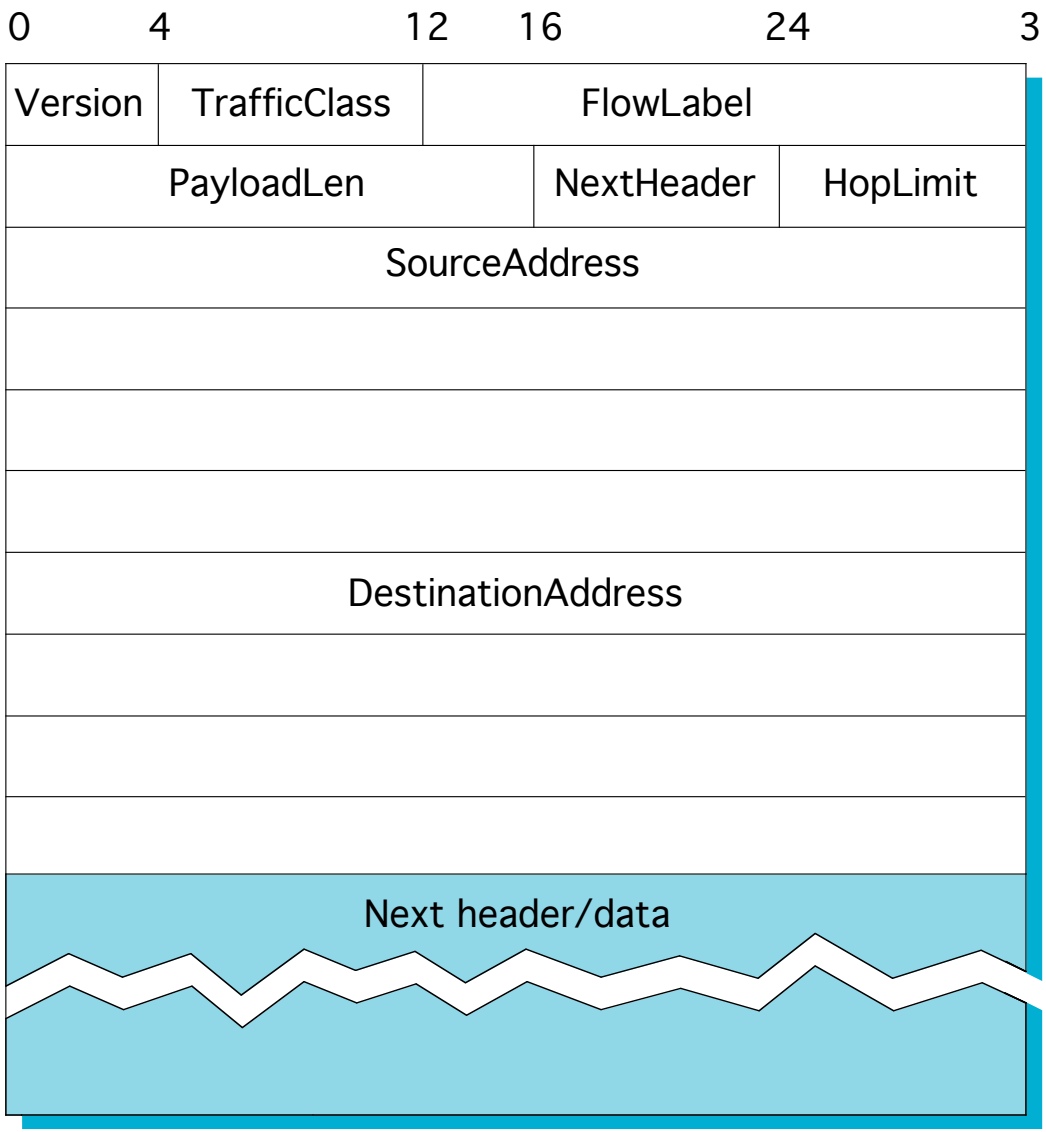
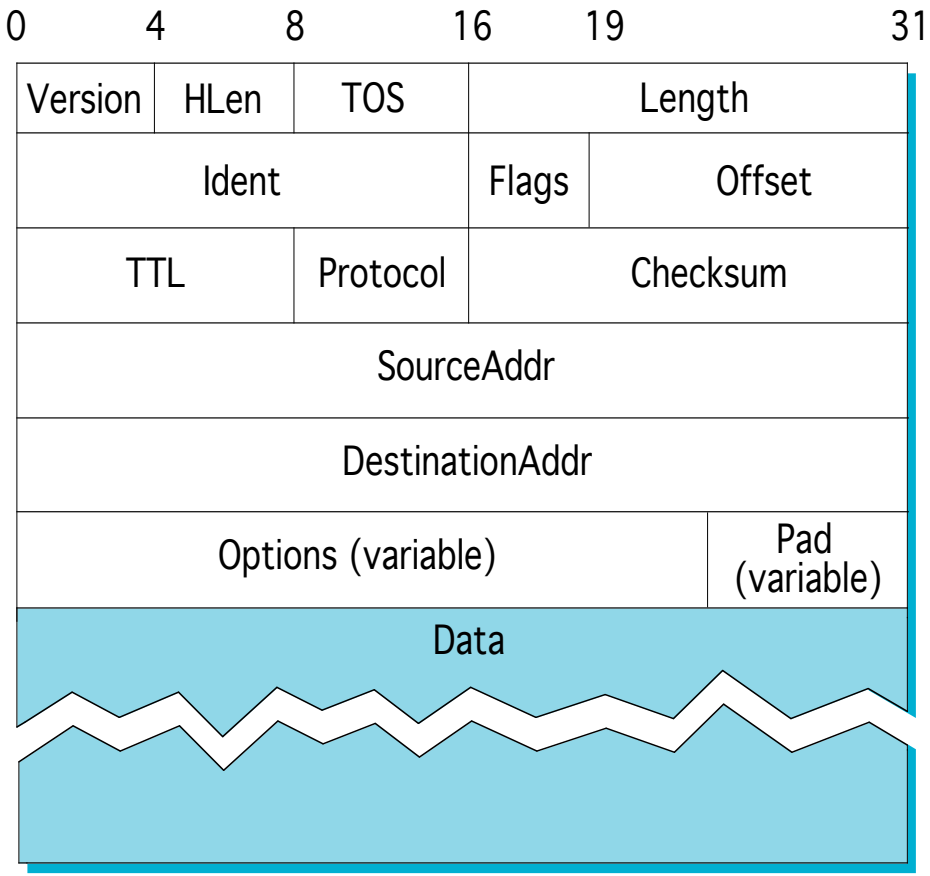
IPv6

- Initial motivation: 32-bit address space exhaustion
- Also, take the opportunity to do some clean-up
  - header format helps speed processing/forwarding
  - IPv6 datagram format: fixed-length 40 byte header
- More specifics:
  - Address length changed from 32 bits to 128 bits
  - IP options moved out of the base header
  - Header Checksum removed
  - Type of Service field removed
  - Fragmentation/Reassembly fields moved to options.
  - Length field excludes IPv6 header
  - Time to Live ➔ Hop Limit, Protocol ➔ Next Header
  - added Flow Label field

Header Format



IPv6



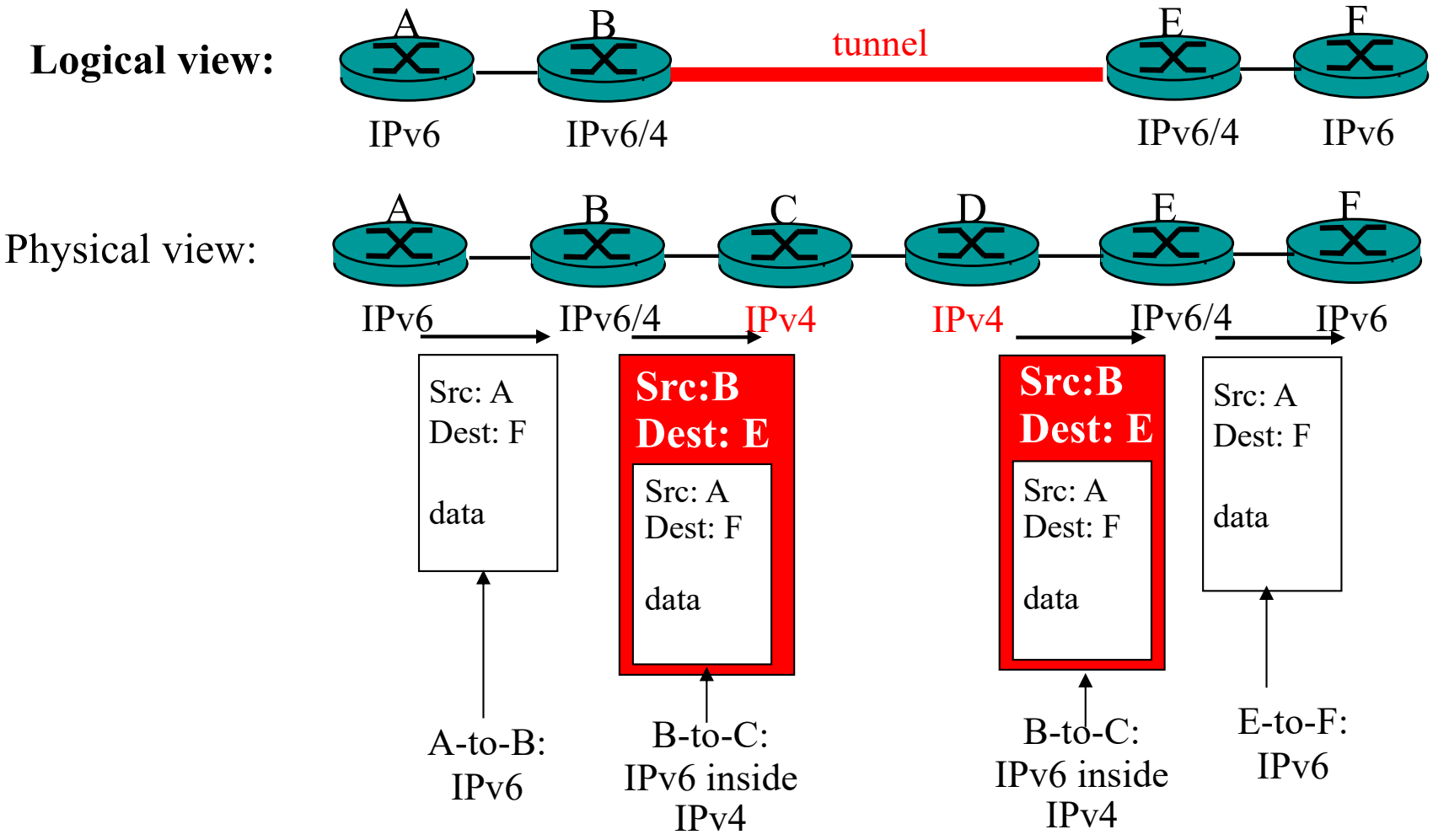
IPv4

Changes from IPv4

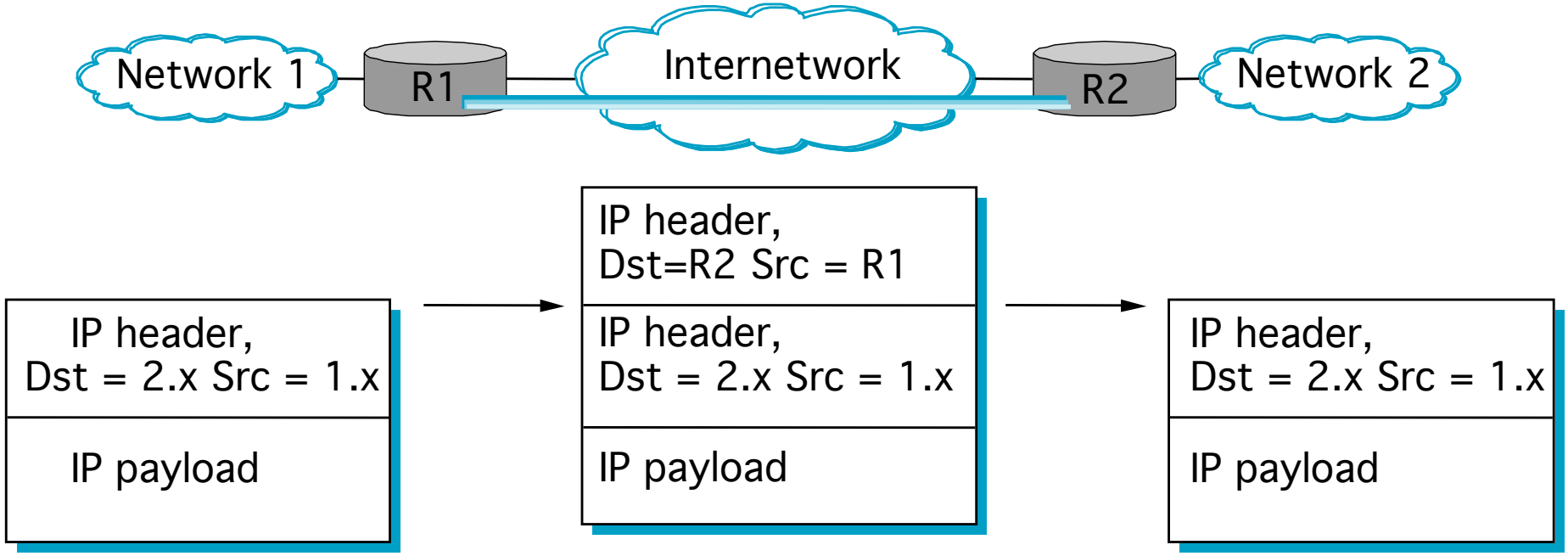
- *Traffic Class:* identify priority among datagrams in flow
- *Flow Label:* identify datagrams in same "flow." (concept of "flow" not well defined).
- *Next header:* identify upper layer protocol for data
- *Checksum*: removed entirely to reduce processing time at each hop
- *Options:* allowed, but outside of header, indicated by "Next Header" field
- *ICMPv6:* new version of ICMP
  - additional message types, e.g. "Packet Too Big"
  - multicast group management functions

Transition From IPv4 To IPv6

- Not all routers can be upgraded simultaneous
- to allow the Internet operate with mixed IPv4 and IPv6 routers : ***tunneling***

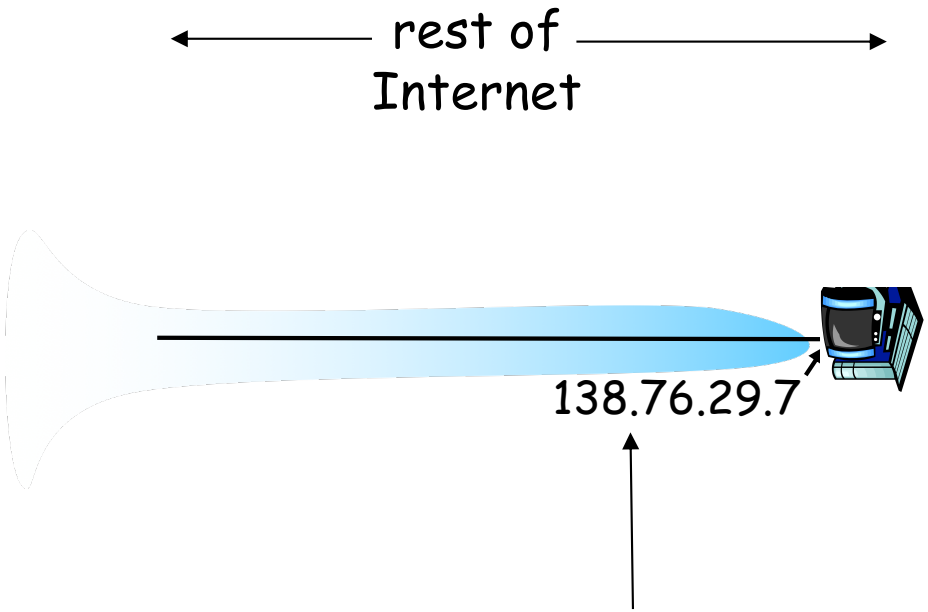


Tunneling



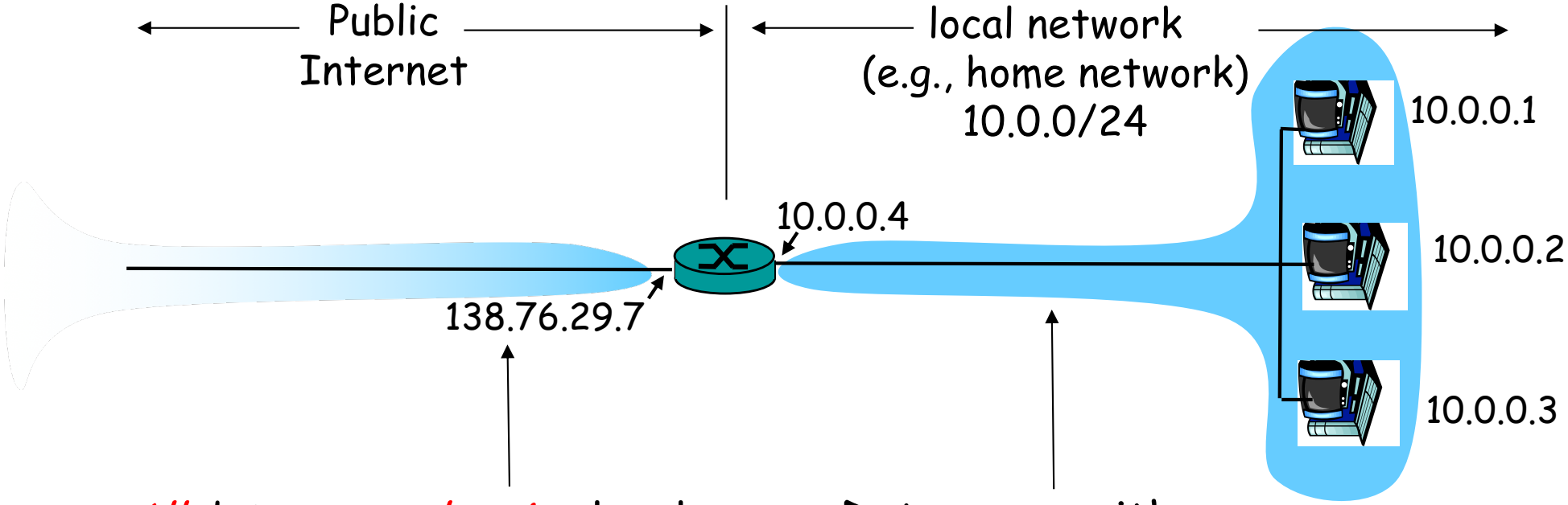
- Tunneling: encapsulates a packet inside another header between two routers (tunnel endpoints).
  - IP-in-IP, IP-in-UDP, ...
- The two endpoints perform encapsulation and decapsulation. The src and dst hosts/apps are not aware of the tunnel.

NAT: Network Address Translation



All datagrams *leaving* local network have same single source public IP address: 138.76.29.7, different source port numbers

NAT: Network Address Translation



All datagrams *leaving* local network have same single source **public** IP address: 138.76.29.7, different source port numbers

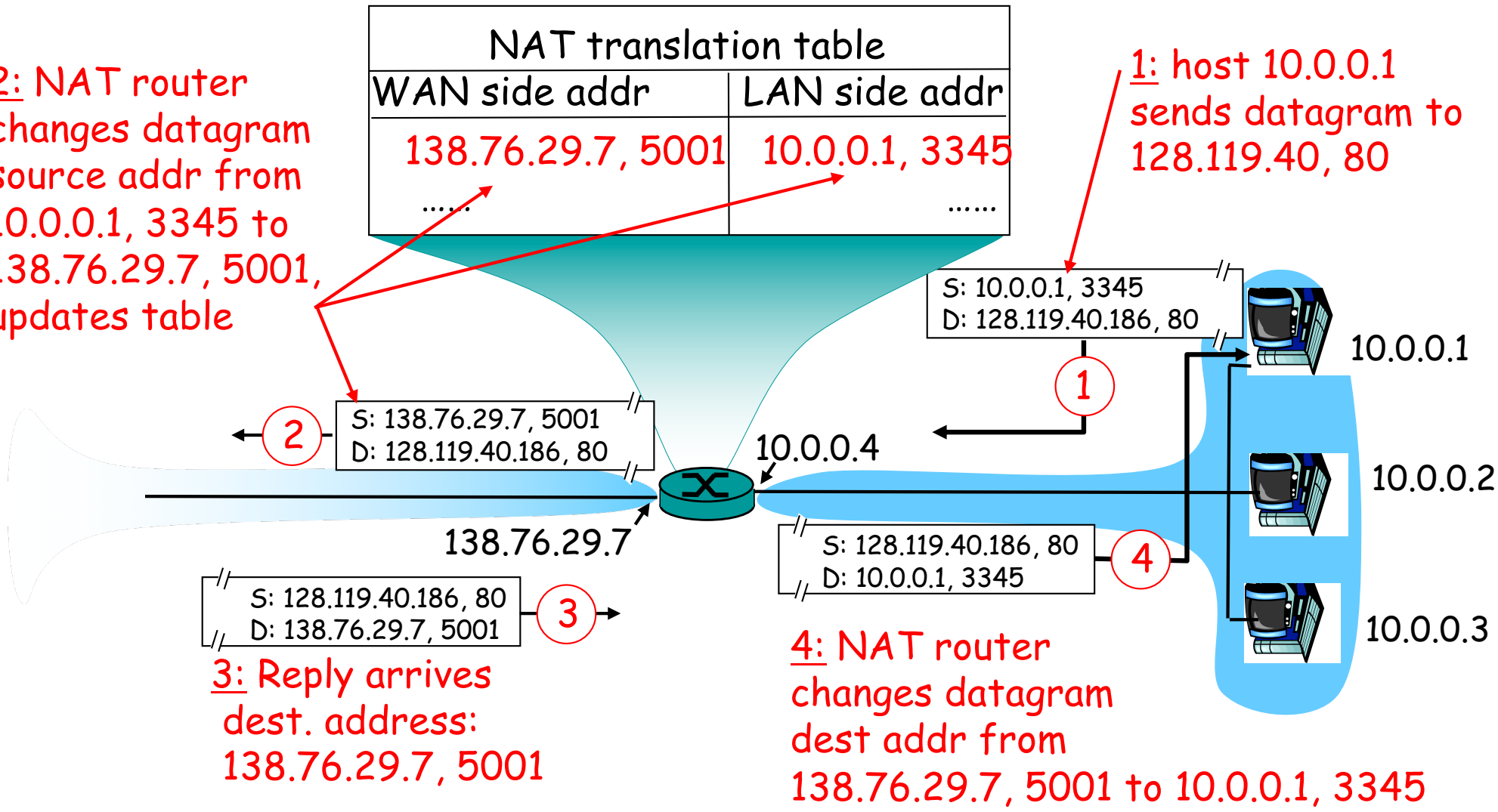
Datagrams with source or destination in this network have **private** 10.0.0/24 address for source, destination (as usual)

Why NAT?

Motivation: Local network uses just one IP address as far as outside world is concerned:

- No need to be allocated a range of addresses from ISP: just one IP address is used for all devices
- Can change addresses of devices in local network without notifying outside world
- Can change ISP without changing addresses of devices in local network
- Devices inside local net not explicitly addressable or visible by outside world (a security plus)
- Easy to deploy: no changes to any device other than a NAT box in local network.

How NAT Works



NAT implementation

NAT router must do the following:

- *outgoing* packets: replace [*source* IP address, port #] of every outgoing packet to [NAT IP address, new port #]
  - . . . remote clients/servers will respond using (NAT IP address, new port #) as destination address.
- remember (in NAT translation table) every [source IP address, port #] to [NAT IP address, new port #] translation pair
- *incoming* packets: replace [NAT IP address, new port #] in *destination* fields of every incoming datagram with corresponding [source IP address, port #] stored in NAT table

Problems caused by NAT

- 16-bit port-number field: limits the total number of connections supportable
- Cannot run services from inside a NAT box
  - All communications must be initiated by internal hosts.
- Reduced robustness
- NAT is *controversial*:
  - violates the assumption of globally unique addresses.
  - NAT possibility must be taken into account by app designers, eg, P2P applications

Address shortage should instead be solved by IPv6

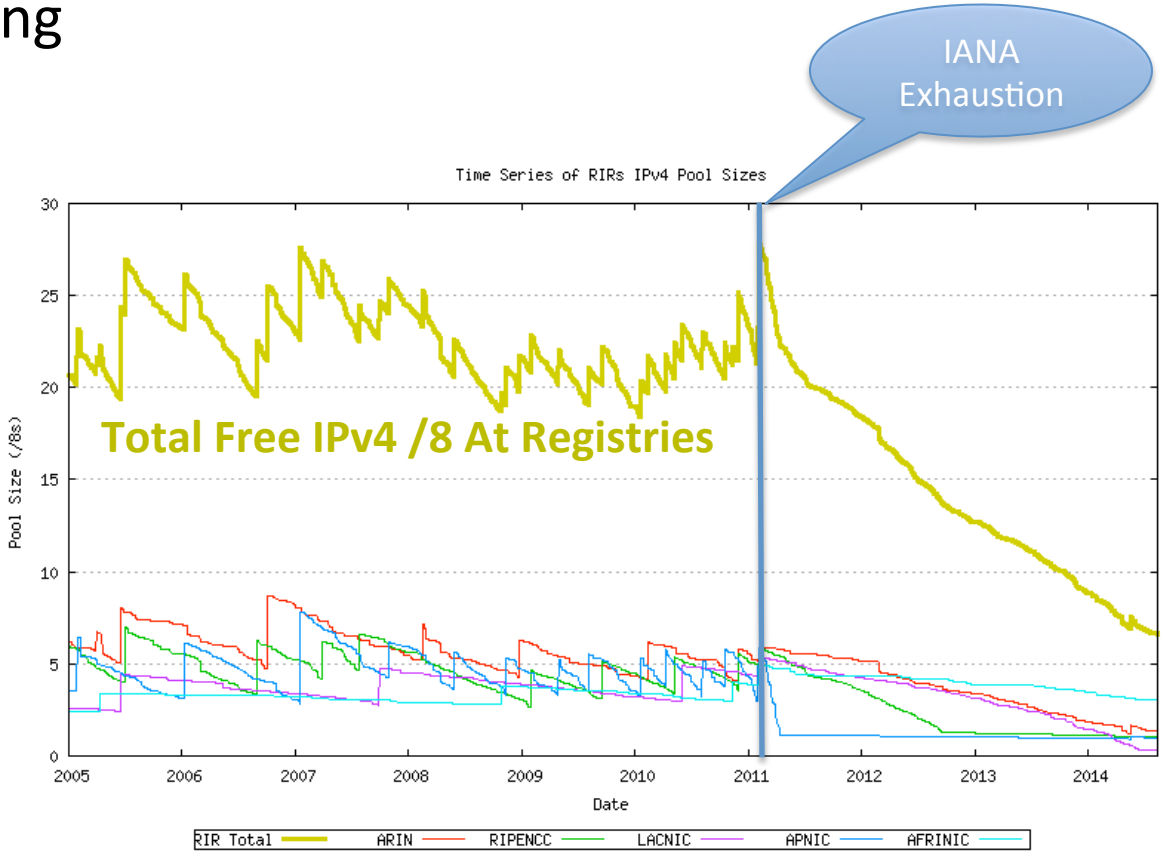
Measuring IPv6 Adoption

Jakub Czyz, University of Michigan
Mark Allman, International Computer Science Institute
Jing Zhang, University of Michigan
Scott Iekel-Johnson, Arbor Networks
Eric Osterweil, Verisign Labs
Michael Bailey, University of Michigan and University of Illinois

SIGCOMM 2014
Chicago, IL, USA
August 17-22, 2014

Why Study IPv6 Adoption Now?

- Internet continues growing
- IPv4 space shrinking…
- IPv4 exhaustion events:
  - **IANA: February 2011**
  - Asia/Pacific: April 2011
  - Europe: September 2012
  - Latin America: June 2014
- IPv6 Community Flag Days
  - 2011 & 2012



(Image source: Geoff Huston, http://www.potaroo.net/tools/ipv4)

Our Study

- **Goal:** a systemic "big picture" of IPv6 adoption
  - Trading off depth for breadth
  - Are there cross-perspective insights?
- **Multi-perspective**: 10 datasets
- **Multi-year**: 2-10 years
- **Multi-aspect**: 12 metrics
- **Findings: IPv6 adoption**
  - varies by where you measure (region)
  - varies by what you measure
  - recently made a qualitative jump

Data Analyzed

- **Existing/Public Datasets**:
  - RIR allocation
  - Route Views BGP, RIPE-RIS BGP
  - Google.com clients,
  - Verisign zone files, (DNS)
  - CAIDA Ark RTT (ping)
- **New Datasets**:
  - **Traffic**: Arbor Networks global traffic
  - **Naming**: Verisign .com/.net queries via IPv4, via IPv6
  - **Content**: Testing data of Alexa top-10K sites

Metrics

Prerequisite IP Functions

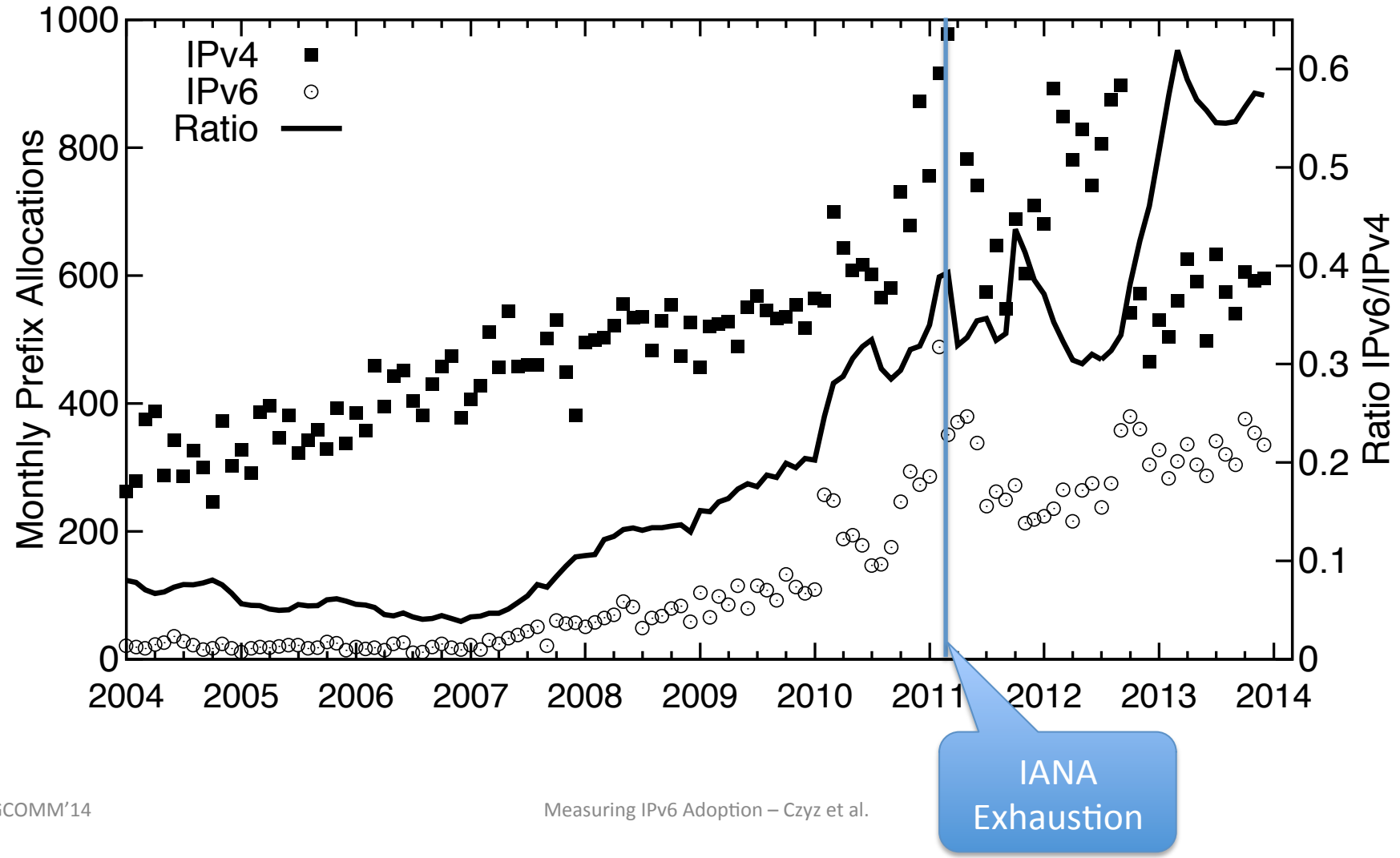
- Address Allocation
- Address Advertisement
- Topology
- DNS Name servers
- DNS Resolvers
- DNS Queries
- Server Readiness
- Client Readiness

Operational Characteristics

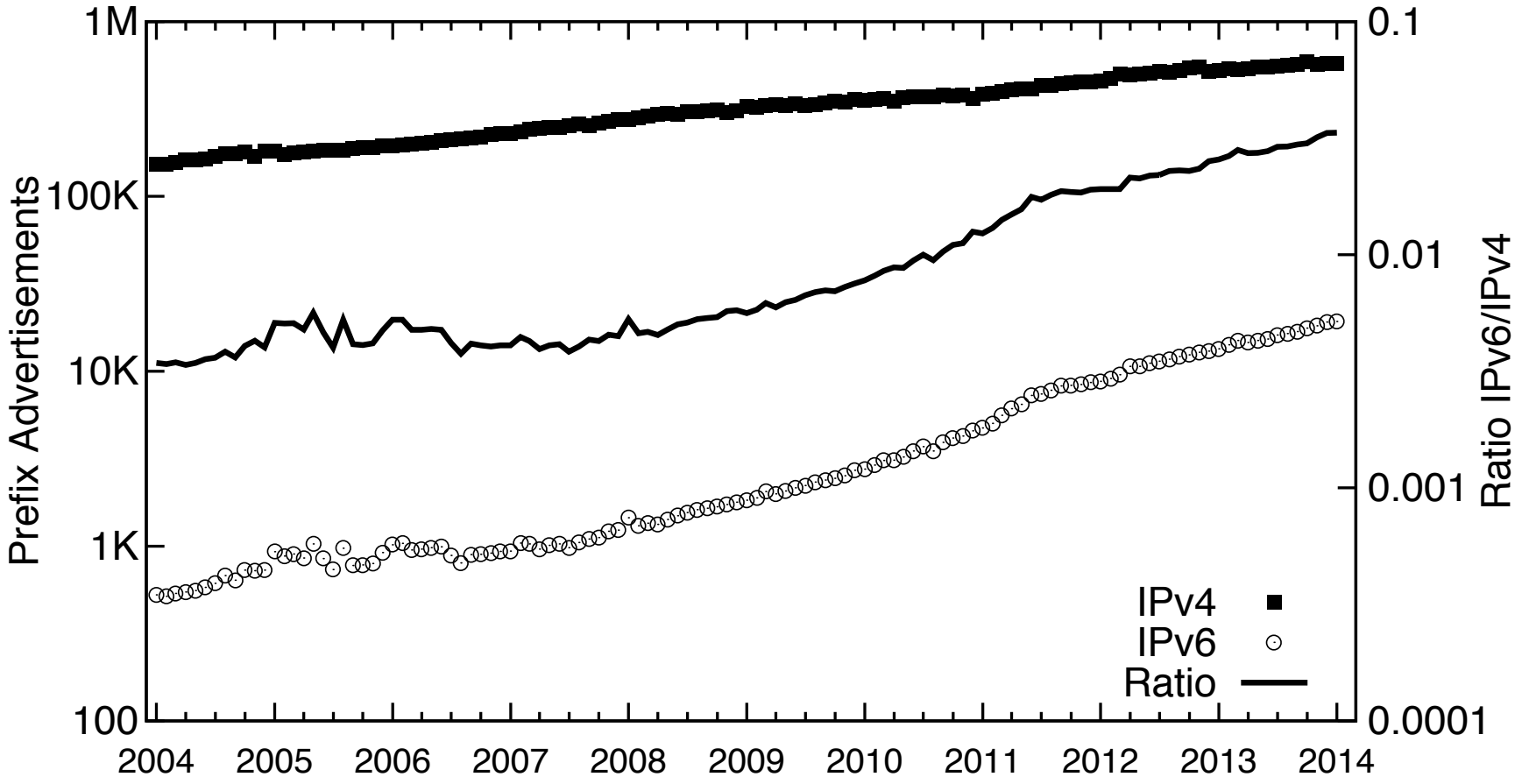
- Traffic Volume
- Application Mix
- Transition Technologies
- Performance (RTT)

"IPv6 adoption" = level relative to IPv4

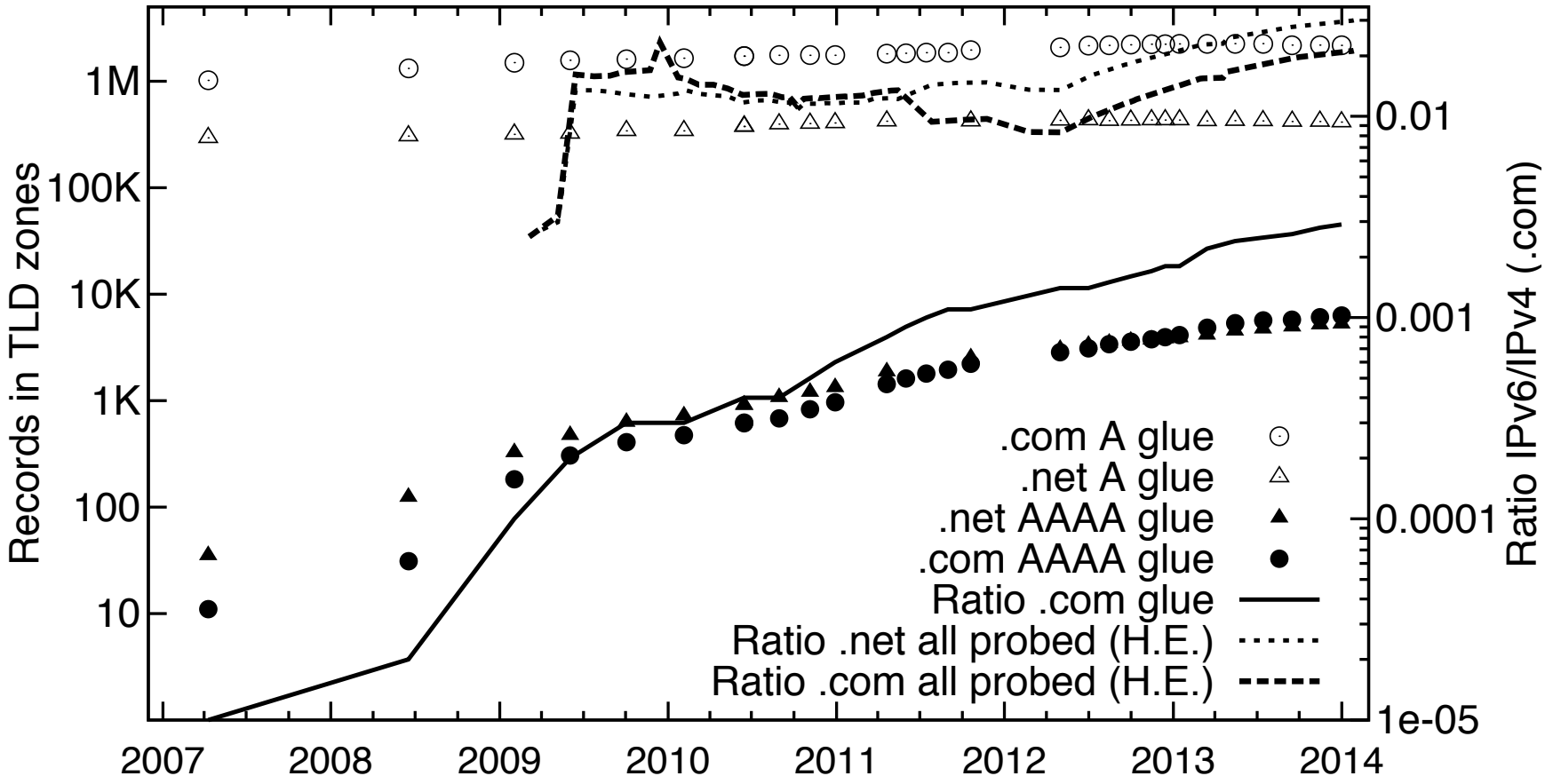
Prefix Allocation



Prefix Advertisement

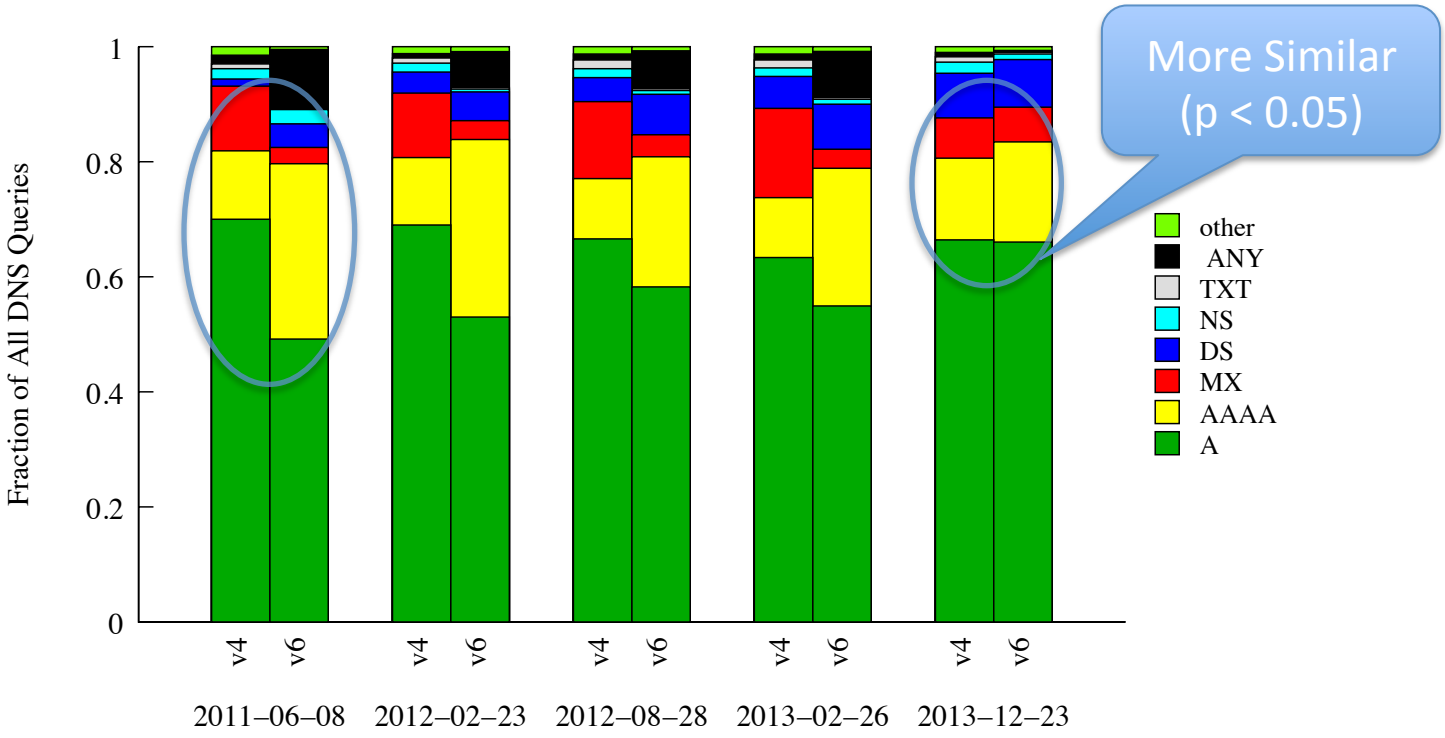


DNS: .com & .net Zones

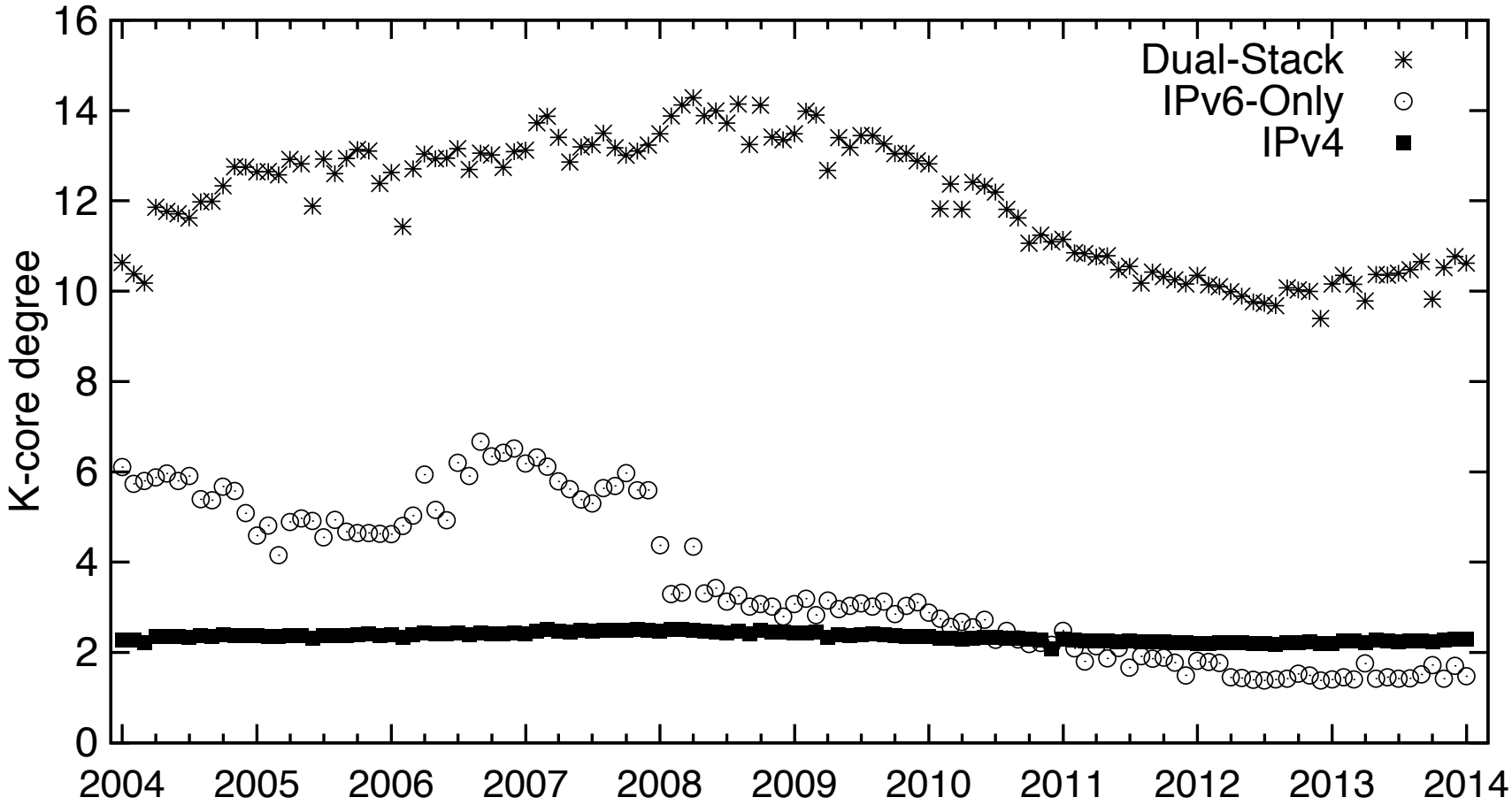


Naming: Domains & Record Types

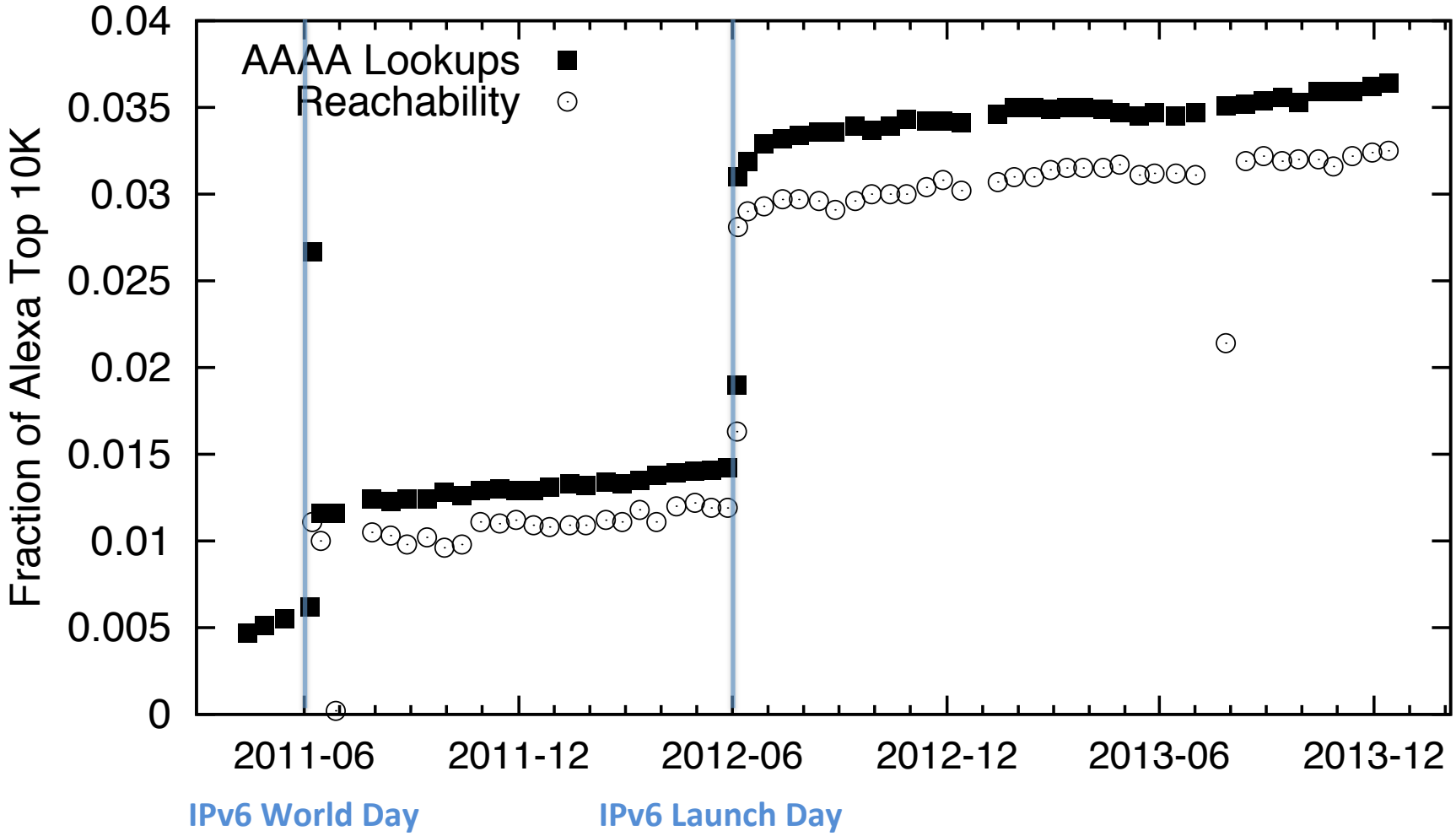
- Queries from .com/.net; IPv4 & IPv6 name servers
  - Five day-long packet samples over 2.5 years
  - IPv6 DNS users query similar **domains** as IPv4
  - Query **types** are converging over this time period:



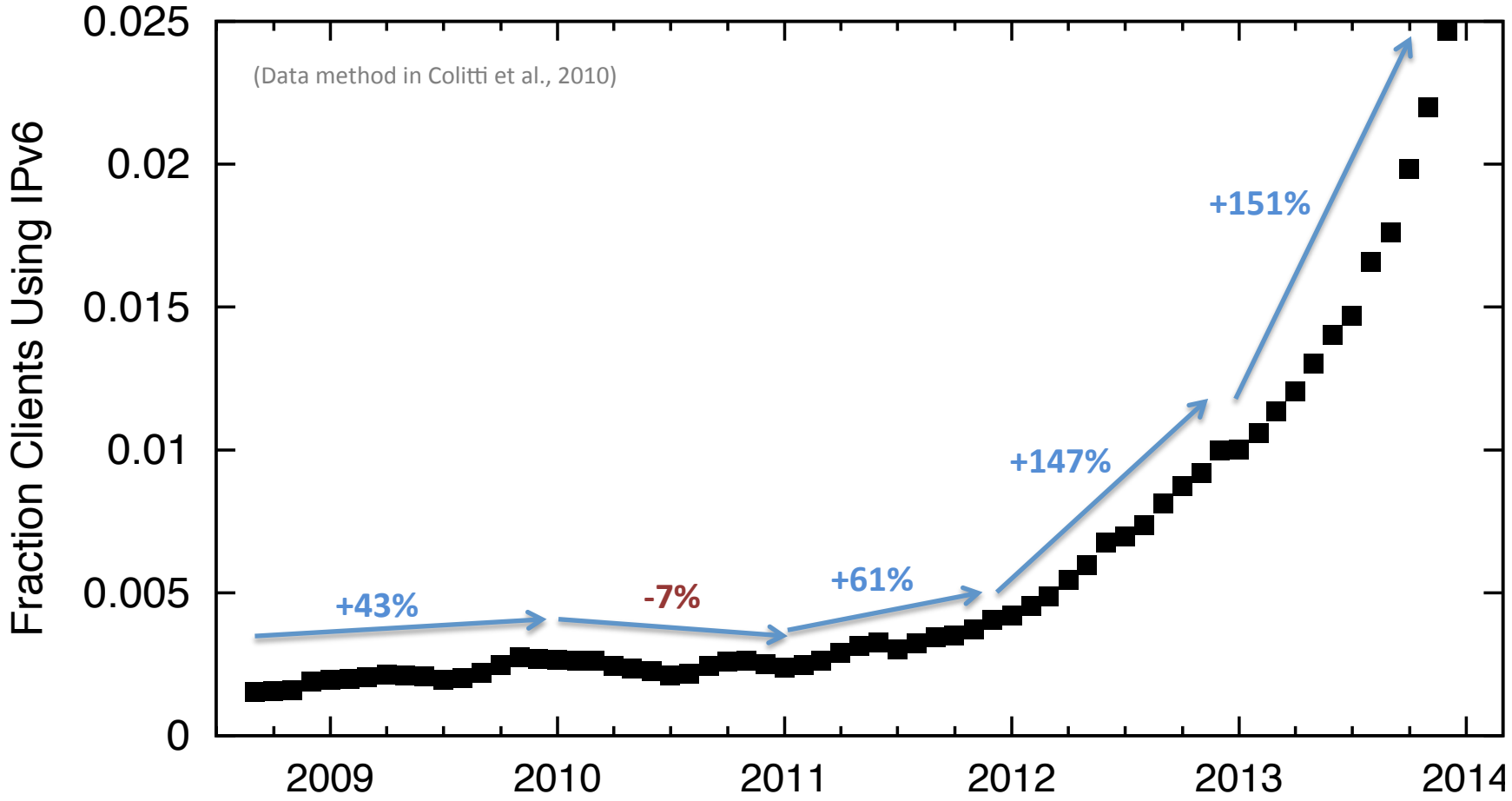
AS Centrality



Server Readiness: Alexa Top Domain Reachability

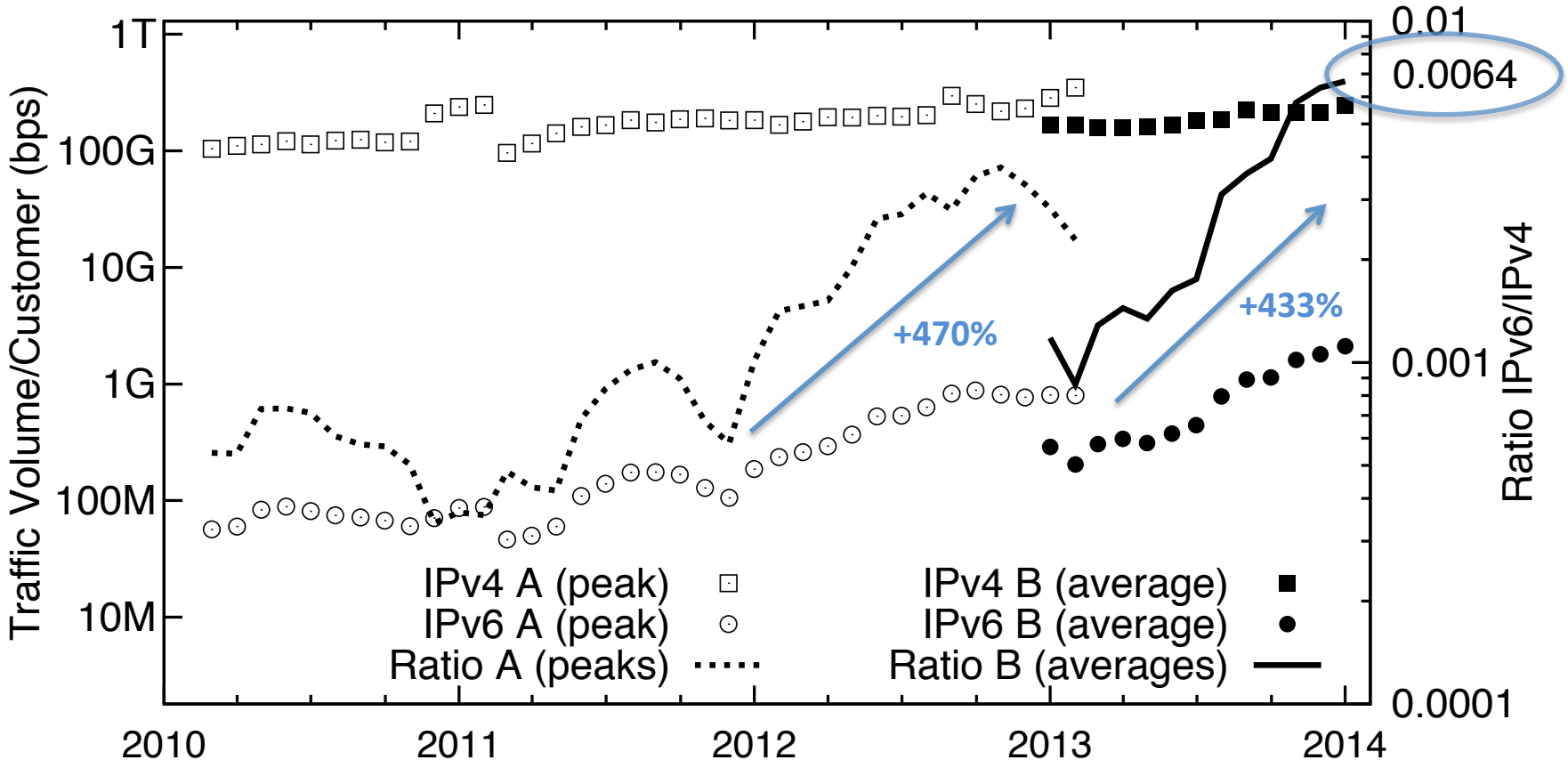


Client Readiness: visitors to google.com



Global Traffic

- Arbor Networks global provider netflow data
  - 260 service providers (Dataset B) ~ 1/3 – 1/2 of all inter-AS traffic

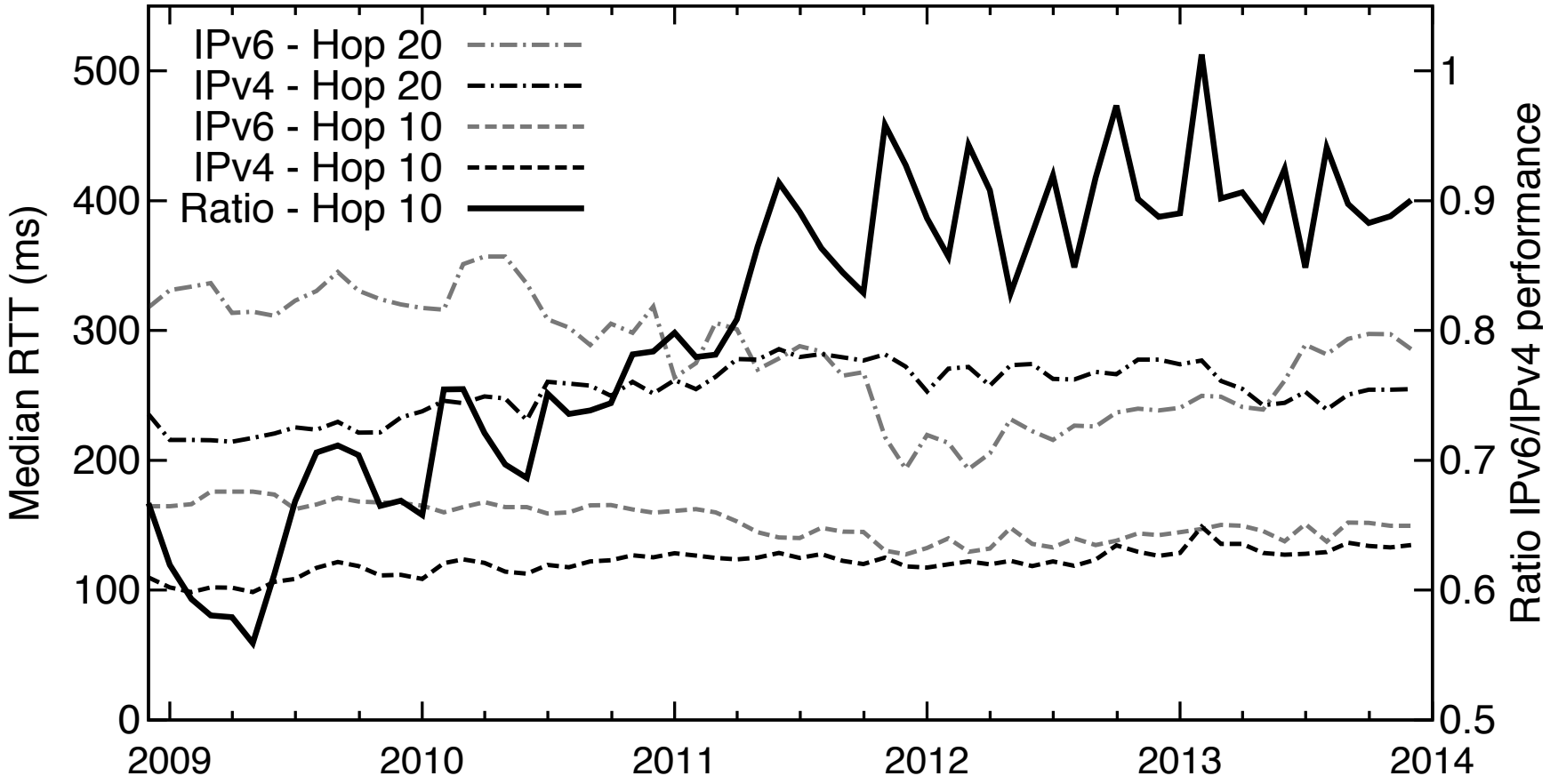


Application Mix (% of IPv6)

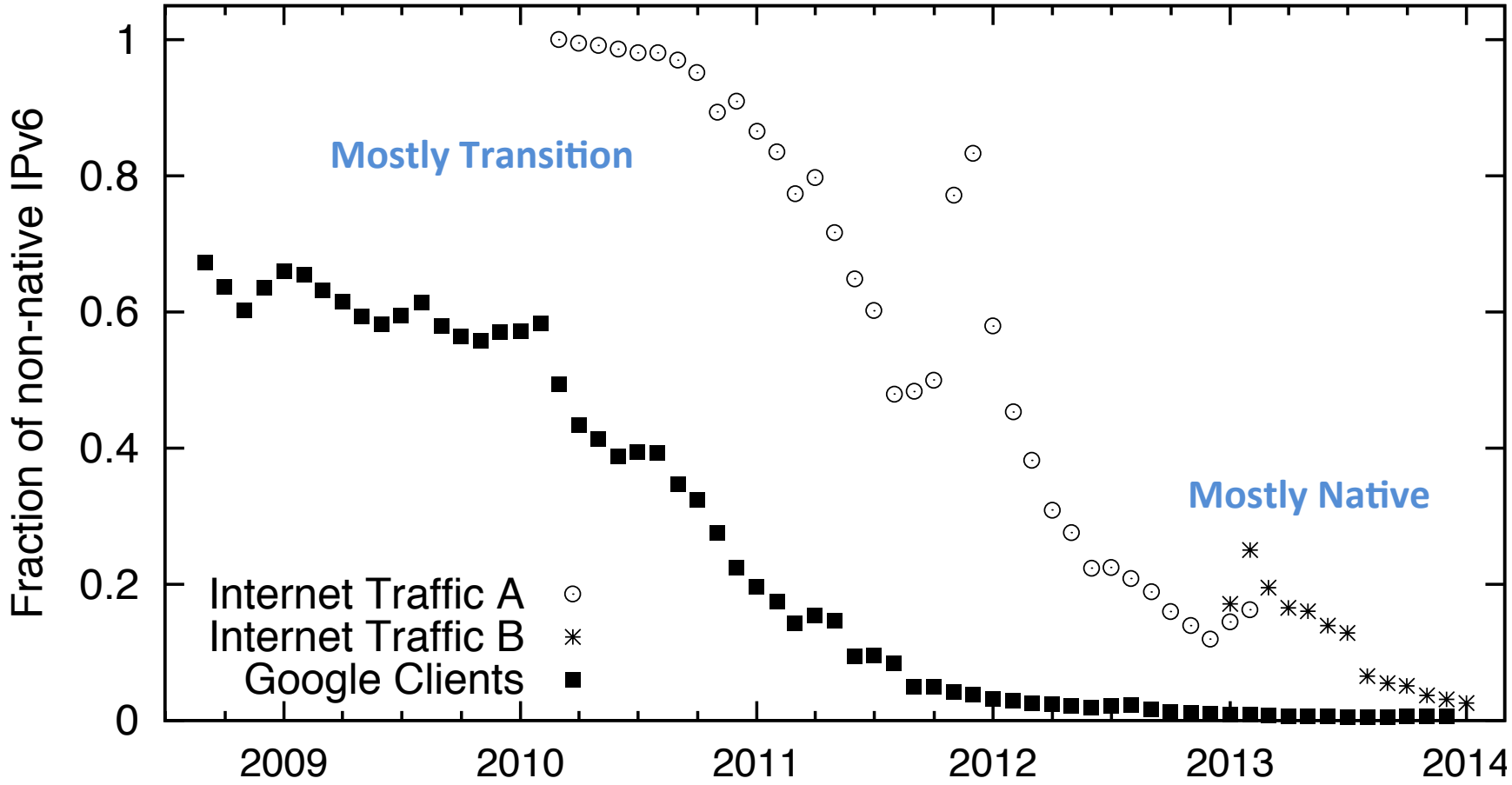
User content {

Application	Dec 2010 IPv6	Apr–Dec 2013 IPv6	Apr–Dec 2013 IPv4
HTTP	5.61	82.56	60.61
HTTPS	0.15	12.66	8.59
DNS	4.75	0.33	0.22
SSH	0.56	0.27	0.20
Rsync	20.78	0.13	0.00
NNTP	27.65	0.00	0.25
RTMP	0.00	0.00	2.74
Other TCP	*	1.66	4.08
Other UDP	*	0.27	2.82
Non-TCP/UDP	*	2.11	20.21

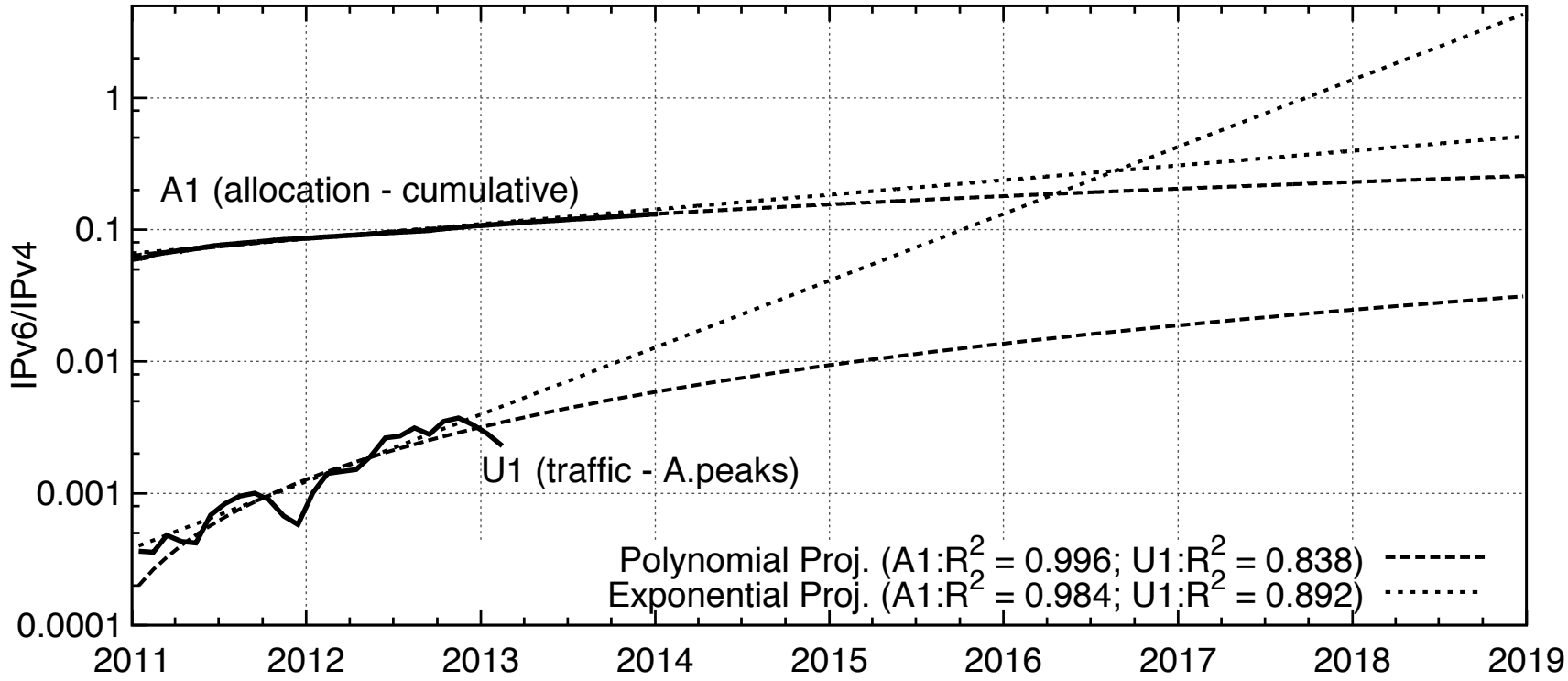
Performance
(using 10- and 20-hop RTT)



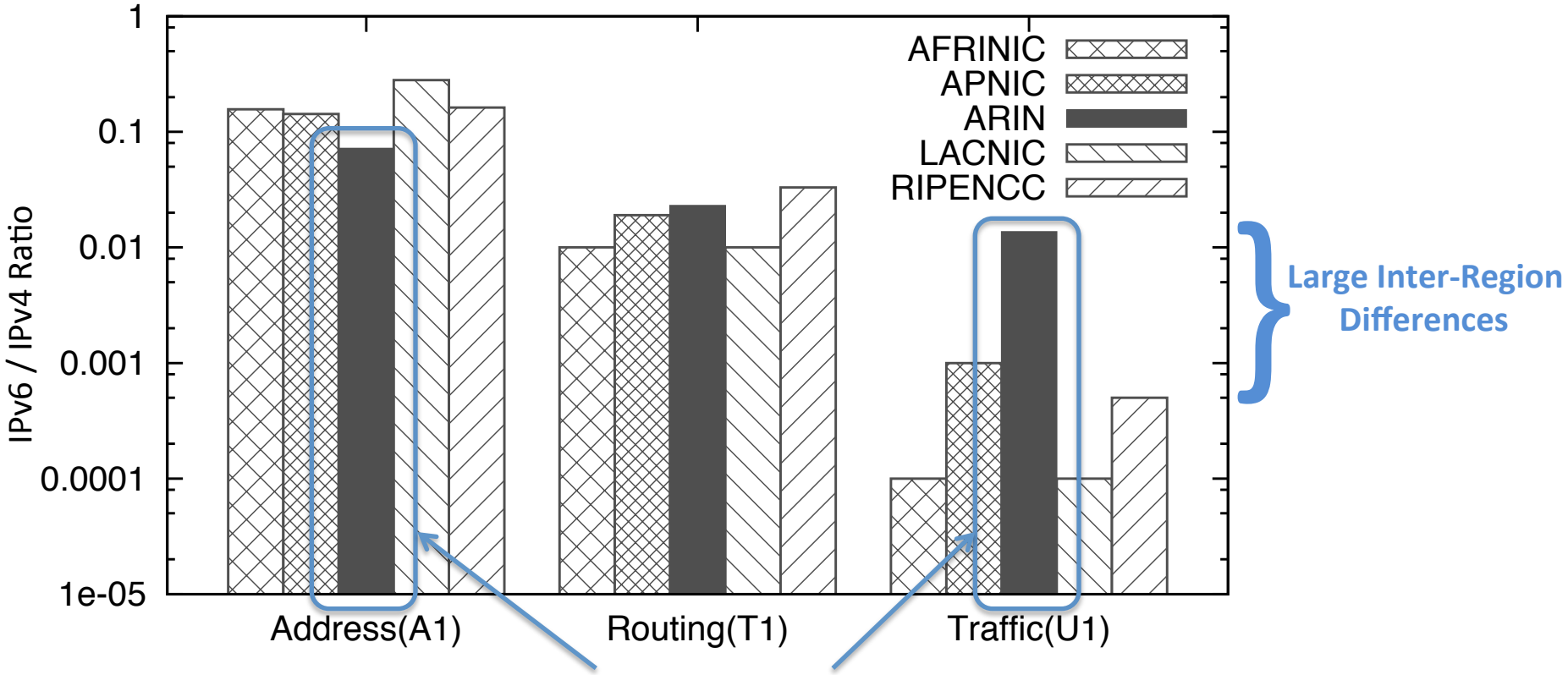
IPv6 Transition Technologies (Teredo + 6to4)



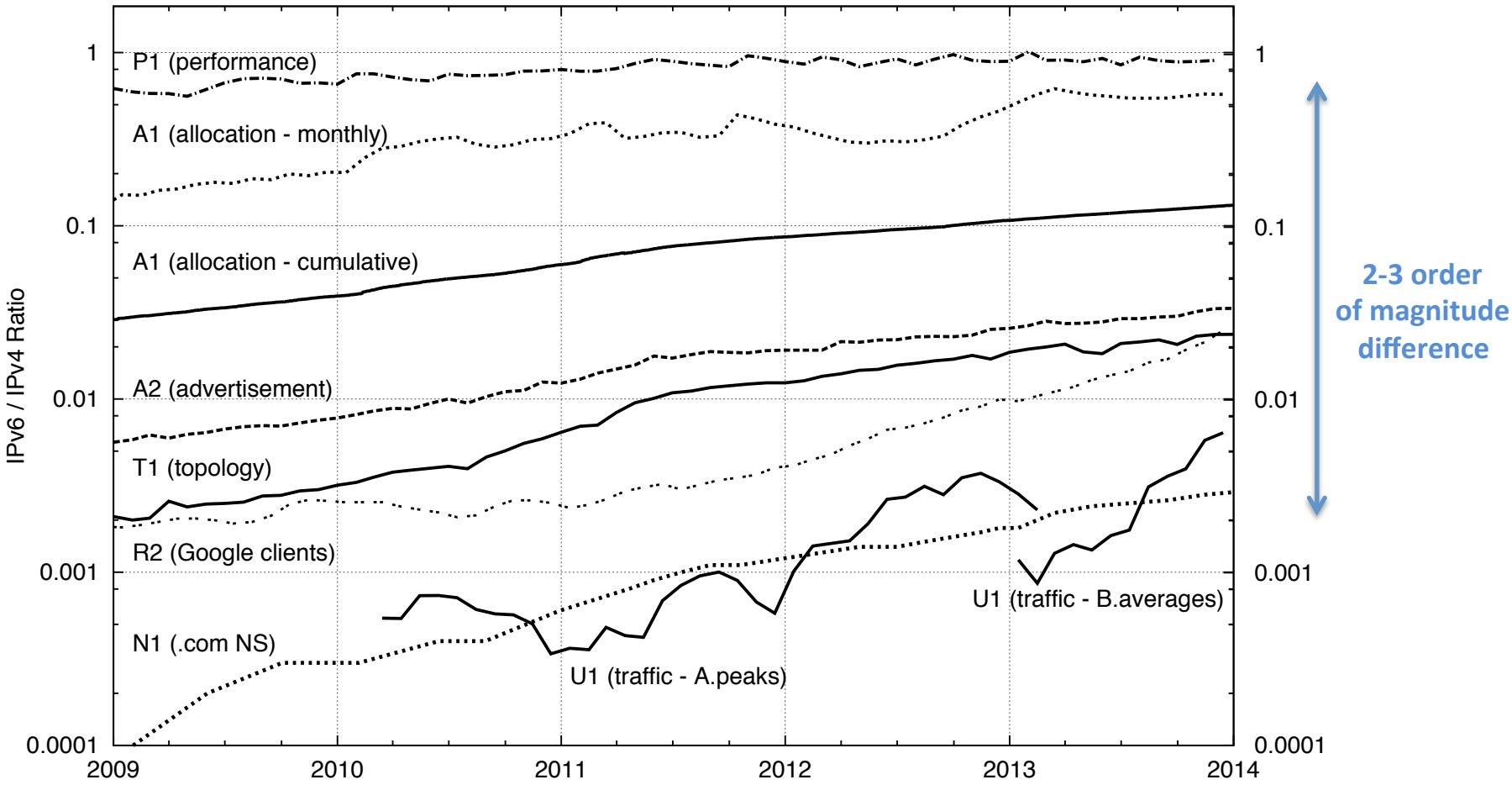
Projections



Conclusion 1: Regions Differ



Conclusion 2: Perspective Matters



Conclusion 3: IPv6 is Real!

Operational Aspect Measured	IPv6 Status at End of:	
	2010	2013
IPv6 Percent of Internet Traffic	0.03%	0.64%
1-yr. Growth vs. IPv4 (*Mar-2010 – Mar-2011)	−12%*	+433%
Content's Portion of Traffic (HTTP+HTTPS)	6%	95%
Native IPv6 Packets vs. All IPv6	9%	97%
Native IPv6 Google Clients	78%	99%
Performance: 10-hop RTT^{-1} vs. IPv4	75%	95%

← 20x growth!

← 15x growth!

← Traffic Flipped

← Nearly on-par

https://www.google.com/intl/en/ipv6/statistics.html#tab=ipv6-adoption