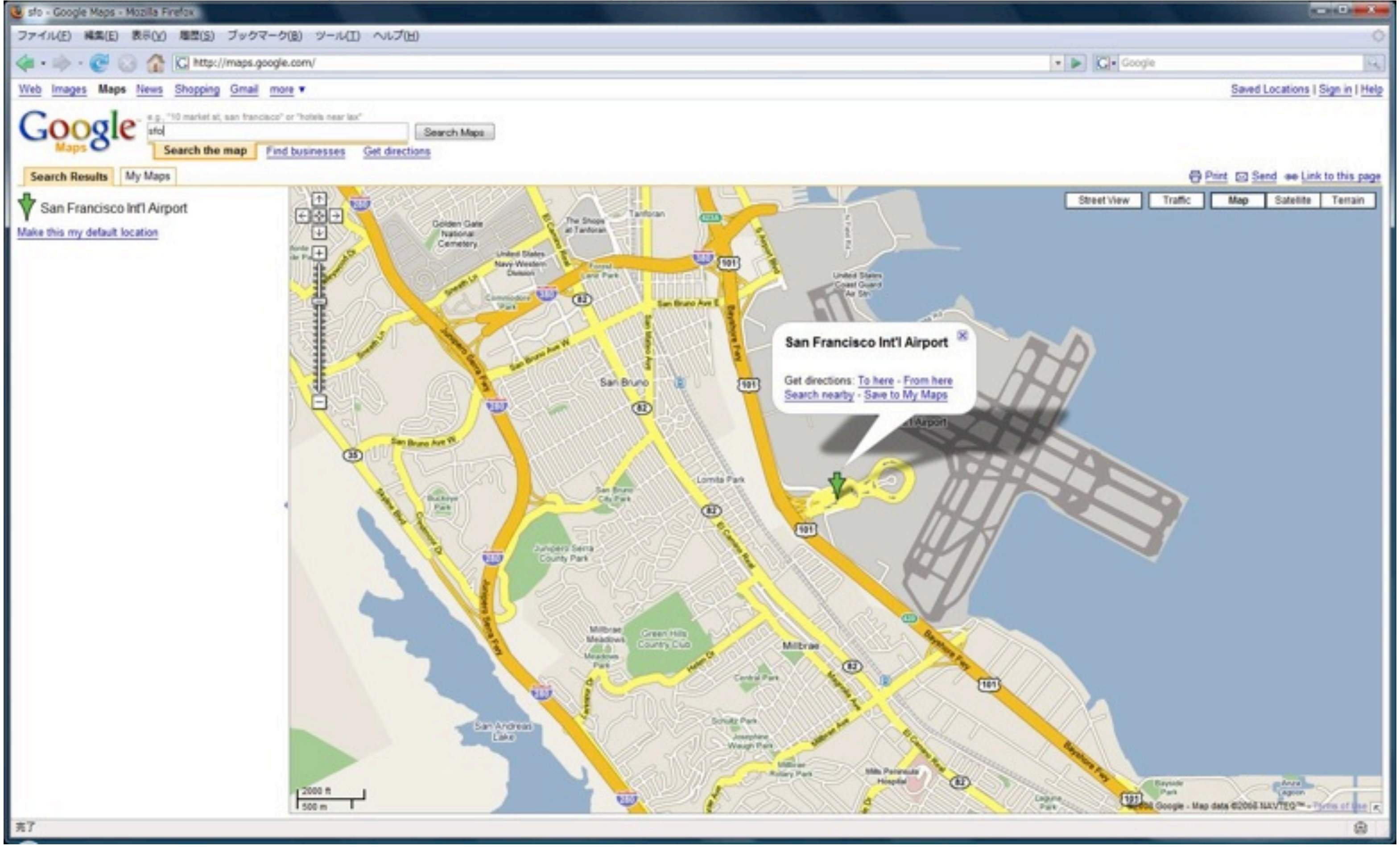
Impact of NAT Port Limits

Example: GoogleMaps with Max 30 Connections

Example/Slides Courtesy of NTT, See Also:
Hiroshi Esaki: www2.jp.apan.net/meetings/kaohsiung2009/presentations/ipv6/esaki.ppt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e.g., "10 market st, san francisco" or "hotels near lax"
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Search the map
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Get directions: To here - From here
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Golden Gate National Cemetery
The Shops at Tanforan
Tanforan
United States Navy Western Division
United States Coast Guard Air Stn
San Bruno
San Bruno Ave W
El Camino Real
Bayshore Fwy
Junipero Serra Fwy
Junipero Serra County Park
Lomita Park
Millbrae
Green Hills Country Club
Millbrae Meadows
Central Park
San Andreas Lake
Mills Peninsula Hospital
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101
380
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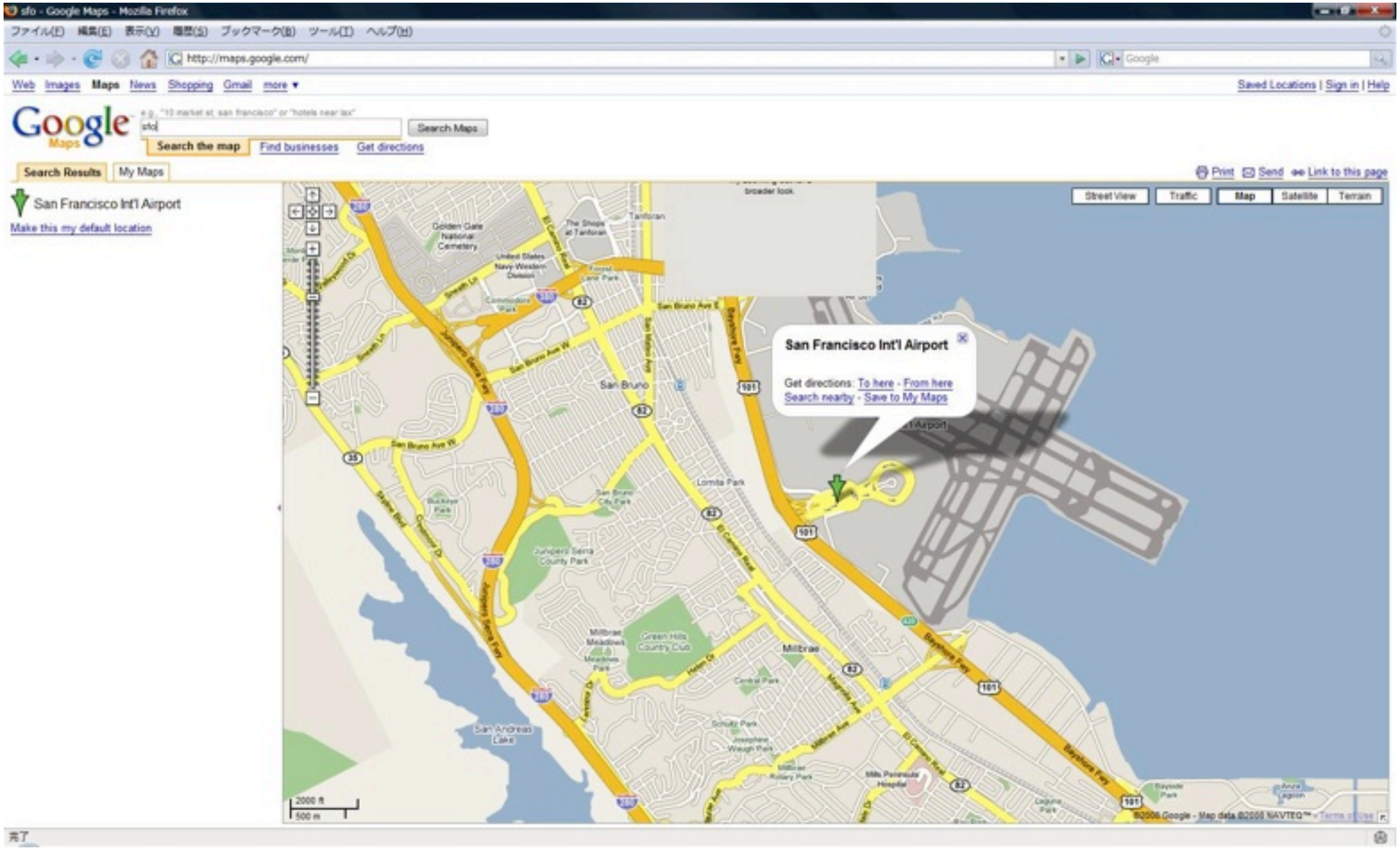
完了

Max 20 Connections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e.g., "10 market st, san francisco" or "hotels near lax"
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Search the map
Find businesses
Get directions
Search Results
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Print
Send
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San Francisco Int'l Airport
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Street View
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Golden Gate National Cemetery
The Shops at Tanforan
Tanforan
San Bruno
Lomita Park
Millbrae
Junipero Serra County Park
Green Hills Country Club
San Andreas Lake
Bayshore Fwy
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San Bruno Ave W
2000 ft
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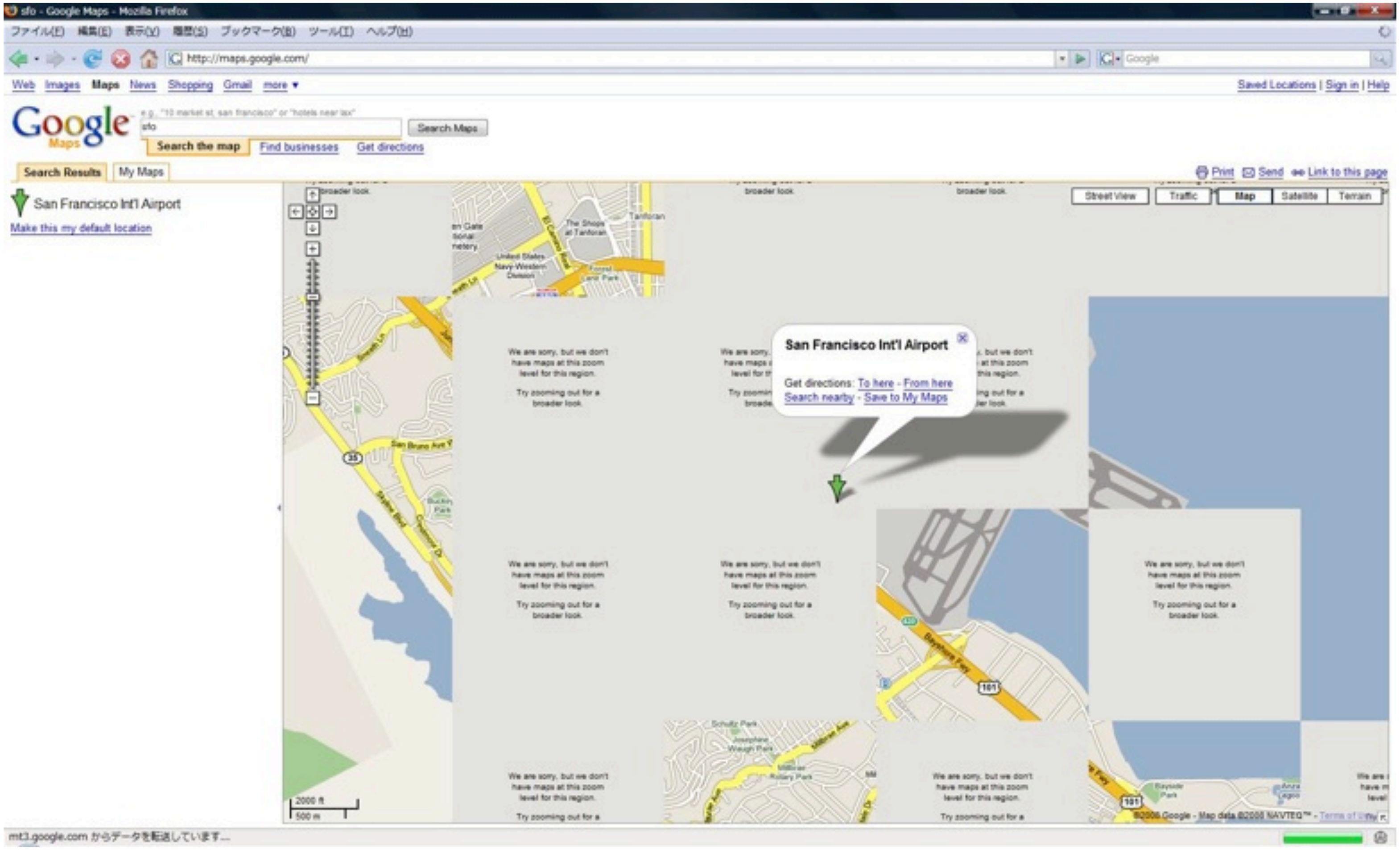
Max 15 Connections



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http://maps.google.com/

e.g. "10 market st, san francisco" or "hotels near lax"

sfo

San Francisco Int'l Airport

Make this my default location

We are sorry, but we don't have maps at this zoom level for this region.

Try zooming out for a broader look.

San Francisco Int'l Airport

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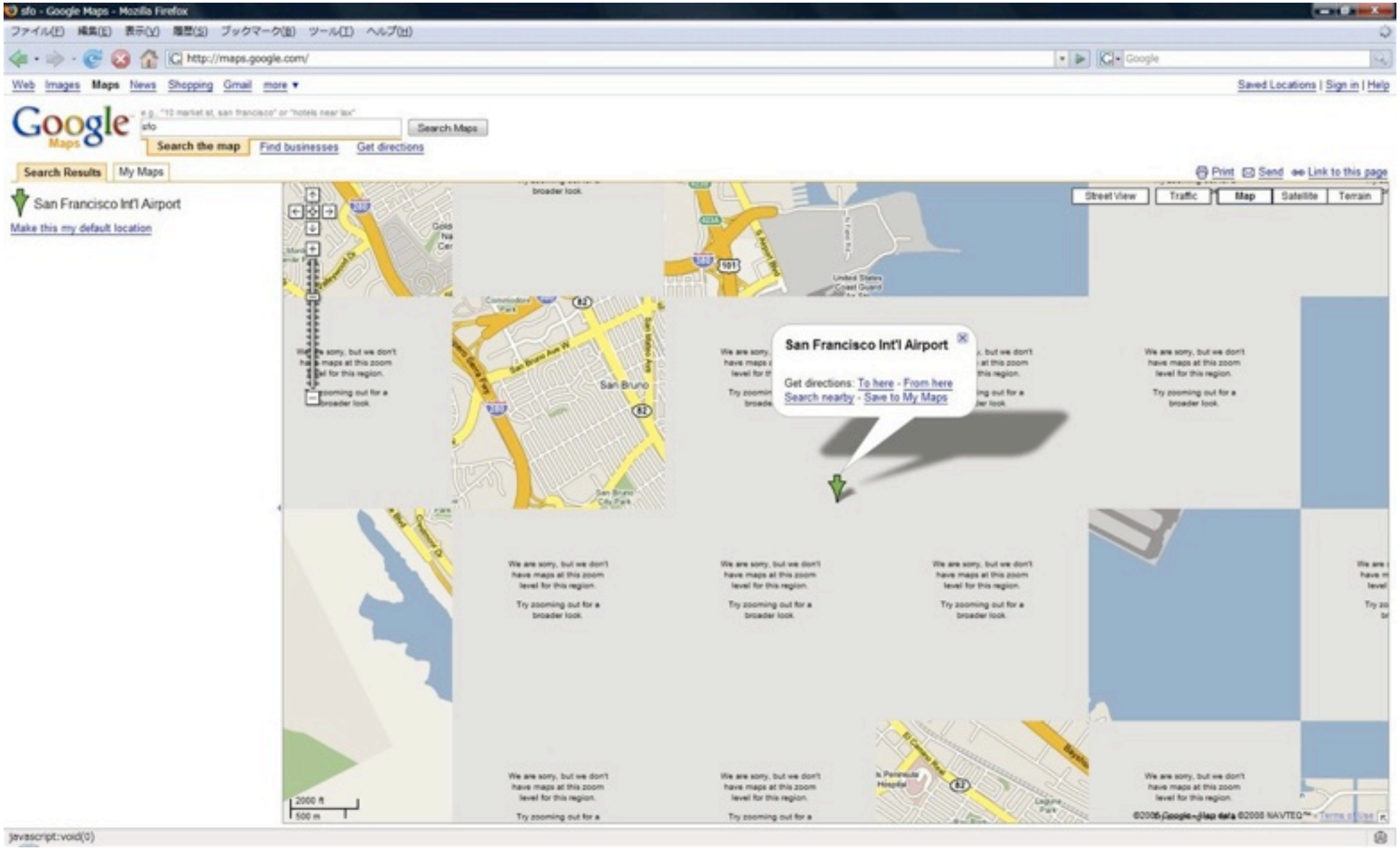
Max 10 Connections



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Google Maps
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Search Maps
Search the map
Find businesses
Get directions
Search Results
My Maps
Print
Send
Link to this page
Street View
Traffic
Map
Satellite
Terrain
San Francisco Int'l Airport
Make this my default location
San Bruno
2000 ft
500 m
javascript:void(0)

San Francisco Int'l Airport

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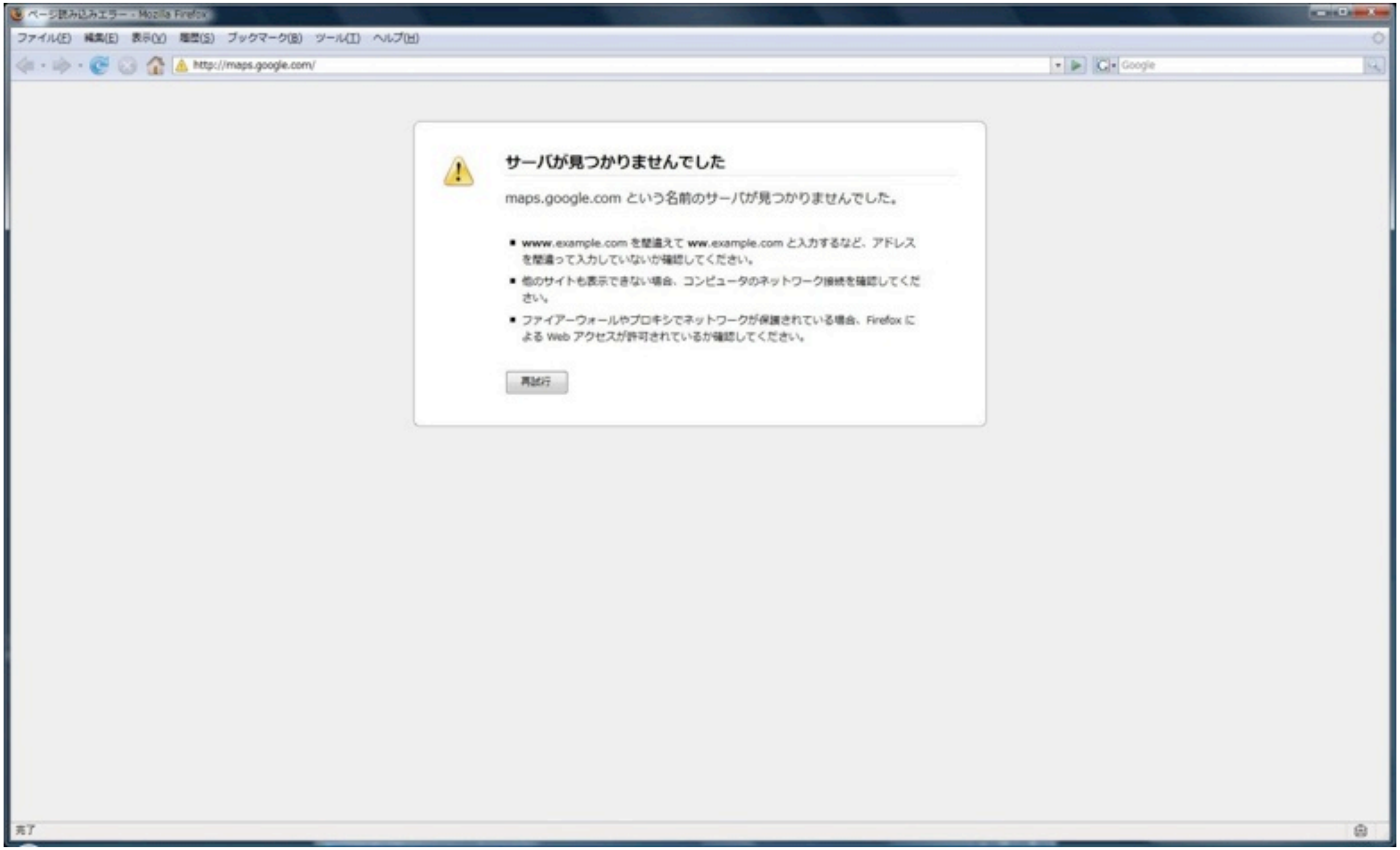
Max 5 Connections



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完了

サーバが見つかりませんでした

maps.google.com という名前のサーバが見つかりませんでした。

- www.example.com を間違えて ww.example.com と入力するなど、アドレスを間違って入力していないか確認してください。
- 他のサイトも表示できない場合、コンピュータのネットワーク接続を確認してください。
- ファイアーウォールやプロキシでネットワークが保護されている場合、Firefox による Web アクセスが許可されているか確認してください。

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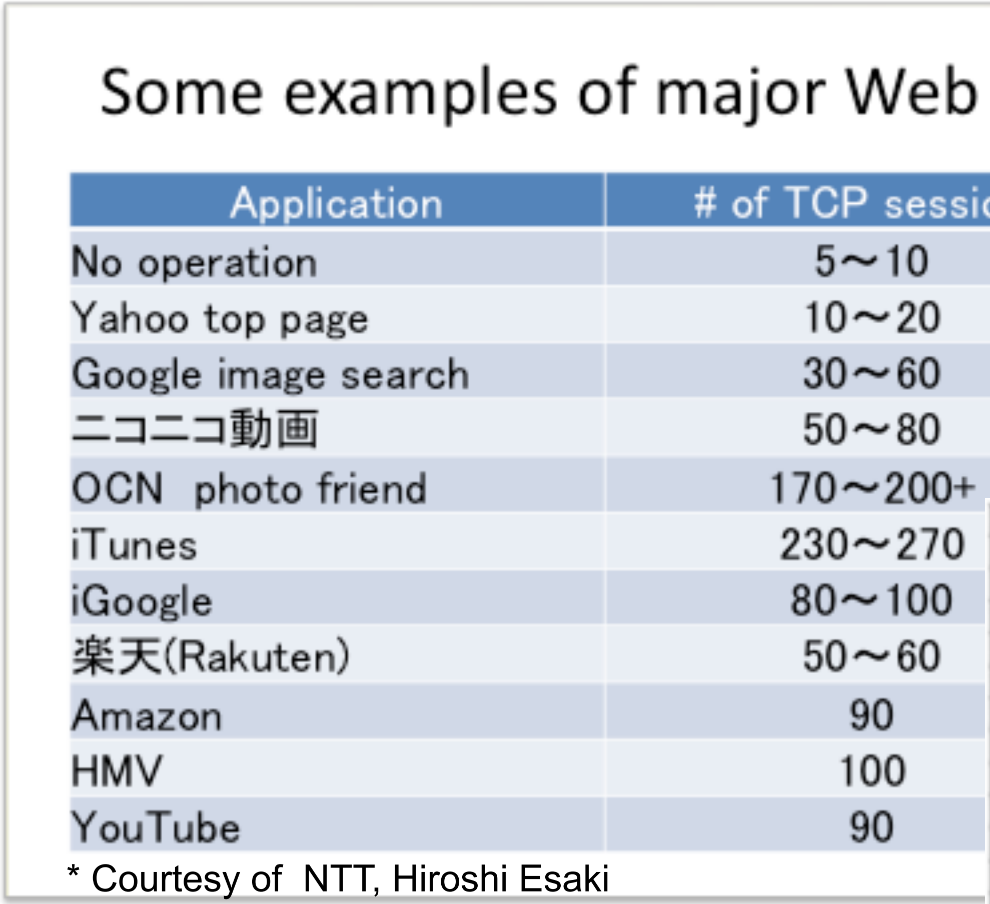
Number of Sessions for Some Applications



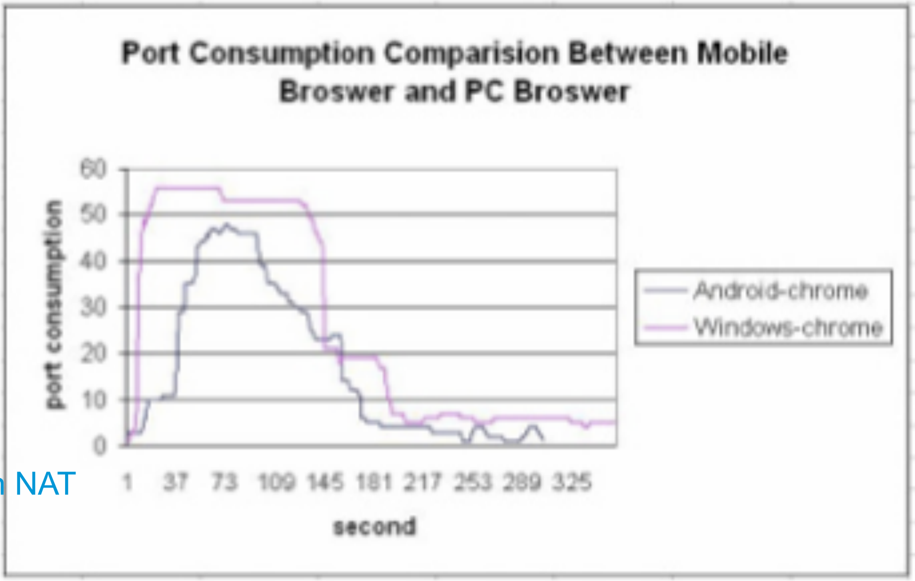
Some examples of major Web site

Application	# of TCP sessions
No operation	5～10
Yahoo top page	10～20
Google image search	30～60
ニコニコ動画	50～80
OCN photo friend	170～200+
iTunes	230～270
iGoogle	80～100
楽天(Rakuten)	50～60
Amazon	90
HMV	100
YouTube	90

* Courtesy of NTT, Hiroshi Esaki

Port Consumption can be big

- Eg. AJAX-based applications with tens-hundreds of TCP sessions
- Eg. Relaunching Firefox with Tabs opens hundreds of sessions



Source:
Application behaviors in in terms of port/session consumptions on NAT
http://opensourceaplusp.weebly.com/experiments-results.html

See also “An Experimental Study of Home Gateway Characterist
https://fit.nokia.com/lars/papers/2010-imc-hgw-study.pdf
http://www.ietf.org/proceedings/78/slides/behave-8.pdf

Default Session Timers – example

Type	Default Value
ICMP	60 sec
UDP init	30 sec
UDP active	120 sec
TCP Init	120 sec
TCP active	30 min

***) Default Refresh Direction is Bidirectional (configurable to OutBound only)**

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CGN Session Logging

- Data Retention Law compliance, user trackability

  Who posted a content to a server on Tue at 8:09:10pm?

  - Global IP:port → CGN Log → Private IP:port → MSISDN
  - Directive 2006/24/EC - Data Retention

- Logging Format

  Must be fast and efficient (think 1Msps)

  - ASCII format (Syslog) – very chatty (113B add-event), inefficient, no sequence #
  - Binary Format (Netflow) – efficient (21B add event), sequencing

- Netflow V9 Logging

  21B add-event, 11B delete-event

  Up to 68 add-events per 1500B export packet

  - Dynamic, template-based format (1 Msps = cca 176 Mbps, 14.7 Kpps)

  Future evolution → IPFIX (SCTP – reliable streaming, multi-core CPU's)

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Netflow v9 logging

Tip: IsarFlow – tested CGN NFv9 Collector
www.isarnet.de

Add Event Template 256 (21B)

Field ID	Attribute	Value
234	Incoming VRF ID	32 bit ID
235	Outgoing VRF ID	32 bit ID
8	Source IP Address	IPv4 Address
225	Translated Source IP Address	IPv4 Address
7	Source Port	16 bit port
227	Translated Source Port	16 bit port
4	Protocol	8bit value

Delete Event Template 257 (11B)

Field ID	Attribute	Value
234	Incoming VRF ID	32 bit ID
8	Source IP Address	IPv4 Address
7	Source Port	16 bit port
4	Protocol	8bit value

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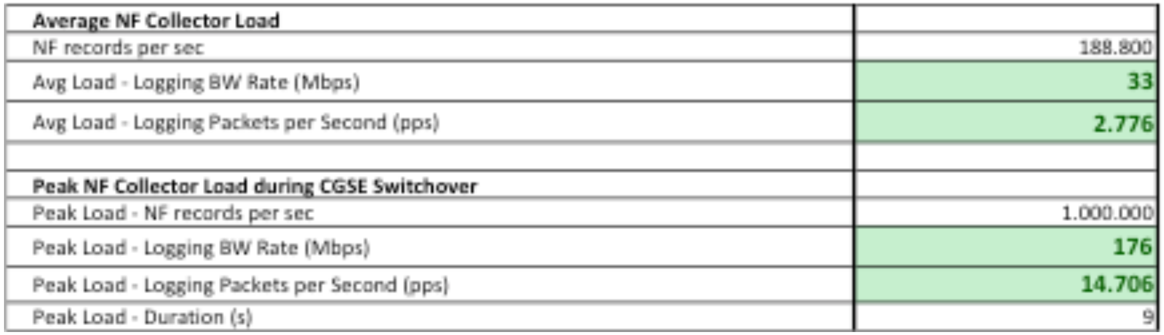
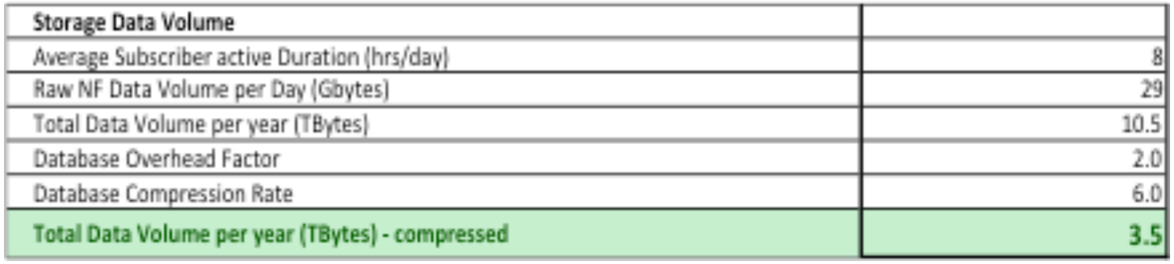
Netflow logging Data Volume example

Collector Performance – 100K users, average and peak



Average NF Collector Load	
NF records per sec	188.800
Avg Load - Logging BW Rate (Mbps)	**33**
Avg Load - Logging Packets per Second (pps)	**2.776**
Peak NF Collector Load during CGSE Switchover	
Peak Load - NF records per sec	1.000.000
Peak Load - Logging BW Rate (Mbps)	**176**
Peak Load - Logging Packets per Second (pps)	**14.706**
Peak Load - Duration (s)	9

Storage Capacity – includes per-day user behavior



Storage Data Volume	
Average Subscriber active Duration (hrs/day)	8
Raw NF Data Volume per Day (Gbytes)	29
Total Data Volume per year (TBytes)	10.5
Database Overhead Factor	2.0
Database Compression Rate	6.0
Total Data Volume per year (TBytes) - compressed	3.5

Reality check: 100K CGN users would consume 3.5TB storage per year (compressed, fully SQL searchable data)

E-Shop: 4TB disk, 300 Euro…

Usually no need to bother with logging reduction…

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Logging reduction

- Bulk port range allocation
  - Pre-allocates a port-set per user (eg. 512 ports)
  - Logs only once (when port-set is allocated/deallocated)
- Deterministic NAT
  - Port-sets are determined algorithmically from user IP (patented)
  - No logging until port-set overflows

ISSUES

- Breaks TCP port randomization (user security consequences)
- Inefficient usage of global IP pools
  (active users eat hundreds of ports, inactive users eat only few ports)
- Troubles to get acceptance in IETF (BEHAVE WG)
- Mutually exclusive with DBL (Destination Based Logging)

→ It is not worth it and is NOT RECOMMENDED. It's better to use Netflow.

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DBL (Destination Based Logging)

Add Event Template 271 (27B)

Field ID	Attribute	Value
234	Incoming VRF ID	32 bit ID
235	Outgoing VRF ID	32 bit ID
8	Source IP Address	IPv4 Address
225	Translated Source IP Address	IPv4 Address
7	Source Port	16 bit port
227	Translated Source Port	16 bit port
12	Destination Address	IPv4 Address
11	Destination Port	16 bit port
4	Protocol	8 bit value

DBL logs also destination IP:port

- data retention vs. user privacy
- keeps EIM/EIF behavior

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CGN Scale and Performance

Session = full-duplex, bidirectional L4 flow

- Session Setup Rate [sps] – sessions per second

  Average # of New Sessions per User, during peak hours

  - Huge load during a failover scenarios or after a power blackout
  - Failing to cope with SPS = huge TCP delays, timeouts/retransmissions

- Maximum Number of Concurrent Sessions [cs] per CGN

  Average # of Concurrent Sessions per User, during peak hours

  - UDP must not expire in less than 2 minutes (RFC4787)
  - UDP/TCP timers for Initializing and Established sessions should be configurable

- Throughput per CGN [bps]

  Aggregate (downstream + upstream) bandwidth

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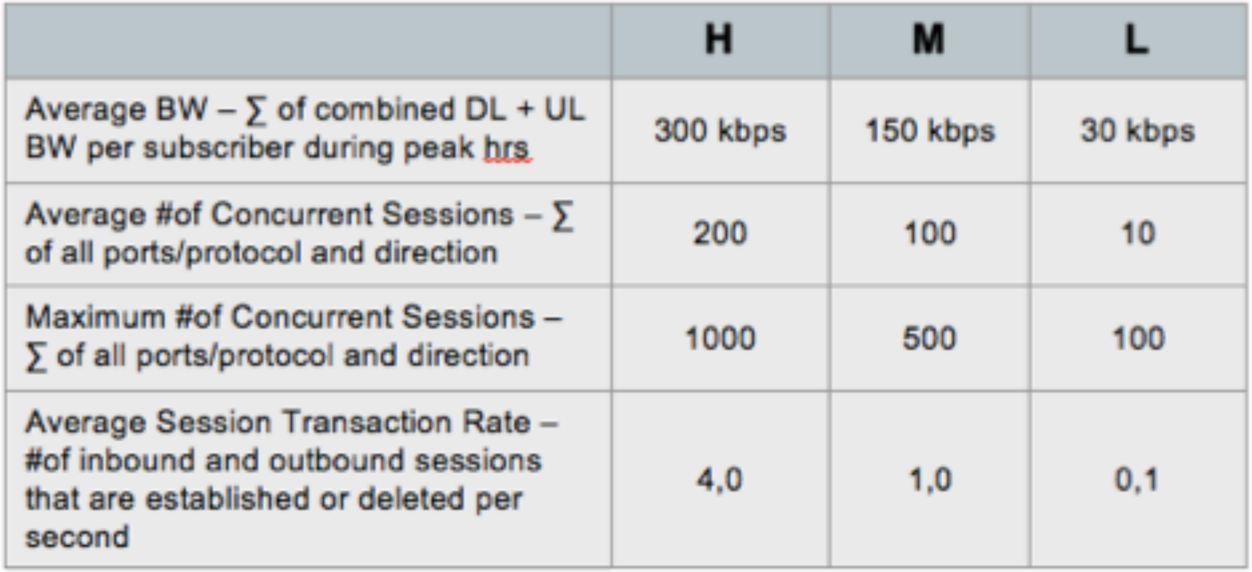
CGN Scale and Performance – design

L (Low-scale) Scenario – 3G mobile users, smart-phones

M (Medium-scale) Scenario – ADSL subscribers, PC users with 3G/4G dongles, Tablets, WiFi and top smart-phone users

H (High-scale) Scenario – heavy Broadband users, Internet sharing



	H	M	L
Average BW – ∑ of combined DL + UL BW per subscriber during peak hrs	300 kbps	150 kbps	30 kbps
Average #of Concurrent Sessions – ∑ of all ports/protocol and direction	200	100	10
Maximum #of Concurrent Sessions – ∑ of all ports/protocol and direction	1000	500	100
Average Session Transaction Rate – #of inbound and outbound sessions that are established or deleted per second	4,0	1,0	0,1

100K BB users = up to 100Ksps and 10Mcs during peak hour!

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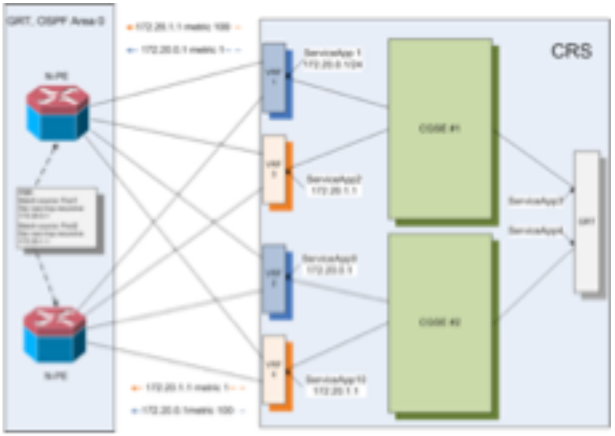
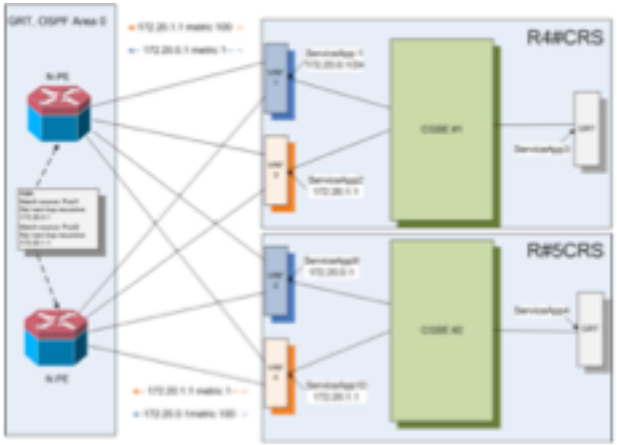
CGN Redundancy

- High Availability scenarios
  - Intra-chassis, Inter-chassis
  - Active/Standby, Active/Active

- Stateful or stateless
  - Millions of short-lived Layer-4 session
  - Stateful sync makes no sense for such ephemeral state (memory & CPU) – eg.





- Stateless redundancy
  - 1Msps = 100K active users (10Mcs) are up in 10s → minimal loss
  - Load-sharing = simple ECMP routing
  - Best Practice: Simple Non-Revertive 1:1 Warm Standby

CGN design: Basic Scenarios

▬ CGN module

1+1 Redundancy

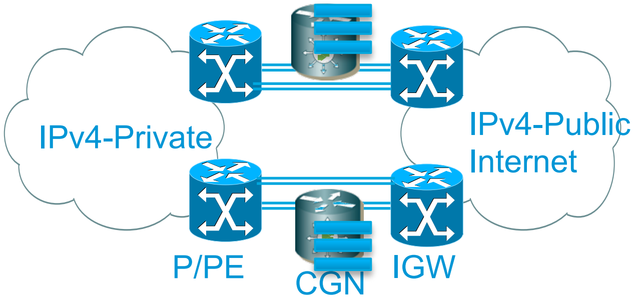
- 3+3 in this example

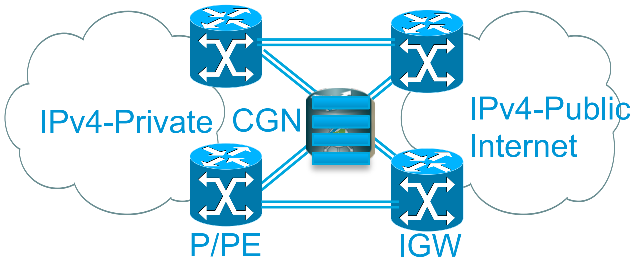
N+1 Redundancy

- 3+1 in this example

Bump-in-a-wire Design

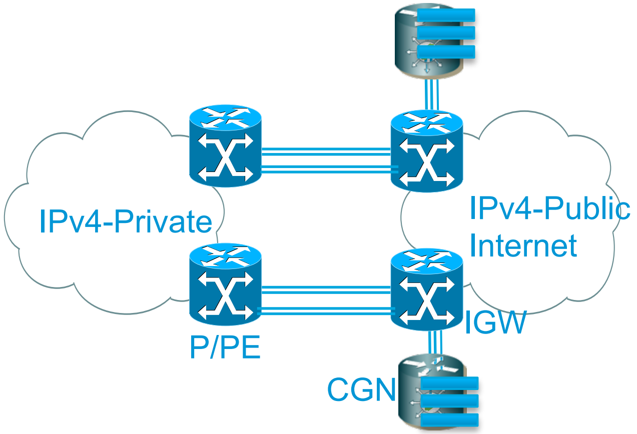
- new 4xTGE per box in this example

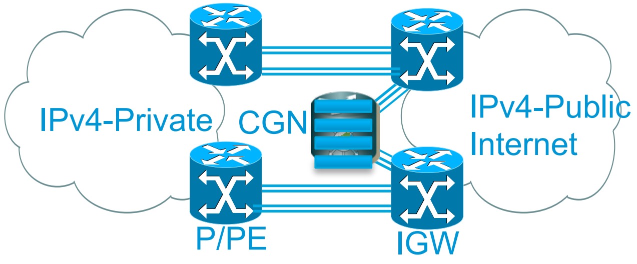




Router-on-a-stick Design

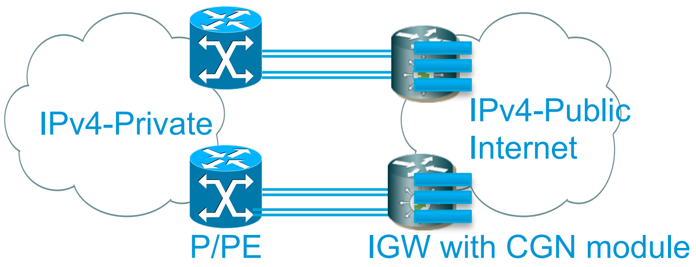
- new 3xTGE per box in this example

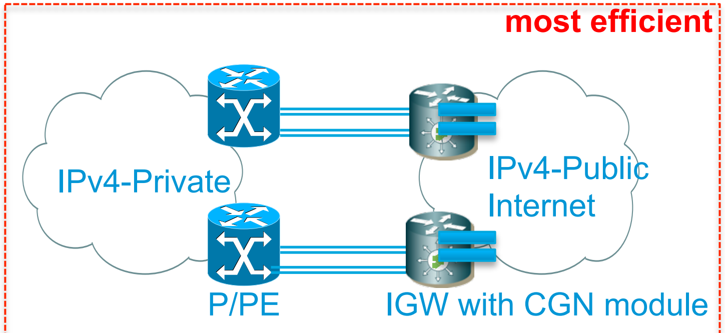




Integrated Design

- No new ports





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Summary

- CGN is here to overcome IPv4 exhaust before IPv6 migration
- CGN is ISP element, focus on transparency
- CGN is not firewall
- CGN behavioral requirements
- CGN logging
- CGN performance – SPS, # of sessions, deployment options

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Thank you.

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