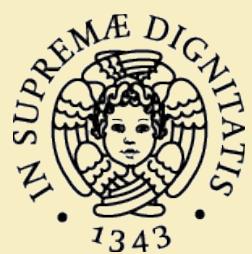


Internet routing

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Origins

- Exterior Gateway Protocol (EGP)
 - Adopted in the first global IP-based network (NSFNET, 1984)
 - **Strictly hierarchical:** two levels, one global core →
 - A sono VAILE RETI,
O CUNA DEIE QUAE E^I
UR AS CARBIAHO OS SANO core
 - **No direct connections** allowed between non-backbone ASes
- EGP's strict requirements demonstrated not to be applicable in practice →
 - Other factors drive connectivity and routing decisions of an autonomously administrated network
- BGP development followed
 - No constraints on the hierarchy
 - Policy-based routing →
 - Possiamo uscire
RETI SU COSE
DIVERSE E COSE NO-
 - Version 4 finally released to account for CIDR

SI È FATTO UNO CONSENSO PER
ESSERE QUESTO COSÌ



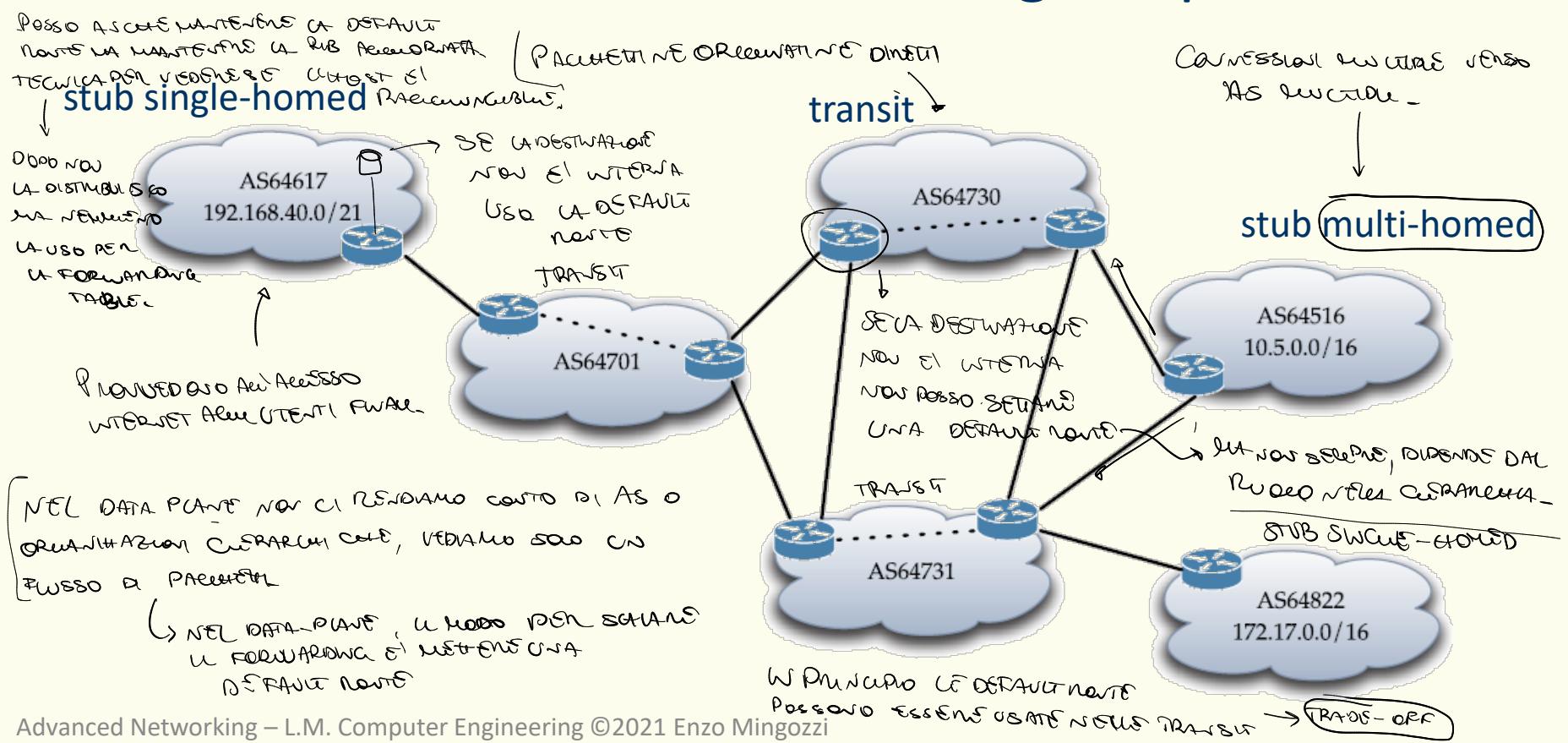
Che AS hanno a conoscenza tra di loro, per inter-AS multica non posso vedere del tutto una topologia.

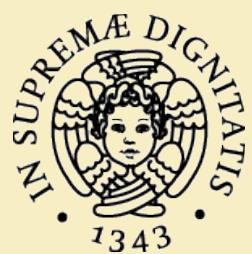
Possiamo uscire
RETI SU COSE
DIVERSE E COSE NO-

Global routing



- Full default-free routing tables at transit ASes
 - ↳ NON POSSANO USARE DEFAULT NELL'NEI TRANSIT AS, QUINDI USANO UNA COMPLETA LISTA DESTINAZIONI
 - Not needed at stub ASes, though implemented





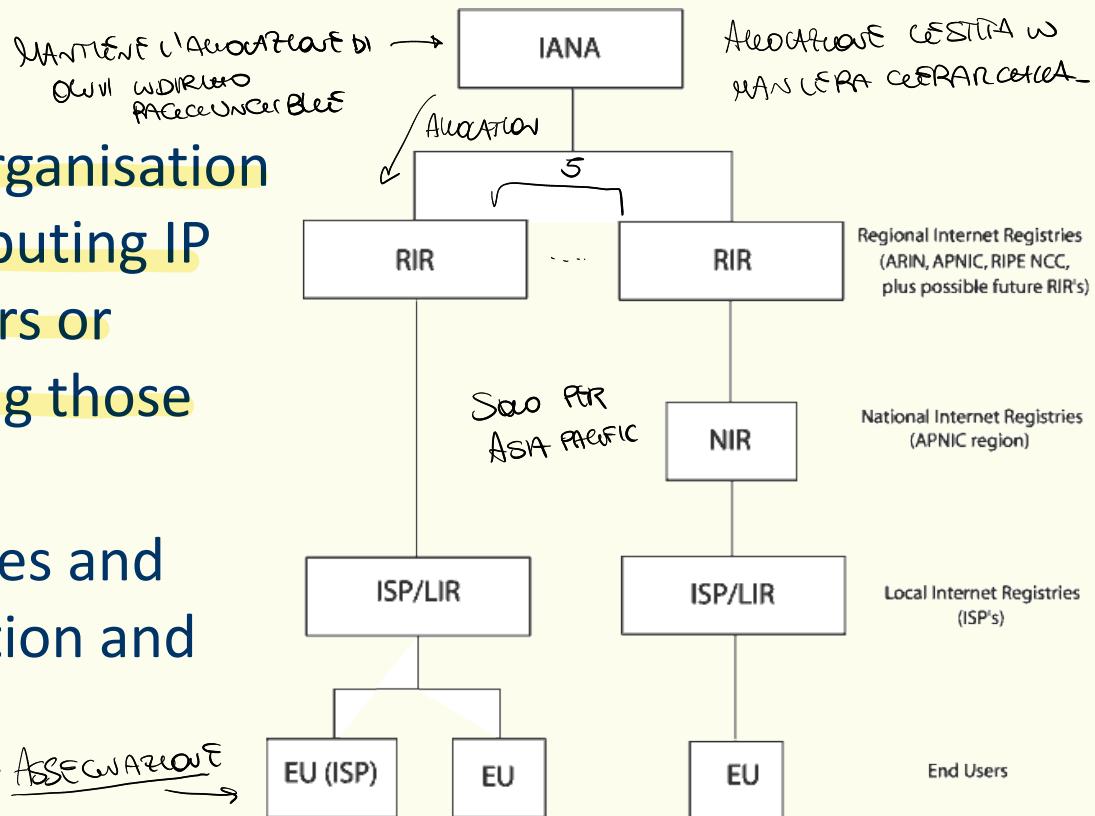
IP address allocation

- Internet Corporation for Assigned Names and Numbers (ICANN)

An **Internet Registry** is an organisation that is responsible for distributing IP address space to its members or customers and for registering those distributions.

Each registry has its own rules and pricing for IP address allocation and AS number assignment

*(INDIRETTO ESSERE USATO DIRETTO
HOST DEL END-USER)*



<https://www.ripe.net/publications/docs/ripe-policies>

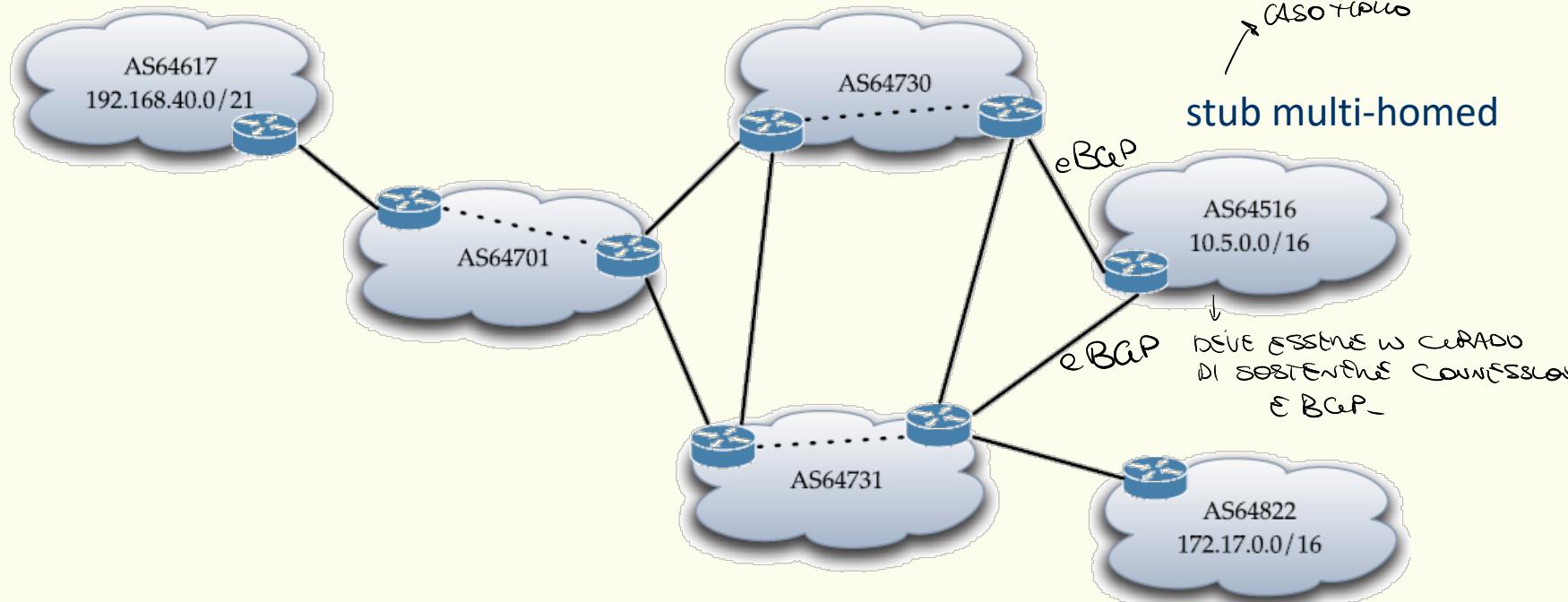
IP address allocation

Case 1. An organization gets both an IP address block and AS number

- Establish multi-home connectivity
- Establish eBGP sessions with upstream ISPs

Ogni RIR HA LE SUE REGESE E UNA RETE DI CORE CHE POSSONO PRENDERE IN AS NUMBER
E' AVENUE UNA CONNESSIONE CON ALTRI AS (STUB multi-homed)

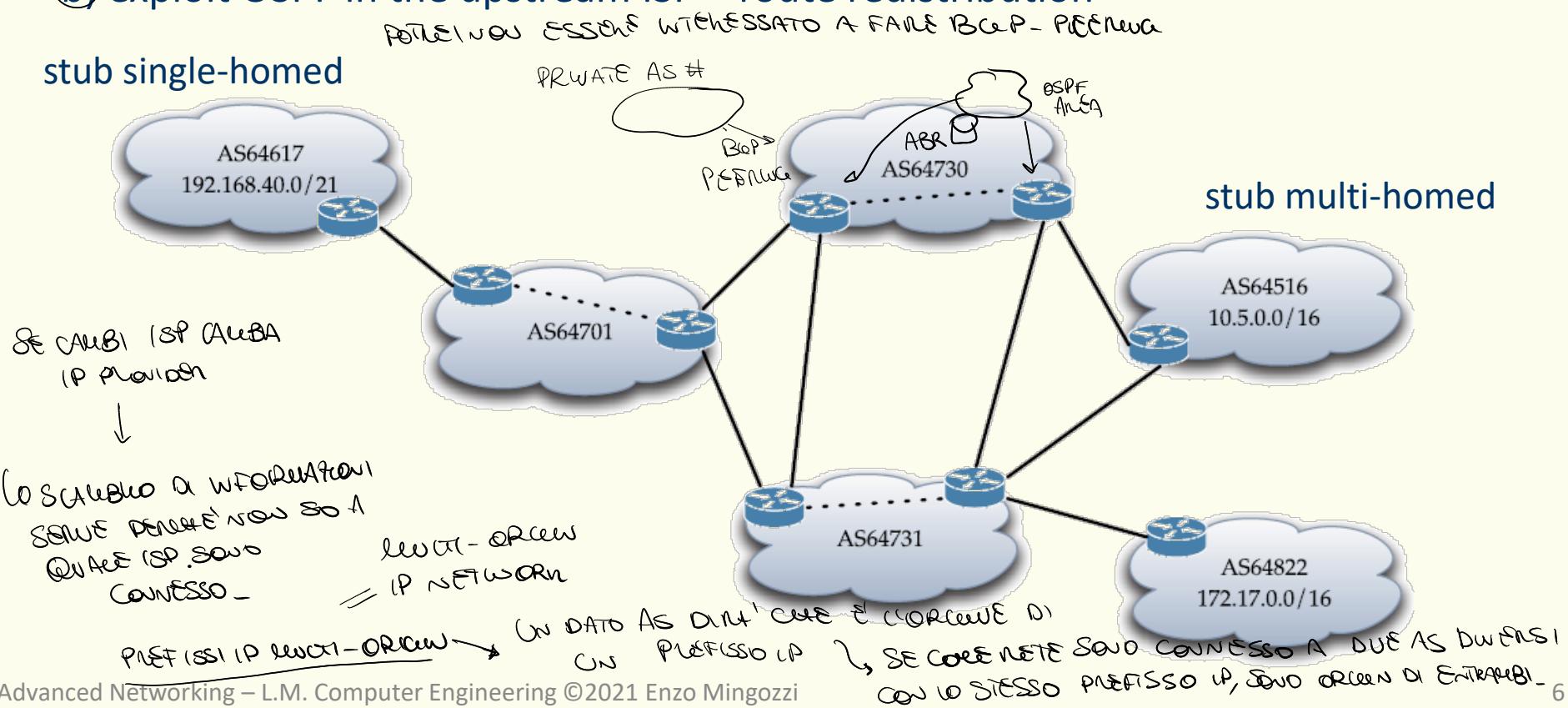
stub single-homed



IP address allocation

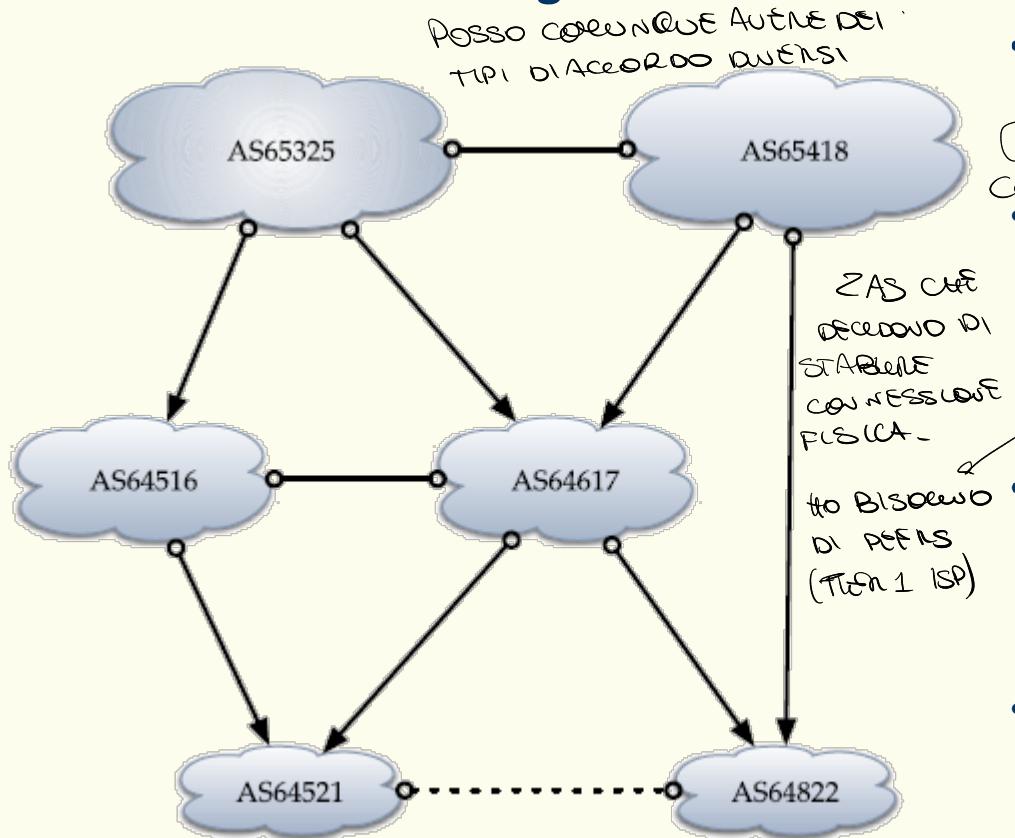
Case 2. An organization gets an IP address block but not an AS number

- Establish an agreement with an ISP to serve as 'home' AS, then either
- (a) setup private AS numbering + BGP peering
- (b) exploit OSPF in the upstream ISP + route redistribution



ISP commercial agreements

Business relationships between ASes arise from **contracts** that define the **pricing model** and the **exchange of traffic between ASes**

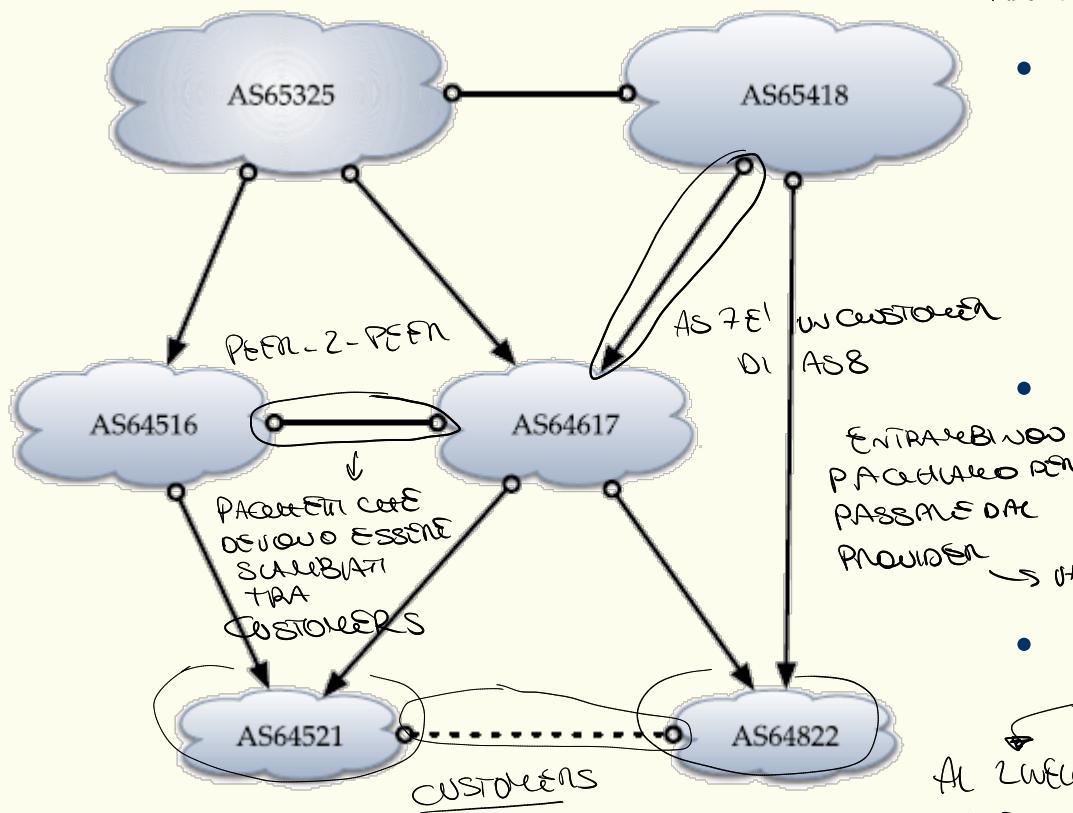


- **Multilateral agreement:** Several ISPs build/use shared facilities and share cost (e.g., public or private exchange points) INTERNET EXCHANGE POINTS
COPRIMARE INFRASTRUCTURE DI RETE E CONDIVIDERE COSTI
- **Bilateral agreement:** Two providers agree to exchange traffic if traffic is almost symmetric, or agree on a price, taking into account the imbalance in traffic swapped (e.g., in a private peering) SOLAMENTE SANTA PACIA ESENTO di un traffico di tipo peer-peer (esterno)
- **Unilateral agreement for transit:** A customer pays its provider an “access” charge for carrying traffic (e.g., a tier 4 ISP would pay a charge to the tier 3 ISP)
- **Sender Keeps All (SKA):** ISPs do not track or charge for traffic exchange. This is possible in private peering and in some public peering. Usually true for tier 1 ISPs



ISP commercial agreements

Business relationships between ASes are often schematically categorized in the literature into the following basic types



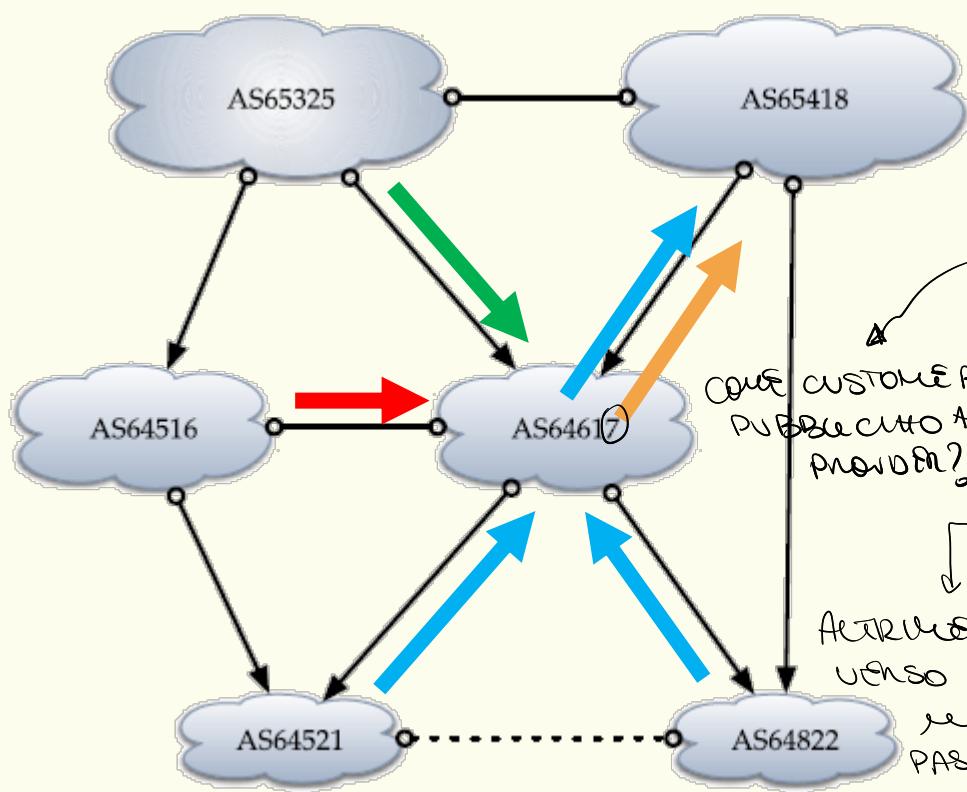
Possibili categorizzazioni

- **Customer-to-Provider:** A *customer* AS pays its *upstream AS provider* to be connected to the rest of the Internet
 CUSTODIEN DOWNSTREAM
 PAESE PER IL TRASITO DEL TRAFFICO
 NO AL SINGOLO CUSTODIEN O UPSTREAM.
- **Peer-to-Peer:** peer ASes exchange traffic, typically without any payment involved
 NO AL SINGOLO CUSTODIEN O UPSTREAM.
- **Sibling-to-Sibling:** sibling ASes act like a provider to each other

AL LIVELLO PIÙ BASSO, PER ESEMPIO CON UNO DI FAKE LEVEL DEL PROVIDER DEL PROTOCOLO.

Customer-to-Provider

A customer AS buys **transit access** to the provider AS to reach all networks it cannot reach otherwise



Once I update my Policy BGP?
Export policies

A customer AS exports to the provider AS

- its **routes**
- its **customer routes**

usually it does not export

- its (other) **provider routes**
- its **peer routes**

to avoid to transit their traffic

AVVOLGONO UNA ROUTE
VIA SO UN CERTO
PER PASSARE
UNA

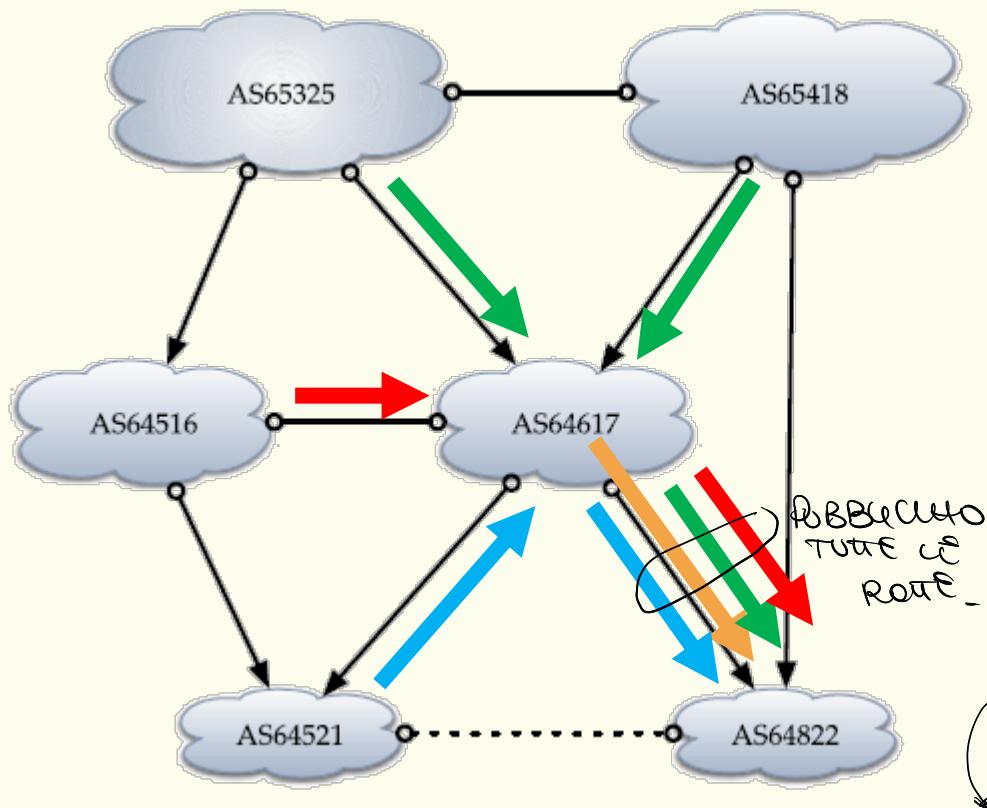
SE HO DO' PROVIDER
NON ESPORTO LA
ROUTE
DEL PROV.

DEL PROV.
PROVIDER -

SE LE ESPORTO PROV.
SERVIZIO DI TRANSIT
APPROVATO CLAUDIO PROVIDER -
PALESTRA OLE NON SONO CERTI
POSSONO APPROVARE L'AS

Customer-to-Provider

A **customer AS** buys **transit access** to the **provider AS** to reach all networks it cannot reach otherwise



Export policies

A **provider AS** exports to the **customer AS**

- its **routes**
- its **customer routes**
- its **provider routes**
- its **peer routes**

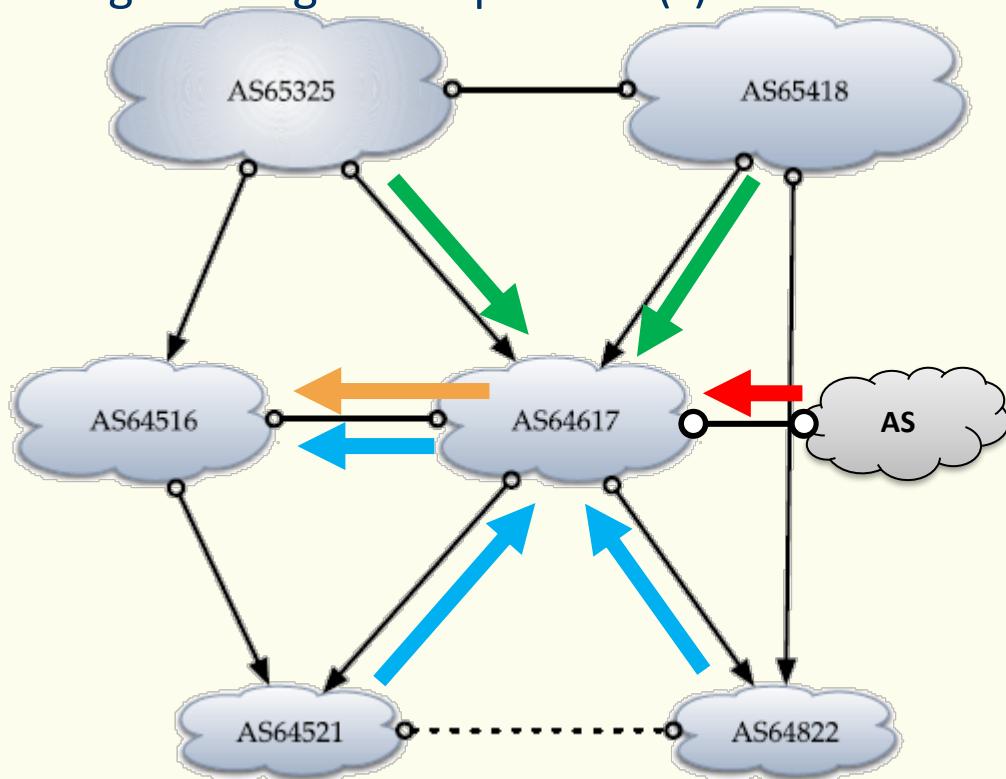
to allow the customer AS reach all the Internet destinations

In essence, the provider advertises to the customer either its **full routing table** or a **default route**

DONDESSO NON ESSENTE VITRIBUATO A
ROUTE TABLE

Peer-to-peer

Peer ASes agree on **exchanging** traffic (typically **without any payment** involved) in order to **reach each other** and **their respective customer routes**, without the need to go through their provider(s)



Export policies

An **AS** exports to the peer **AS**

- its **routes**
- its **customer routes**

usually it does not export

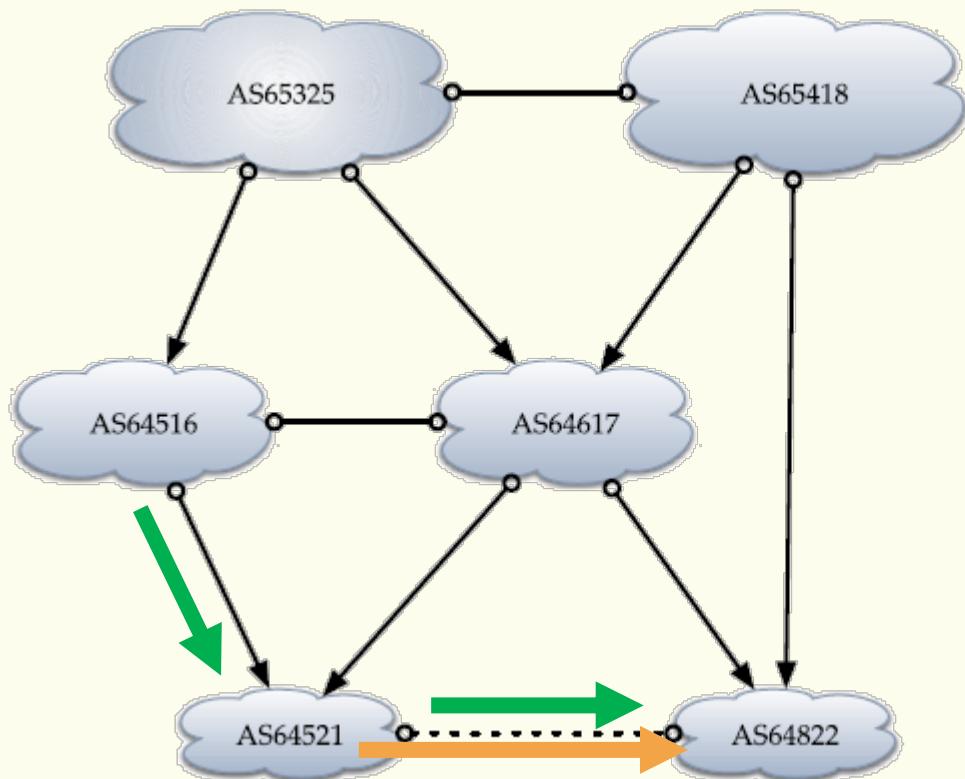
- its **provider routes**
- its (other) **peer routes**

to avoid to transit their traffic



Sibling-to-sibling

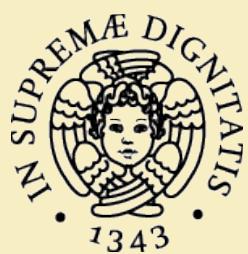
Each AS acts like a provider to the other, e.g., the two ASes belong to the same ISP



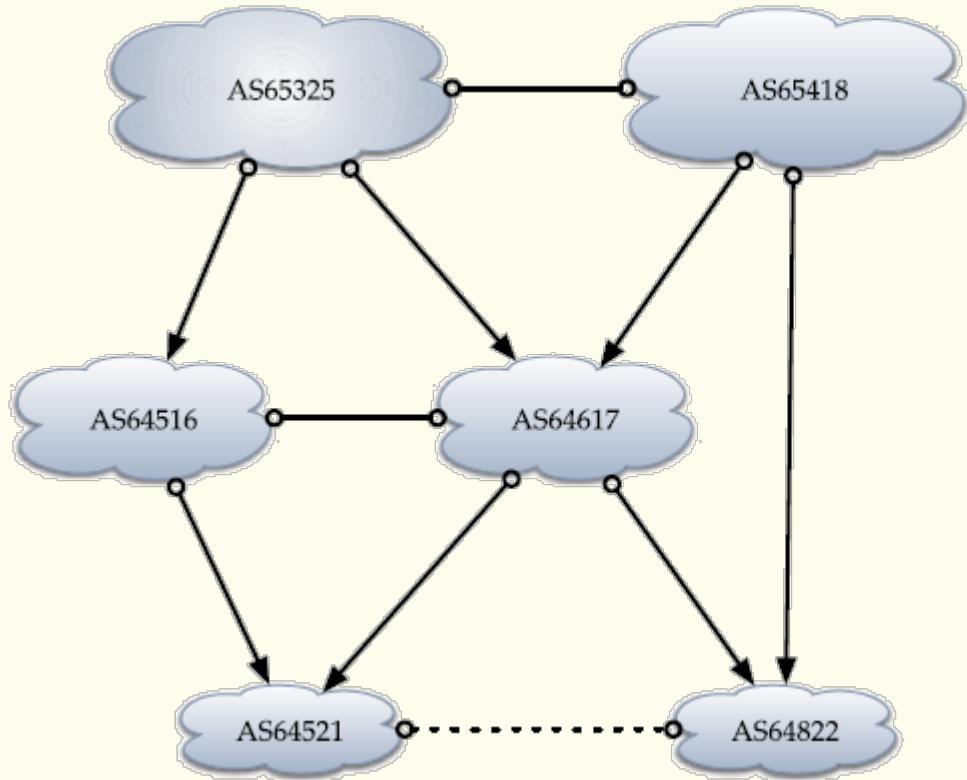
Export policies

An **AS** exports to the sibling AS

- its **routes**
- its **customer routes**
- its **provider routes**
- its **peer routes**



Valley-free property



Valley-free property: “After traversing a provider-to-customer or peer-to-peer edge, the AS path cannot traverse a customer-to-provider or peer-to-peer edge”

Examples

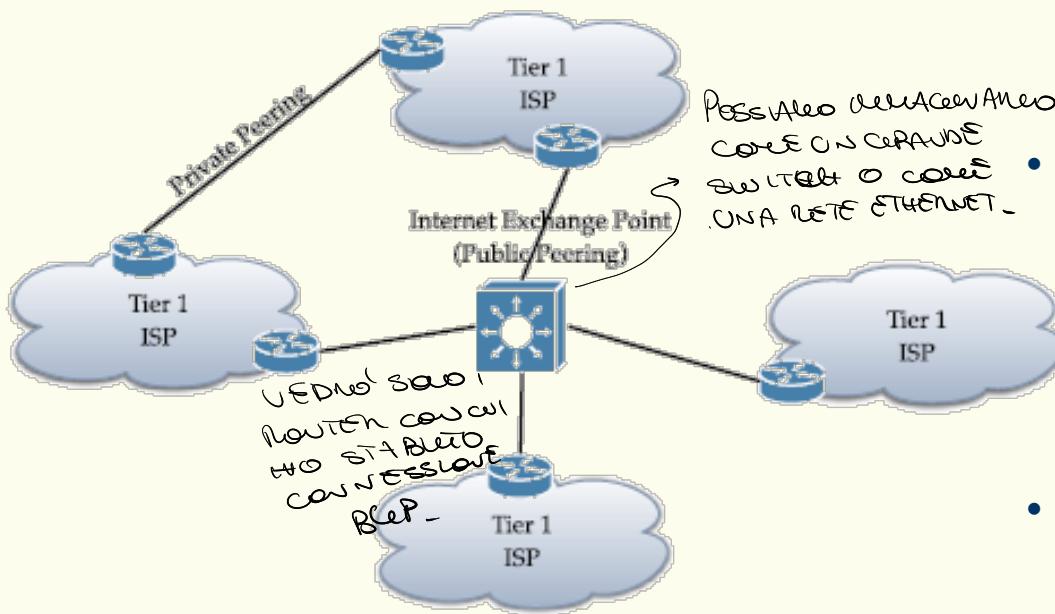
- Path (AS64516, AS65325, AS64617) is valley-free
- Path (AS64516, AS64521, AS64822, AS64617) is not valley-free

The valley-free property is demonstrated to be true for each advertised BGP path, if the corresponding export policies are obeyed by each AS

Lixin Gao, "On inferring autonomous system relationships in the Internet," in *IEEE/ACM Trans. on Networking*, vol. 9, no. 6, pp. 733-745, Dec. 2001

Internet exchange points (IXPs)

Possano essere pubbliche o private riferendosi all'accesso all'IXP.



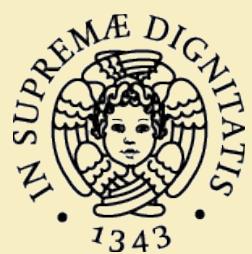
- ISPs peer **privately** or meet at an Internet exchange point (**IXP**)
- IXPs are usually operated by neutral entities that play the role of **providers** for **traffic exchange services** to ISP customers. Such arrangement is known as **public peering**
- Private network exchange points are also possible

- Customers' routers are collocated in the **same physical (distributed) facility**
- In essence, an IXP is a **giant traffic switching point**. Connectivity is provided at very high speeds (1GE to 100GE), at **L2 or L3**.

→ A FOCUS PRINCIPALE E' LA NEUTRALITY.

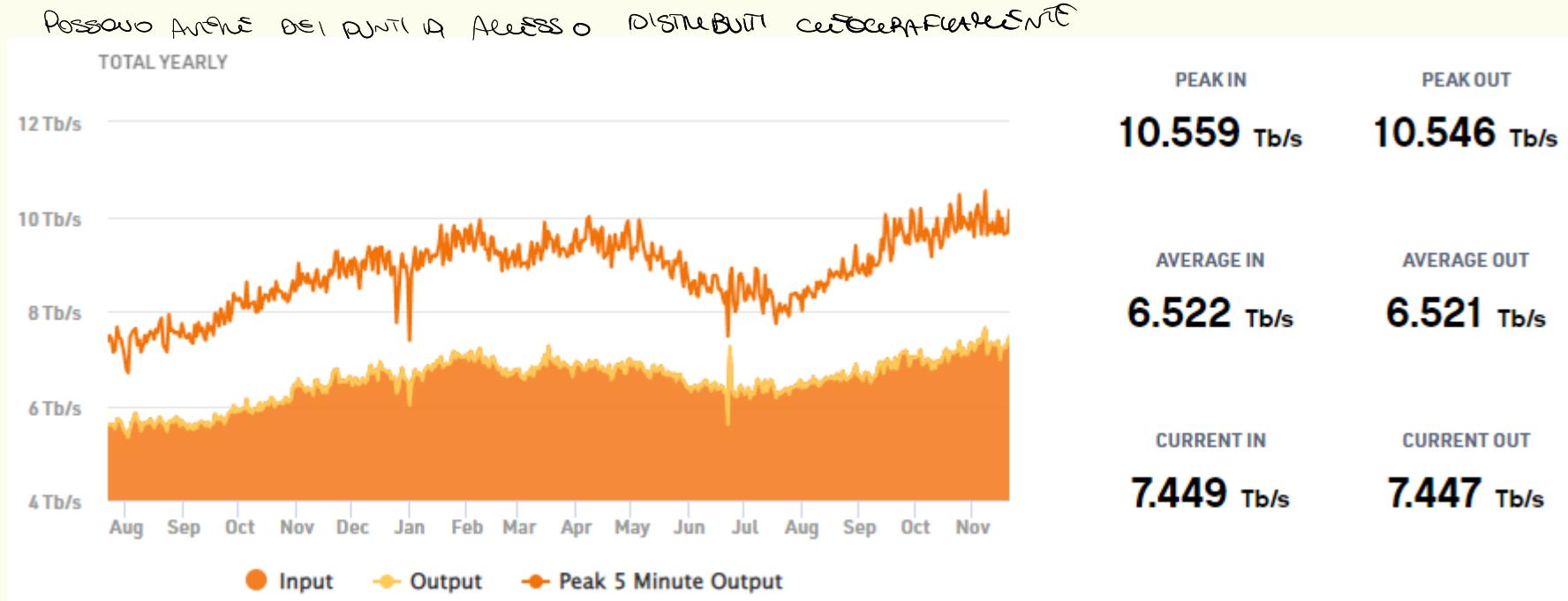
- IXPs have **well-defined policies** for joining the IXP
- Many **Content Providers** now also peer at IXPs to interconnect with major ISPs

→ USANO LEIRI NEGLETTI DEI CONTENUTI, FORNENDO AL PUBBLICO AL CUSTODIRE.



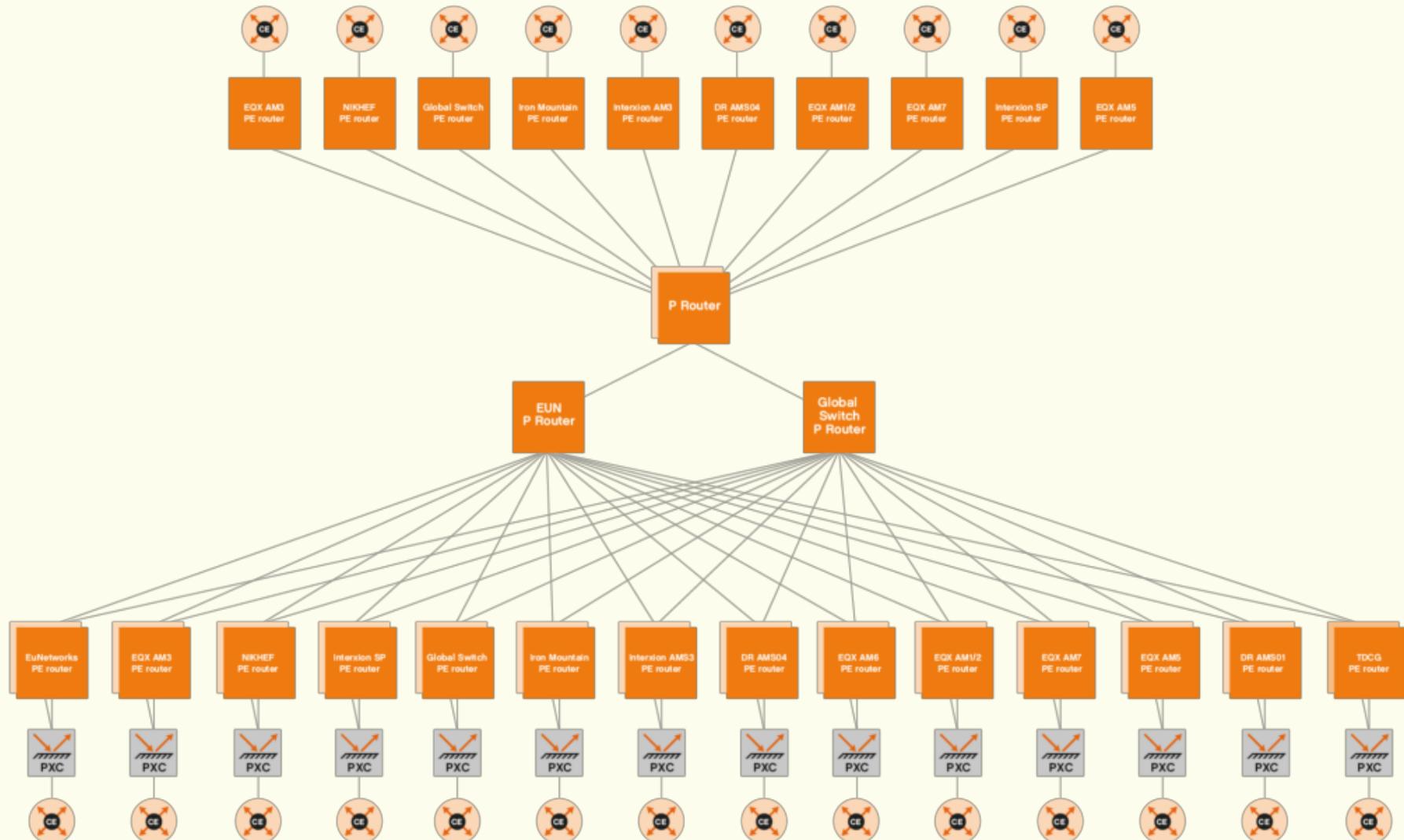
Internet exchange points (IXPs)

Amsterdam Internet Exchange (AMS-IX) is considered the largest IXP worldwide
767 route server peers, 883 total connected ASes



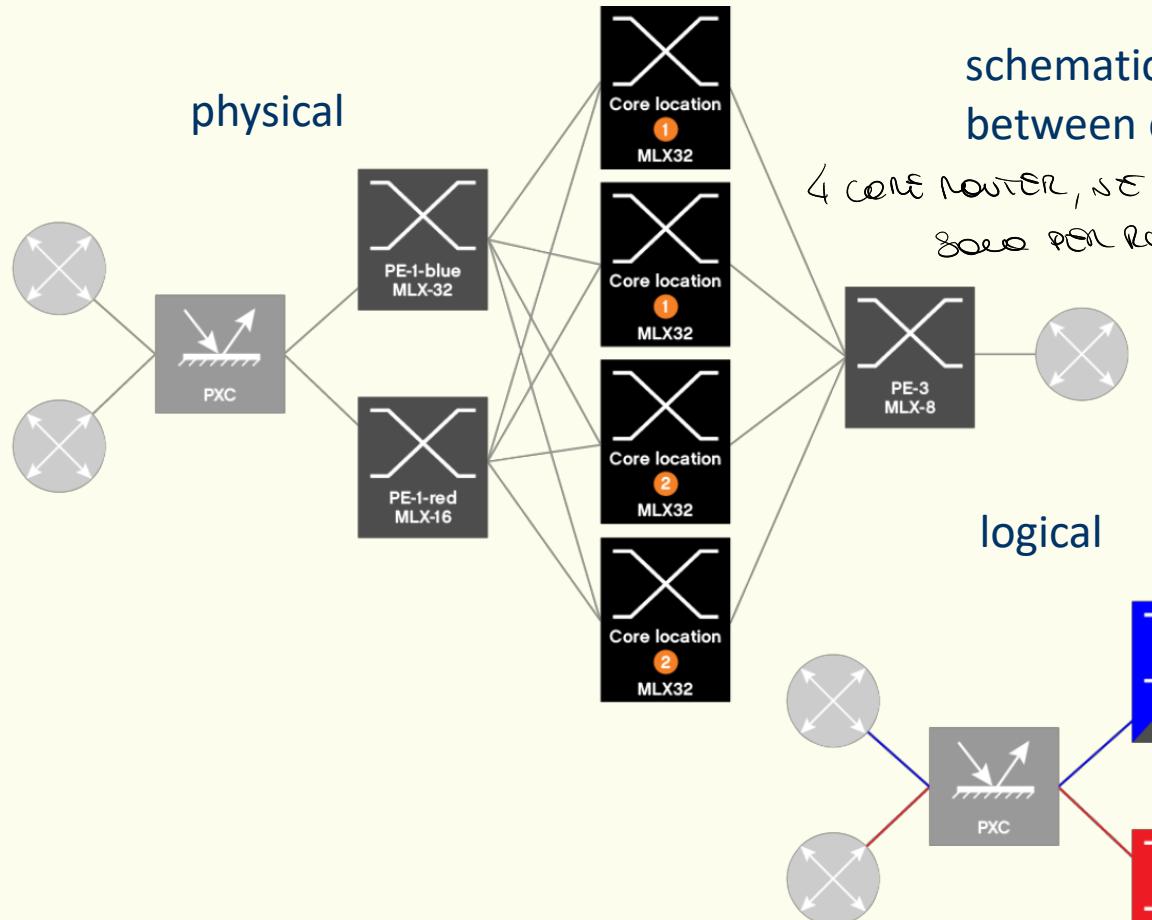
<https://www.ams-ix.net/ams/documentation/total-stats>

Internet exchange points (IXPs)



Internet exchange points (IXPs)

physical

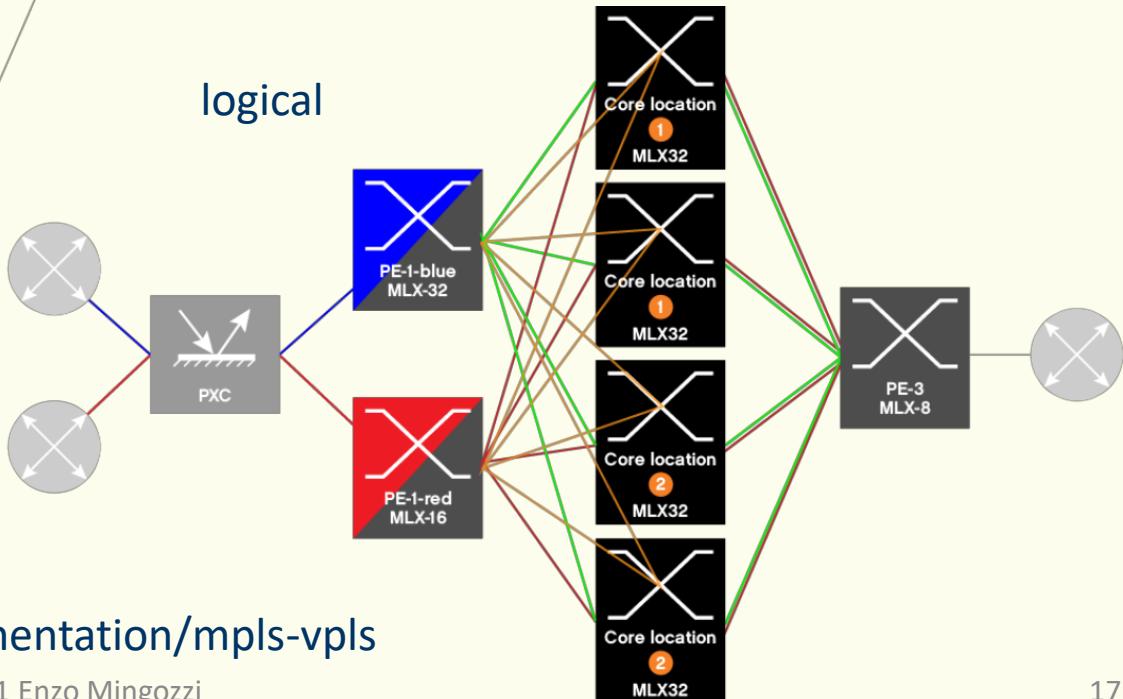


schematic drawing of the typical connections between customers

4 core router, se seruirebbe 1
8 core per redondanza

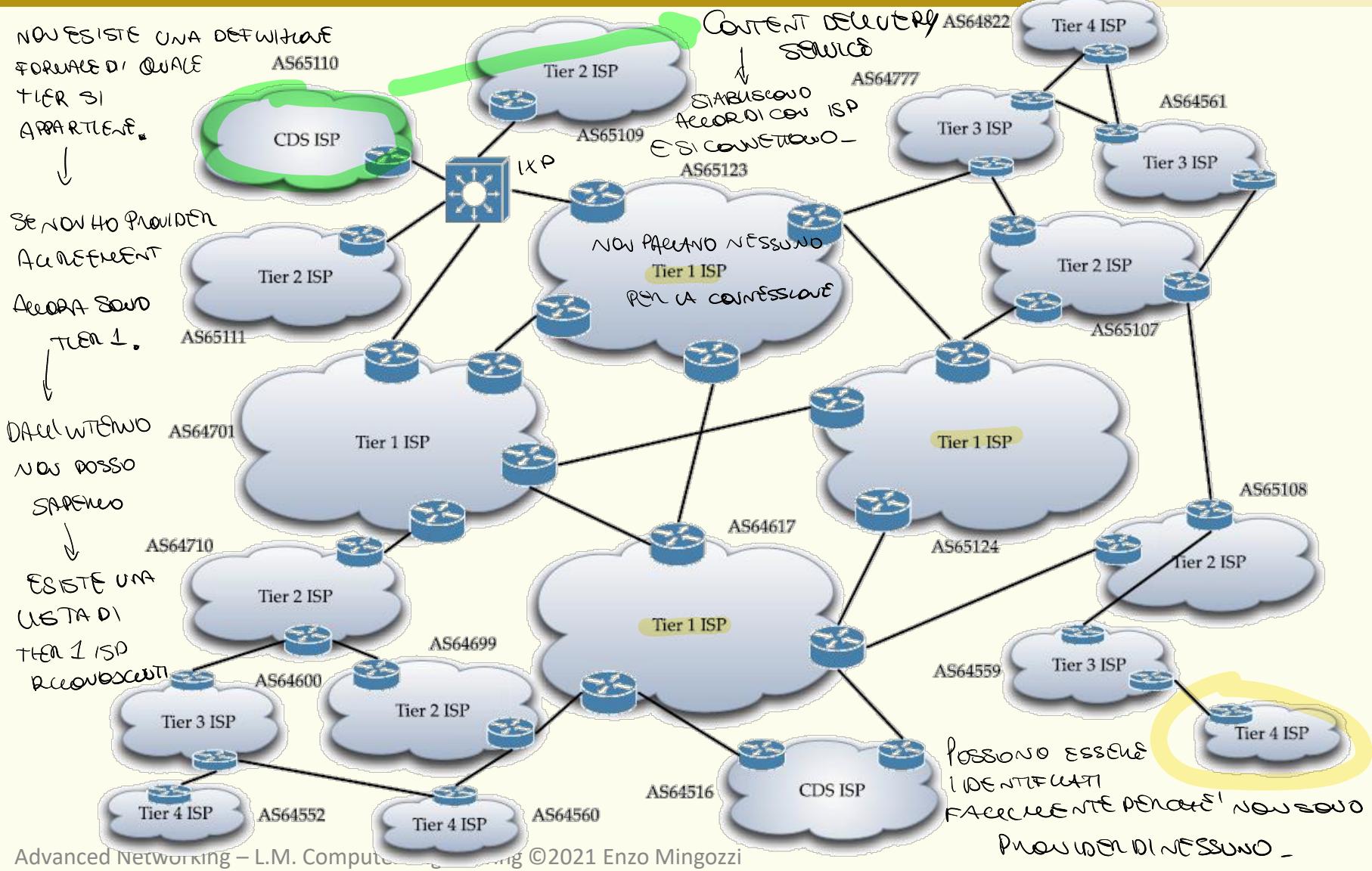
2 w con 2eo
2 w su Alteo

logical



<https://www.ams-ix.net/ams/documentation/mpls-vpls>

Internet connectivity

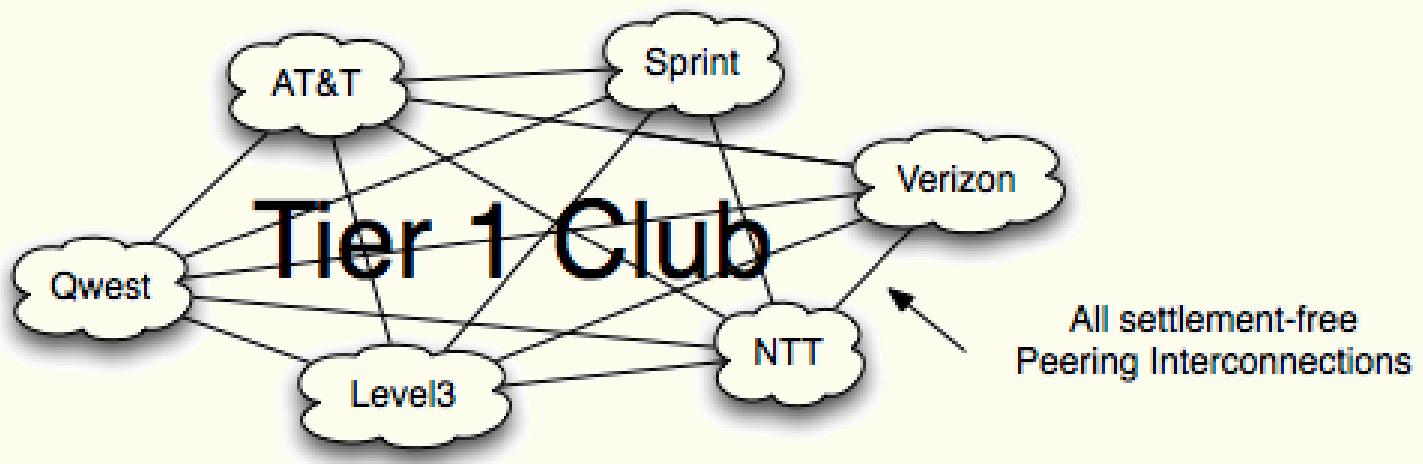




Tier 1 ISPs

A **Tier 1 ISP** can reach every other network on the Internet **without purchasing IP transit or paying settlement**

A **Tier 1 ISP** has **no providers**

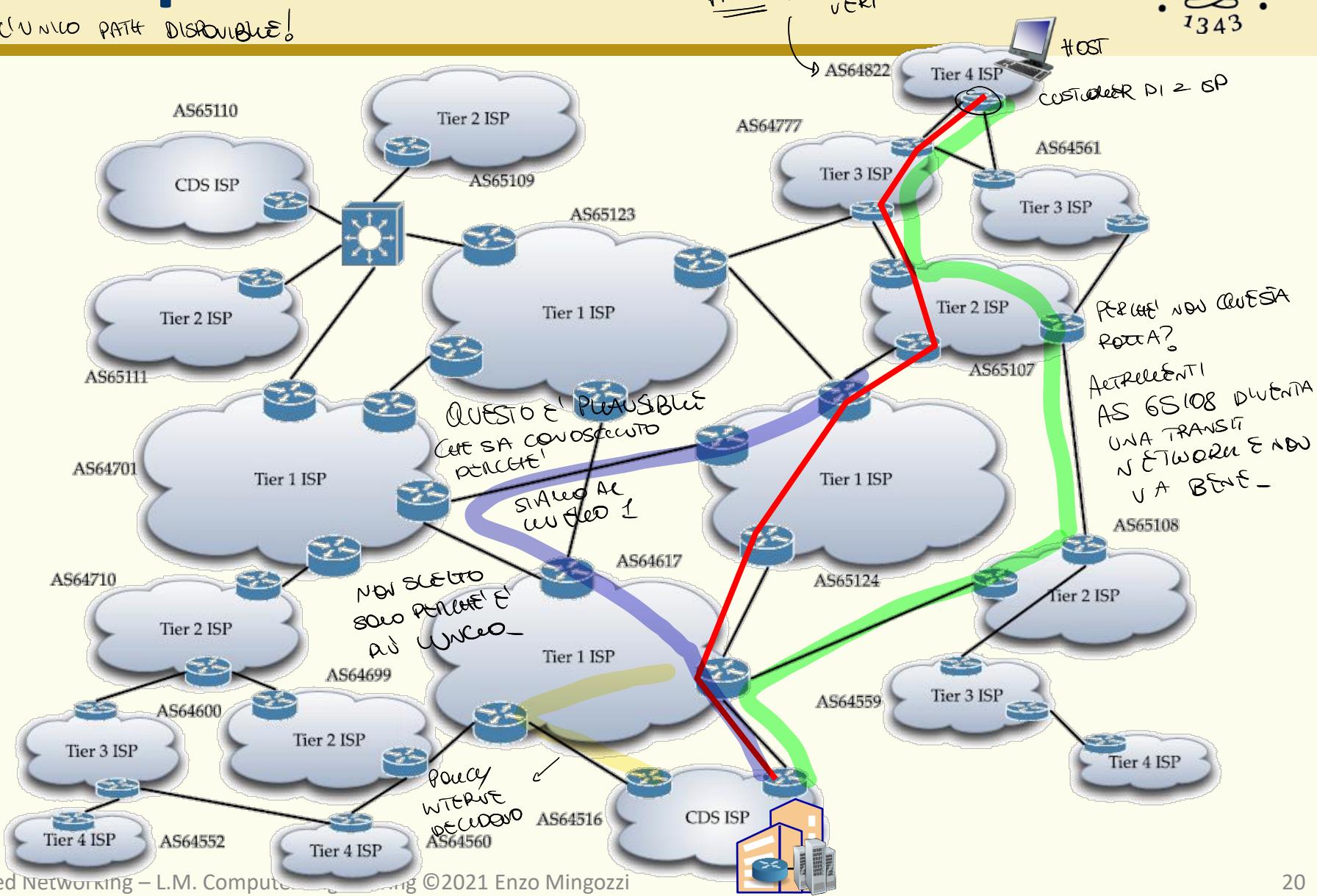


A list of universally recognized Tier 1 networks is available here:
https://en.wikipedia.org/wiki/Tier_1_network

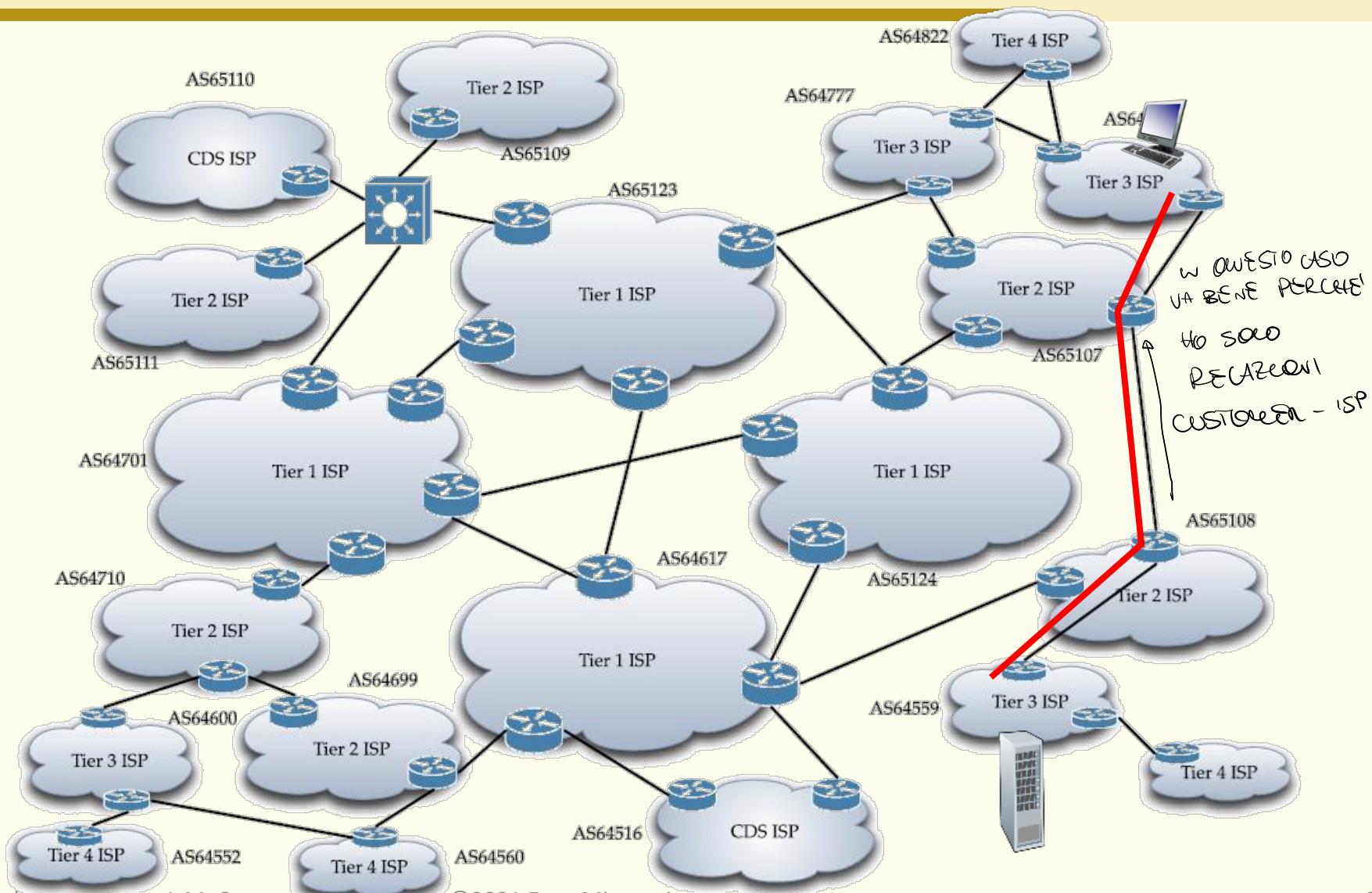


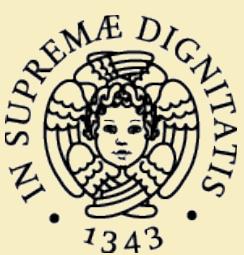
Example sessions

NOW E' UN NUOVO PATH DISPONIBILE!

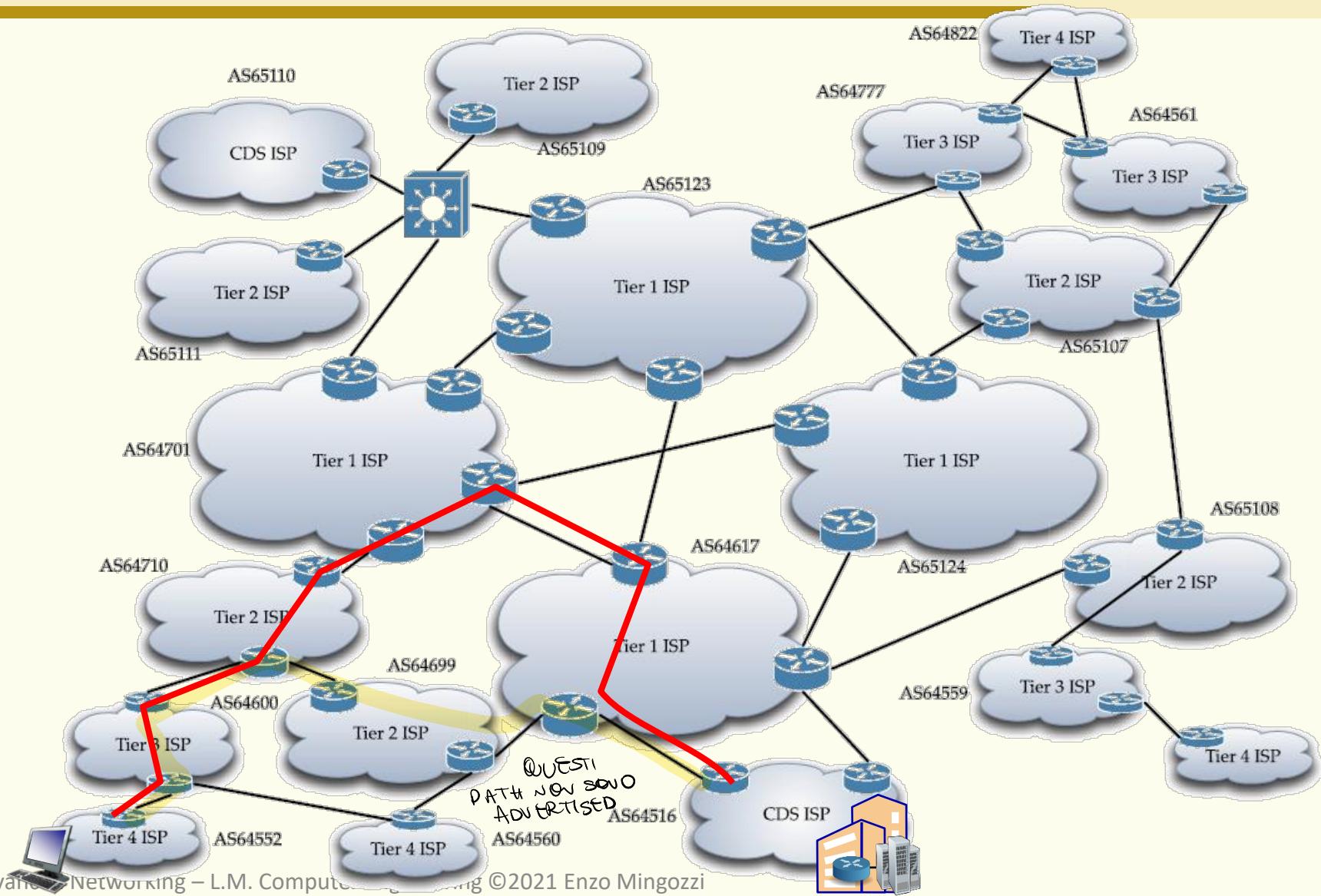


Example sessions



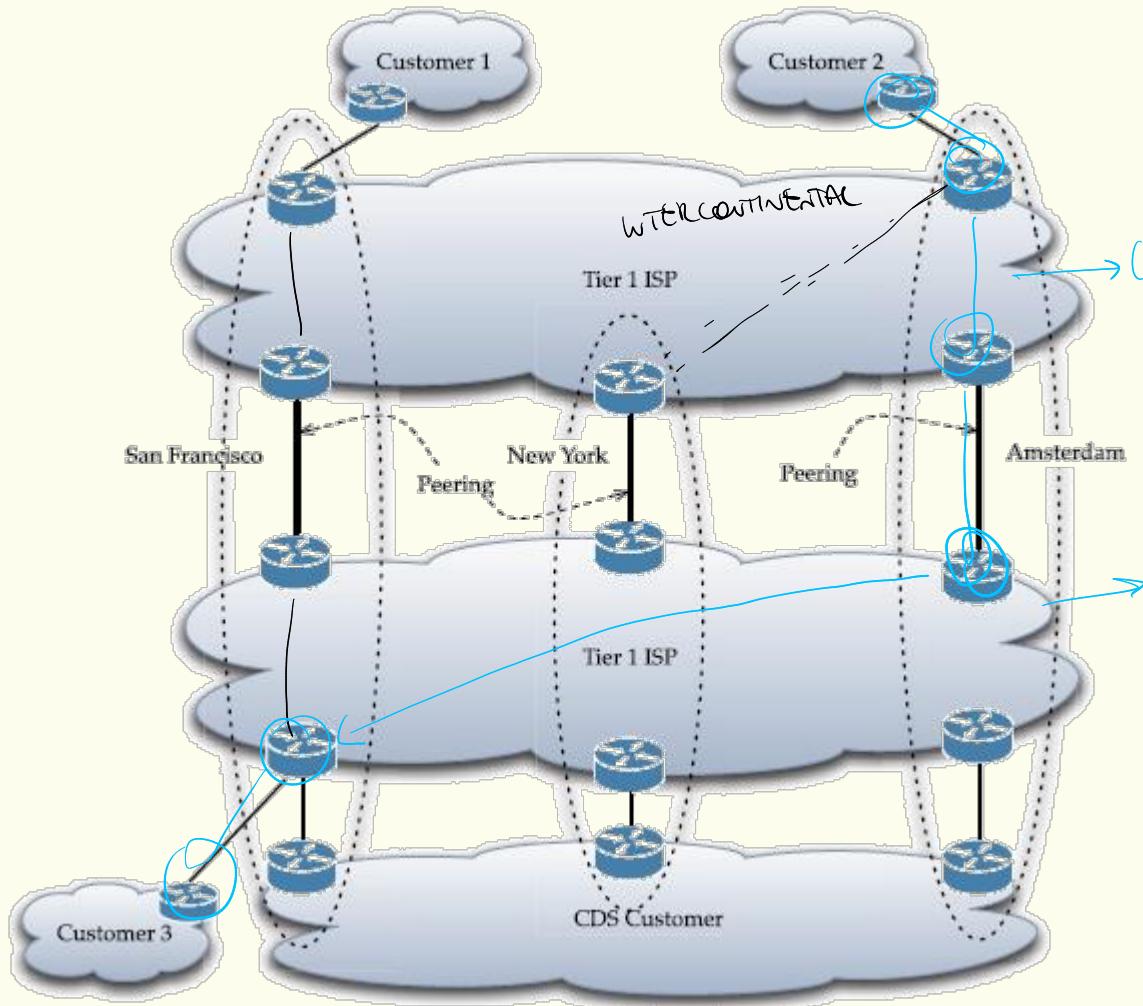


Example sessions





Geographic perspective

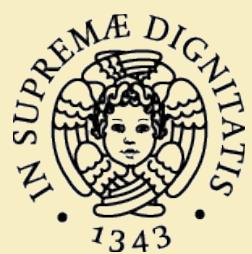


- ① Customer 1 to Customer 3
- ② Customer 2 to Customer 3
3. Customer 1/2 to CDS

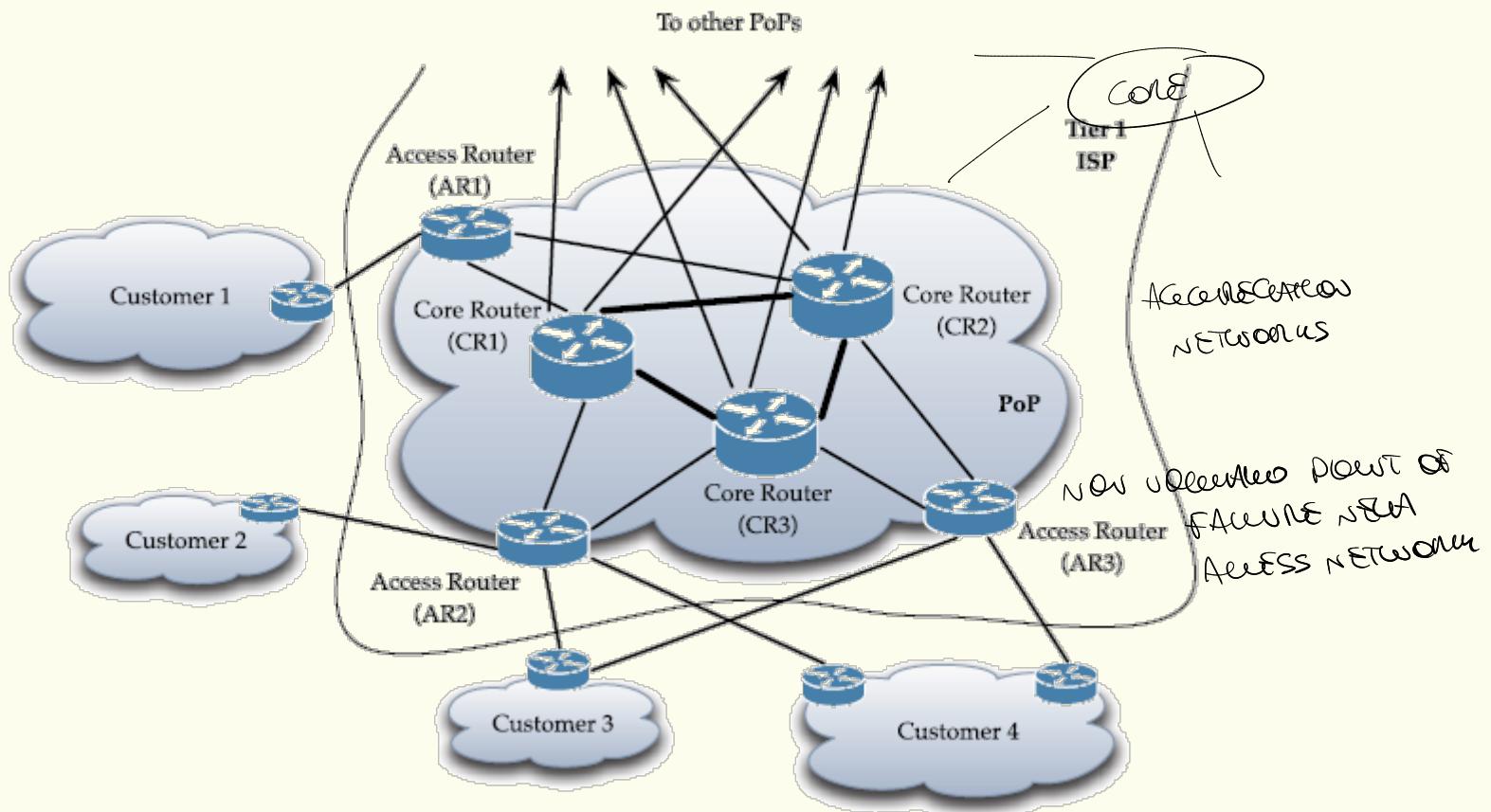
Local Area Network, see parente -

il secondo ISP è out-of-area
si occupa di trasporto comunitario
è UNFAIR? no perché nell'altra
direzione è uscita -

<https://peering.google.com/#/>



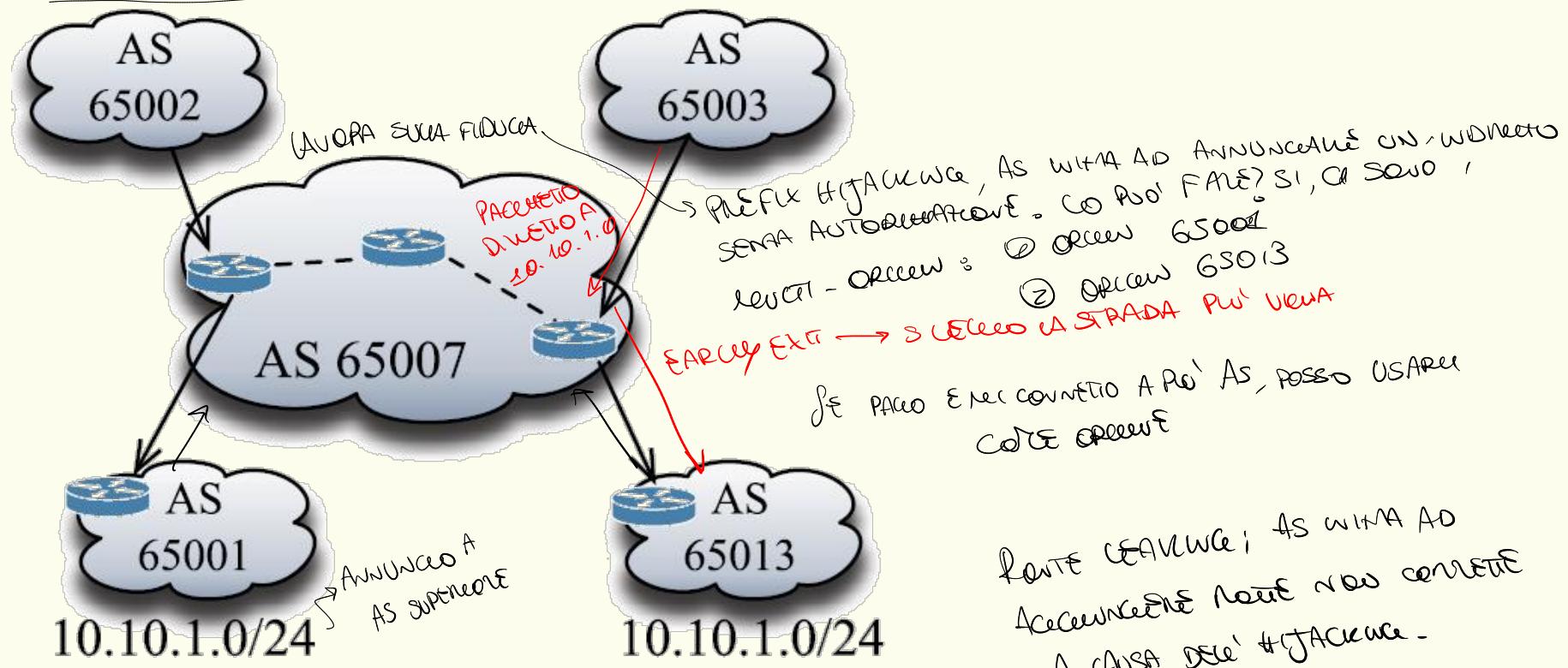
Point of Presence (PoP)





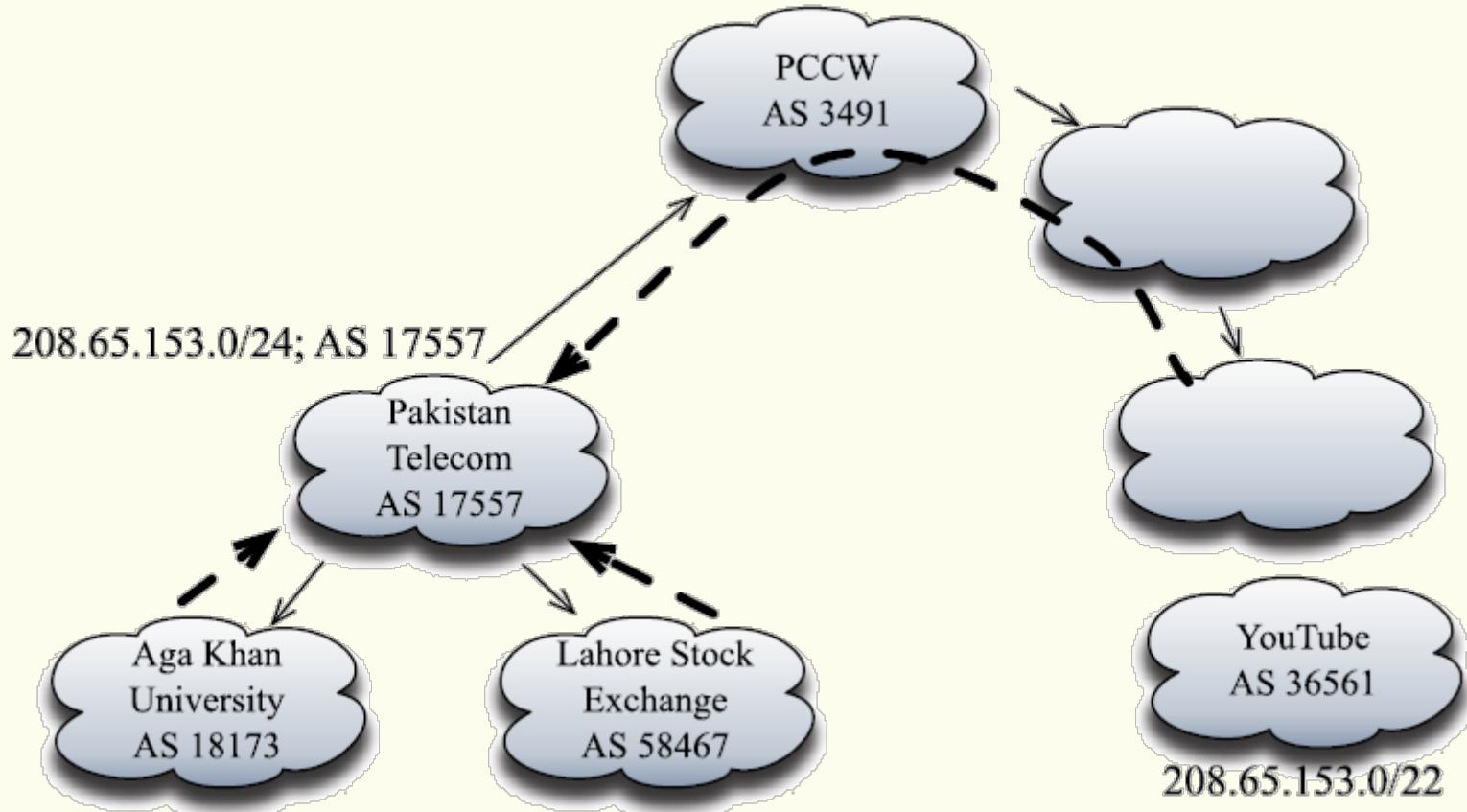
Prefix hijacking

The entire BGP announcement process works on trust: the AS that announces an IP prefix is assumed to be the owner of the address
IP prefix hijacking refers to the situation when an AS announces an IP prefix without any authorization



Prefix hijacking

YouTube hijacking by Pakistan Telecom (February 2008)



Hiran R., Carlsson N., Gill P. (2013) Characterizing Large-Scale Routing Anomalies: A Case Study of the China Telecom Incident. In: Roughan M., Chang R. (eds) Passive and Active Measurement. PAM 2013. Lecture Notes in Computer Science, vol 7799. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-36516-4_23



Size and growth of the Internet

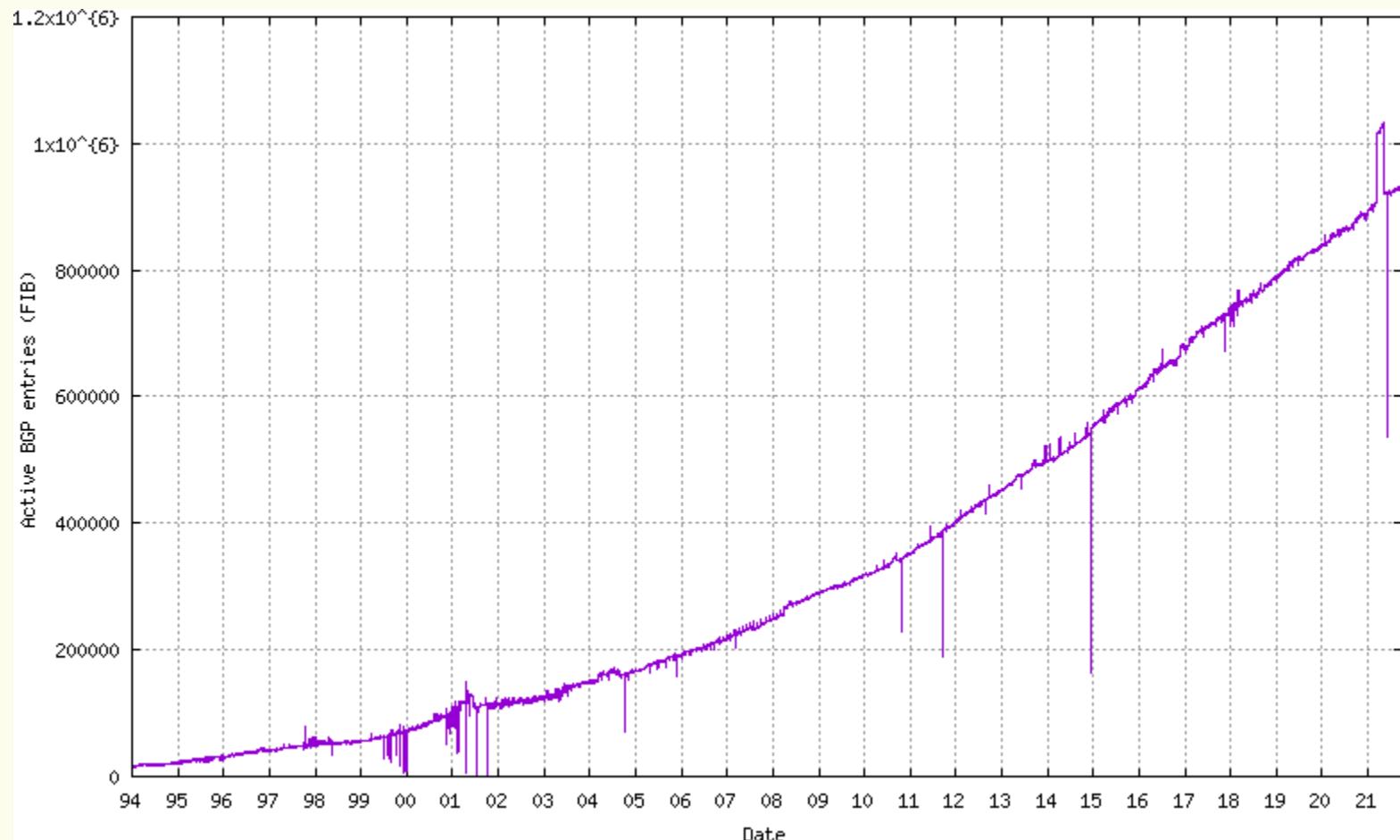
The time trend of the number of unique AS numbers advertised within the BGP table. The associated metrics characterise AS's into origin only, transit only, or mixed (origin and transit), and also look at the trends of advertised address space as related to the number of ASes. [BGP data obtained from AS6447, <https://bgp.potaroo.net/as6447/>]

AS Reports (plots)	Data Sets(txt)
Unique ASes	70786
Origin only ASes	59493 (84,04%)
Transit only ASes	401 (0,57%)
Mixed ASes	10892 (15,39%)
Multi-Origin Prefixes	6894
ASes originating a single prefix	24687
Average entries per origin AS	12.6264
Average address range span for an origin AS	40755.0398



Size and growth of the Internet

Active BGP entries. [BGP data obtained from AS6447, <https://bgp.potaroo.net/as6447/>]





References

- D. Medhi, K. Ramasamy, **Network Routing: Algorithms, Protocols, and Architectures**, 2nd/ed. Morgan Kaufmann, ©2018
- RFC
 - **RFC4271**, A Border Gateway Protocol 4 (BGP-4), Jan. 2006
 - **RFC4360**, BGP Extended Communities Attribute, Feb. 2006