PI-Grau
(Internet Protocols)

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- **Topic 1: Internet Architecture&Addressing.**
  - Objectives
    - Understand the **general architecture** of Internet
    - Identify the **main actors** in the Internet architecture
    - Identify the **main organizations** implied in Internet
    - Understand **IPv4 address depletion problem**
    - Is it **IPv6** the solution to IPv4 depletion problem ?

- **Topic 1: Internet Architecture&Addressing.**
  - Internet Architecture: ISP's, corporate networks and access networks.
  - Organizations that manage the operation of businesses on the Internet: RIR (Regional Internet Registers), LIR (Local Internet Registries).
  - Internet Addressing: IPv4 depletion and IPv6.
  - Exchange Points.

Topic 1: Internet Architecture & Addressing.

- **IT (Information's Technology) Architecture** is a term applied to both the process and the outcome of thinking out and specifying the overall structure, logical components, and the logical interrelationships of a computer, its operating system, a network, or other conception.
  - Example: **client-server architecture**
- An **IT architect** primarily posses technical skills in planning, architecting and implementing enterprise-class IT solutions and services.
  - Network architectures
  - Software architectures
  - Security architectures
  - Entreprise/application/Service architectures
  - etc

Topic 1: Internet Architecture & Addressing.

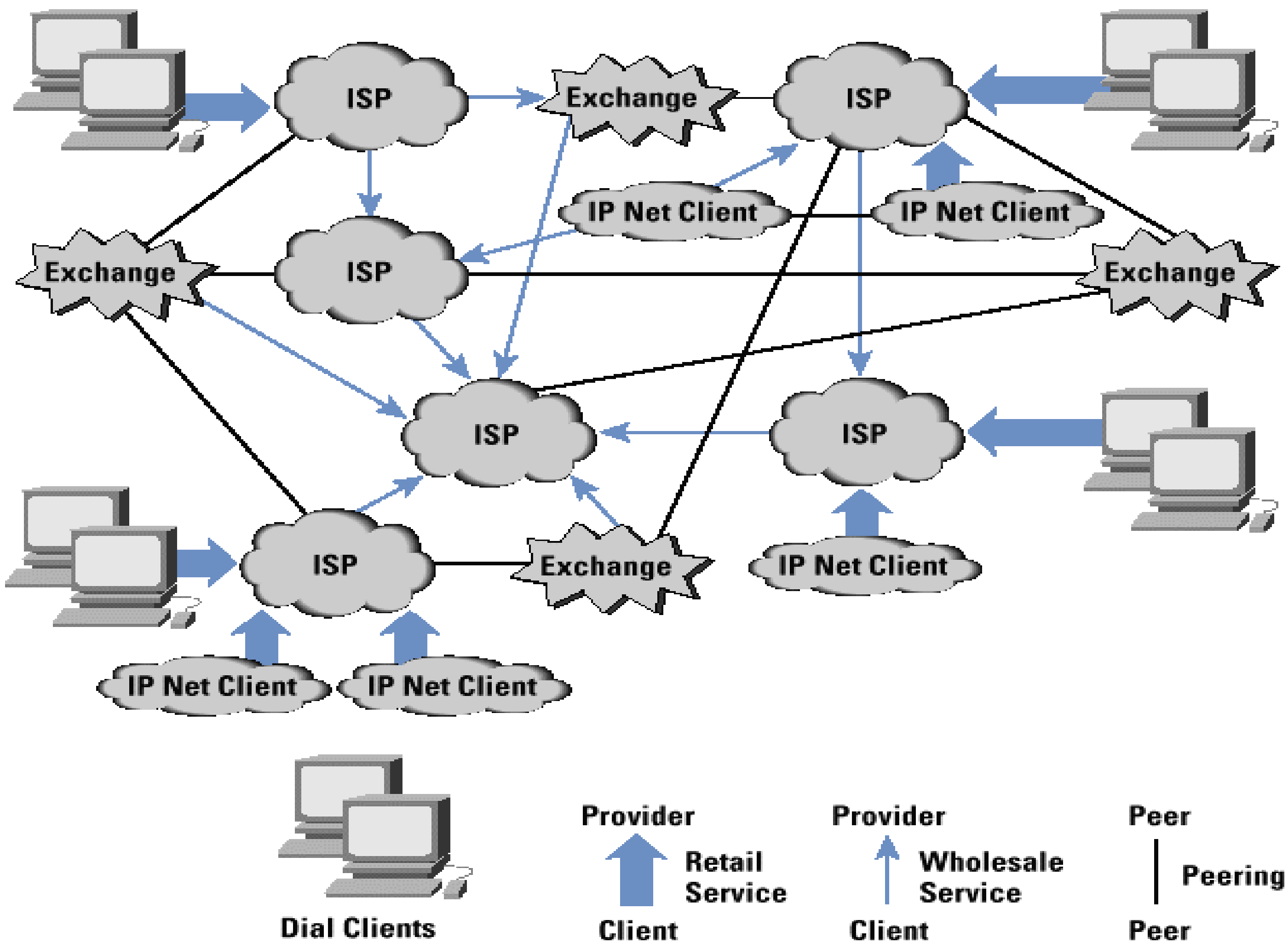
- **Internet:** global system of interconnected computer networks that use the standard TCP/IP suite protocol to connect users and applications.
  - Users are inter-connected through ISP (Internet Service Provider)

- **Internet Service Provider (ISP)**
  - Provides connectivity and services to **end users** (Dial-up), **corporative networks** (IP-Net Clients) and **other ISPs**

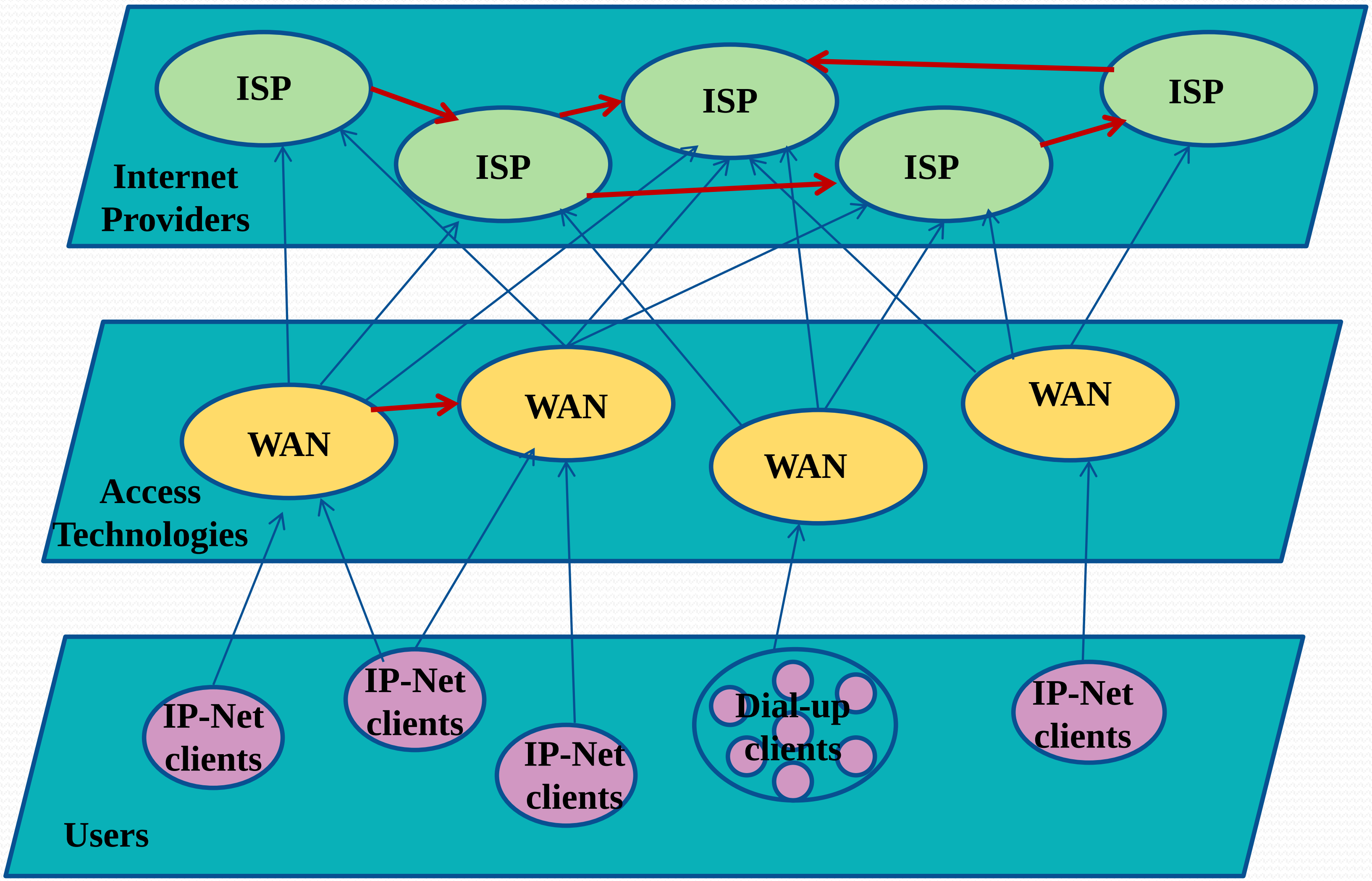
Internet Service Provider

- End users (Dial-clients):
  - Contract an access line (i.e., modem, ADLS, …). The ISP may be a telecom operator or has sub-contracts with telecom operators to offer service connectivity
- Corporative Networks (IP-Net-client)
  - Local Area Networks (LANs)
  - Contract switched/dedicated lines for linking their sites forming a VPN
  - Contract one or several lines (backup, redundancy, load balancing, …) to the ISP
- ISP
  - Peering between ISPs: ISPs act with con client-to-provider, peer-to-peer and provider-to-client relationships
  - ISPs connections may be **private** (using Telecom operator lines) or **public** (“***Exchange points***”)
  - **Retail services** (directly to customers) versus **Wholesail services** (in large quantities that later can be re-selled)

- Internet Architecture



- Internet Architecture



Internet Service Provider

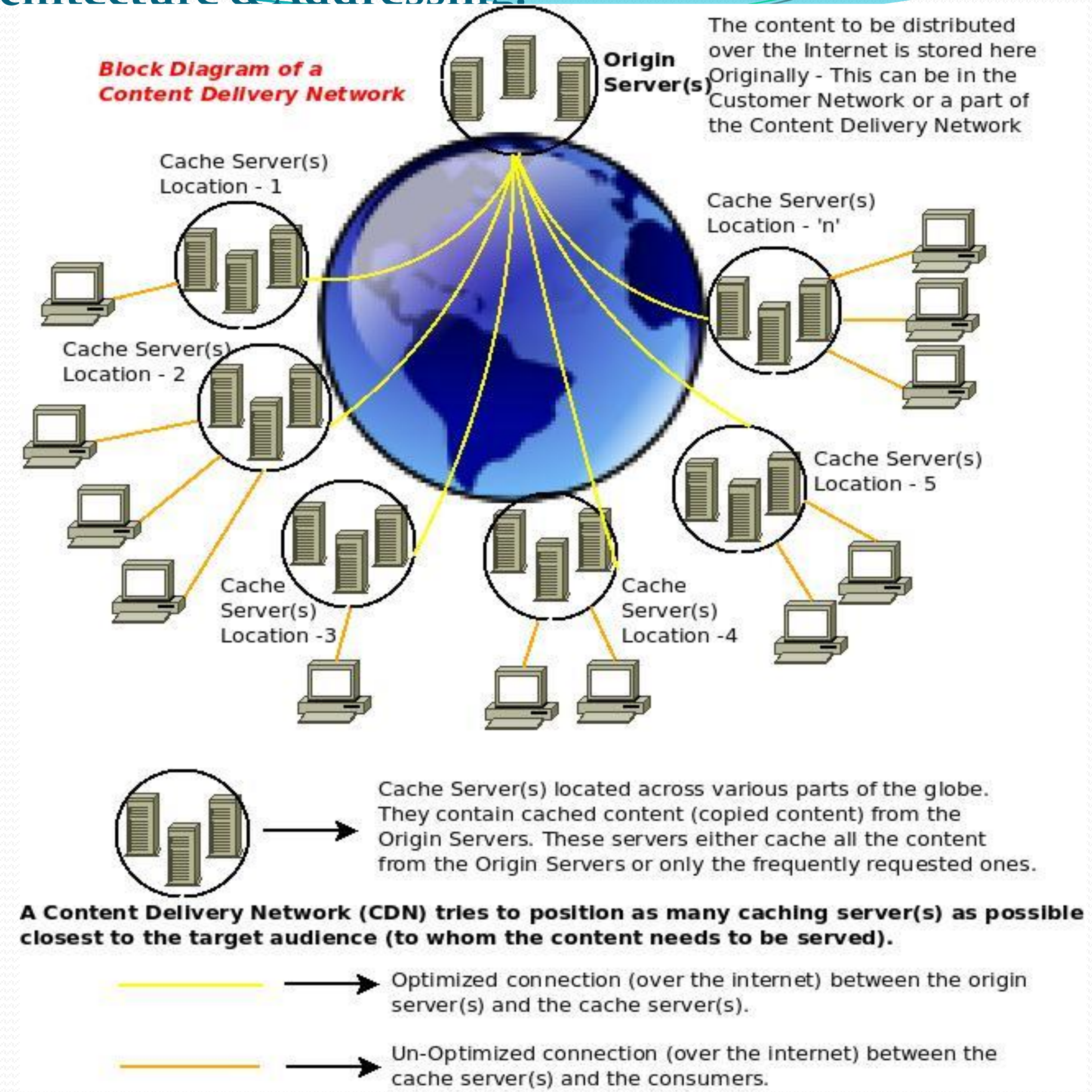
- ISP offer different types of services
  - **Dedicated Internet Access services**
    - T1/E1 lines (1.5, 2 Mbps), T3/E3 (45, 34 Mbps), OC3 (155 Mbps), OC12 (622 Mbps), OC48 (2.5 Gbps), etc
  - **Switched Internet Access services**
    - FR (Frame Relay) or ATM
  - **Other Internet Access services**
    - Modems, ADSL, RDSI (BRI, PRI), etc
  - **Hosting/housing Services and CPD services**
    - Racks, servers (e.g.; Web), equipment, etc
  - **End user services**
    - VPNs, e-mail, news, Web, IP multicast, etc
  - **Content Provider services** (Content Distribution Networks such as Akamai)

Content Service Provider

- **Network Operator Content Networks**:
  - Proxing caches: the operator store content in caches in order to offer better access services,
  - **Goal:** save bandwidth,
  - Examples: Internet Cache Protocol (ICP), Hypertext Caching Protocol (HTCP),
- **Content Providers Content Networks:**
  - **Farm servers**: local content networks that offer load balancing and thus better capacities and high availability of content, **Goal:** high availability & capacity,
  - **Mirrors**: distributed servers in several geographical localizations (manual access: the user has to choose the mirror server), **Goal:** reduce RTT,
  - **CDNs (Content Distribution Networks):** distributed servers in several geographical localizations (automatic: AKAMAI has more than 15.000 servers), **Goal:** reduce RTT, allow monitoring services, give value added services,
- **User Content Networks**:
  - Peer-to-peer (P2P): e.g. Gnutella, freenet, napster, …, **Goal:** share content,

- **Content Distributions Networks (CDN):**
  - **Problem:**
    - Access to content may suffer from large RTT (Round Trip Times) when servers are located very far away from clients.
    - Access to content may suffer of peak load of demands that will impact in the QoS (Quality of Service) given to the clients.
  - **Solution:**
    - Put content as near the client as possible.
    - However, clients are around the globe, thus, a "unique" server can not be "near" all the potential clients distributed around the globe.
    - CND's solve this problem, bringing client request to the near servers that cache the same content.

- **Content Distributions Networks (CDN):**



Content Distributions Networks (CDN):

- CDNs optimize content delivery by **putting the content closer** to the consumer and shorting the delivery path via global networks of strategically placed servers.
- CDNs also **manage and maintain** the network elements that deliver Web content, such as text, images, and streaming audio and video, to the end user, streamlining the entire process.
- Moreover, a CDN offers unique possibility to **provide for value added services** like customization and adaptation of content, virus scanning and ad insertion.

- **Content Distributions Networks (CDN) functions:**
  - **Redirection of services**: to direct a request to the cache server that is the closest and most available.
  - **Distribution services**: a distributed set of surrogate servers that cache content on behalf of the origin server, mechanisms to bypass congested areas of the Internet or technologies like IP-multicast, and replication services.
  - **Accounting services**: to handle, measure, and log the usage of content.

- **Content Distributions Networks (CDN):**
  - Methodologies used in CDN's
    - **Request Routing mechanisms (RFC 3568):** A request routing system uses a set of metrics in an attempt to direct users to surrogate that can best serve the request.
      - **DNS request routing:** a specialized DNS server is inserted in the middle of the DNS resolution process, returning a different set of A, NS or CNAME records based on user defined policies, metrics, or a combination of both
      - **Transport request routing:** the Request-Routing system inspects the information available in the first packet (client's IP address, port information, and layer 4 protocol) of the client's request to make surrogate selection decisions
      - **Application request routing:** Deeper examination of client's packets provides fine-grained Request-Routing control down to the level of individual objects. E.g. HTTP info, MIME, cookies,…

- **Content Distributions Networks (CDN):**
  - **Examples**: AKAMAI
    - 240,000 servers in 1,500 networks across 120 countries, in Sept 2018
    - Uses DNS entries (CNAME)
    - If the object is cached → deliver the content
    - If the object is dynamic → handle it to the original server
  - **Summary** - advantages of using CDNs
    - Reduced Latency
    - High Scalability
    - High Availability
    - Increased Offload

- **DNS request routing:**

nslookup
\> **www.microsoft.com**
Server: 147.83.32.3
Address: 147.83.32.3#53

Non-authoritative answer:
www.microsoft.com canonical name = **toggle.www.ms.akadns.net**.
toggle.www.ms.akadns.net canonical name = g.www.ms.akadns.net.
g.www.ms.akadns.net canonical name = lb1.www.ms.akadns.net.
Name: lb1.www.ms.akadns.net
Address: 65.55.12.249
\> **www.cisco.com**
Server: 147.83.32.3
Address: 147.83.32.3#53

Non-authoritative answer:
www.cisco.com canonical name = **www.cisco.com.akadns.net**.
www.cisco.com.akadns.net canonical name = geoprod.cisco.com.akadns.net.
geoprod.cisco.com.akadns.net canonical name = www.cisco.com.edgekey.net.
www.cisco.com.edgekey.net canonical name = www.cisco.com.edgekey.net.globalredir.akadns.net.
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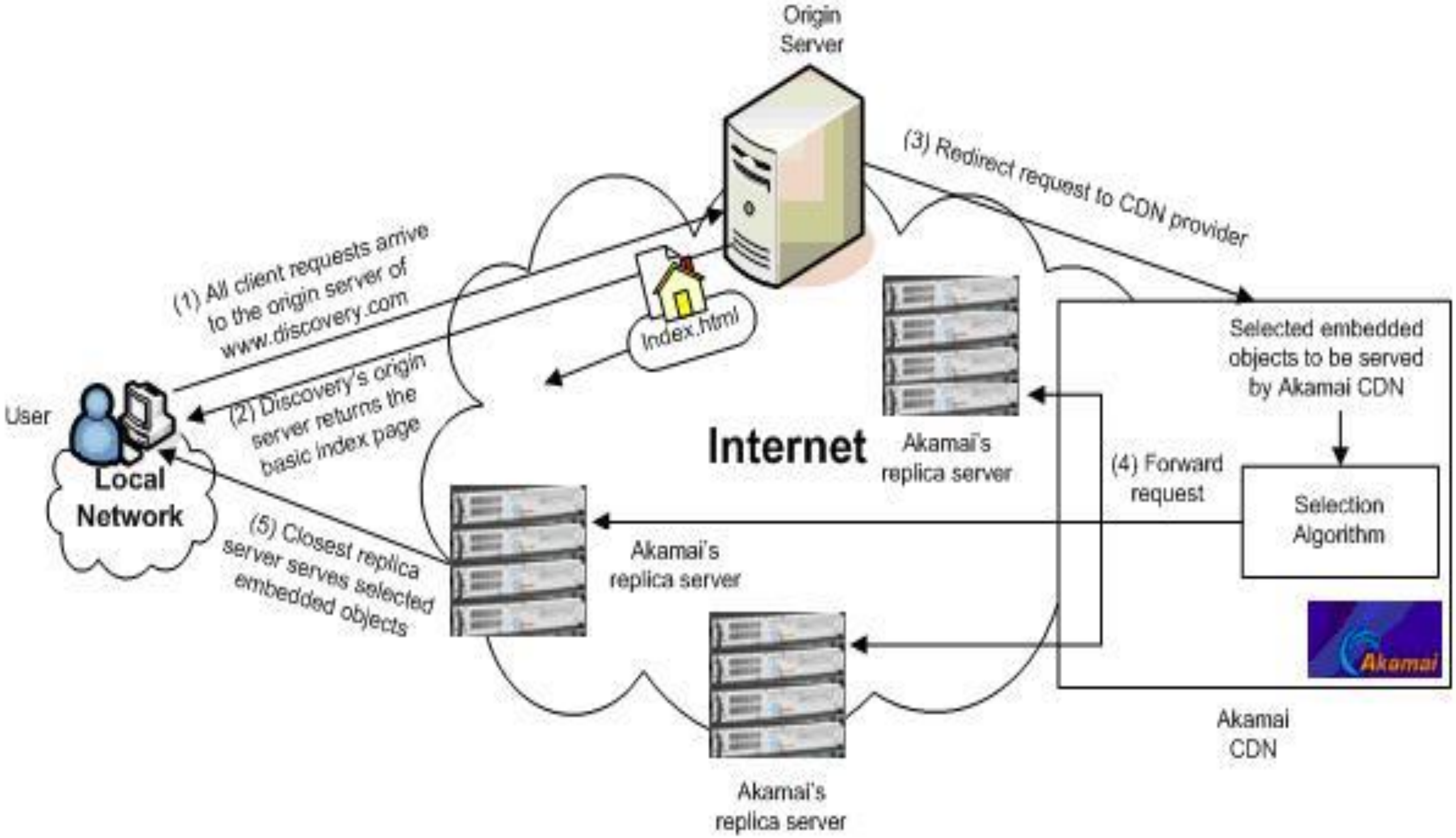
Address: 88.221.32.170

Topic 1: Internet Architecture & Addressing.



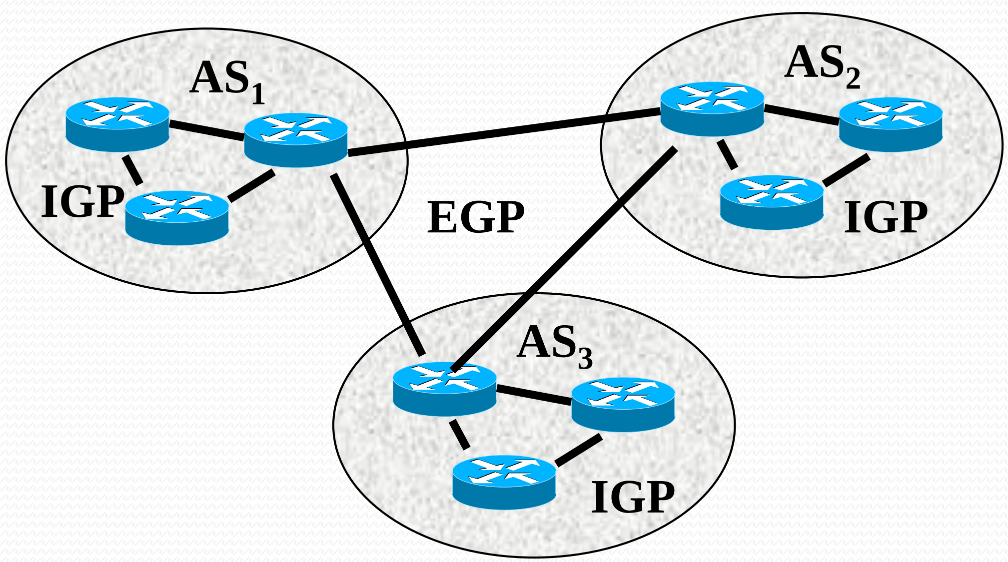
Topic 1: Internet Architecture & Addressing.

- **SLA (Service Level Agreement):** agreement that guarantees the contract offered by an ISP and that penalize the ISP if this one does not comply the contract.
  - **Customer-based SLA**: An agreement with an individual customer group, covering all the services they use.
  - **Service-based SLA**: An agreement for all customers using the services being delivered by the service provider.
    - An email system for the entire organization.
  - **Multi-level SLA**: The SLA is split into the different levels, each addressing different set of customers for the same services, in the same SLA:
    - **Corporate-level SLA**: Covering all the generic **service level management** (**SLM**) issues appropriate to every customer throughout the organization.
    - **Customer-level SLA**: covering all SLM issues relevant to the particular customer group, regardless of the services being used.
    - **Service-level SLA**: covering all SLM issue relevant to the specific services, in relation to this specific customer group.

Topic 1: Internet Architecture & Addressing.

- **SLA (Service Level Agreement)** - aspects a SLA address:
  - Availability level (% of time that the customer agrees in losing connectivity) → measured as the number of delivered packets respect to the transmitted
  - Bandwidth contracted (Mb/s)
  - Throughput (Mb/s) in high availability (rushy hours)
  - Response time against connectivity failures (e.g. 24/7 service), penalize with respect the amount of time without connectivity
  - Redundancy (multi-homing)
  - Security
  - Monitoring services
  - Quality of Service (QoS): service levels (e.g. Gold, Silver, …)
    - Packet marking, dropping, end-to-end delays, ….
- El SLA is a customer support service
  - http://www.ndo.com/service-level-agreement.html
  - http://www.localisp.com/Company/Policies/SLA-T1.pdf
  - http://aws.amazon.com/es/s3-sla/

- **Autonomous Systems (AS) or Routing Domain: is a group of IP networks run by one or more network operators with a single, clearly defined routing policy.**
  - AS are identified with 16 bits (65535 AS's)
  - AS's exchange routes (IP subnets) using **Inter-domain Routing Protocols** such as BGPv4
  - Internally, AS's exchange routes (IP subnets) using **Intra-domain Routing Protocols** such as OSPF, IS-IS, EIGRP, …



- **Internet Service Provider (ISP) and Autonomous Systems (AS):**

  - An ISP is an administrative entity that may have one or more AS numbers assigned depending of its architecture and geographical situation
  - In general an AS number may be assigned to an ISP or to a Corporative Network,
  - Thus, not all AS are ISP, however all ISPs have one or more AS number assigned
  - We will clarify ISP in the next sections

ICANN, IANA and IETF

- **ICANN (Internet Corporation for Assigned Names and Numbers):** in charge of making policy decisions about how the domain name system is run.
  - ICANN performs the actual technical maintenance work of the Central Internet Address pools and DNS root zone registries pursuant to the Internet Assigned Numbers Authority (IANA) function contract.

- **IANA (Internet Assigned Numbers Authority):** is responsible for managing all of the various number spaces that make the various protocols work.
  - Oversees global IP address allocation, autonomous system number allocation, root zone management in the Domain Name System (DNS), media types, and other Internet Protocol-related symbols and Internet numbers.
  - Delivers IP@ and ASN to RIRs
  - IANA depends on ICANN.

- **IETF (Internet Engineering Task Force):** is in charge of the engineering activities.
  - Develops and promotes voluntary Internet standards (TCP/IP suite, not L1/L2 that are on IEEE or ITU standards).

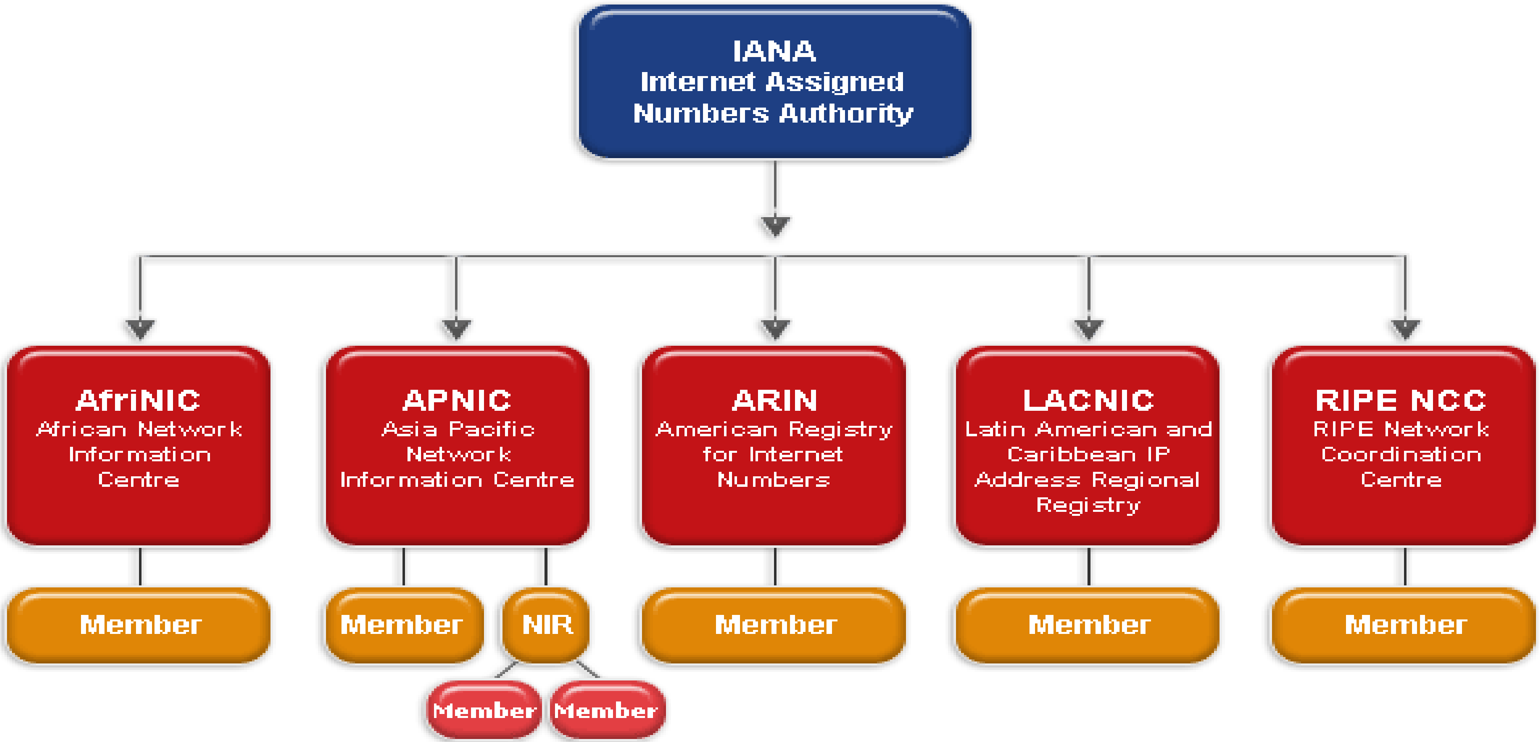
Regional Internet Registries (RIRs):

- Independent organizations that supports Internet resources coordination in a geographical region and develop consistent policies and promote best current practice for the Internet.

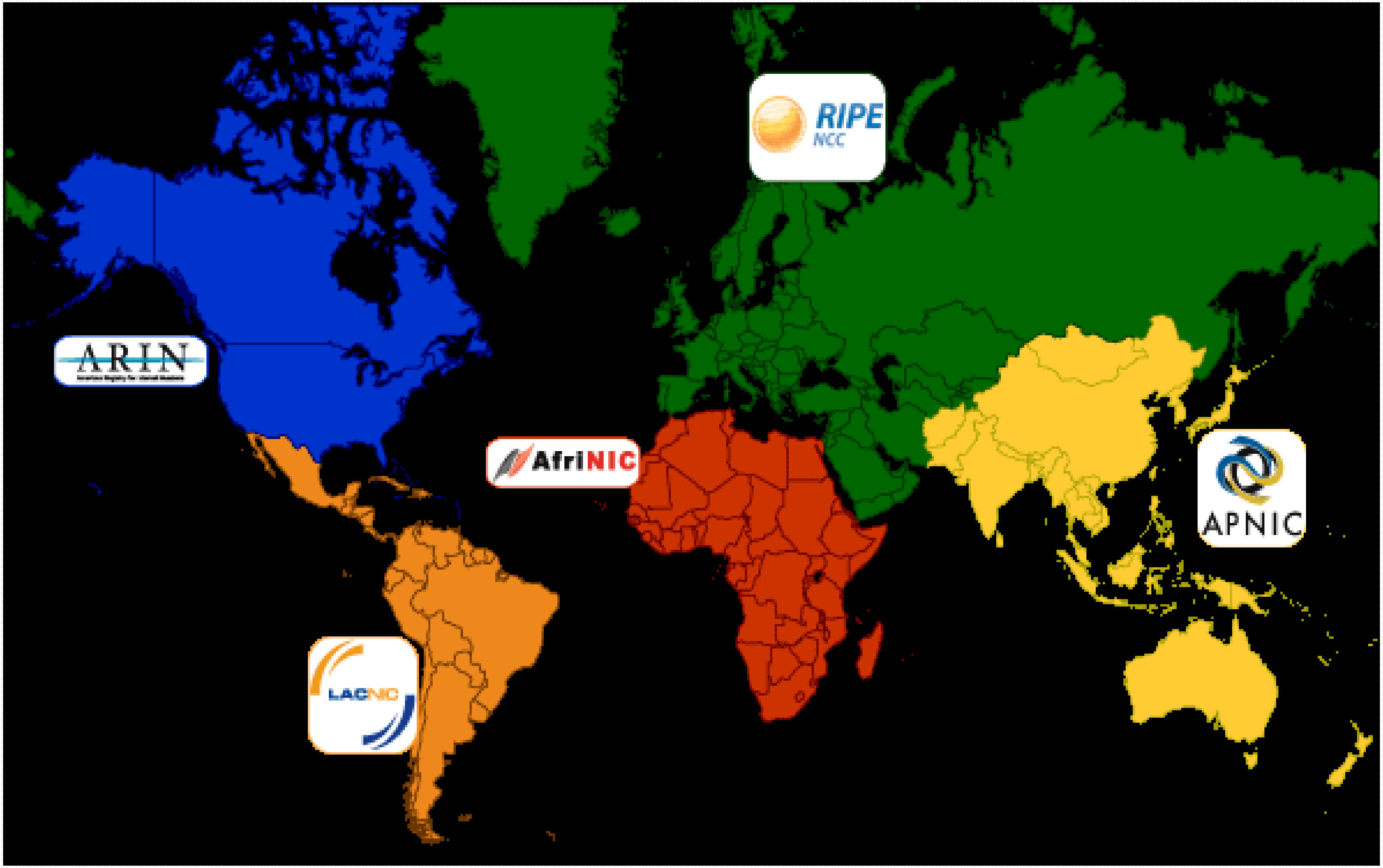
- Each RIR **manage**:
  - **IPv4 and IPv6 Address blocks** and **AS number** assignments
  - **DO NOT** manage Name Domains (done by ICANN: Internet Corporation for Assigned Names and Numbers)

- There are 5 Regions
  - ARIN, RIPE, AFRINIC, LACNIC, APNIC

- **Regional Internet Registries (RIRs):**
  - LIR (Local Internet Registry)→ Members of RIR
  - NIR (National Internet Registry) → coordinate IP allocations at national level. There are no NIR in Europe, but APNIC and LACNIC have them.
  - **RIRs allocate IP address space and AS Numbers to Local Internet Registries (LIRs) that assign these resources to End Users**



- Regional Internet Registries (RIRs):



- **RIPE NCC (http://www.ripe.net/)**
  - Provides Internet resource allocations, registration services and coordination activities that support the operation of the Internet globally.

    - RIPE engages in a range of activities that can be defined as "**Internet Governance**". These activities include working with the technical community, governments, regulators, civil society and law enforcement agencies.

    - **LIR (Local Internet Register) Services:** members of a RIR

    - **Data & Tools:** provides databases and monitoring tools that support stable, reliable and secure Internet operations.
      - RIPE Database support: contains registration details of IP addresses and AS Numbers originally allocated by the RIPE NCC
      - Operates 1 of the 13 K-root Name Servers
      - Provides high-quality measurements and analysis that can be used for a variety of operational, media, governmental and law enforcement activities.

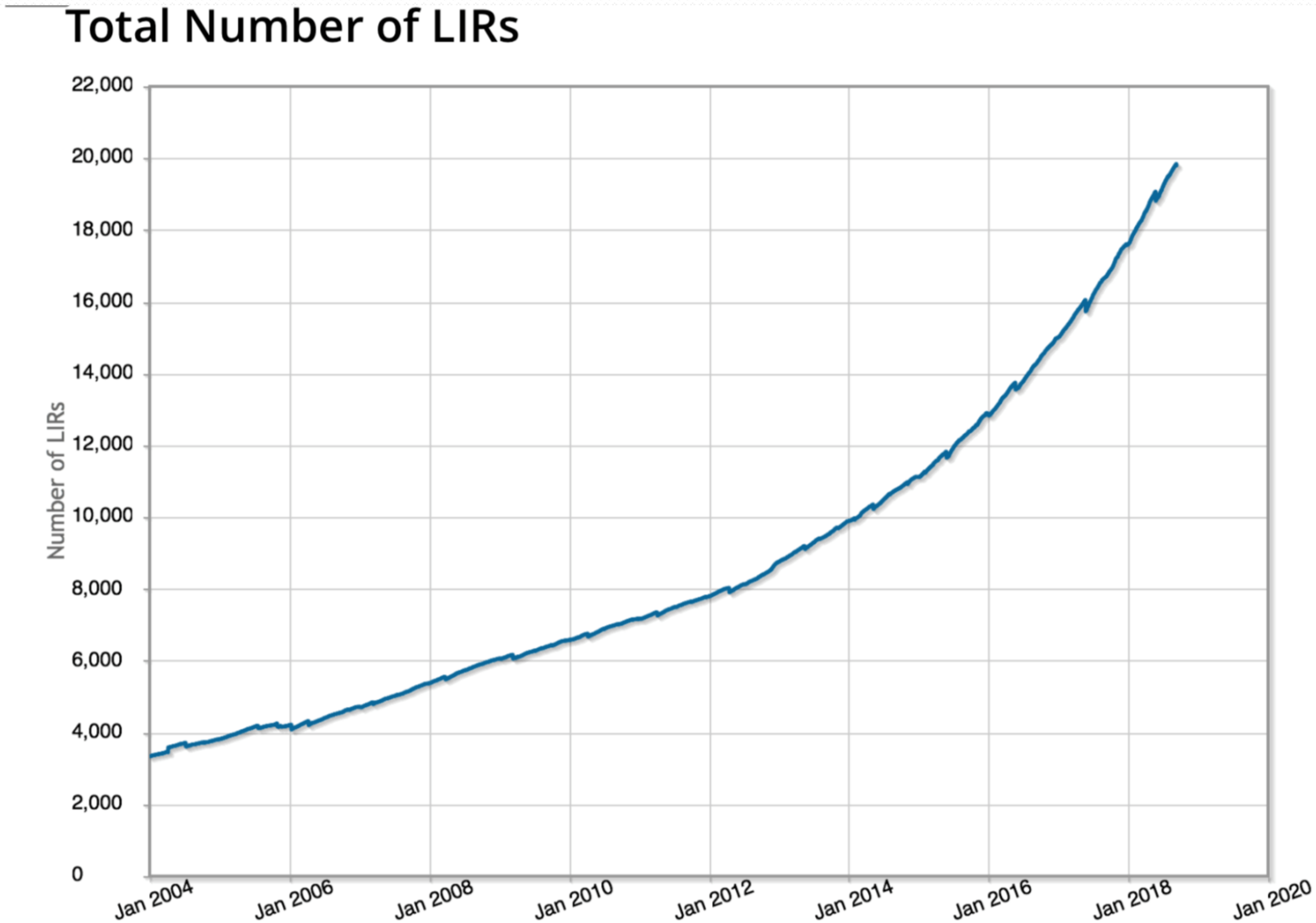
- **Criteria to obtain an AS number**
  - Only when the routing policy is different from your ISP provider routing policy (RFC 1930)
    - That implies that the customer has to be connected to at least two ISP (multi-homing) with different routing policies
  - ¿What is a **LIR (Local Internet Registry)** ?
    - A LIR is an organization that has been allocated a block of IP addresses by a RIR, and that assigns most parts of this block to its own customers.
    - Most LIRs are ISP's, enterprises, or academic institutions.
    - Membership in an RIR is required to become an LIR, so any member of a RIR is a LIR
    - See http://www.ripe.net/membership/maps/ in order to see ISP and LIR in any geographical zone covered by RIPE

Topic 1: Internet Architecture & Addressing.

- **Look at some Statistics from RIPE:**
  - https://www-public.imtbs-tsp.eu/~maigron/RIR_Stats/RIR_Delegations/World/ASN-ByNb.html
  - https://labs.ripe.net/statistics/
  - **See number of LIRs**
  - **% of membership per country**

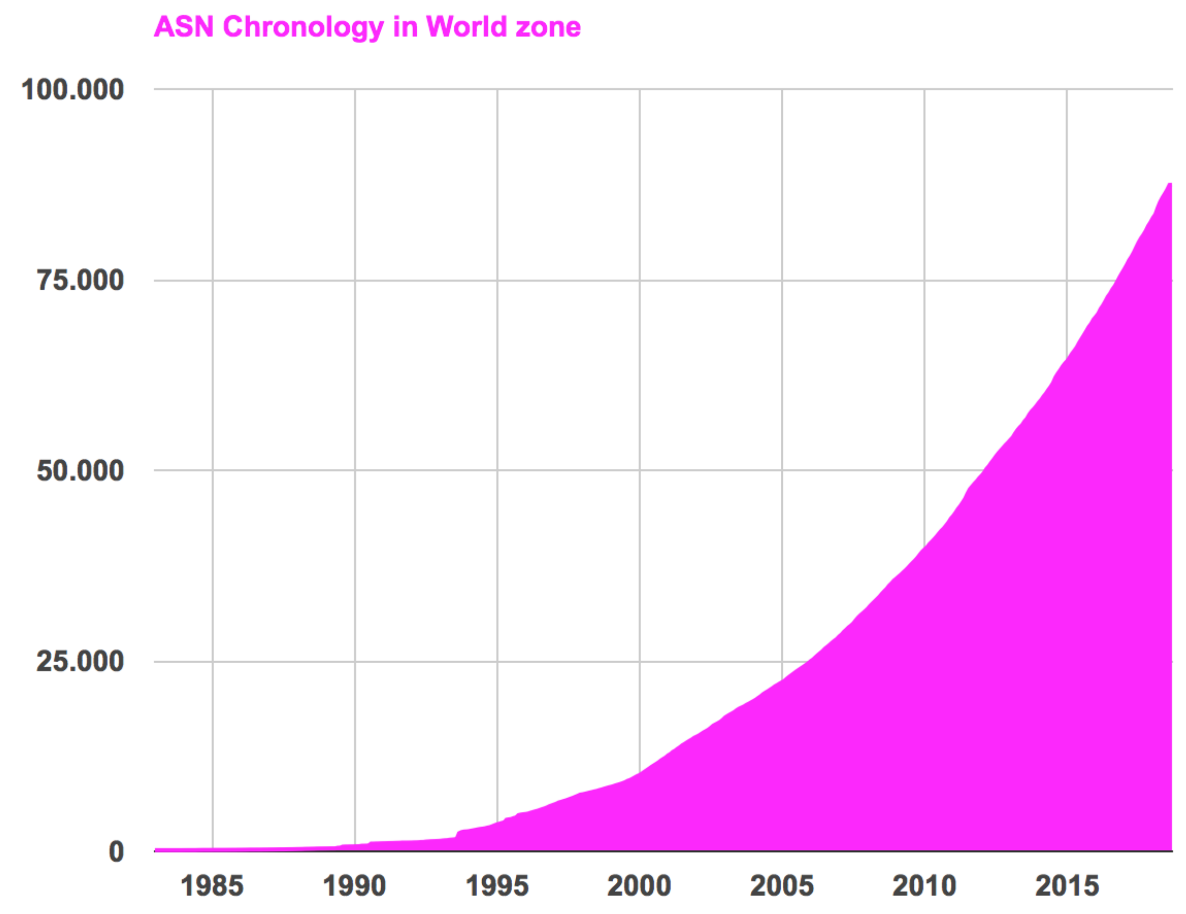
AS numbers in Internet

- Number of LIRs (Sept 2018) in RIPE: 19843 AS's



AS numbers in Internet

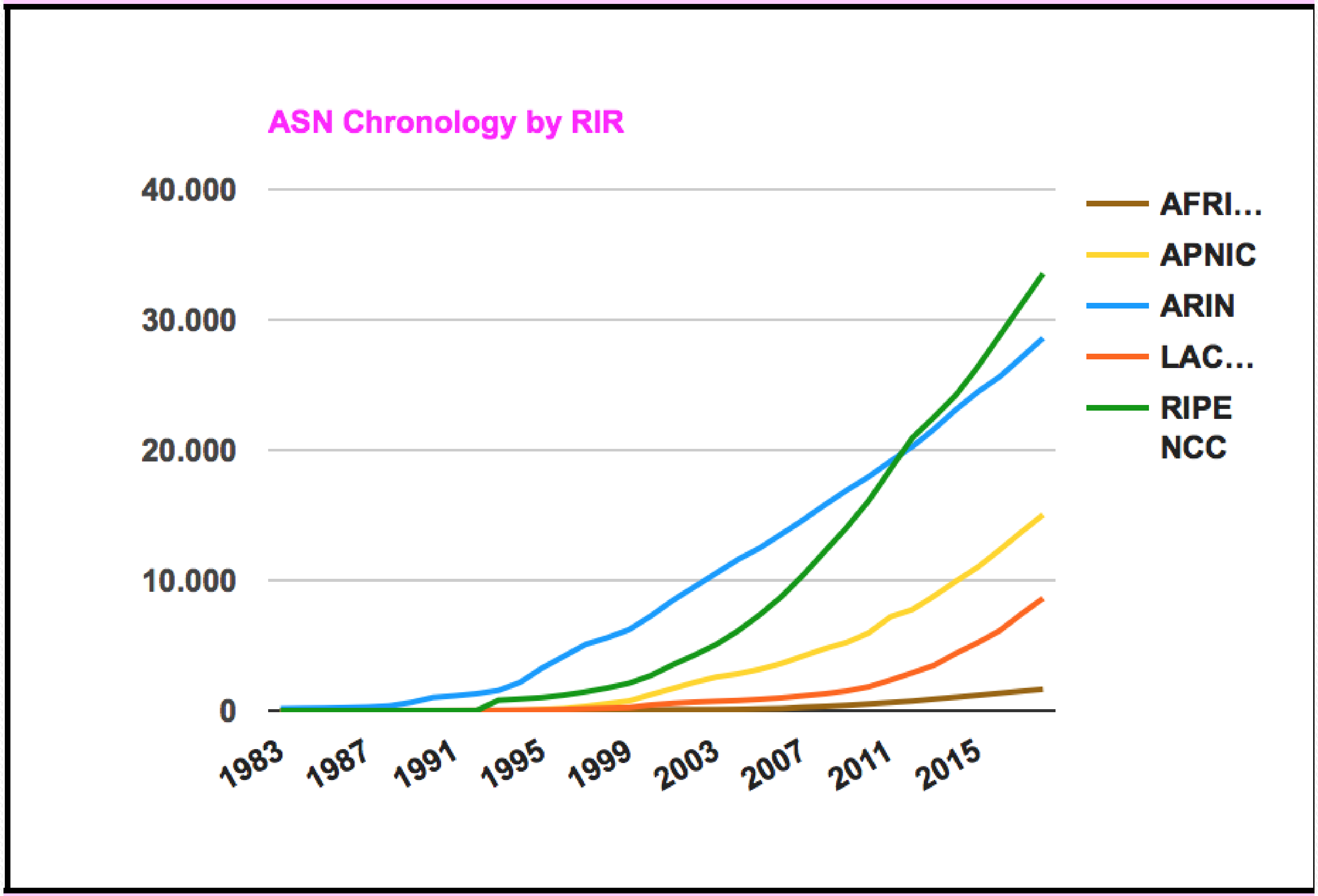
- Number of LIRs (1 Sept 2018) in the world: 87441 AS's



- AS numbers in Internet (Top-20, Sept 2018)

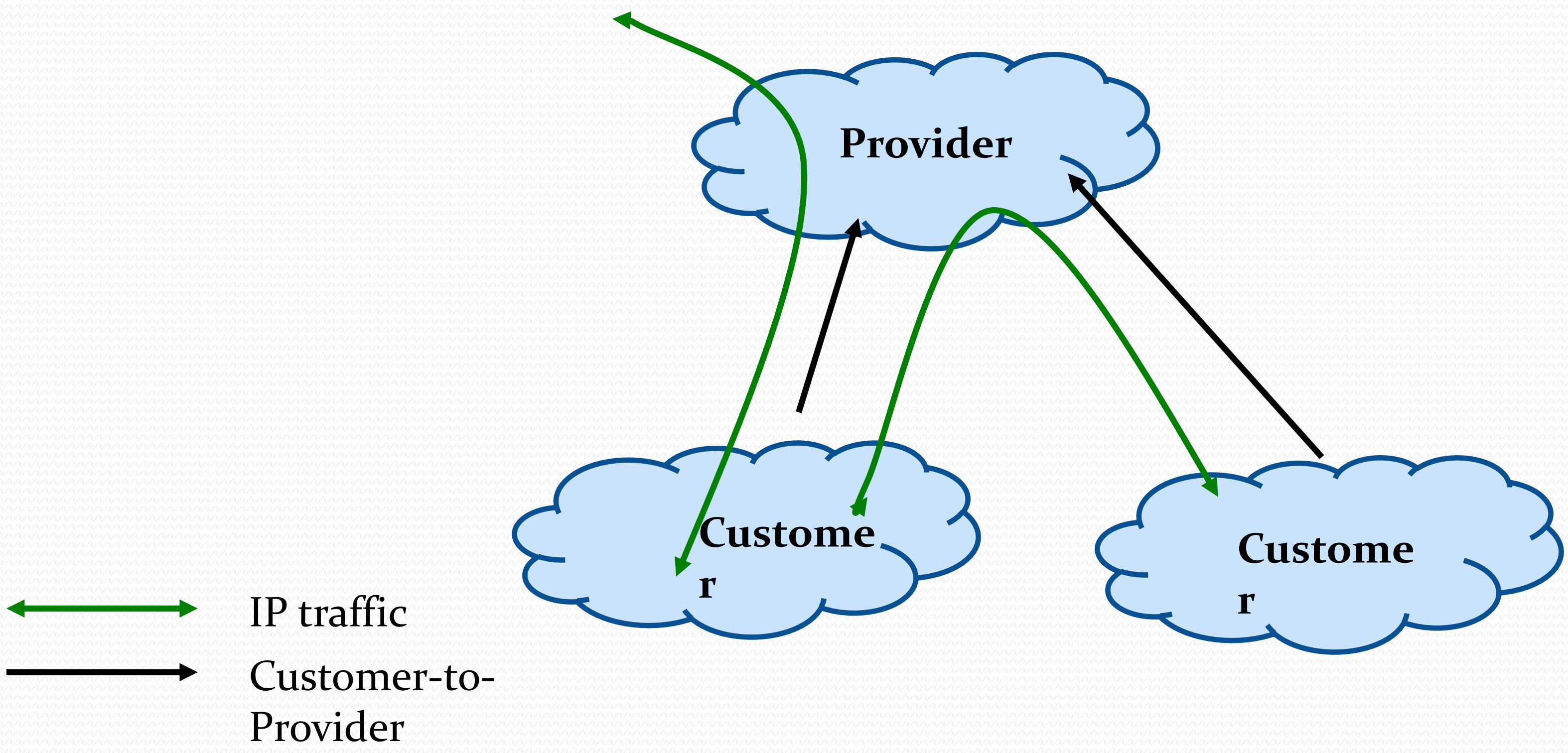
Rank	Country	Code	Number	Percentage
1	United States	US	26 478	30.281 %
2	Russian Federation	RU	6 138	7.020 %
3	Brazil	BR	5 935	6.787 %
4	United Kingdom	GB	2 579	2.949 %
5	Poland	PL	2 492	2.850 %
6	Germany	DE	2 445	2.796 %
7	Australia	AU	2 390	2.733 %
8	India	IN	2 221	2.540 %
9	Ukraine	UA	2 185	2.499 %
10	Canada	CA	2 051	2.346 %
11	China	CN	1 484	1.697 %
12	Indonesia	ID	1 450	1.658 %
13	France	FR	1 384	1.583 %
14	Netherlands	NL	1 280	1.464 %
15	Romania	RO	1 264	1.446 %
16	Japan	JP	1 098	1.256 %
17	Italy	IT	1 050	1.201 %
18	Korea, Republic of	KR	1 025	1.172 %
19	Spain	ES	988	1.130 %
20	Argentina	AR	900	1.029 %

- AS numbers in Internet per RIR (Sept 2018)

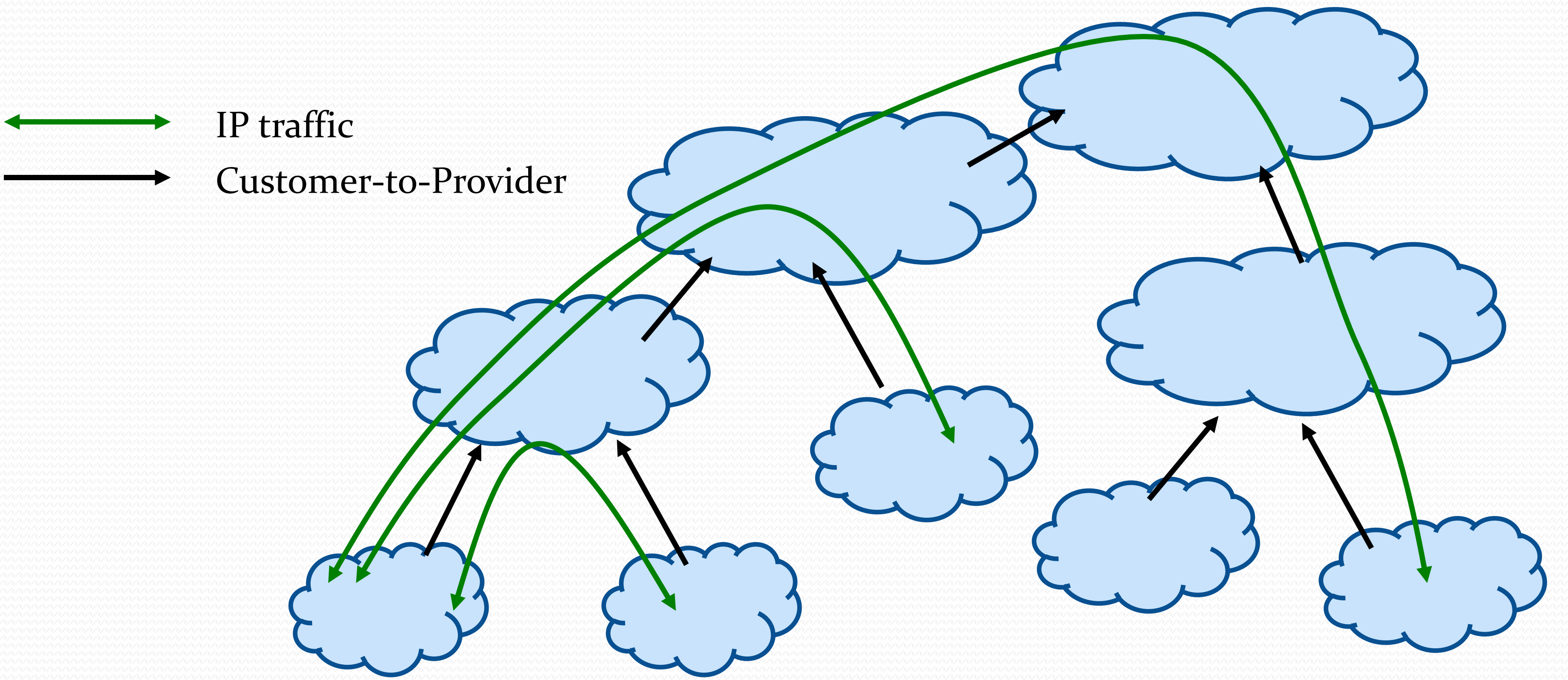


- **Peering (exchange of routes and traffic)**
  - Each AS may establish several types of relationships (peering) with several policies
  - **AS relationships:**
    - **Provider-to-Customer:** provider offer transit services to customers
    - **Customer-to-Provider:** a customer needs at least one provider
    - **Peer-to-Peer (non-transit):** two AS's agree in exchange their routes and their customer routes but do not transit others
    - **Peer-to-Peer transit (Siblings):** two AS's agree in exchange their routes and transit any other route

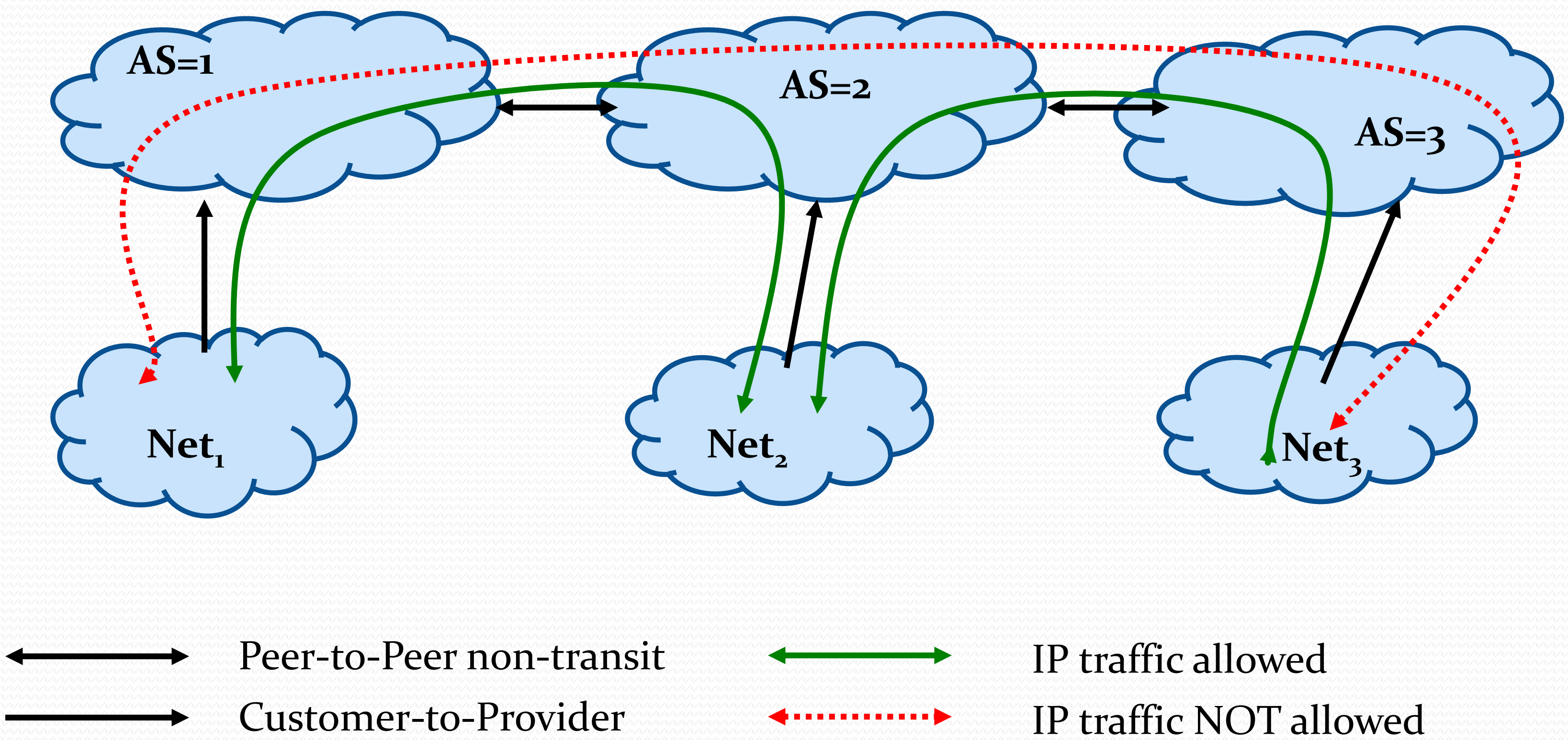
- **Provider-to-Customer:** provider offer transit to customer



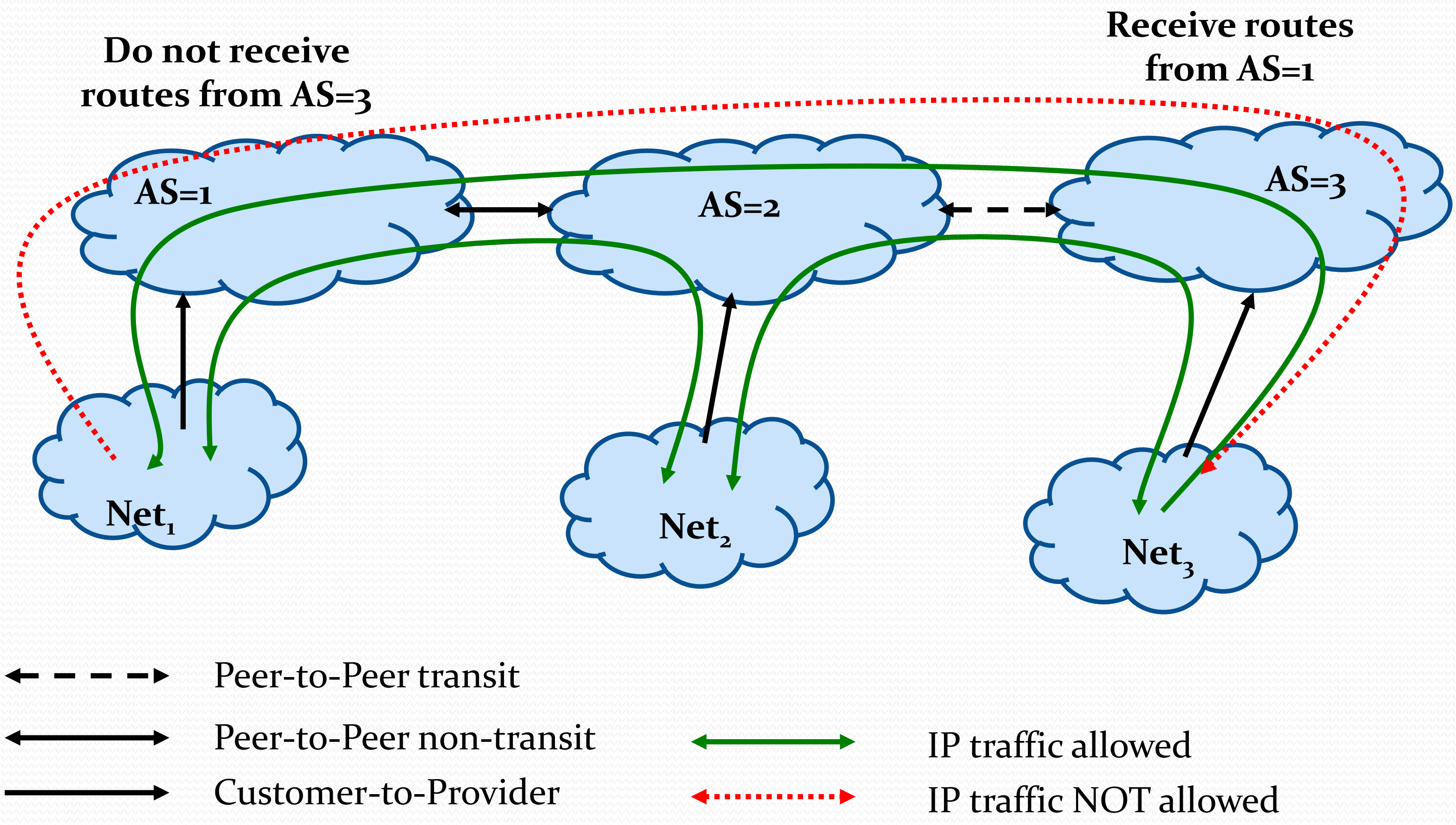
- **Providers form a hierarchy**



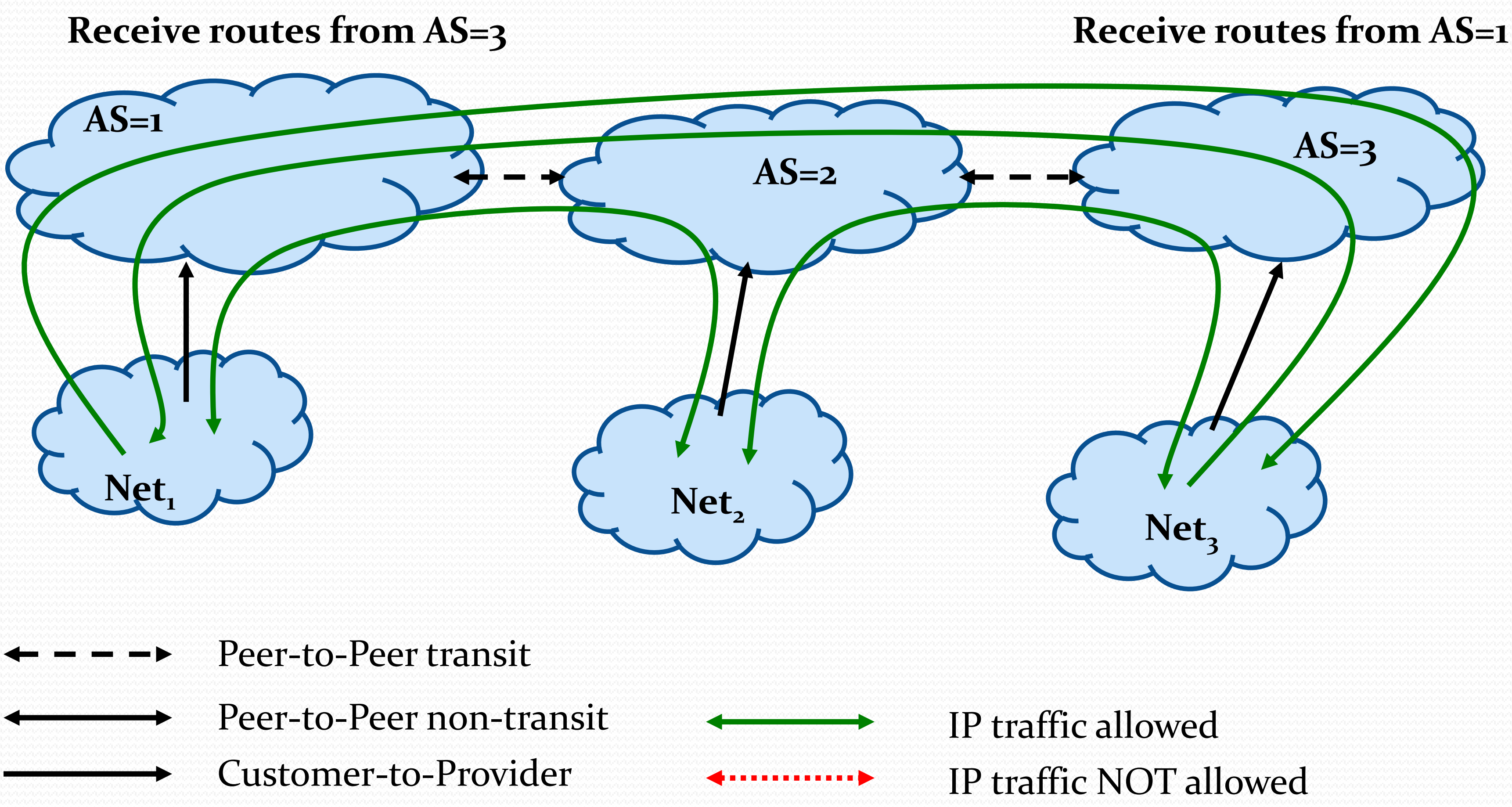
- **Peer-to-Peer non-transit:** two AS's agree in exchange their routes and their customer routes but do not transit others



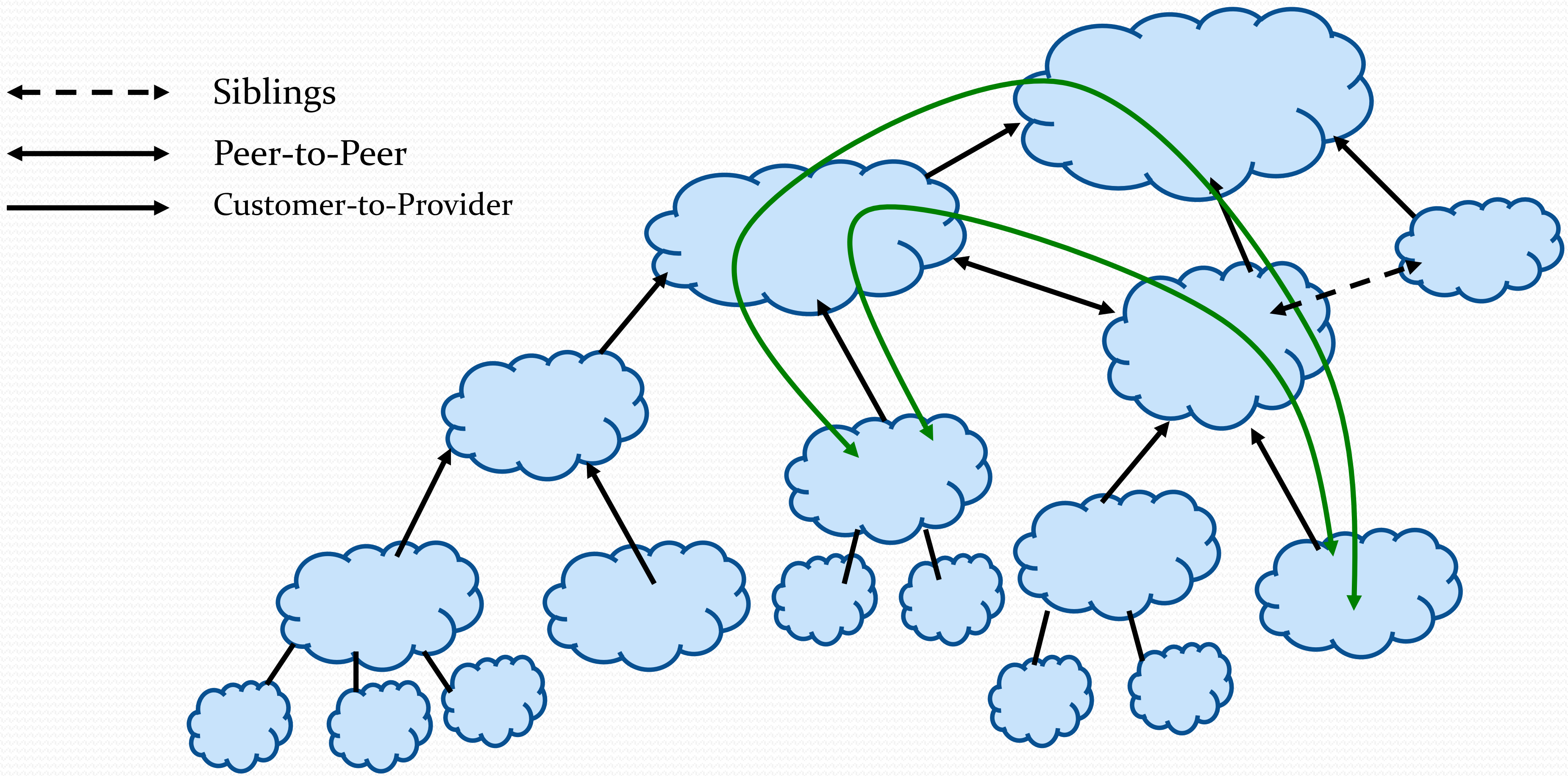
- **Peer-to-Peer transit (siblings):** two AS's agree in exchange their routes and transit any other route



- **Peer-to-Peer transit (siblings):** If bi-directional traffic, there should be bi-directional sibling relationships



- Peer-to-peer and siblings offer short cuts in the Internet architecture



- **Export Routing Policies:**
  - **A customer exports to his provider** all his routes and his customer networks but not his peers and providers

Siblings

Peer-to-Peer

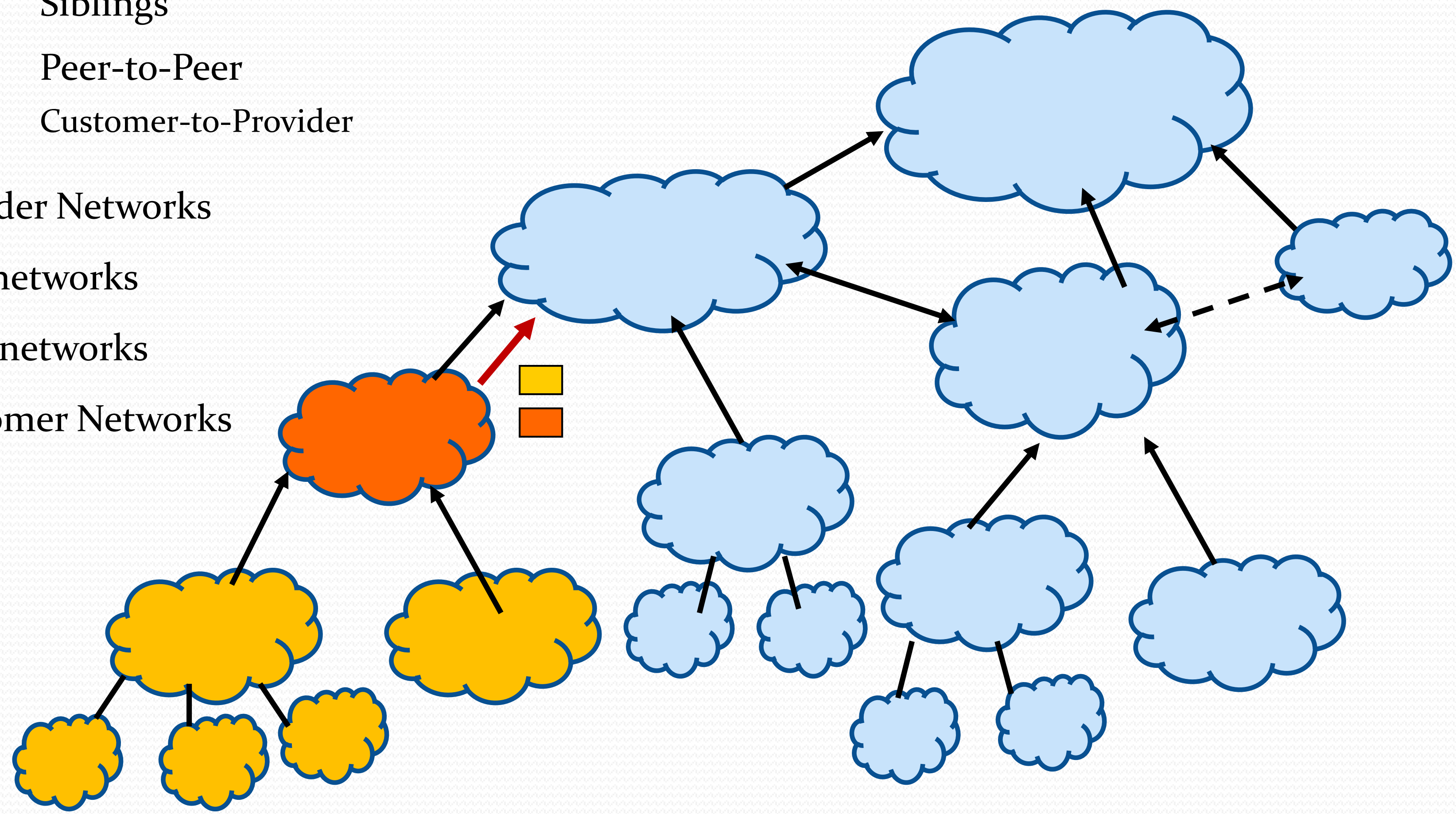
Customer-to-Provider

Provider Networks

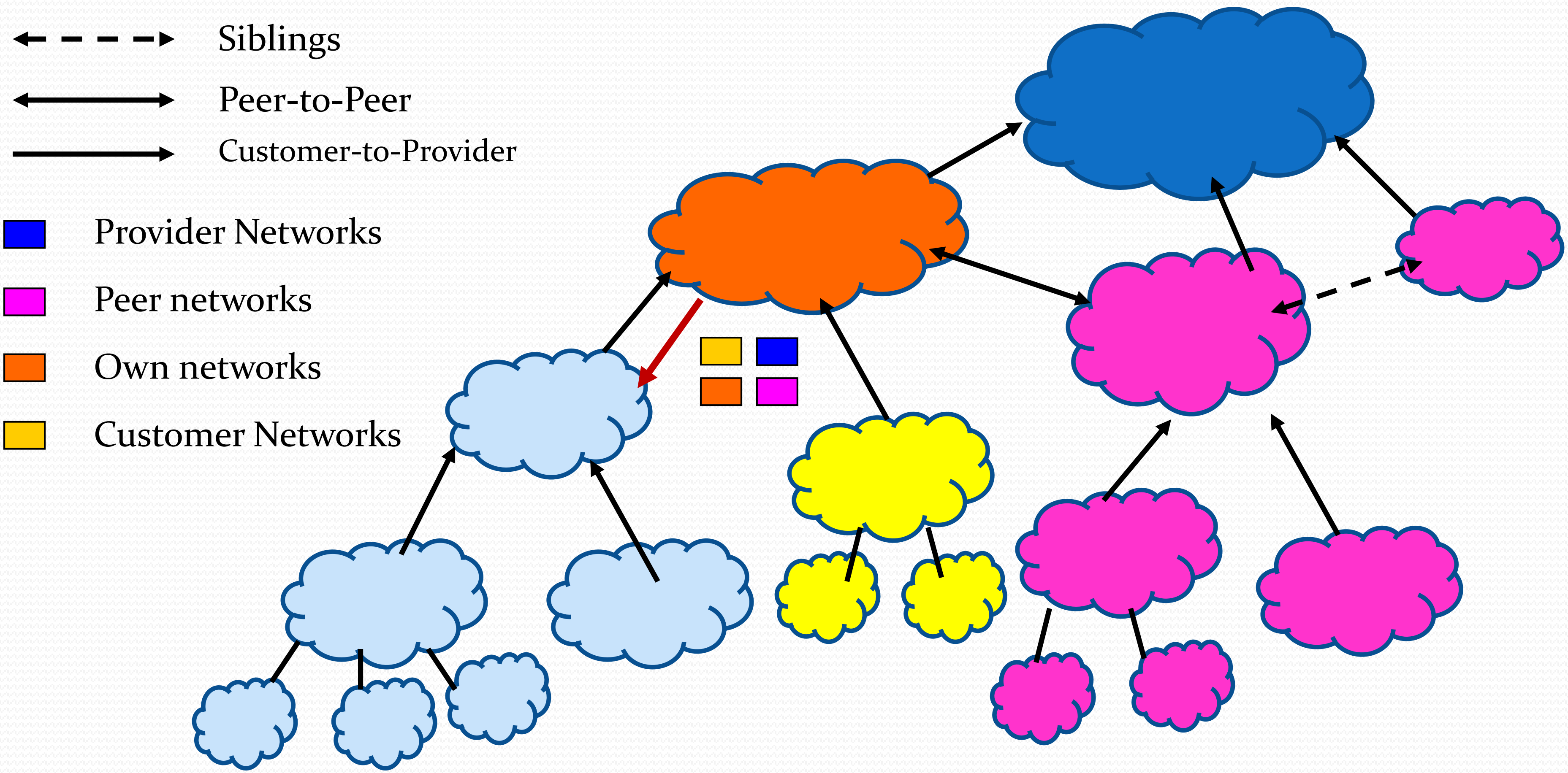
Peer networks

Own networks

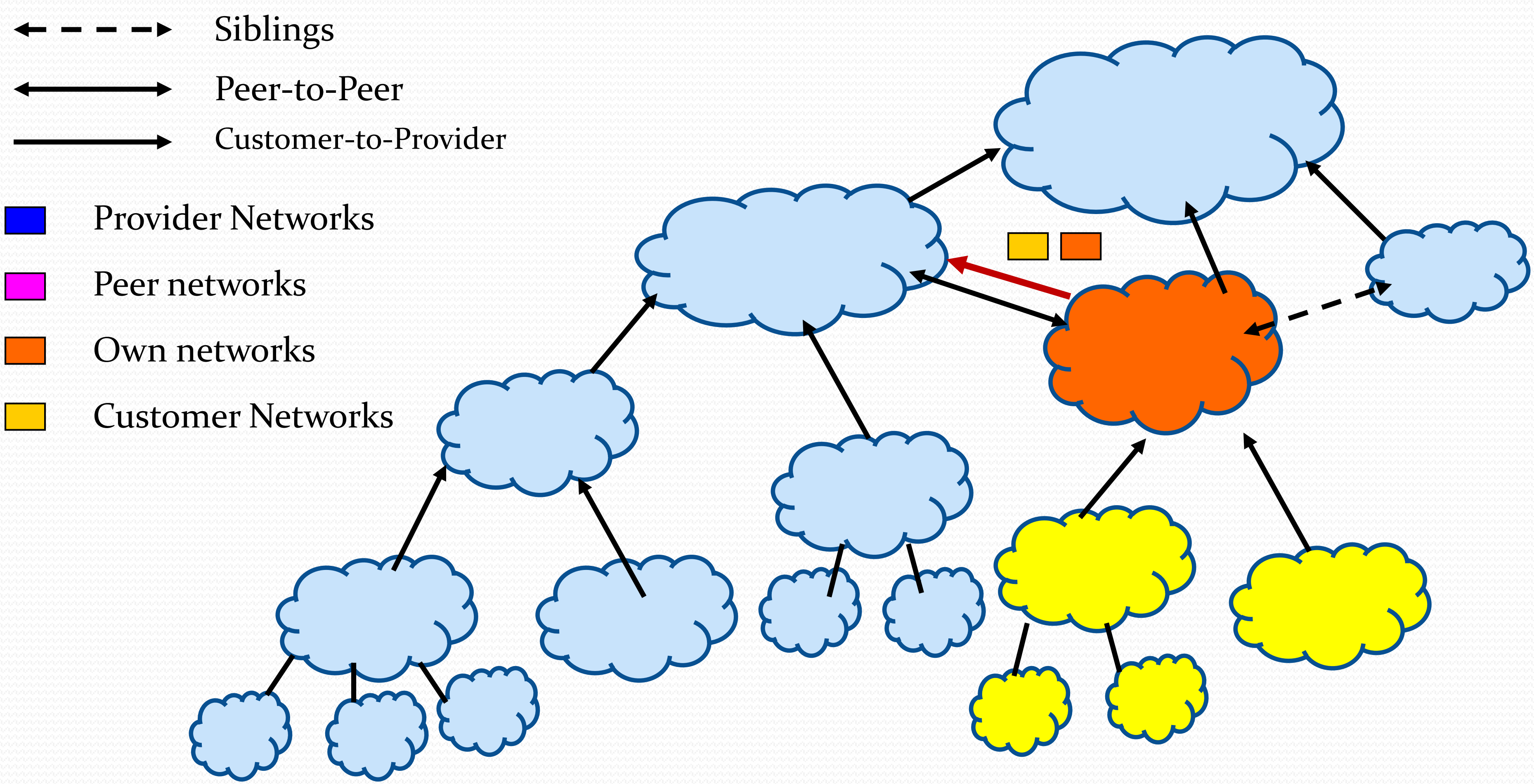
Customer Networks



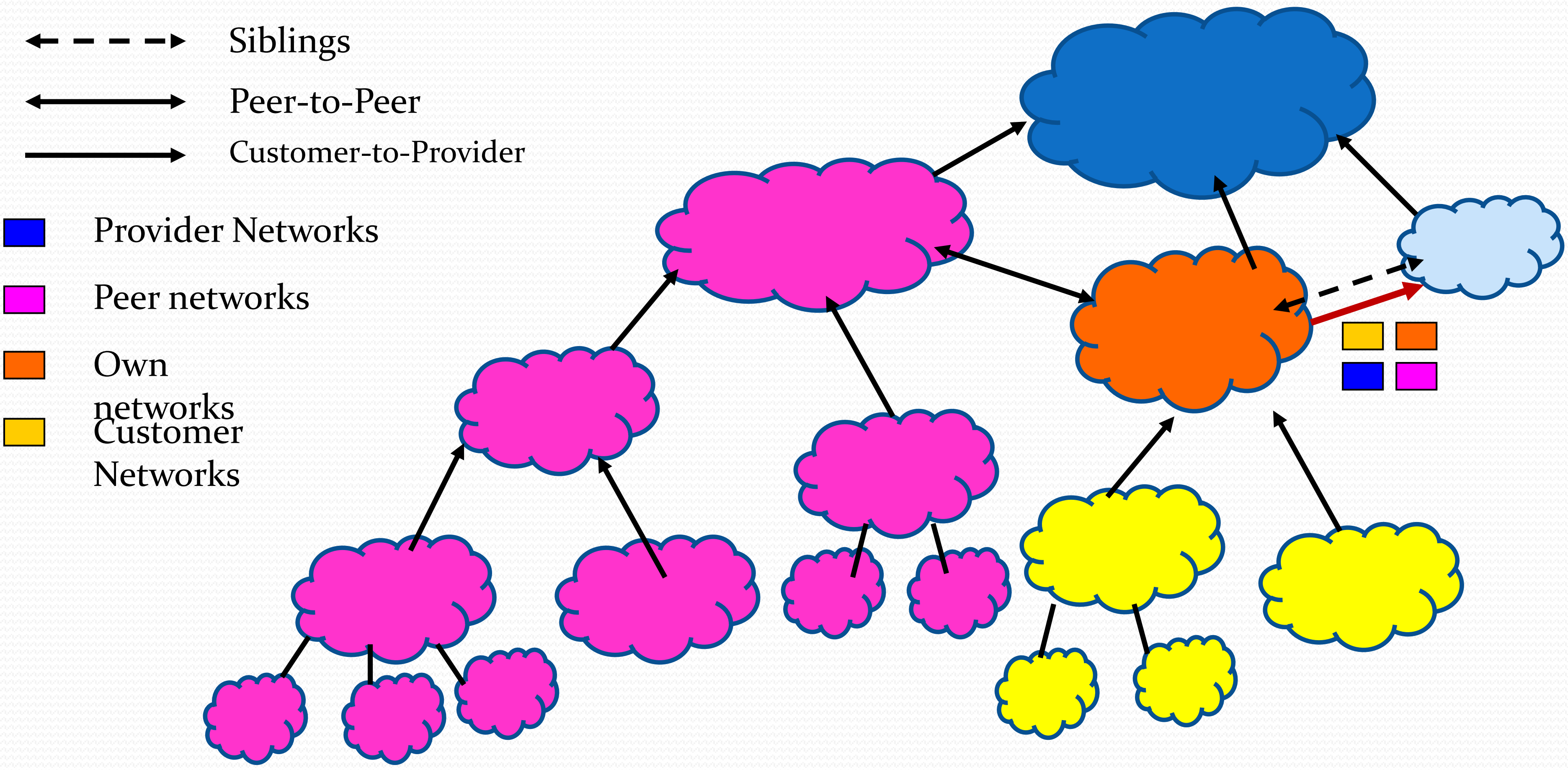
- **Export Routing Policies:**
  - A **provider export to his customers** his whole routing table (other customers, peers, providers and own networks) except customers of the customer



- **Export Routing Policies:**
  - **A peer to peer non-transit exports to other peers** all his routes and his customer networks but not his peers and providers



- ## Export Routing Policies:
  - **A peer to peer transit exports to other peers** his whole routing table (other customers, peers, providers and own networks) except customers of the peer

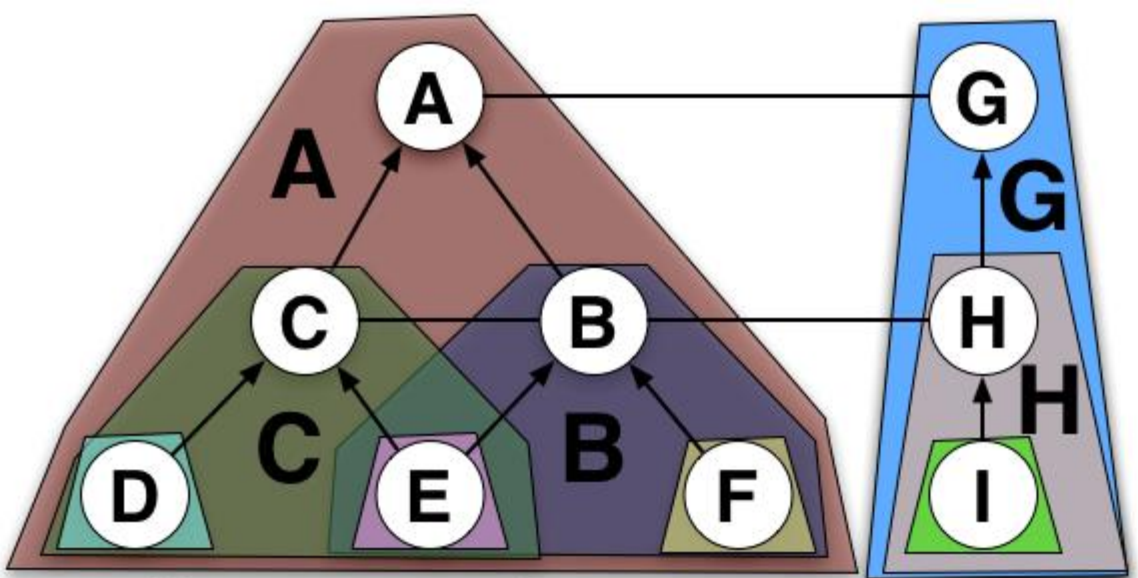


- **The Cooperative Association for Internet Data Analysis (CAIDA)**: **http://www.caida.org/home/**
  - CAIDA investigates practical and theoretical aspects of the Internet in order to:
    - provide macroscopic insights into Internet infrastructure, behavior, usage, and evolution,
    - foster a collaborative environment in which data can be acquired, analyzed, and (as appropriate) shared,
    - improve the integrity of the field of Internet science,
    - inform science, technology, and communications public policies.
  - E.g.
    - AS core IPv4 & IPv6 maps
    - AS ranking
    - Visualization of the IPv4 address space
    - AS rank by **customer cone**
    - DNS workload maps
    - …

- **Customer Cone:**

  http://as-rank.caida.org/?n=50&ranksort=1&mode0=as-intro#customer-cone

  - **Definition**: The set of ASes, IPv4 prefixes, or IPv4 addresses that can be reached from a given AS following only customer links
  - E.g. AS rank by **customer cone** (http://as-rank.caida.org/)



Customer Cones

- **Customer Cone size:**

  http://as-rank.caida.org/?n=50&ranksort=1&mode0=as-intro#customer-cone

  - **Peering cone size ratio** as the ratio in customer cone sizes of a pair of ASes if they (hypothetically) peered.
  - Similar customer cone sizes will have this ratio closer to 100, also an indication the ASes have more incentive to peer.
  - The closer this ratio is to zero, the larger the difference in customer cone sizes, and the less incentive the larger provider will have to peer with the smaller.

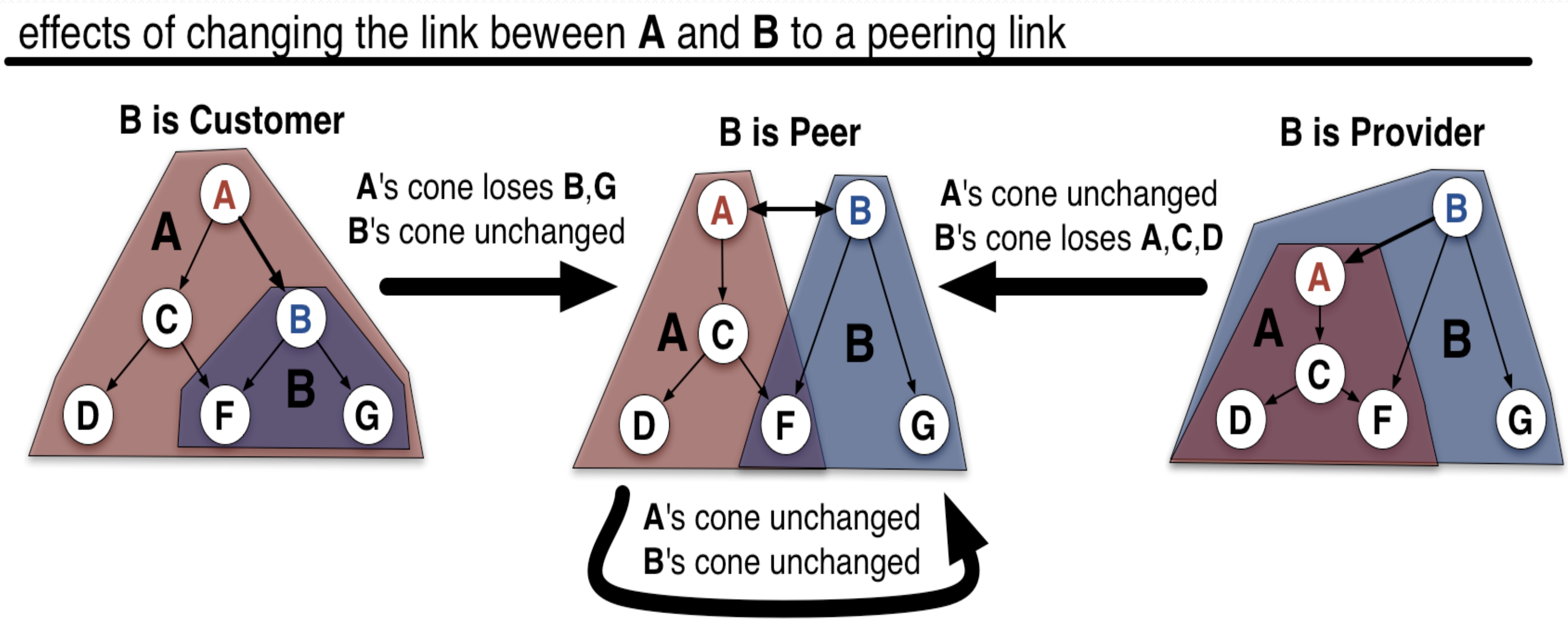
  - To compare magnitude of differences, the **peering cone size ratio** always uses the larger customer cone as the denominator.

    - For example, for AS pair S and N, with customer cone sizes C(S) and C(N), respectively , if C'(S) and C'(N) were their respective customer cone sizes if S and N became p2p peers (with other links unchanged), then the **peering cone size ratio** is C'(N)/C'(S) if C'(S) > C'(N), otherwise C'(S)/C'(N).

- **Customer Cone size:**

http://as-rank.caida.org/?n=50&ranksort=1&mode0=as-intro#customer-cone

If the original graph had **B** as a customer of **A** then **A**'s cone contains 7 ASes: **A,B,C,D,E,F,G**. **B**'s cone contains three ASes:**B,F,G**. If the link between **A** and **B** is changed to a peering link, **A** loses customers **B** and **G**, which it had access to exclusively through its customer relationship with **B**. **A**'s cone does not lose **F**, since it can still reach it through its customer relationship with **C**. **A**'s cone size thus shrinks to 4 ASes: **A,C,D,F**. Since AS **B** did not previously reach any customers through **A**, its customer cone is unaffected by this change.



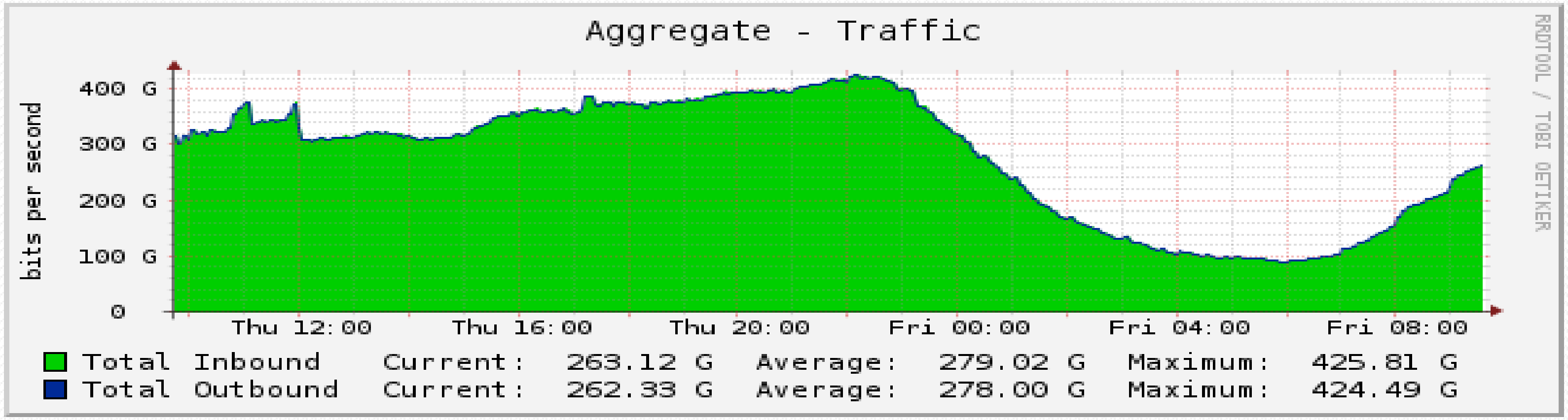
Topic 1: Internet Architecture & Addressing.

- **The Cooperative Association for Internet Data Analysis (CAIDA)**: **http://www.caida.org/home/**
  - E.g. AS rank examples (check them):
    - **Telefonica backbone (AS 12956)**
    - **Telefonica (AS 3352)**
    - **Jazztel (AS 12715)**
    - **Ono (AS 6739)**
    - **Orange (AS 12479)**
    - **Vodafone-ES (AS 12430)**
    - **Others ….**

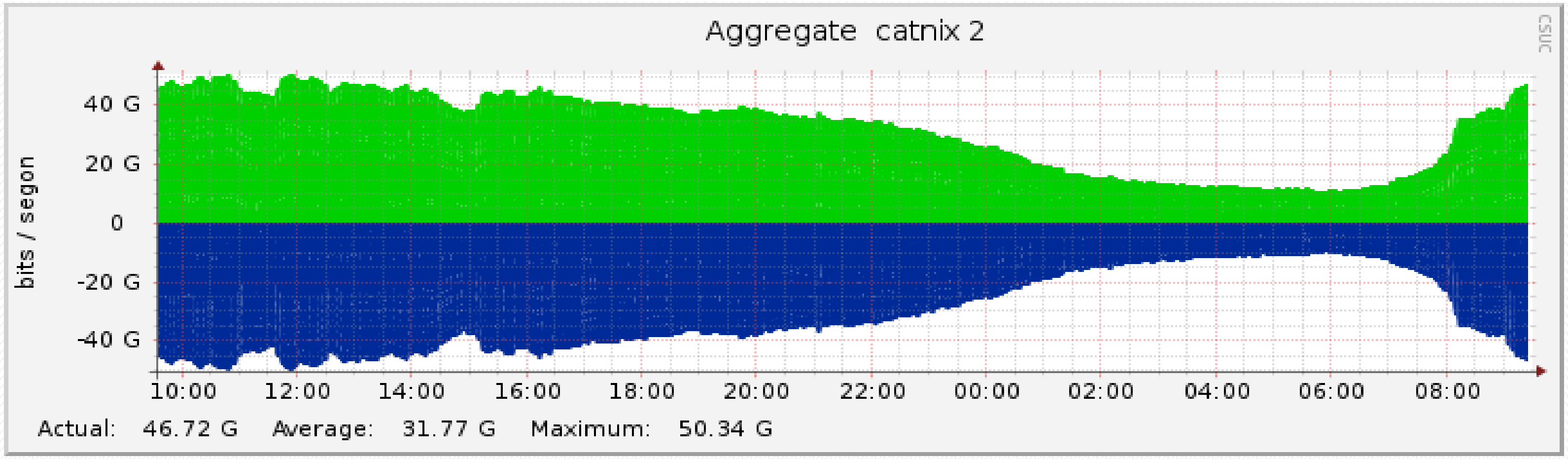
- ISP peering
  - Private peering
    - Point-to-point connections among two AS in order to transport routes and traffic
      - Increase link reliability and offer high bandwidth but at cost increases
    - Alleviate the traffic that crosses public exchange points
    - Connections are bi-laterally negotiated among the ISP (peer-to-peer basis)
    - Routing and business treats are confidential and only known among partners (peers)

- **ISP peering**
  - **Public peering**
  - **National**: inter-connect ISP belonging to the same country
    - Espanix (www.espanix.net) with 45 partners and 96 averaged Gb/s of traffic, Catnix (www.catnix.net) with 24 partners and approx 700 switched Mb/s, EuskoNix with 7 partners and 100 Mb/s
  - **International**: inter-connect National IXP; EuroIX (www.euro-ix.net) with 105 European IXP
    - The inter-connectivity matrix between IXP will give us information about ISP peering
    - Not all ISP are connected to IXP

- **Espanix Traffic (07/Feb/2019)**



- **Catnix Traffic**



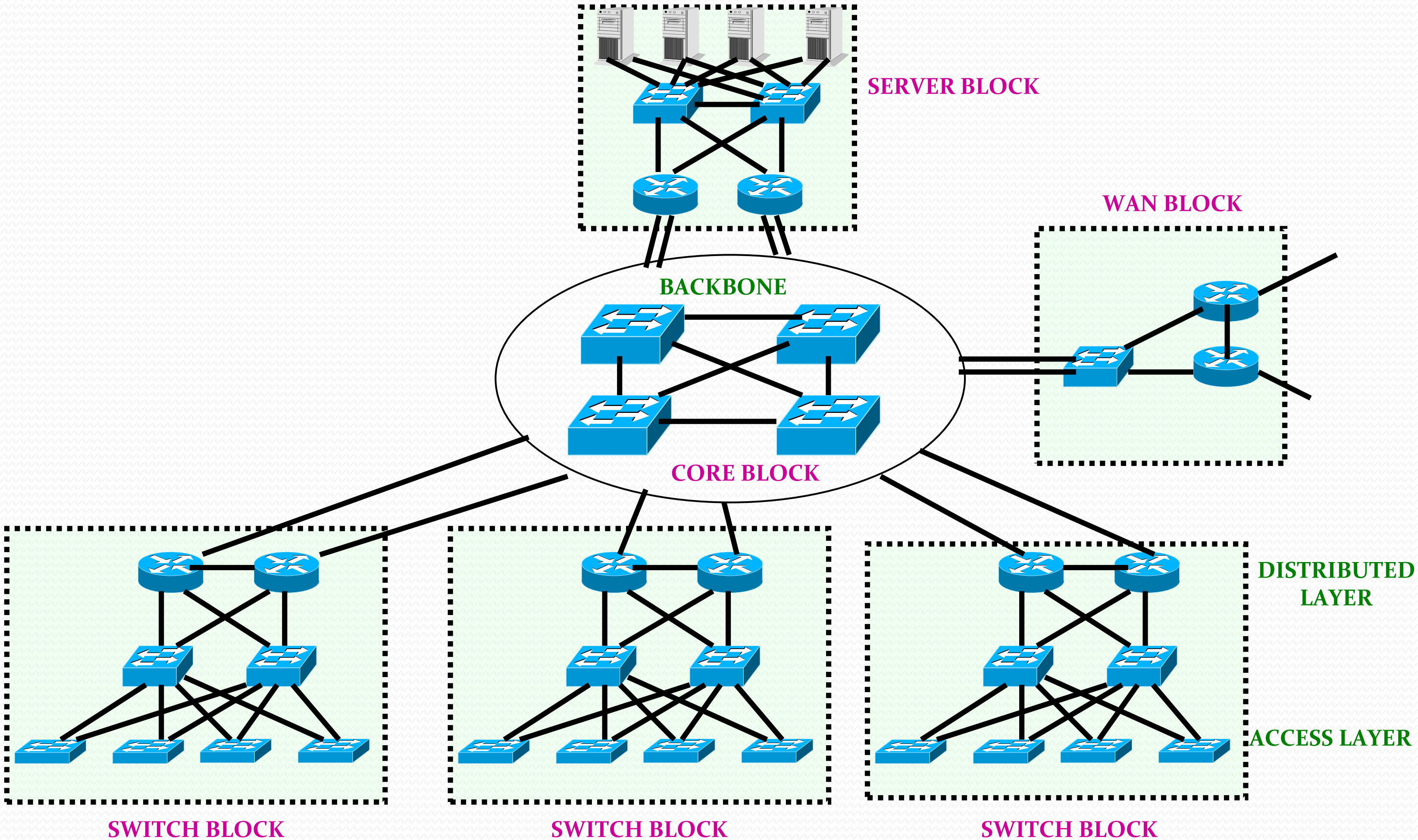
- **Tiers:**
  - **Tier 1 ISPs (troncales)** are large and together hold all the world's **Internet routes**, and **peer** with each other to give each other access to all Internet routes.
  - **Tier 2 ISPs** buy connectivity (**upstream transit**) to the world Internet routes from one or more tier 1 ISPs, and hence their IP network(s) becomes a sub-set of those tier 1's IP networks. Tier 2 ISPs will also peer with each other to minimize the amount of traffic to and from the tier 1 ISPs from whom they buy upstream transit.
  - **Tier 3 ISPs** buy upstream transit from Tier 2 ISPs and so on, however the model becomes increasingly vague, since an ISP may buy upstream transit from both a tier 1 ISP and a tier 2 ISP, and may peer with tier 2 and tier 3 ISP's and occasionally a tier 1 ISP, and so on. The term is really only of use to differentiate between tier1 ISPs who do not need to buy upstream transit due to their peerings with other tier 1 ISPs, and the rest of the ISPs, tier 2 and below.

Tier 1 (International), Tier 2 (National/regional) and Tier 3 (regional/local)

Corporative Networks or IP-Net Client

- Companies with ***end users*** and ***end services***
- As any end user, they are connected to other end users and other corporative networks via an ISP
- A corporative network can be something ranging between:
  - Small company with few users, to a large company with thousands of users
- A corporative network may:
  - Manage their services in a CPD (Centre Processing Data) located in the Main Site
  - Manage their services via others (e.g. either another corporative network or an ISP) that provides the service (e.g. hosting, housing, virtualization, …)

- **Corporative Networks or IP-Net Client**



* “Internetwork Design Guide”, CISCO documentation

- **Internet Scalability**
  - Scalability impacts Internet architecture
  - **IP addresses**: define two issues in Internet
    - End-point identity (host identity)
    - Forwarding or location identity (network identity)
  - **Address organization**:
    - IANA has blocks of /8 that leases to RIR (Regional Internet Registers).
    - RIRs leases subnneting blocks from /8 to LIRs (ISPs)
    - ISPs use the addresses or lease parts of blocks to dial-up end users and IP-Net clients
    - **NAT**: intermediate solution to leverage exhaustion in the use of IP addresses
    - **IPv6** should be the final solution

- **IANA* IP blocks (221 blocks of /8)**
  - Any individual IPv4 address could be in any one of five states:
    - reserved for special use, or
    - part of the IANA unallocated address pool,
    - part of the unassigned pool held by an RIR,
    - assigned to an end user entity but not advertised in the routing system, or
    - assigned and advertised in BGP.

- **Types of IPv4 addresses in Internet**
  - **PA (Provider Aggregatable):**
    - Blocks of addresses that may be sub-assigned to other ISPs or to other companies that also may leased the addresses to their customers
    - May be aggregated by routing protocols
    - If an entity changes its ISP and its IP block is PA, he has to **return** the IP block to the original provider and obtain a new block from the new ISP, except if the block was directly obtained from RIPE
  - **PI (Provider Independent):**
    - Blocks of addresses that can not be sub-assigned to other ISP (RIPE does not already assign this kind of blocks) and only may be assigned to end users
      - If a Corporative network wants this kind of blocks , he may ask to RIPE (via its ISP)
    - Can not be aggregated by routing protocols
    - These blocks are **portable** (changing ISP implies that you may keep the block)

- **IPv4 space management:**
  - IP address blocks **are not** bought, they are a public resource shared by LIR that obtain from RIR and that they can use always that (i) fulfil RIR rules, (ii) are a LIR member (annual maintenance payment).
    - If you are not a member (LIR) you can not get an IP block from RIR, and you will have to contact with an ISP.
  - RIR do not assign IP classes (A,B,C), since they use **CIDR** (*Classless Inter-Domain Routing)*.
  - Last 5 /8 blocks were delived by IANA at Feb 2011, one block to each RIR. Thus, RIPE currently has the remaining of a single /8 block.
    - One /8 is equal to 16.8 million IPv4 addresses.

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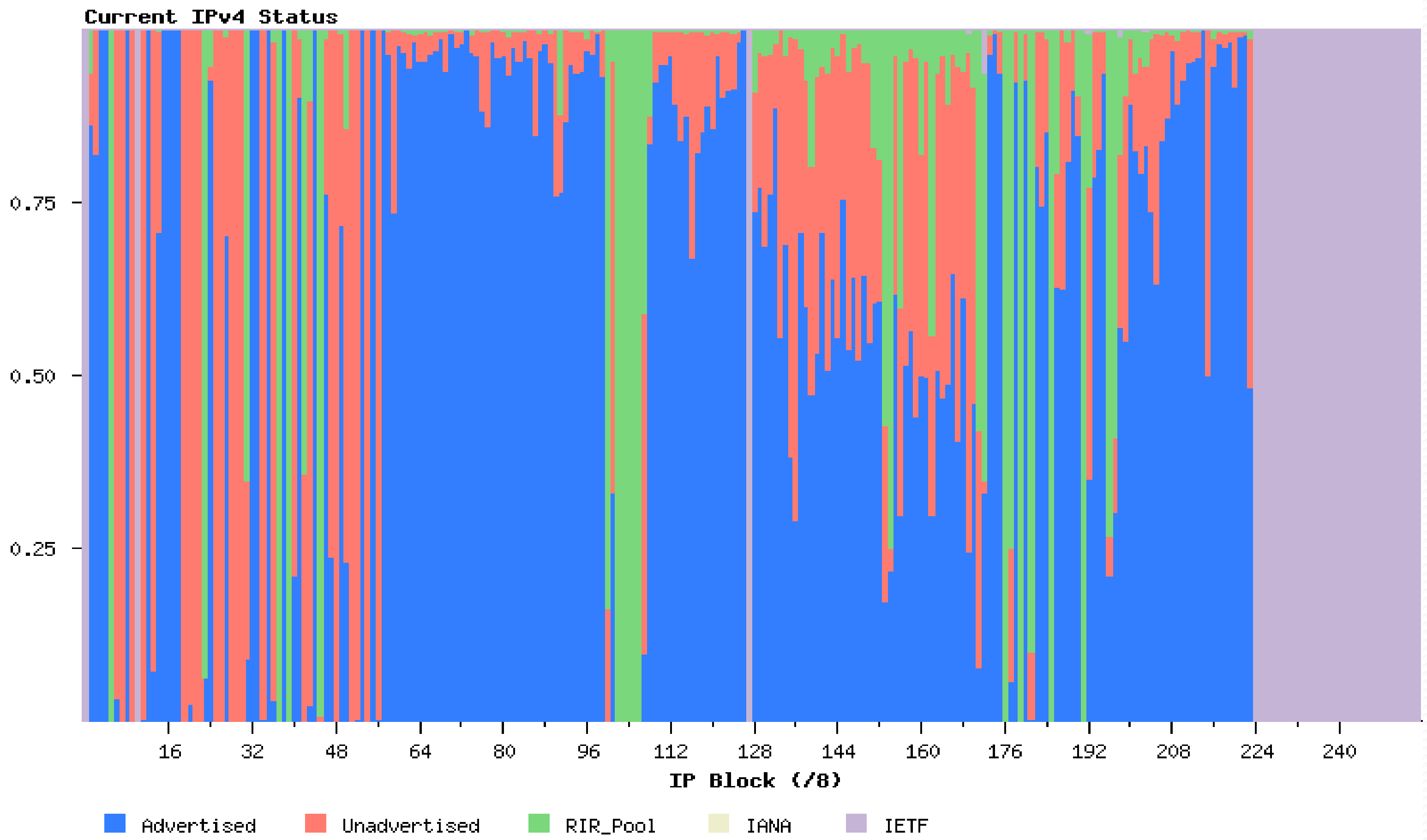
- **IPv4 blocks** advertised and unadvertised



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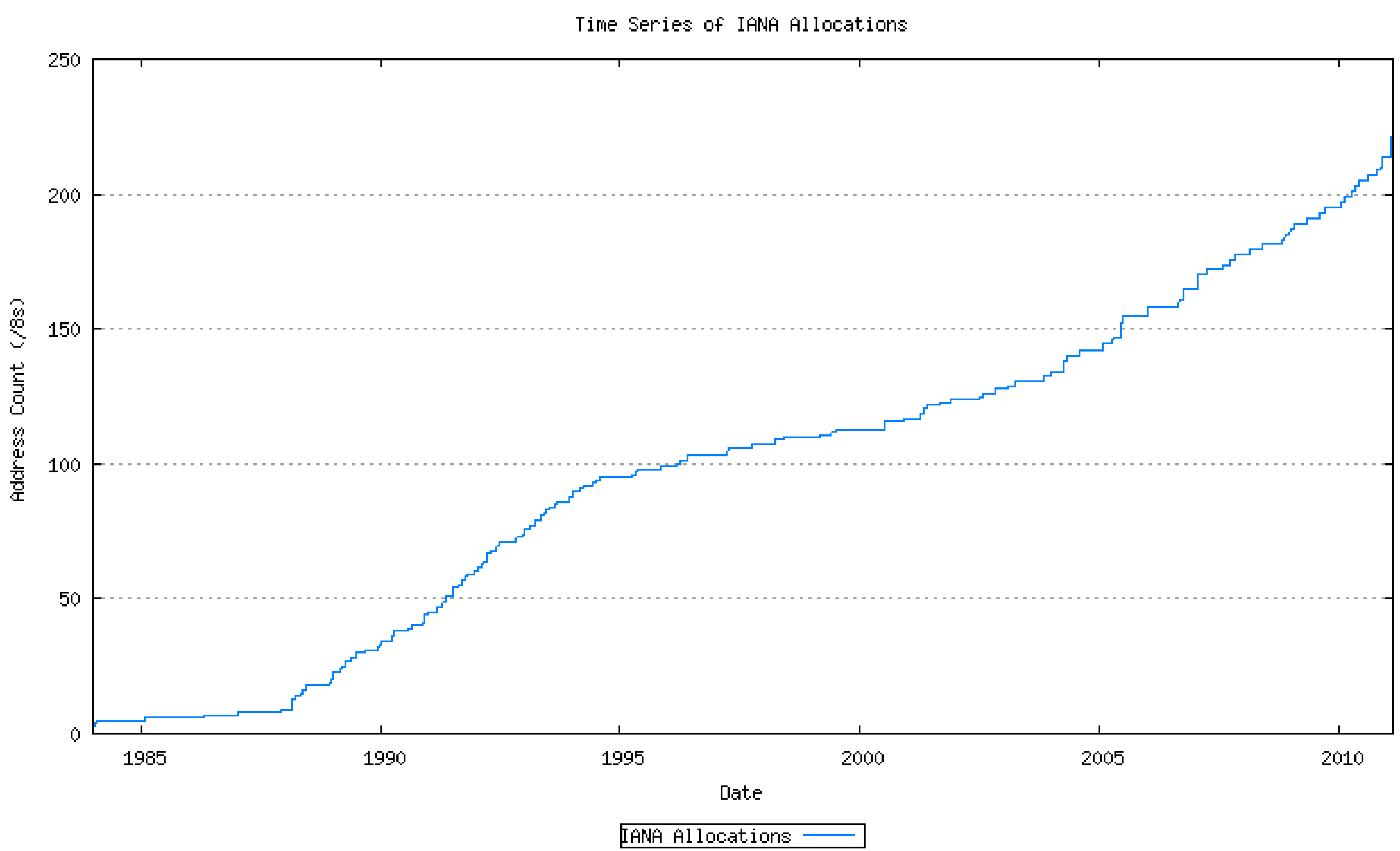
- **IANA IP blocks (221 blocks of /8) (YEAR 2010)**



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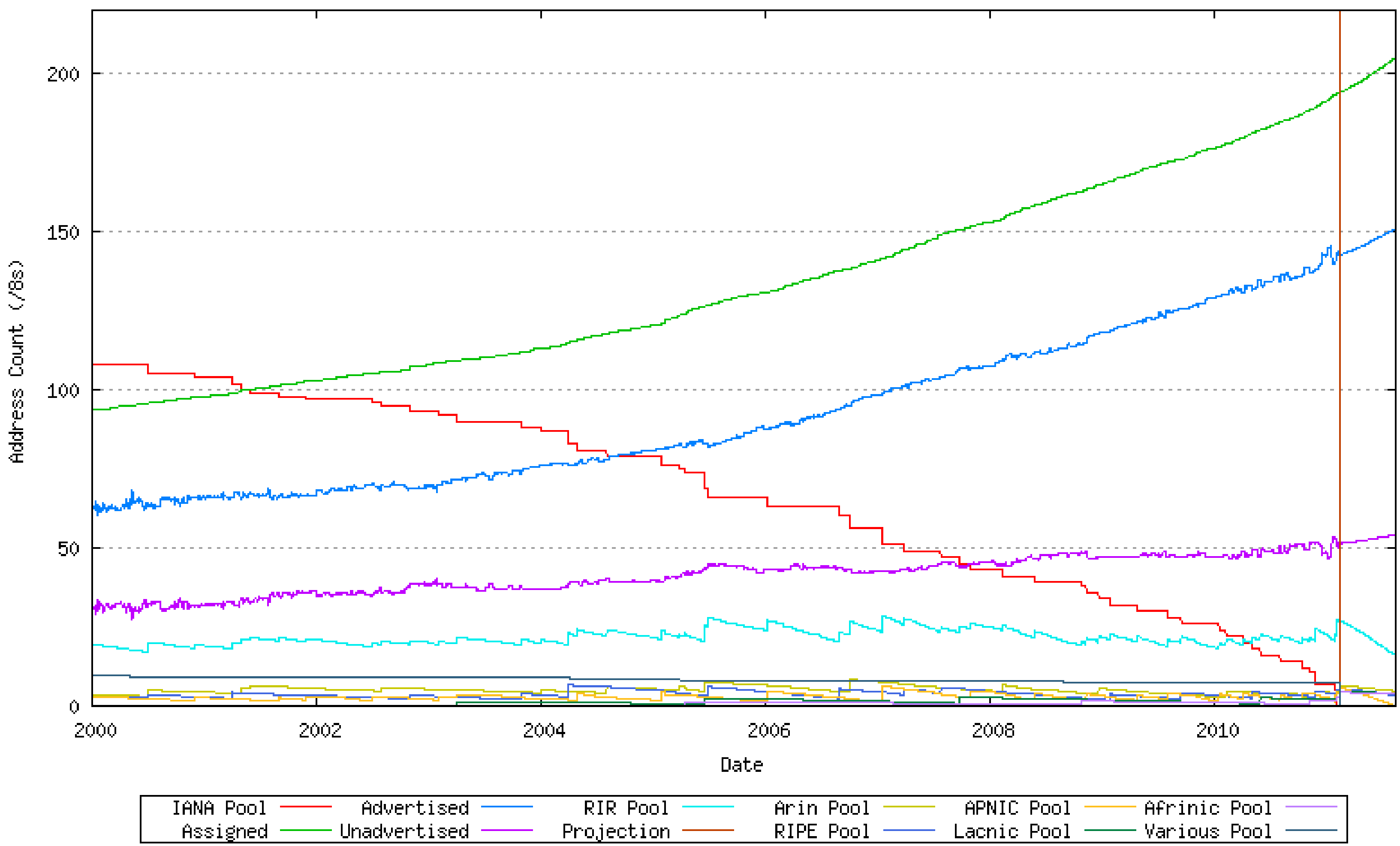
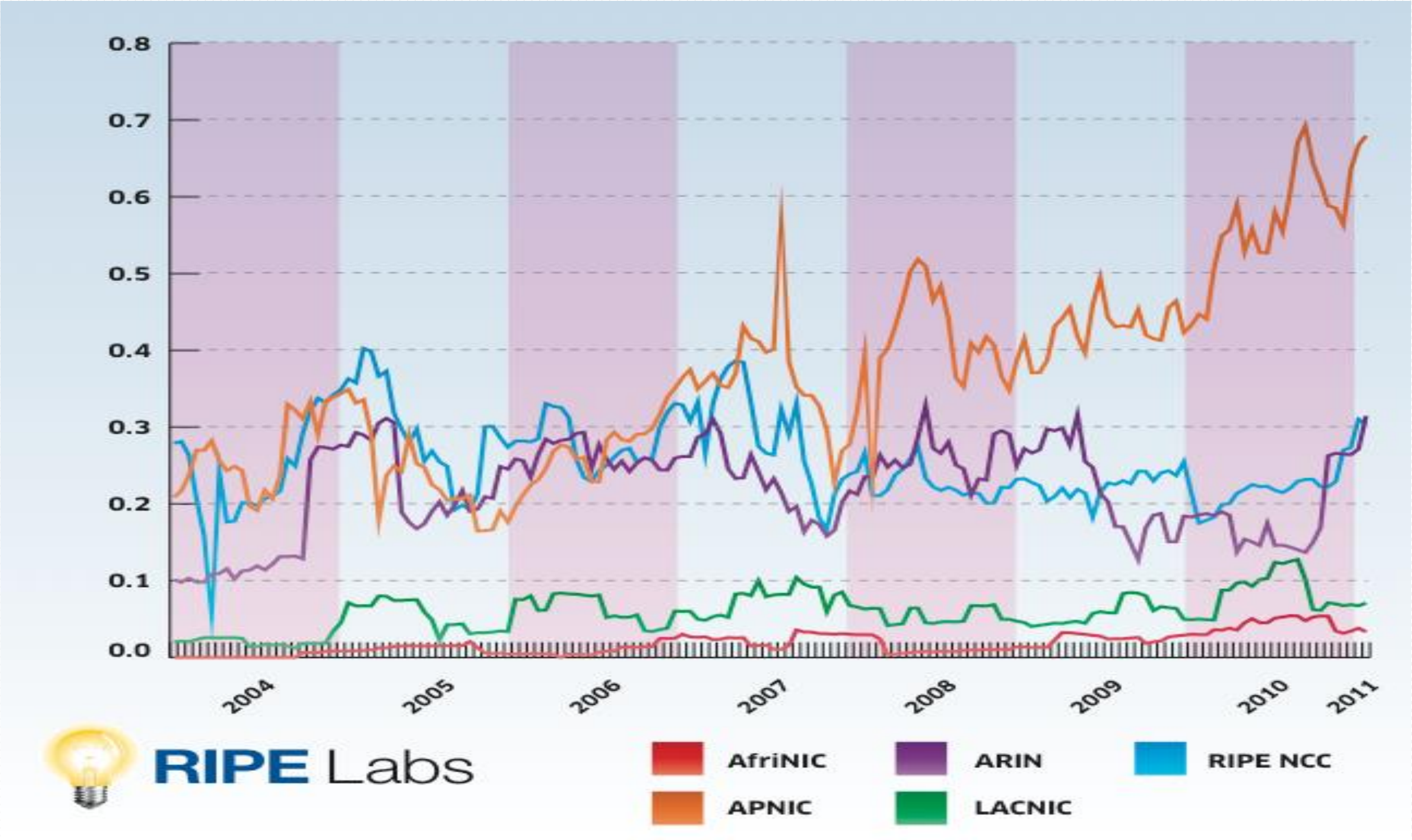
- **IPv4 exhaustion → IANA (Feb/2011), RIR (08/2011)**



- **RIPE policy with respect the last /8 block:**
  - **Rate of change:** week allocations per RIR



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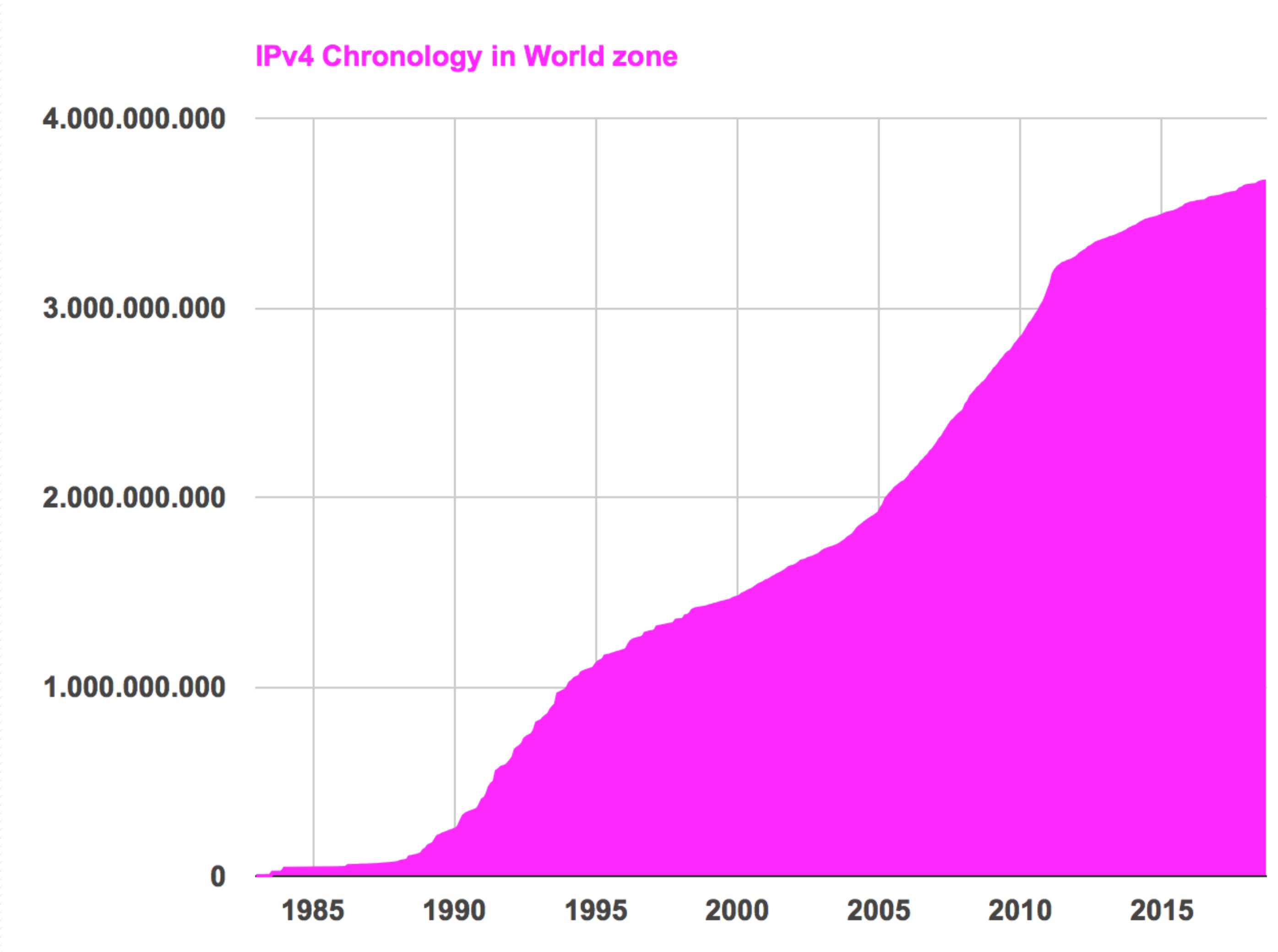
- **IPv4 addresses:** 3.647 Millions of IPv4 addresses (Sept 208)



- Top 20 countries using IPv4 addresses

Rank	Country	Code	Number	Percentage
1	United States	US	1 604 288 256	43.772 %
2	China	CN	340 350 464	9.286 %
3	Japan	JP	204 060 672	5.568 %
4	United Kingdom	GB	121 786 648	3.323 %
5	Germany	DE	121 167 488	3.306 %
6	Korea, Republic of	KR	112 449 024	3.068 %
7	Brazil	BR	84 733 184	2.312 %
8	France	FR	82 224 688	2.243 %
9	Canada	CA	70 277 632	1.917 %
10	Italy	IT	54 787 136	1.495 %
11	Australia	AU	48 521 728	1.324 %
12	Netherlands	NL	47 405 280	1.293 %
13	Russian Federation	RU	45 475 328	1.241 %
14	India	IN	40 892 672	1.116 %
15	Taiwan, Province of China	TW	35 539 200	0.970 %
16	Spain	ES	30 987 584	0.845 %
17	Sweden	SE	30 204 008	0.824 %
18	South Africa	ZA	29 108 480	0.794 %
19	Mexico	MX	28 888 064	0.788 %
20	Belgium	BE	28 443 520	0.776 %

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- **Look at RIPE statistics and RIPE IPv4 exhaustion webpage**

http://www.ripe.net/internet-coordination/ipv4-exhaustion

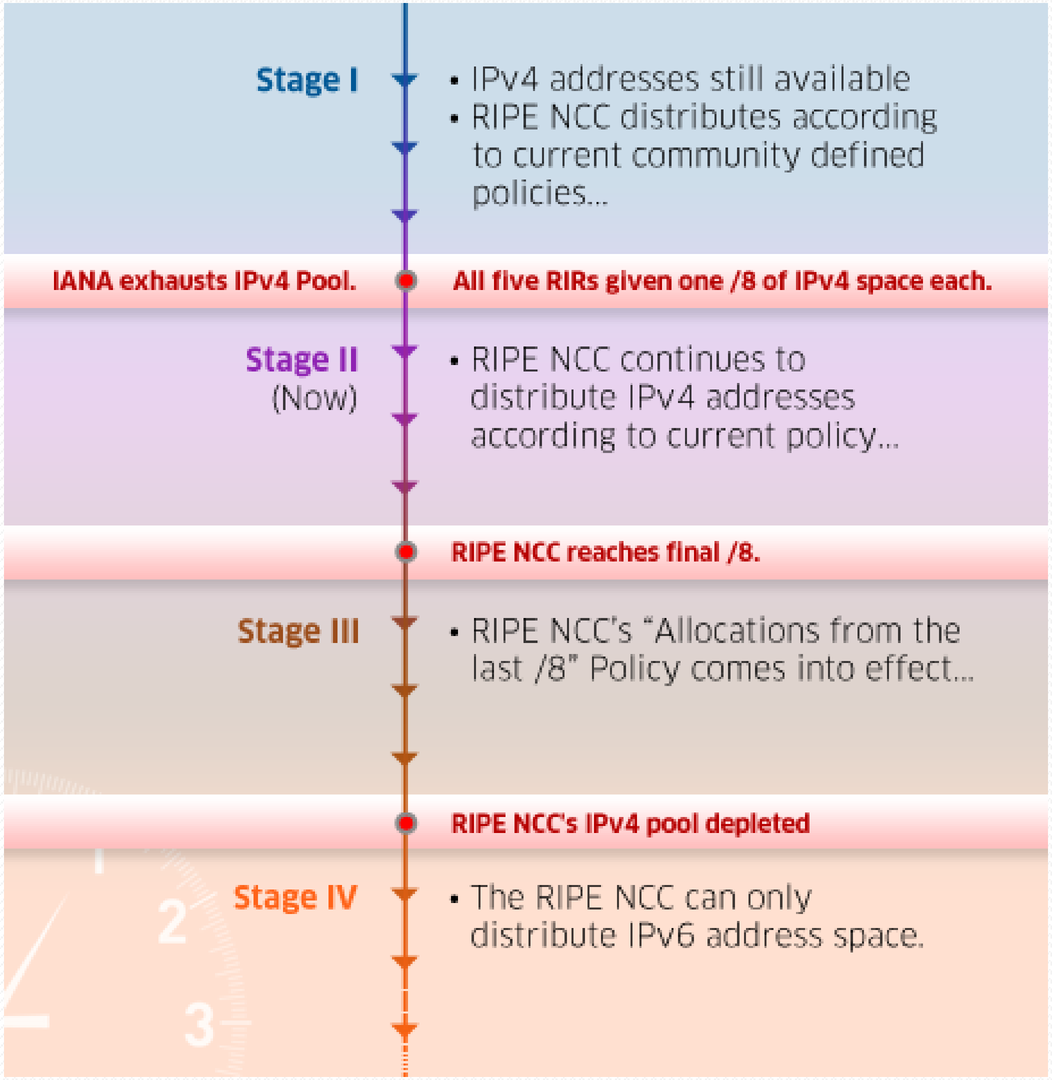
https://labs.ripe.net/statistics/?tags=ipv4

- **RIPE policy with respect the last /8 block:**
  - Each Local Internet Registry (LIR) can receive **only one** /22 (1,024 IPv4 addresses) upon application for IPv4 resources.
  - To obtain this /22 allocation, the LIR must already have an IPv6 allocation.
  - No new IPv4 Provider Independent (PI) space will be assigned.

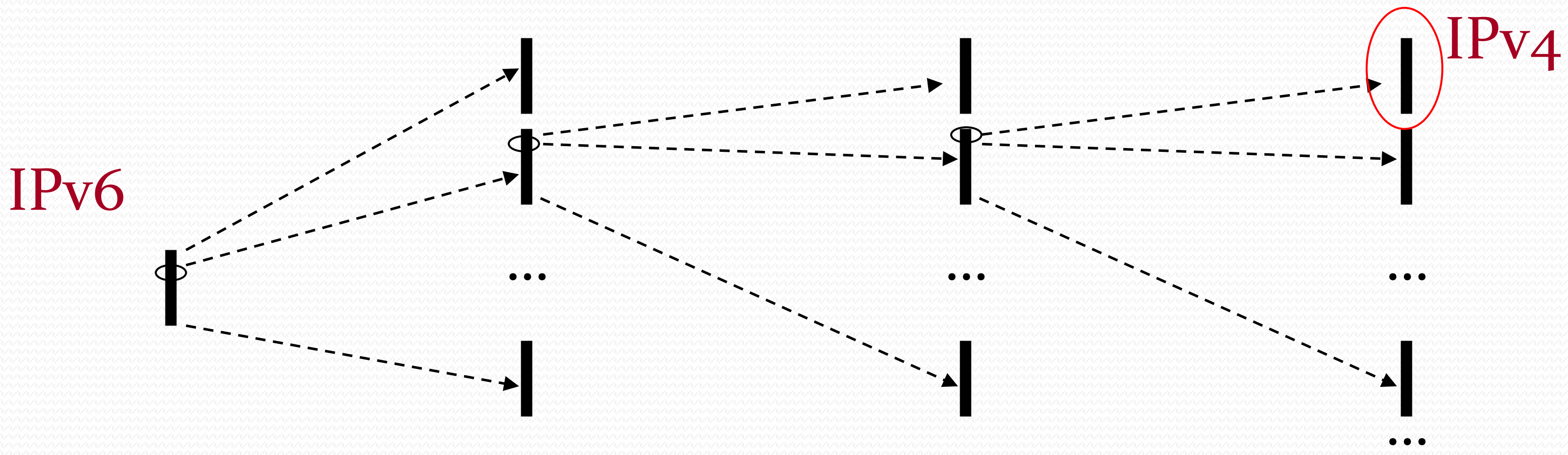
  - See the following URL to check the RIPE IPv4 pool:

  http://www.ripe.net/internet-coordination/ipv4-exhaustion/ipv4-available-pool-graph

- **RIPE policy with respect IPv4 exhaustion Timeline:**



- **IPv6:**
  - Address scheme that increases the number of IPv4 addresses from 32 bits (2^{32} space) to128 bits (2^{128} space)
  - Improves IPv4 Address space and other issues such as security (IPSEC)



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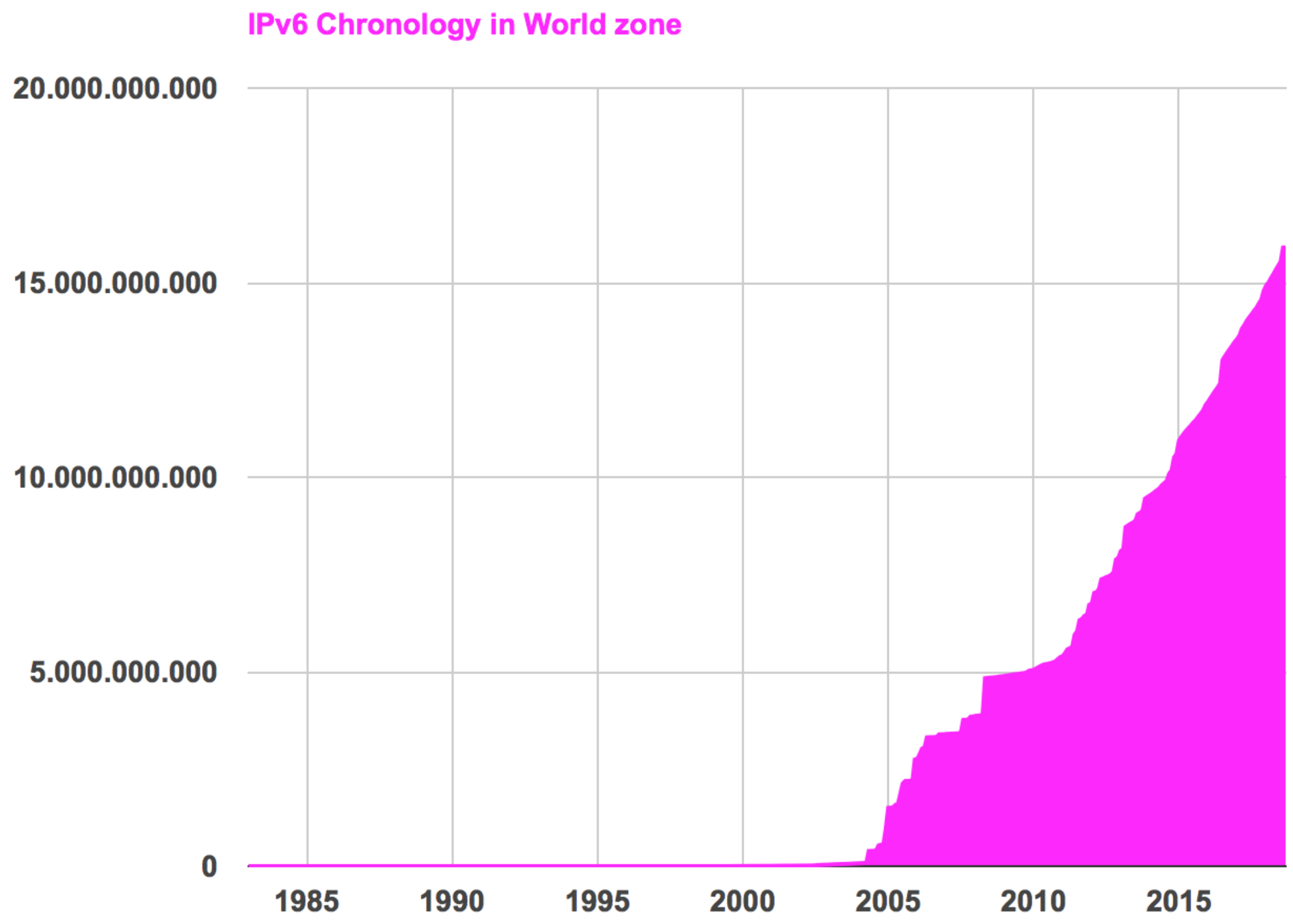
- **IPv6 addresses:** 15.900 Millions of IPv6 addresses (Sept 208)



- Top 20 countries using IPv6 addresses

Rank	Country	Code	Number	Percentage
1	United States	US	2 961 114 084	18.620 %
2	China	CN	1 815 609 378	11.417 %
3	Germany	DE	1 258 029 530	7.911 %
4	United Kingdom	GB	1 220 542 647	7.675 %
5	France	FR	822 542 434	5.172 %
6	Japan	JP	638 066 856	4.012 %
7	Australia	AU	589 759 527	3.709 %
8	Italy	IT	530 841 618	3.338 %
9	Russian Federation	RU	508 756 230	3.199 %
10	Netherlands	NL	441 778 475	2.778 %
11	Korea, Republic of	KR	344 457 221	2.166 %
12	Brazil	BR	340 339 359	2.140 %
13	Argentina	AR	329 583 160	2.073 %
14	South Africa	ZA	307 560 572	1.934 %
15	Spain	ES	301 793 302	1.898 %
16	Poland	PL	298 647 741	1.878 %
17	European Union	EU	285 540 362	1.796 %
18	Egypt	EG	269 090 818	1.692 %
19	Switzerland	CH	178 454 668	1.122 %
20	Taiwan, Province of China	TW	155 451 402	0.978 %

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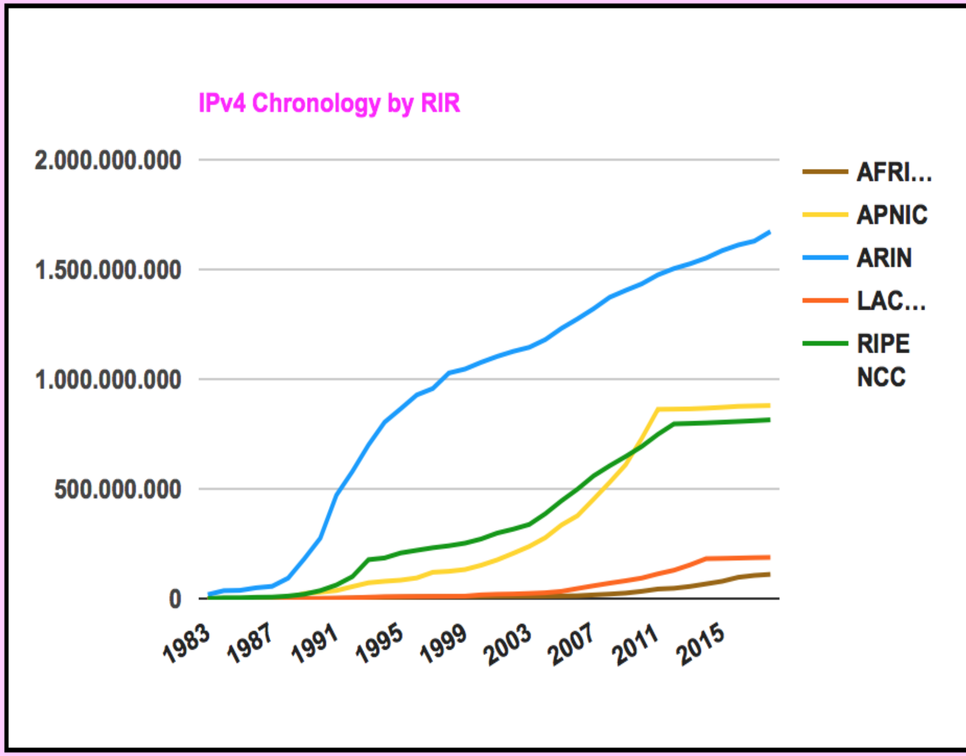
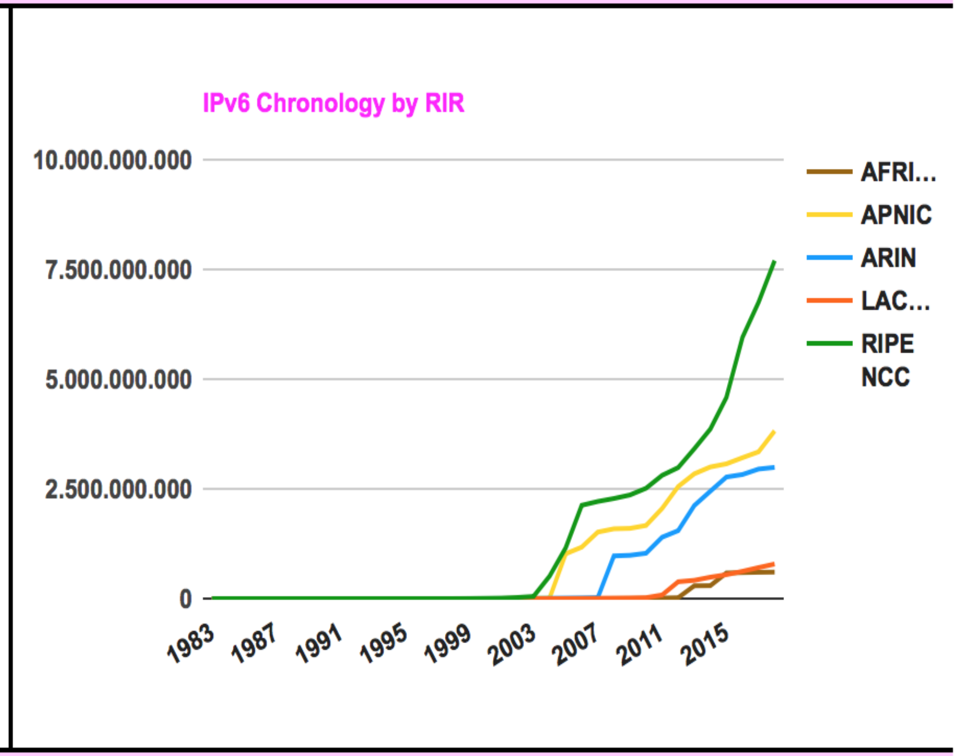
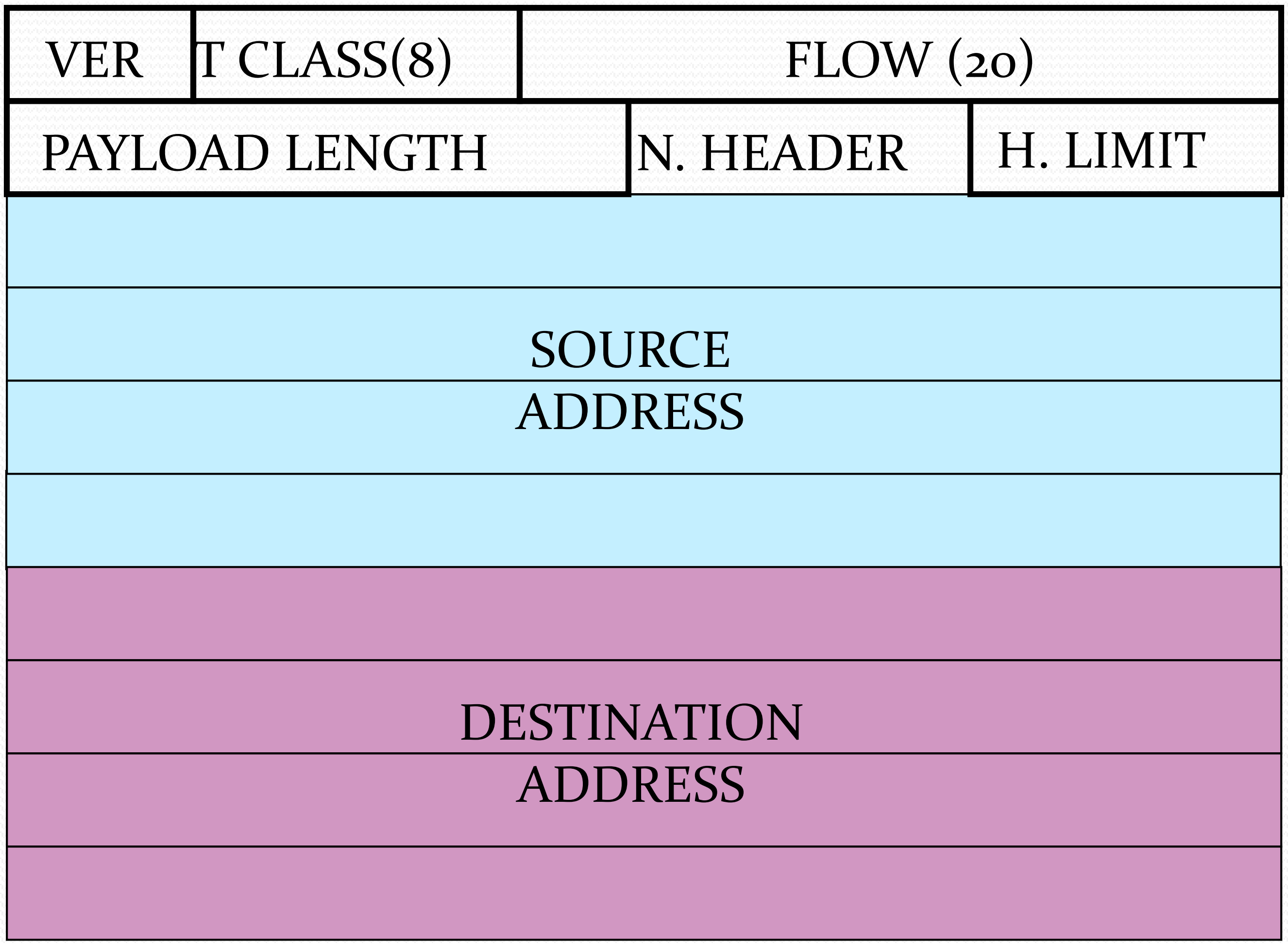
- **IPv4 and IPv6 addresses per RIR**





- **IPv6 deployment:**
  - ISPs and telecom operators use IPv4
  - IPv6 islands
    - IPv6 in IPv4 encapsulation, **dual stack Ipv4v6** and **IPv6 translation to IPv4**
  - From IPv4 to IPv6
    - Technologies that begin with IPv6. E.g UMTS, sensors, vehicular, etc !!! in order to force the massive IPv6 deployment
    - Migrate IPv4 to IPv6 is very costly and should be progressive

IPv6 Header:

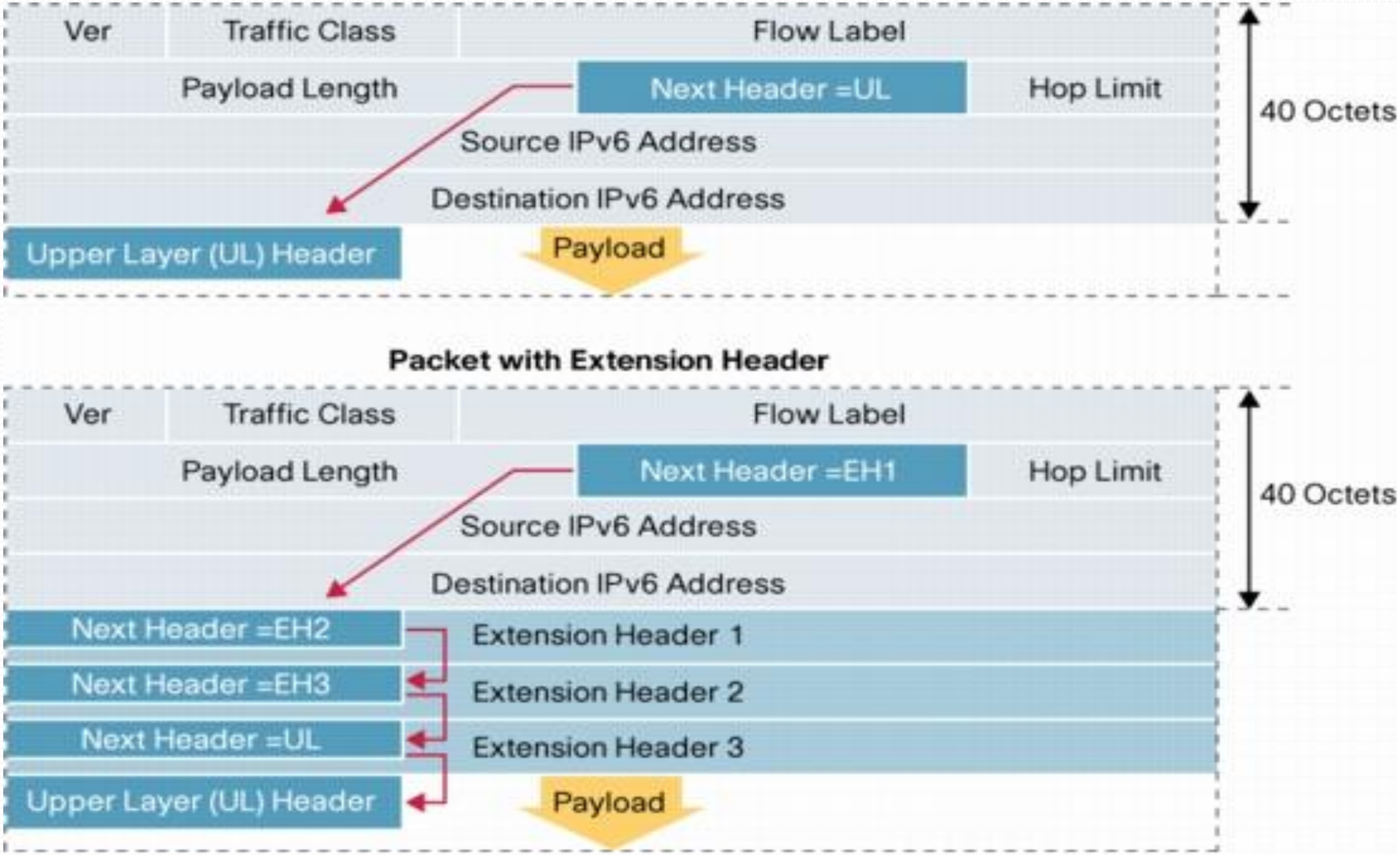


VER
T CLASS(8)
FLOW (20)
PAYLOAD LENGTH
N. HEADER
H. LIMIT
SOURCE
ADDRESS
DESTINATION
ADDRESS

IPv6 Header:

- **Version (4) :** value of 6
- **TOS (8):** type of service
- **Flow Label (20):** (@source, FL) Identifies data flows. Assigned by the origin: should be a random number between 00000 and FFFFF (00000: means that FlowLabel is not used)
- **Payload Length (16):** size of the data (Extension Headers + Payload)
- **Next Header (8):** next header (embbeded headers) in the IPv6 header
- **Hop Limit (8):** decremented each time a packet is forwarded

- **IPv6 header options:**

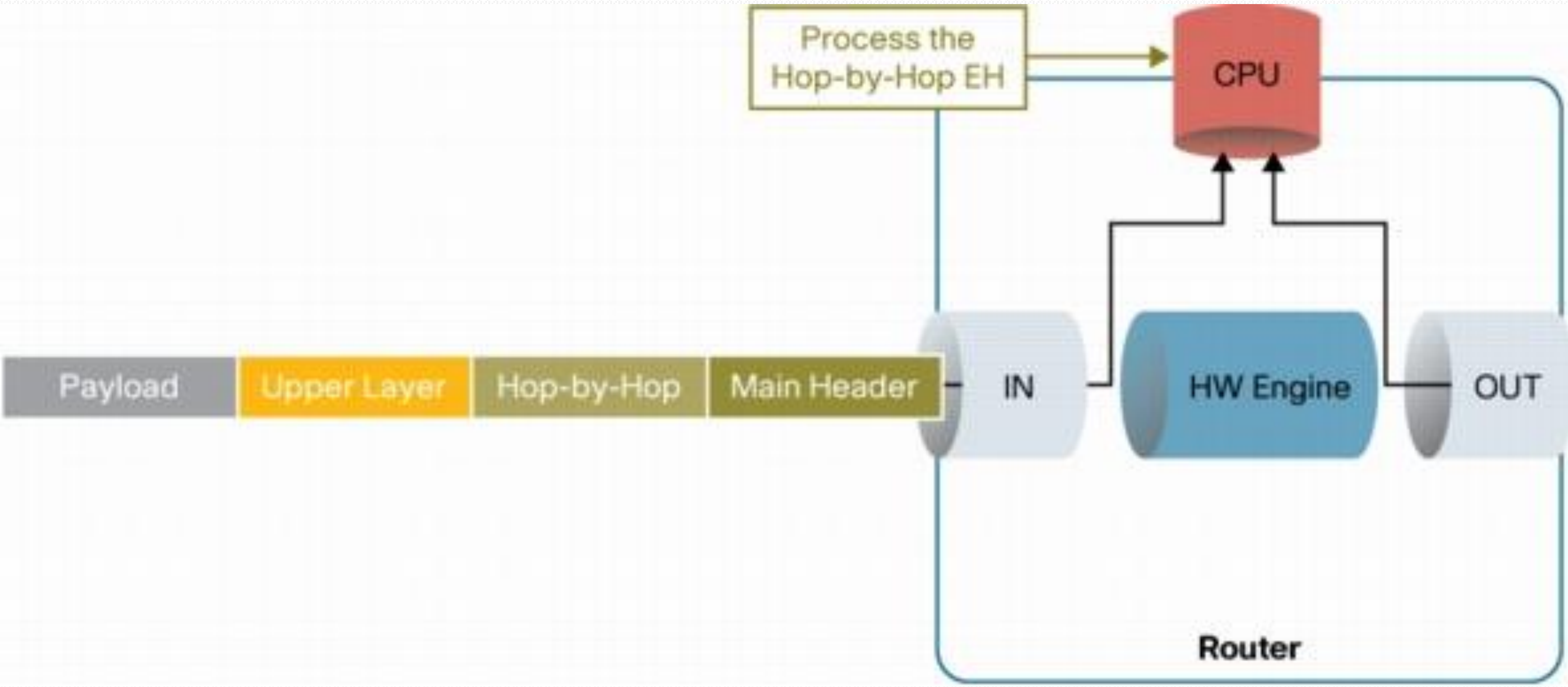


- **IPv6 header options:**

Extension Header	Type	Description
Hop-by-Hop Options	0	Options that need to be examined by all devices on the path (Router Alert, RSVP).
Destination Options (before routing header)	60	Options that need to be examined only by the destination of the packet (used with MIPv6).
Routing	43	Methods to specify the route for a datagram (used with MIPv6).
Fragment	44	Contains parameters for fragmentation of datagrams.
Authentication Header (AH)	51	Contains information used to verify the authenticity of most parts of the packet.
Encapsulating Security Payload (ESP)	50	Carries encrypted data for secure communication.
Destination Options (before upper-layer header)	60	Options that need to be examined only by the destination of the packet.
Mobility (currently without upper-layer header)	135	Parameters used with MIPv6.

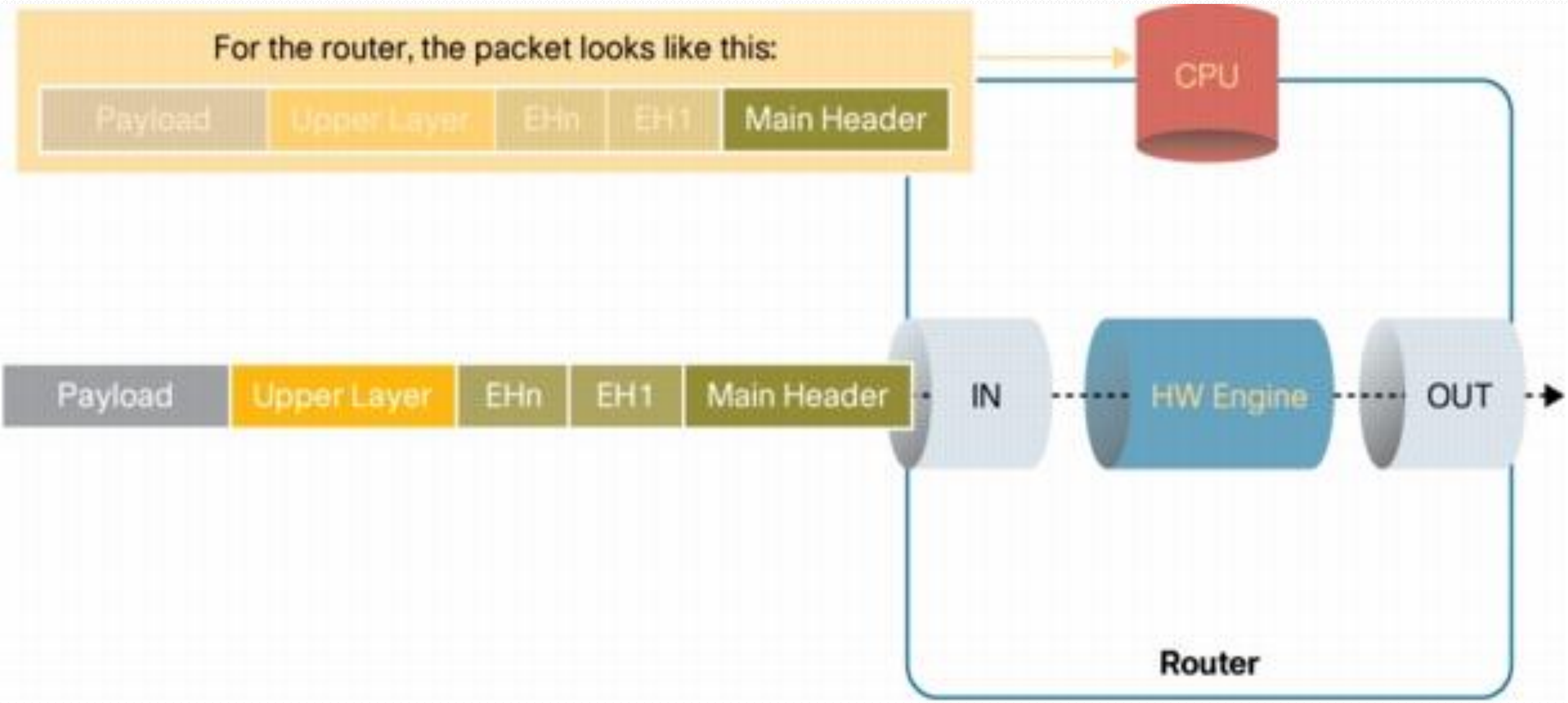
- # IPv6 header options:

Hop-by-hop headers SHOULD be examined by each router → packets can not be forwarded by HW



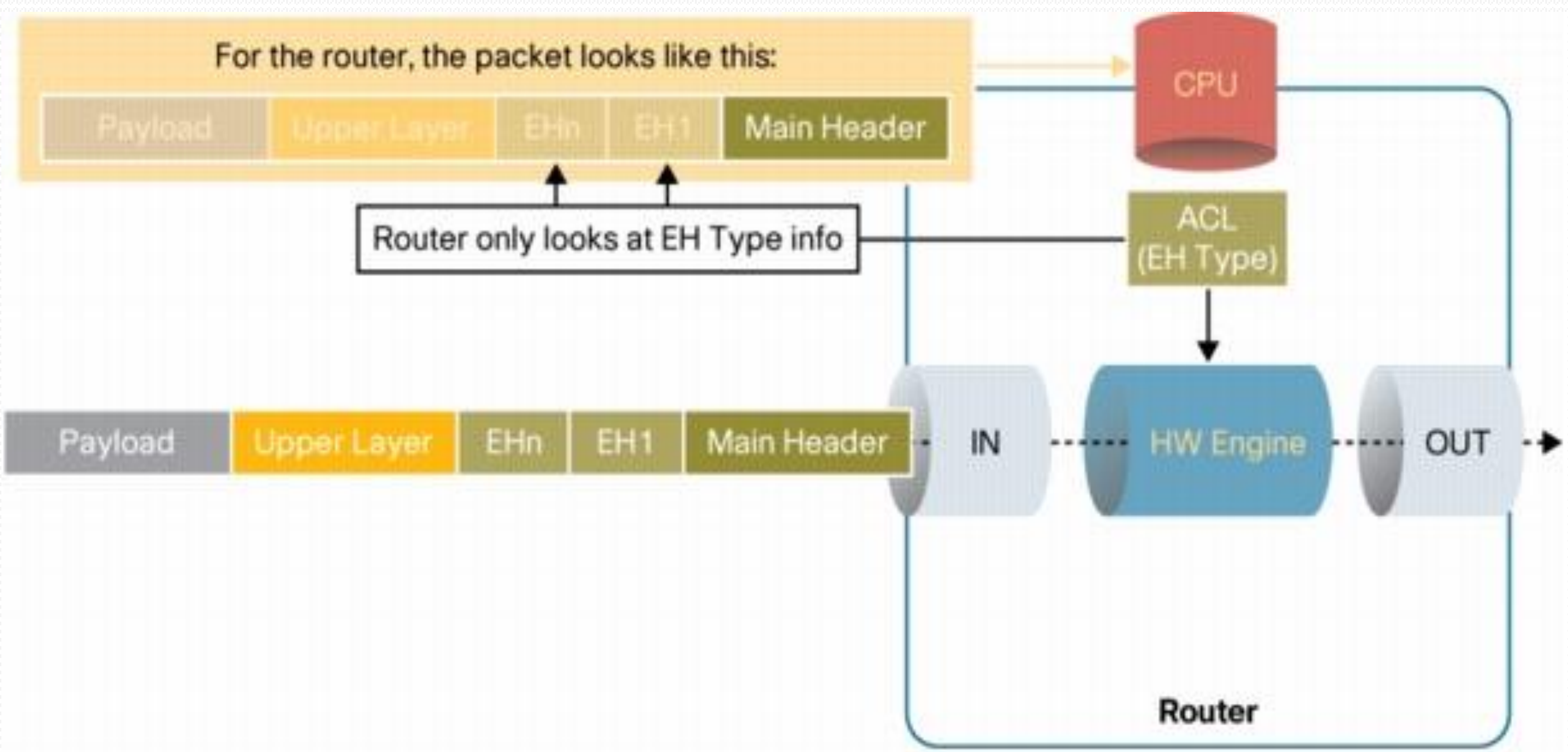
- # IPv6 header options:

The other option headers ARE NOT REQUIRED to be examined by each router → packets can be forwarded by HW



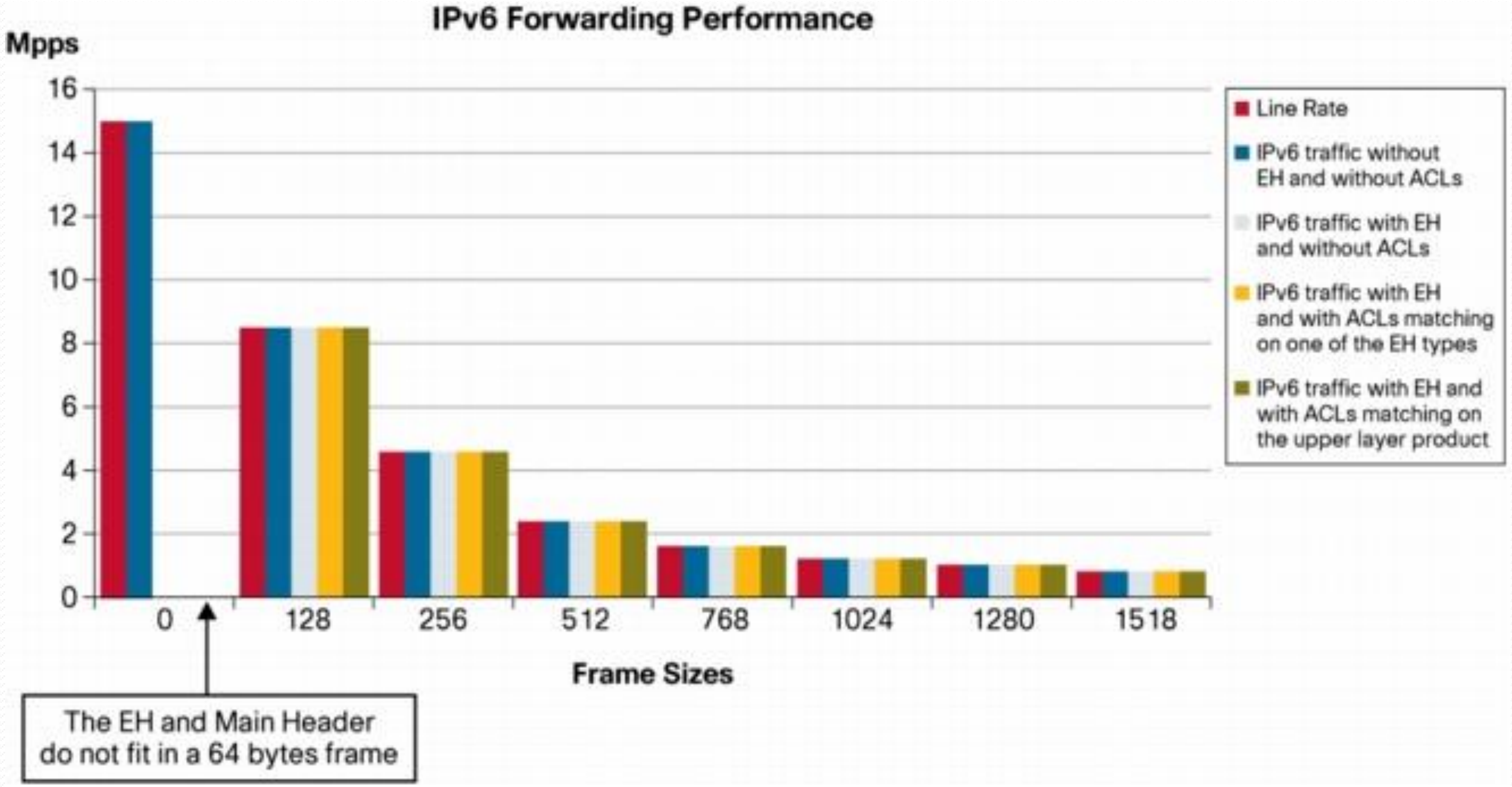
IPv6 header options:

EH headers can be filtered via ACL's → useful if you want to avoid for example source routing, in this case, since the router only takes forwarding decisions, the packet can be handle via SF or HW.



- # IPv6 header options:

Performance in a CISCO E5 10 Gigabit Ethernet Line Cards (mpps is millions of packets per second).



IPv6 Address Notation (128 bit addresses):

Host: $\underbrace{\text{2001:708:310:52}}_{\text{Routing-prefix}}$:$\underbrace{\text{202:2dff:fe4b:a120}}_{\text{Host-Id}}$/64

Routing-prefix size

Compressing the IPv6 address:

fedc:ba78:0000:0000:0001:0000:1212:1111 →

fedc:ba78::1:0:1212:1111

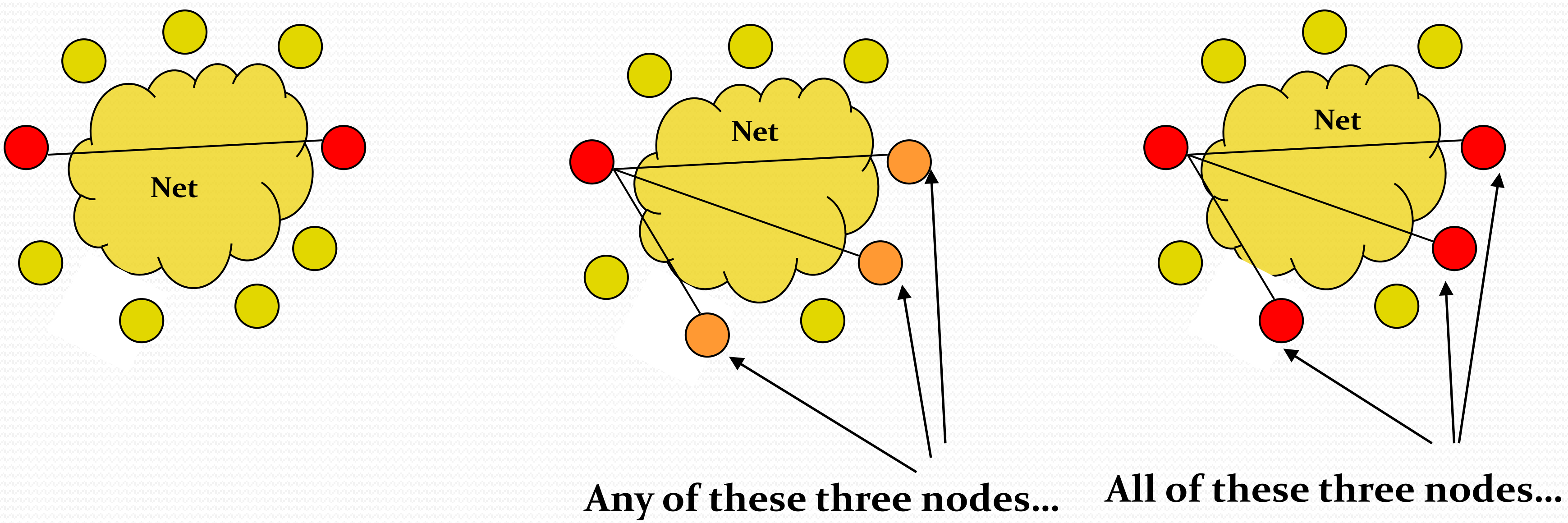
Examples:

0000:0000:0000:0000:0000:0000:0000:0001 → ::1 (loopback)

ff02:0000.0000.0000.0000:0000:0000.0002 →

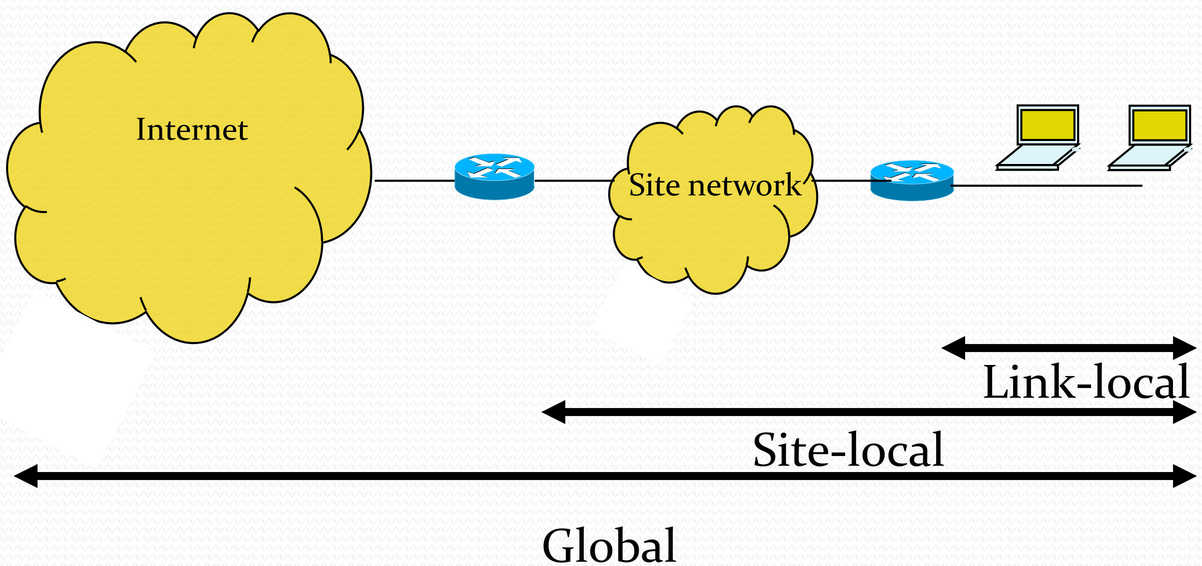
ff02::2 (multicast, all routers, link-local scope)

- **Types of IPv6 addresses:**
  - **Unicast:** only one destination
  - **Anycast:** any destination among a group of destinations
  - **Multicast:** several destinations (**includes broadcast**)



IPv6 addresses:

- Addresses have a scope:
  - **Global** (routed in the whole Internet)
  - **Site Local** (No routed outside the local network)
  - **Link Local** (No routed by routers, allows a Plug&Play with only communication inside a link)



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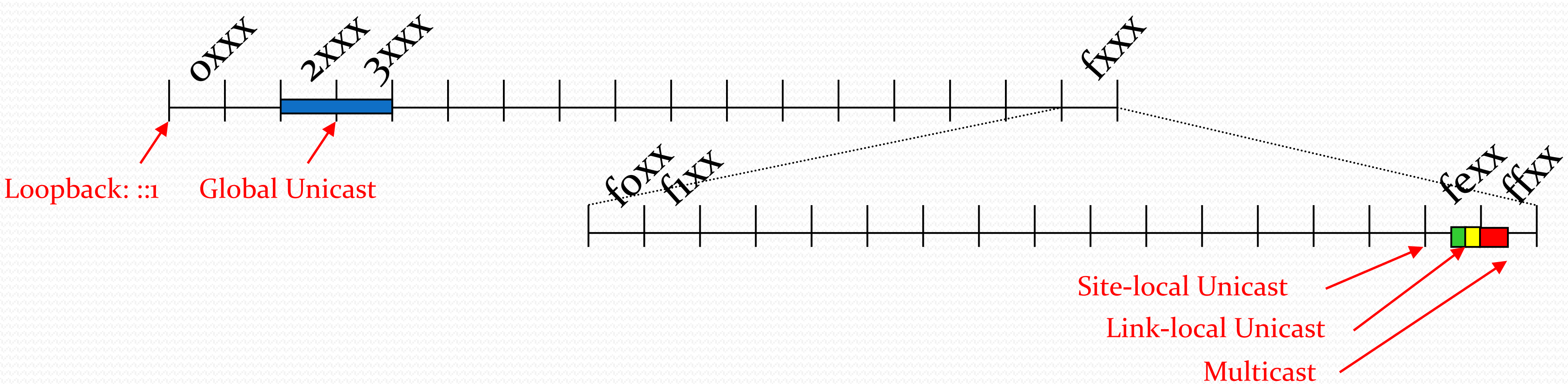
	Unicast	Anycast	Multicast
Global	[2000:…/64, 3fff:…/64]	[2000:…/64, 3fff:…/64]	ff0e::/16 ff1e::/16
Site-local	fec0::/64	fec0::/64	ff05::/16 ff15::/16
Link-local	fe80::/64	fe80::/64	ff02::/16 ff12::/16



IANA IPv6 address assigments:

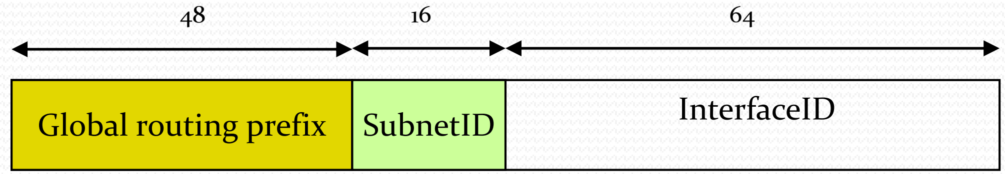
http://www.iana.org/assignments/ipv6-address-space/ipv6-address-space.xml

RIR IPv6 assignments:
http://www.iana.org/assignments/ipv6-unicast-address-assignments/ipv6-unicast-address-assignments.txt

IPv6 addresses - Unicast addresses:

Prefix + Interface ID

- Example: Global Unicast:



- Example : Link-local Unicast → fe80::/10
- Example : Site-local Unicast → fec0::/10
- Example : Loopback → ::1/128
- Example : No specified (no assignable) → ::0/128

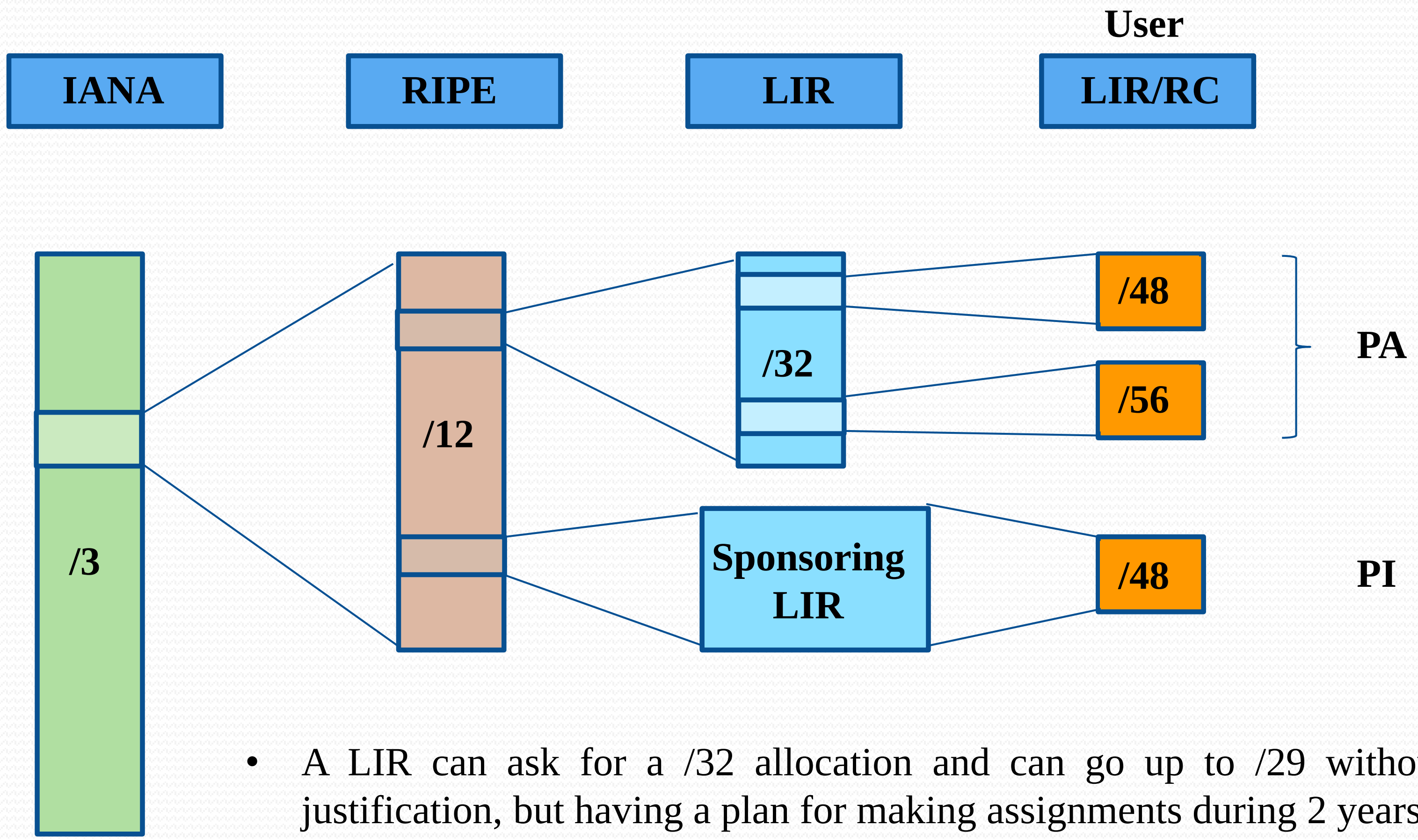
- **IPv6 addresses:** Example of Global Unicast **Aggregatable Global Unicast:**
  - The **prefix** (64-bits) forms a tree of organizations

64

001	TLA (13+8)	NLA (24)	SLA(16)

- TLA: Top Level Aggregator (Tier-1 provider, ex: Sprint)
- NLA: Tier-2 provider, ex: RedIRIS (UPC provider)
- SLA: User Network ID (ex: UPC-DAC)

- **IPv6 addresses:** RIPE assigment



- A LIR can ask for a /32 allocation and can go up to /29 without justification, but having a plan for making assignments during 2 years
- More tan /29 if justified (numbre of customers or size of infrastructure)

- **IPv6 addresses - Several ways of obtaining an IPv6 address (InterfaceID)**

Example: **Auto-configuration address in Ethernet**

Prefix/64 + EUI-64 (Extended Unique ID MAC address)

However MAC Address is 48 bits: 34:56:78:9a:bc:de →

3656:78ff:fe9a:bcde

Bit Universal/Local (inverse of the 7th bit): 0011 0100 → 0011 0110

Constant: **fffe**

Imagine fe80::2 (all routers) and some NIC with MAC 00:00:00:00:00:02

→ It would build a **fe80::2** instead of the **fe80::0200:0:0:2**

- Others
- Example: **IPv4 mapped IPv6 addresses**
- 0 (80 bits) : ffff (16 bits) : IPv4 (32 bits)

- **ICMPv6:** combines some features of ICMPv4 with new ones (e.g., for neighbor discovery)

  - **Neighbor discovery protocol (NDP)** is a function – coded in ICMPv6 messages - that allows among other functionalities:
    - Address resolution: learn L2 address from a host (equivalent to ARP)
    - Router discovery: learn the router to which we are connected
    - Agent discovery: used in MIPv6 (Mobile IPv6, not studied in this course)

- **Neighbor discovery protocol (NDP)** defines 5 types of ICMPv6 packets:
  - **Router Solicitation (Type 133):** Hosts inquire with Router Solicitation messages to locate routers on an attached link
  - **Router Advertisement (Type 134):** Routers advertise their presence together with various link and Internet parameters either periodically, or in response to a Router Solicitation message.
  - **Neighbor Solicitation (Type 135):** Neighbor solicitations are used by nodes to determine the Link Layer address of a neighbor, or to verify that a neighbor is still reachable via a cached Link Layer address.
  - **Neighbor Advertisement (Type 136):** Neighbor advertisements are used by nodes to respond to a Neighbor Solicitation message.
  - **Redirect (Type 137):** Routers may inform hosts of a better first hop router for a destination.

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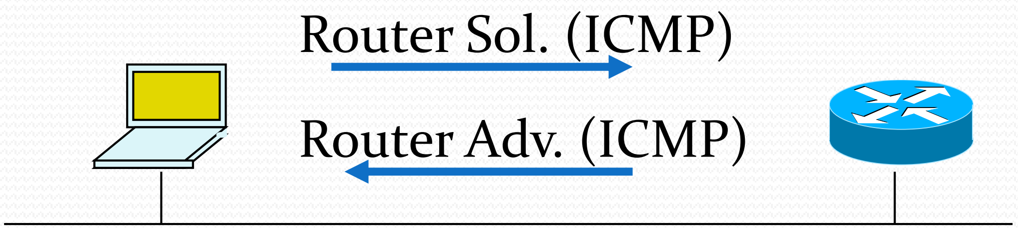
- These messages are used to provide the following functionalities:
  - **Router discovery:** hosts can locate routers residing on attached links.
  - **Prefix discovery:** hosts can discover address prefixes that are on-link for attached links.
  - **Parameter discovery:** hosts can find link parameters (e.g., MTU).
  - **Address autoconfiguration:** stateless configuration of addresses of network interfaces.
  - **Address resolution:** mapping between IP addresses and link-layer addresses.
  - **Next-hop determination:** hosts can find next-hop routers for a destination.
  - **Neighbor unreachability detection (NUD):** determine that a neighbor is no longer reachable on the link.
  - **Duplicate address detection (DAD):** nodes can check whether an address is already in use.
  - **Recursive DNS Server (RDNSS) and DNS Search List (DNSSL) assignment** via a router advertisement (RA) options. This is a new feature and not widely supported by clients.
  - **Packet redirection** to provide a better next-hop route for certain destinations.

- **IPv6 address configuration:**
  - **IPv6 Stateless Address configuration**
    - A router can assign a global address, indicating a prefix to which the host adds its Interface Id (Prefix/64 + Interface Id)



- **IPv6 address configuration:**
  - **Stateless Address configuration: ICMPv6 router solicitation**

IPv6

Hops = 255
@IPsource= fe80::0800:2001:c782 (link-local address)
@IPdst= ff02::2 ← **All routers (link scope)**

ICMPv6

Type, Code= 133,0 **(Router Solicitation)**

ICMP options

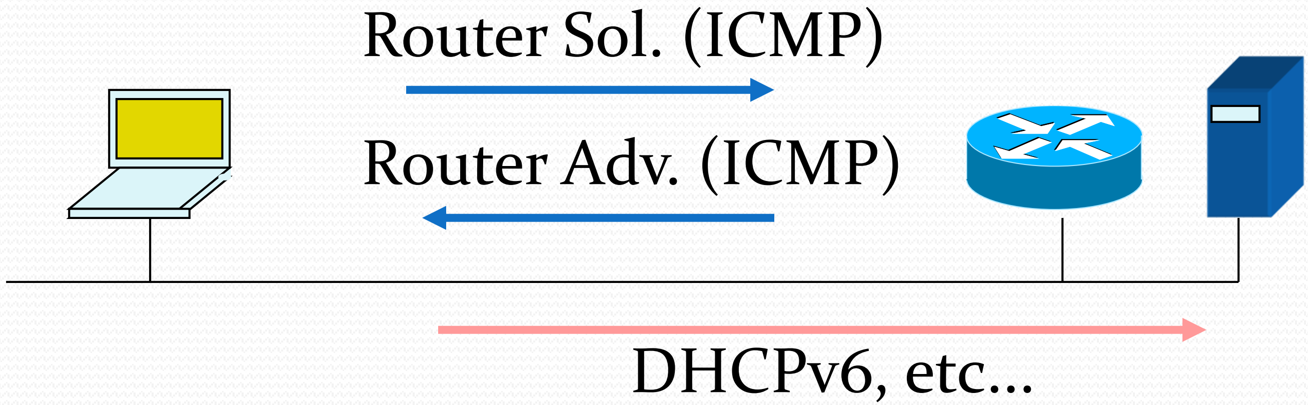
Type= 1 (Sender's Link Address)

The router gives back a **Router Advertisement** with all the information (Route Prefix) that the node needs to configure an IPv6 address .

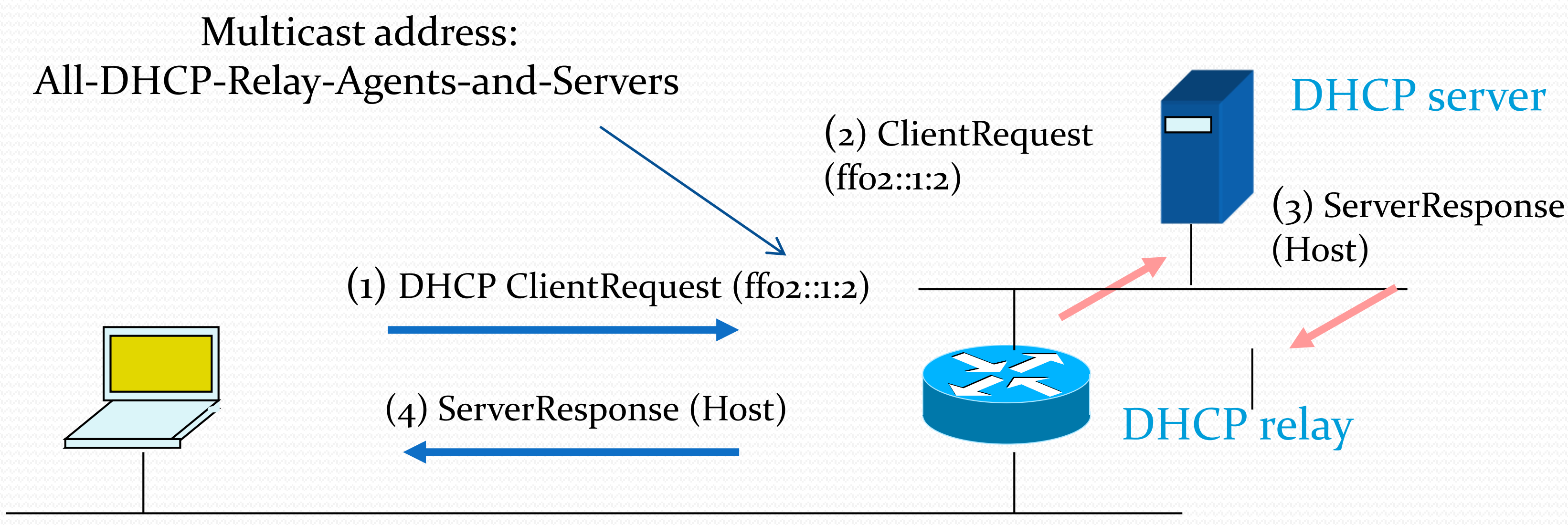
IPv6 address configuration:

IPv6 Stateful Address configuration

- Stateless address configuration requires an adequate configuration in all routers. Thus, the best strategy is to configure a **DHCPv6 server** (Stateful address configuration) that centralizes sending the required information at the cost of reliability (centralized solution), however reducing complexity and adding flexibility.
- DHCPv6 servers can jointly work with DNS servers



- # IPv6 address configuration:
  - ## IPv6 Stateful Address configuration



- **IPv6 Address configuration: DAD (Duplicate Address Detection/Discovery)**

  - Since an IPv6 host can have many IPv6 addresses
    (ex: link local + unicast + several multicast)

  - Send a **Neighbor Solicitation** message with source address :: (null address) and destination the tentative address.
  - If somebody has the destination address will answer with a **Neighbor Advertisement** to address ff02::1 (all nodes on the local network segment)

after auto-configuration processes the host perform **Duplicate Address Discovery** in order to check whether there are several duplicated IPv6 addresses → mechanism similar to Gratuitous ARP

ICMPv6 neighbor discovery:

- The equivalence of **ARP** is done via ICMP Neighbor solicitation/ Neighbor advertisement messages (remember that ARP is done at L2 while Neighbor solicitation is done at L3)

- The destination IP address of the ICMP message that carries the Neighbor Solicitation is the "**multicast solicited-node @**".

- It is formed using prefix **FF02::1:FF00::/104 + the last 24 bits of the IP address** that we are looking for

- Periodically the host sends "Neighbor Solicitation" messages to check whether the hosts are reachable

- **ICMPv6 neighbor discovery**

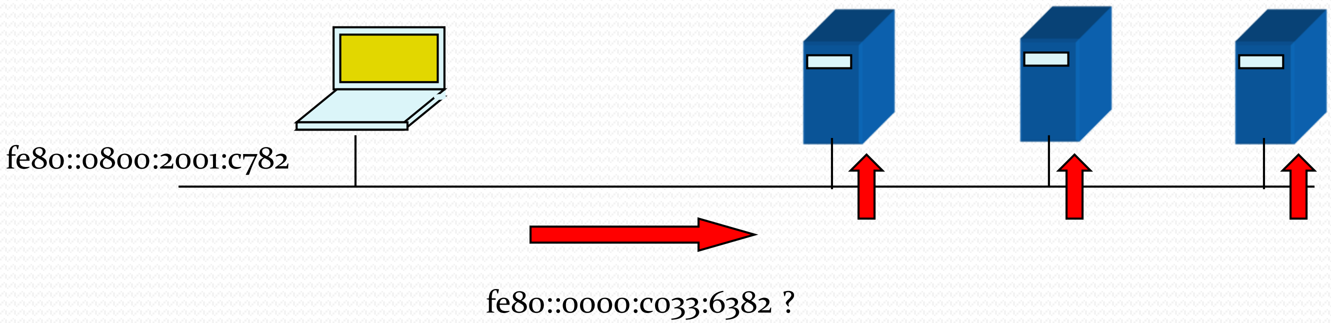
IPv6
ICMPv6
ICMP options

Multicast,
Link-local

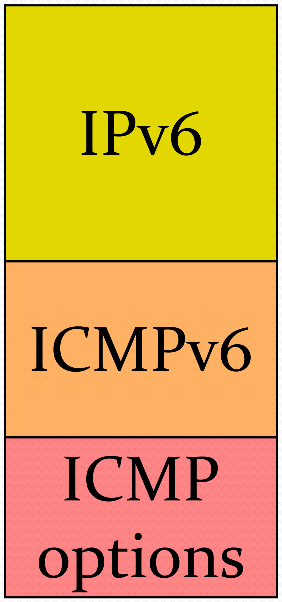
Hops = 255
@IPsource= fe80::0800:2001:c782 (link local)
@IPdst= ff02::1:ff33:6382

Type, Code= 135,0 (Neighbor Solicitation)
Target Address= fe80::0000:c033:6382

Opt Code= 1
Sender's Link Address= 0x08:00:20:01:c7:82



- **ICMPv6 neighbor discovery**

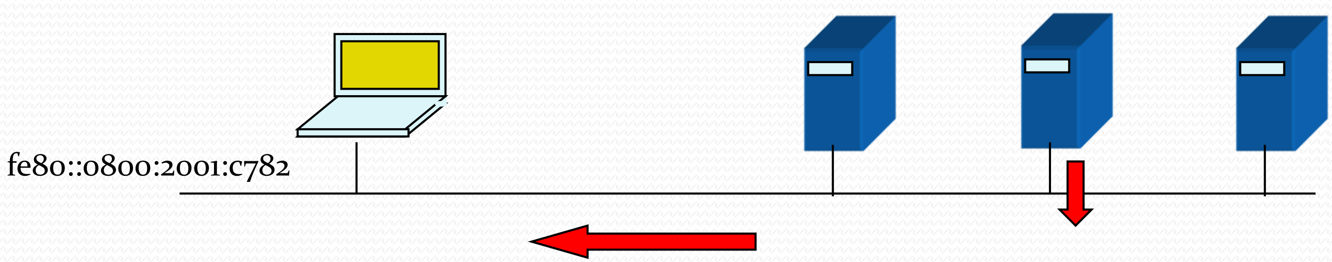


unicast

Hops = 255
@IPsource= fe80::0000:c033:6382 (link-local)
@IPdst= fe80::0800:2001:c782

Type, Code= 136,0 (Neighbor Advertisement)
R= 0 (I'm not a router), S= 1 (I'm answering a question)
O= Override cached link layer @
Target Address= fe80::0000:c033:6382

Opt. Code= 2
Target's Link Address= 0x02:07:01:33:d6:92



I'm fe80::0000:c033:6382
My L2 address is: 0x02:07:01:33:d6:92

- **Homework**
  - Look information on Content Delivery Networks (CDNs), P2P, farm servers architectures
  - Look information on SLA
  - Look at RIPE webpage (RIR governance, IPv4 exhaustion, IPv6 policies, AS maps, LIRs, etc)
  - Look at CAIDA web page (customer cone, peering, AS rank, AS-level Internet graph map. etc)
  - Look information at Exchange Points Espanix, Catnix and Euro-NIX webpages (members, policies, peering matrices, traffic)
  - Look information on Neighbour Discovery protocol and functionalities such as ARP in IPv6 and IPv6 address configuration