Communications Network Design

lecture 19

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Networks of networks

The Internet is a network of networks. Most of the problems we have considered up to this point concern a single network. There are many interesting problems when we consider how these networks interconnect.

the Internet

The Internet has

- many thousands of routers
- many millions of hosts

What does it look like

- can we do shortest path routing?
- should we do shortest path routing?

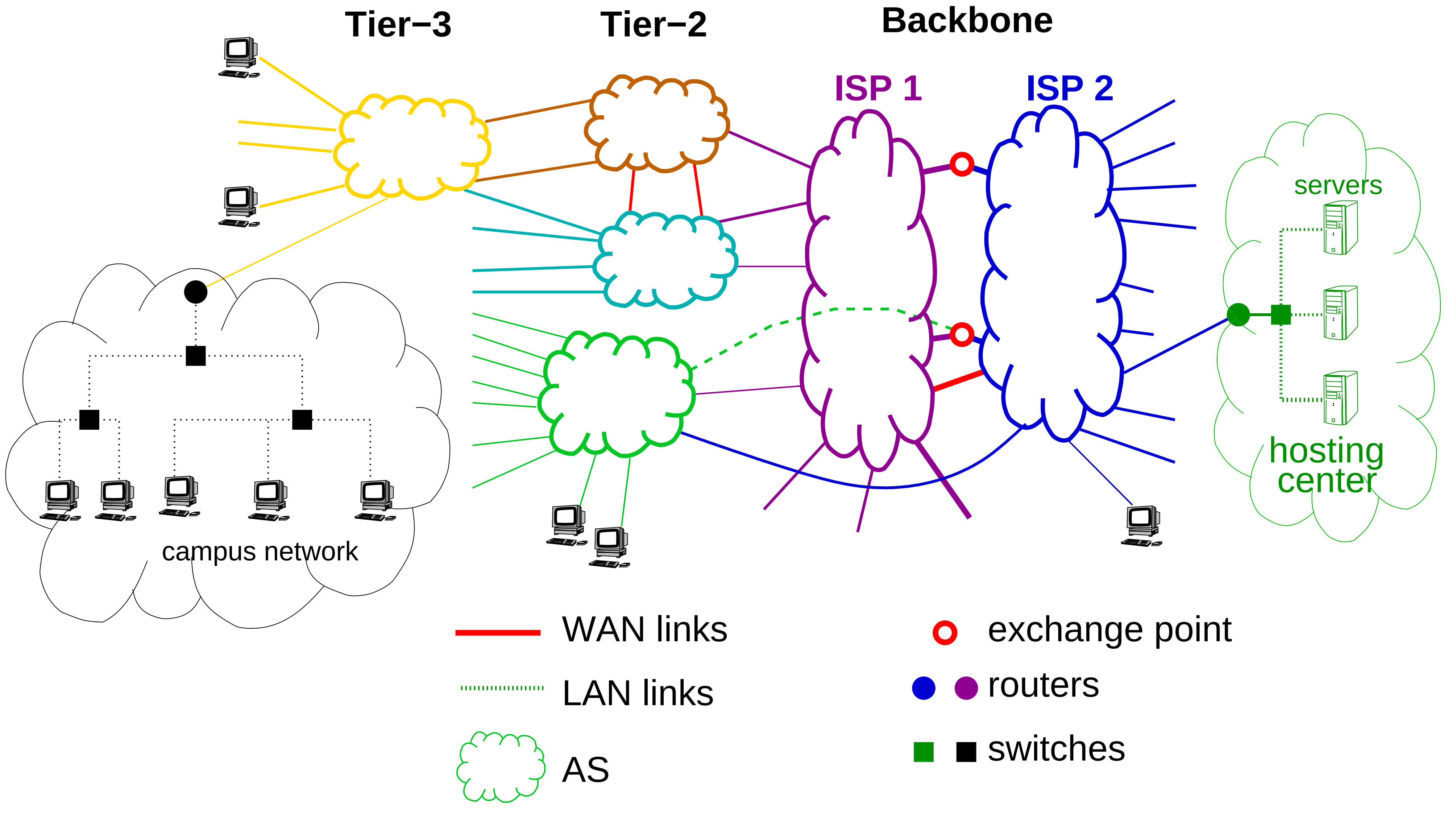
Obviously, we at least need some hierarchy?

Internet Topology

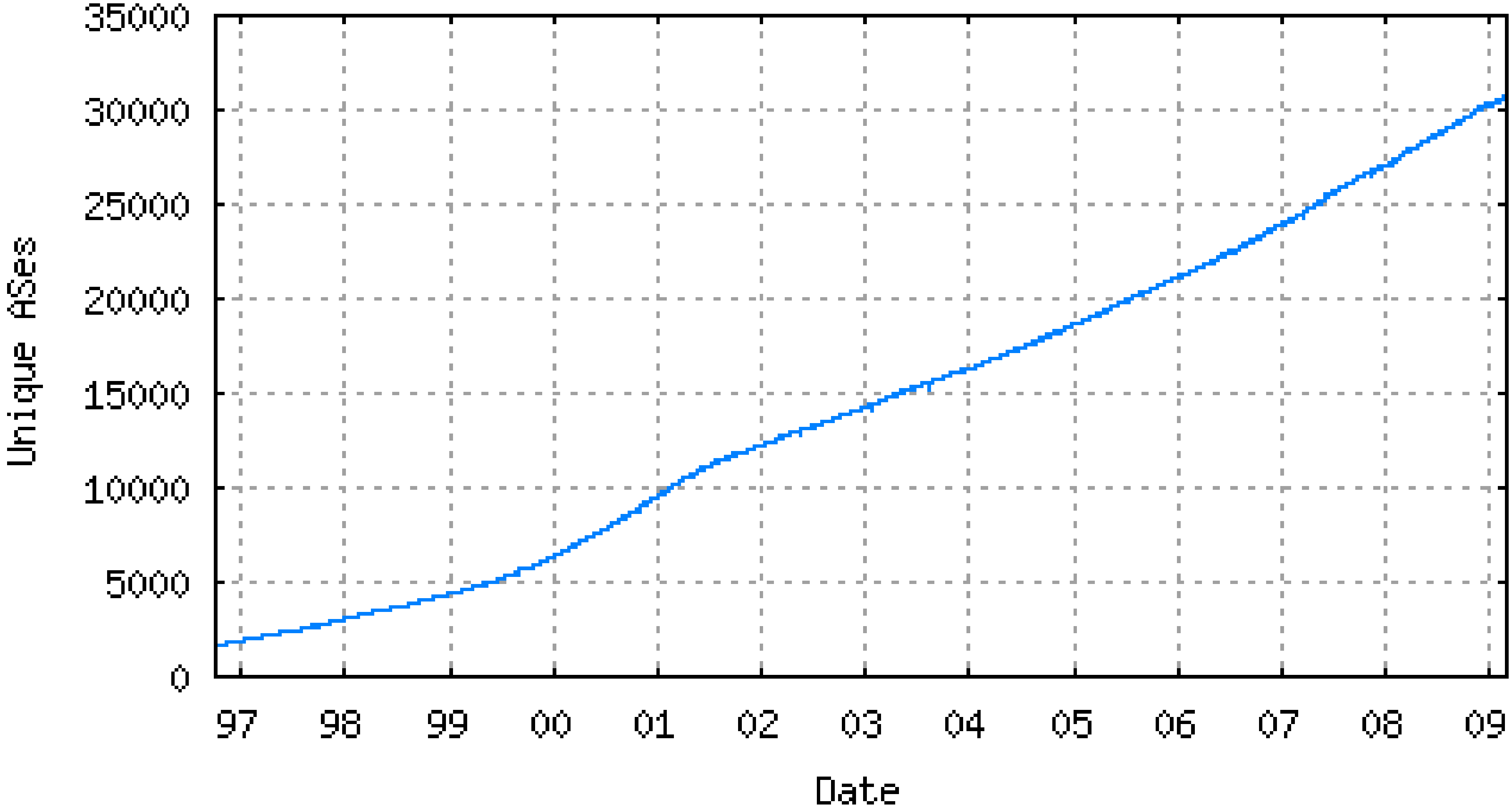
The Internet is broken into more than 10,000 Autonomous Systems (ASes)

- AS is a separately managed network
- within an AS may use different routing, technology, management, ...
- may be a LAN, WAN, or combination
- example ASes:
  - ISP (Internet Service Provider)
  - Campus network
  - Enterprise network
  - Hosting center
- see RFC 1009 for definition (obsoleted by 1812)

the Internet



Number of ASes



http://www.cidr-report.org/

maximum number is $\sim$ 65k

the Internet

- an AS is a network under one administrative domain
  - from the outside, we don't see the details
  - all we see are a set of subnetworks which are reachable via that AS
- subnets
  - either a group directly attached computers
  - or a group of customers' computers
- CIDR (Classless Inter-Domain Routing)
  - subnet = group of IP addresses with a common **prefix**
    - e.g. private addresses 192.168.0.0/16
      - all address with same first **16** bits 192.168
      - 192.168.0.0 – 192.168.255.255

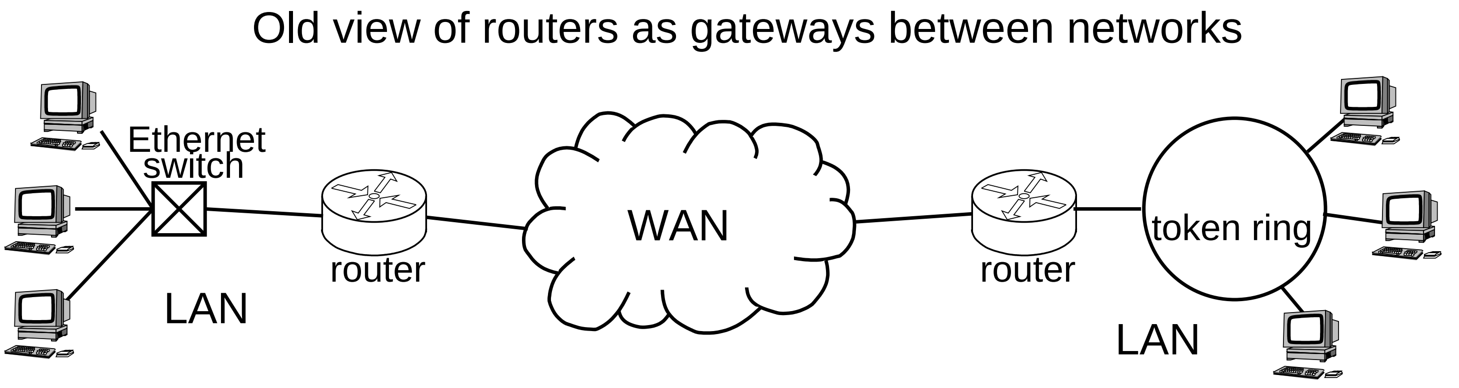
Different Flavours of Routing

Routing is different inside an AS from between ASes

- **intra-domain** (inside an AS)
  - called Interior Gateway Routing (**IGP**) protocols
  - examples: OSPF, RIP, EIGRP, IS-IS, ...
  - can use any one of these
  - can even use more than one at once!
- **inter-domain** (between ASes)
  - called Exterior Gateway Routing (**EGP**) protocols
  - one defacto standard BGPv4
    - Border Gateway Protocol
    - must talk internationally
      - can be only one

An Aside on Gateways

- router sometimes called gateway



  - RFC 1009 “Requirements for Internet Gateways” has definitions of such
  - better to use this term for gateway routers (that join two networks)
  - also for high level (e.g. network level) protocol conversion, e.g. IP to IPX
- but routing protocols still get called 'gateway' protocols

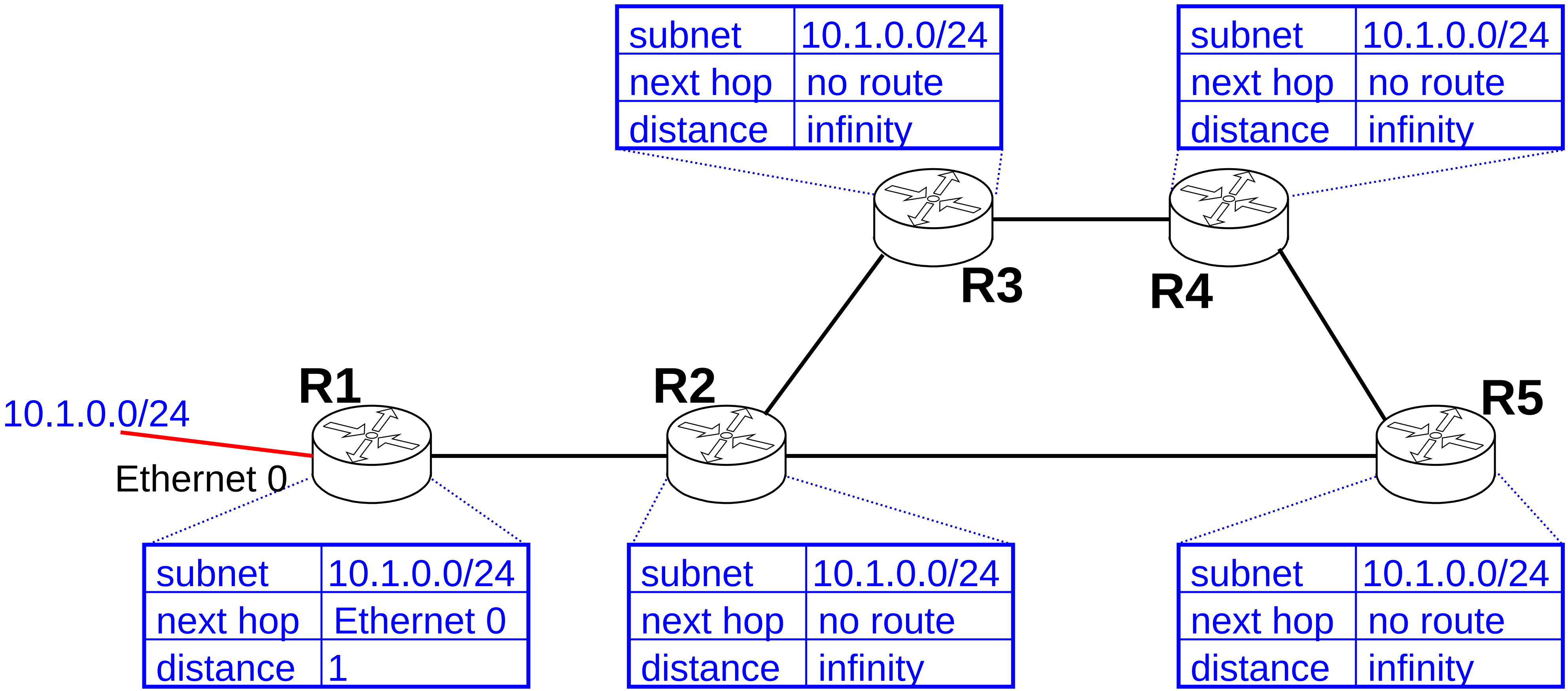
Link state vs Distance Vector

- We saw OSPF was a **link-state** routing protocol
  - floods topology (link states), and computes SPF
  - solves shortest path problem
- alternative is called **distance-vector** protocol
  - examples: RIP, IGRP, ...
  - originally also aimed to solve shortest paths
    - but nodes don't need to know complete topology
  - does BGP still do this?
    - BGP is a generalization called **path-vector** protocol

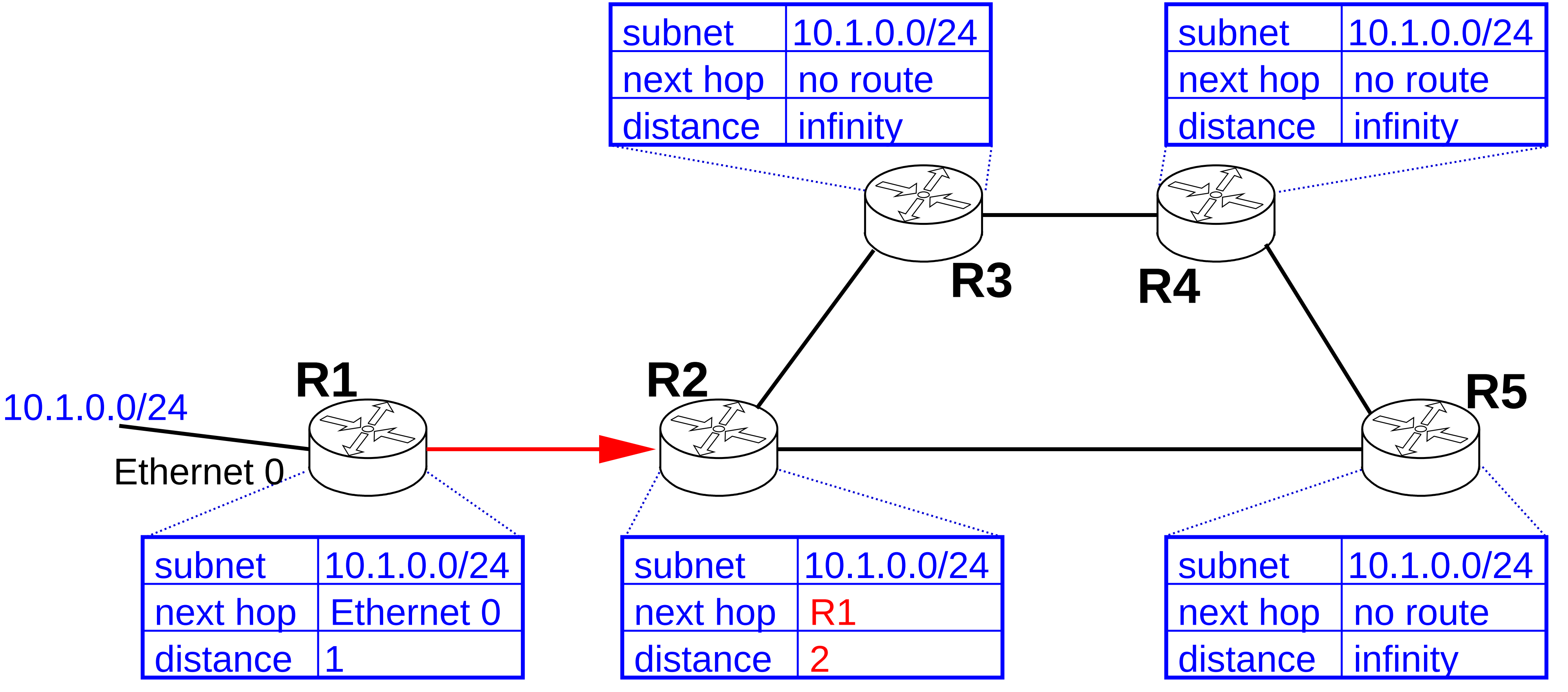
Distance Vector reminder

- Make a list of destinations you can reach and the distance to these destinations.
  - Store in routing table
- Share this list with your neighbours
- Add to routing table new information gained from adjacent routers about the destinations they can reach
  - remember to increment their distance
  - keep the source as the next hop
- If two paths to the same destination exists, keep the shortest distance path.
- Repeat periodically (in RIP every 30 seconds).

Distance Vector example



Distance Vector example



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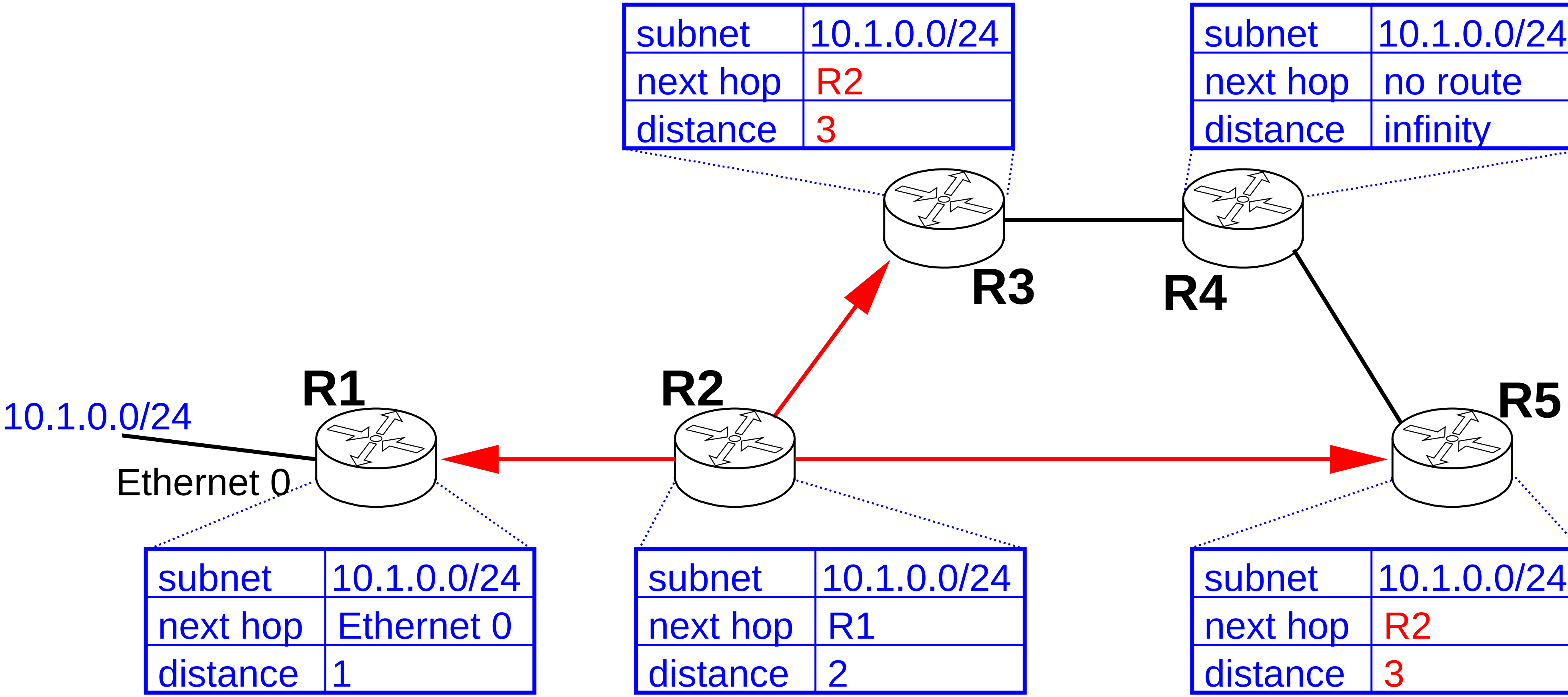

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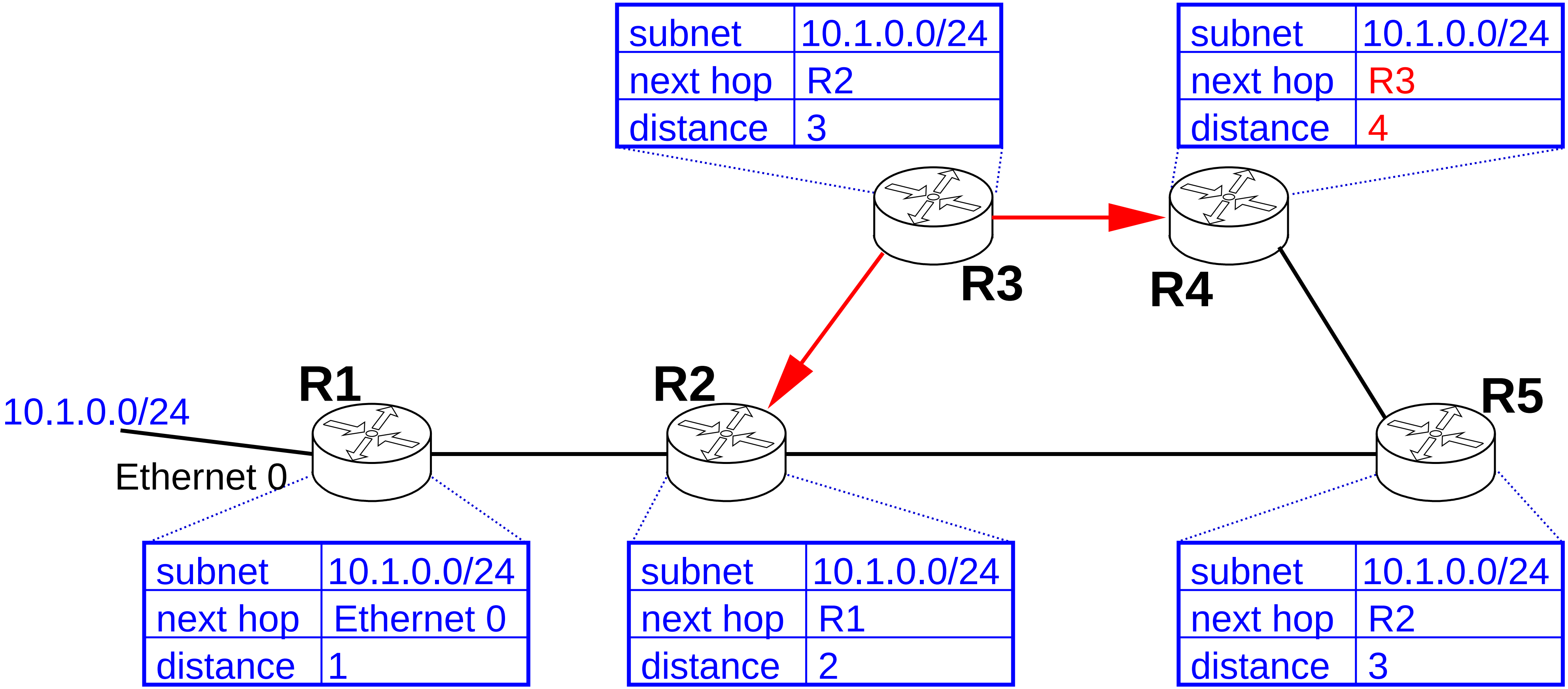

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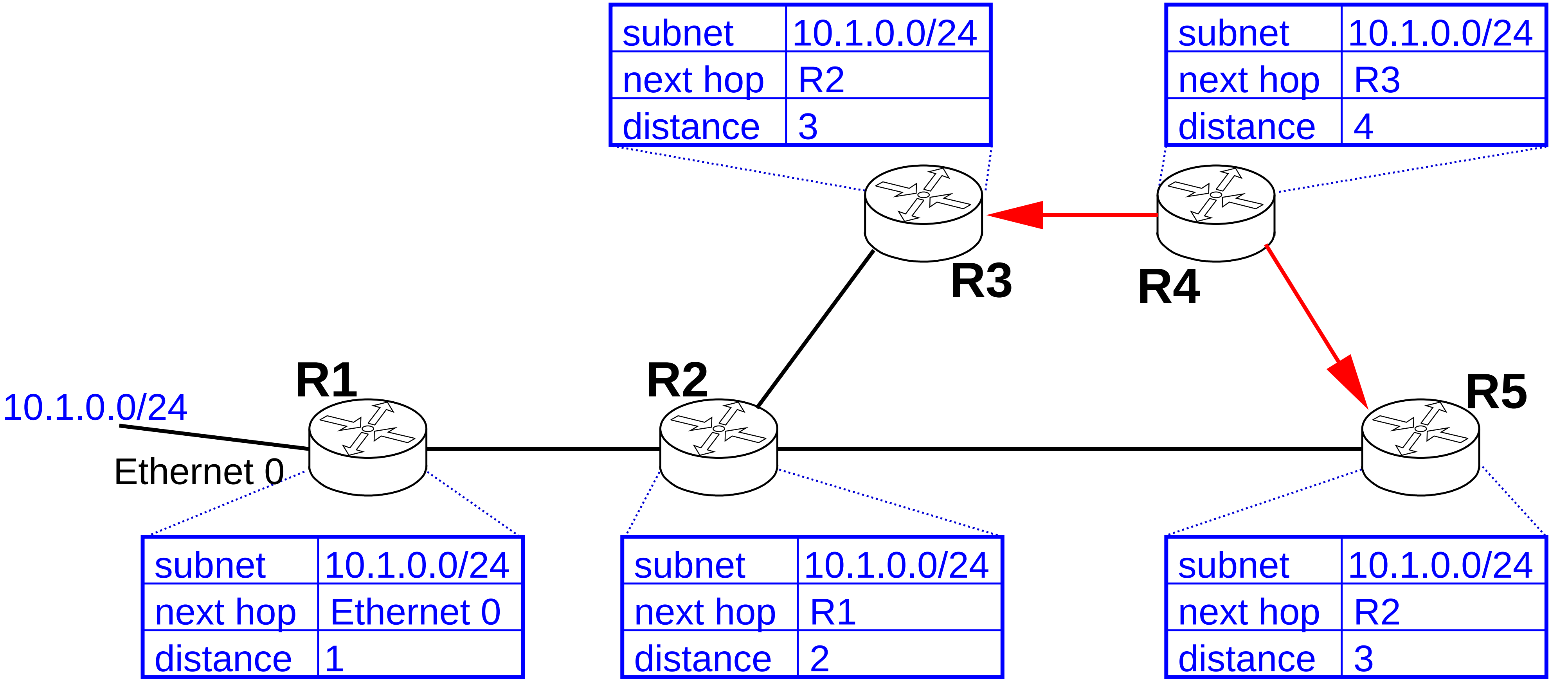


Internet structure/topology

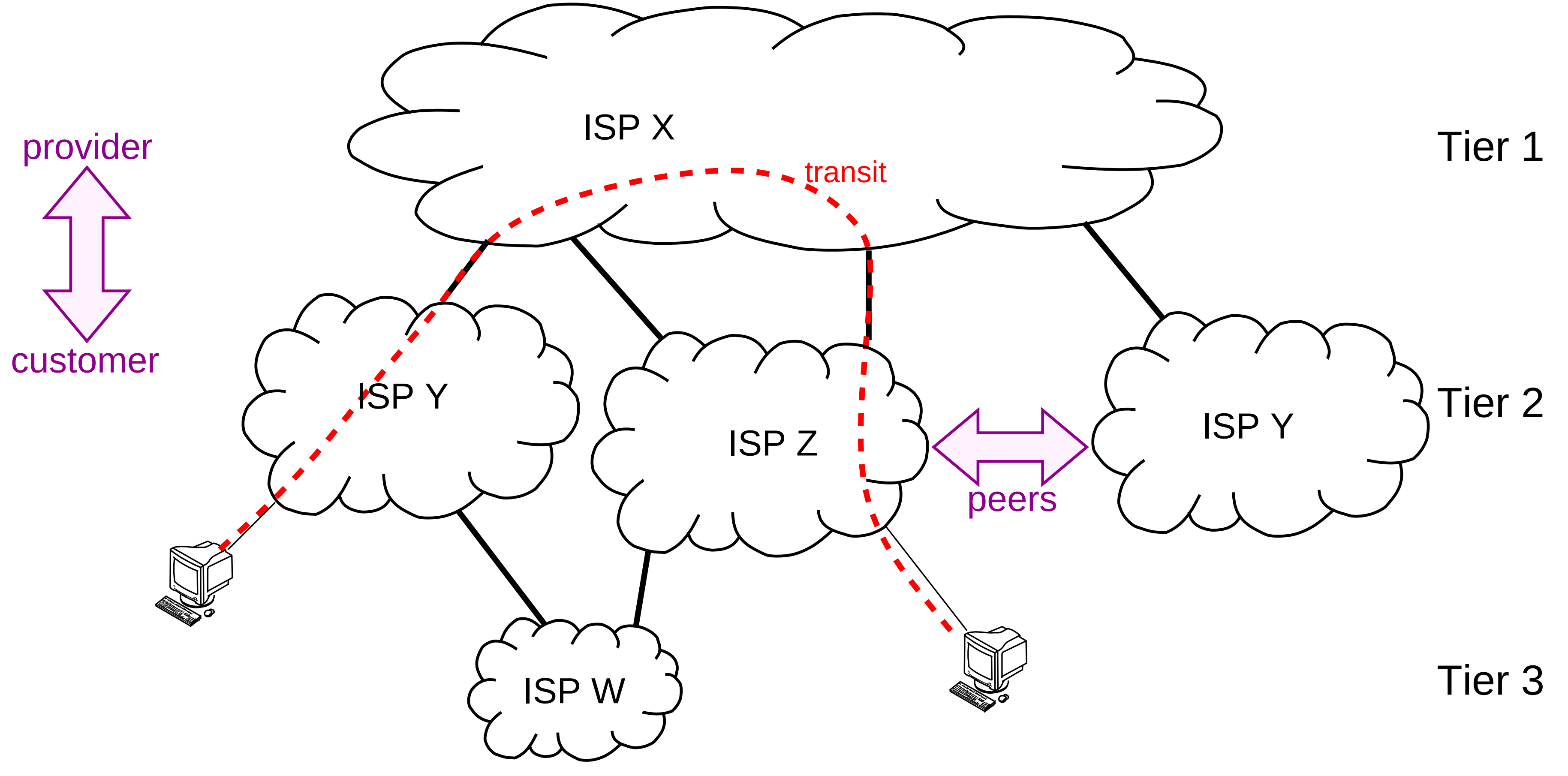
- RIP still used, but only in small networks
  - IGRP similar to RIP, but few improvements to make it more scalable
  - I don't know how widely IGRP is used
- to really understand why distance-vector protocols are so important, we need to look at BGP
- BGP needs to support connectivity between ASes
- structure of AS graph is therefore important
  - tiering
    - customer-provider relationship
  - peering
  - routing **policy**

Tiering

- no hard and fast rules, but
  - tier-1 ISP: international, or national backbone
    - provide transit
    - have at least some default-free routers
    - have connectivity over large geographic area
  - tier-2 ISP: regional ISP
    - provide transit within a geographic area
    - may have default-free routers
  - tier-3 ISP: local ISP
    - do not provide commercial transit services, although they may incidentally provide transit among their customers
  - tier-4 ISP: e.g. company network
    - Internet access through provider only

Tiering

Higher tiers provide **transit** for lower tiers



- Lower tiers are **customers** of higher tiers
- Higher tiers are **providers** for lower tiers

Tiering

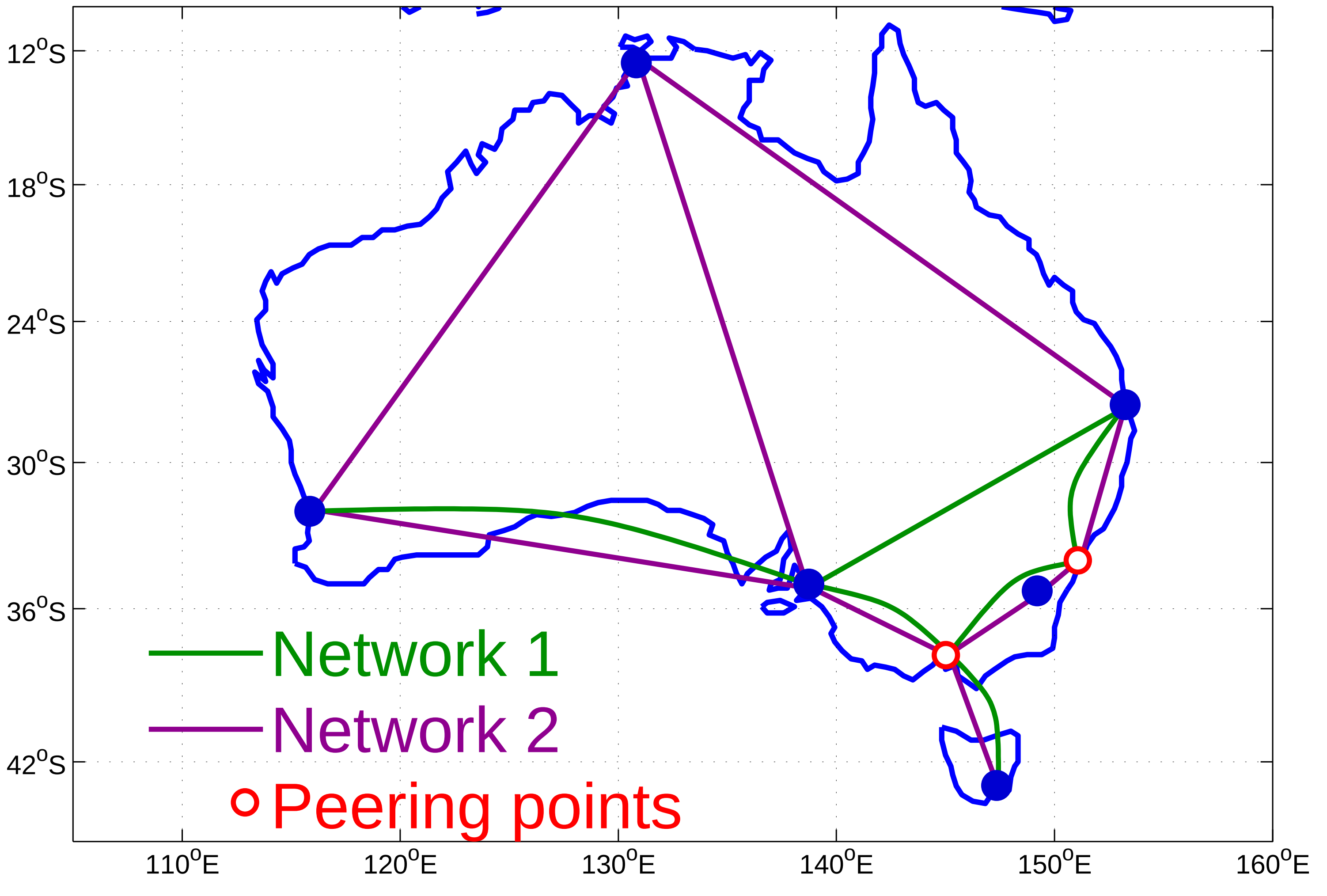
Some “tier-1” ISPs (in no particular order)

- UUNET/WorldCom/MCI (AS 701)
- AT&T (AS 7018 - North American backbone)
- Verio (AS 2914)
- Sprint (AS 1239)
- Level 3 (AS 1)
- Cable & Wireless (AS 3561)
- Global Crossing (AS 3549)
- Qwest (AS 209)

Note that some companies run more than one AS

Peering

Two national networks.



Traffic has to get between them: **peering** links [1, 2].

Peering

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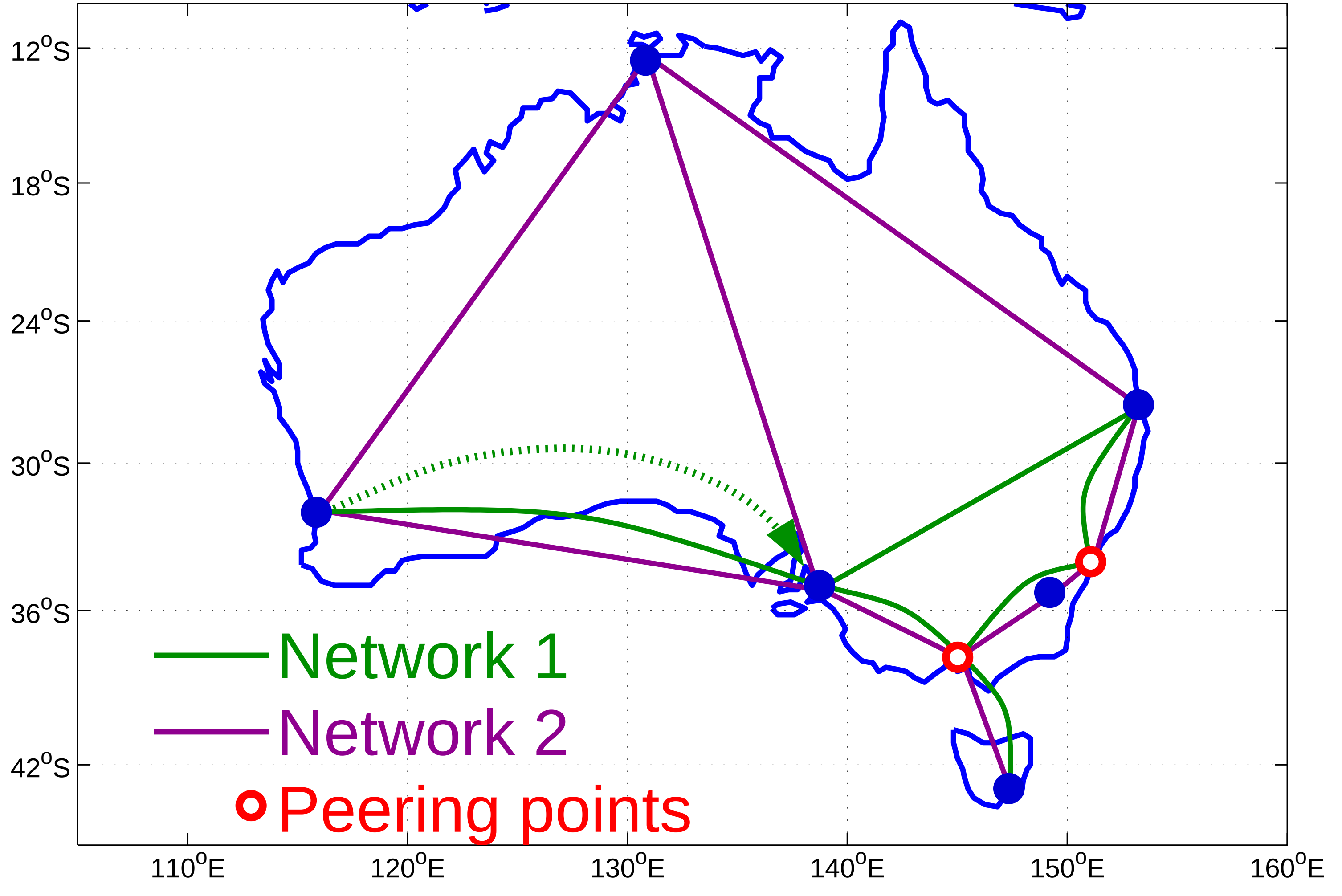

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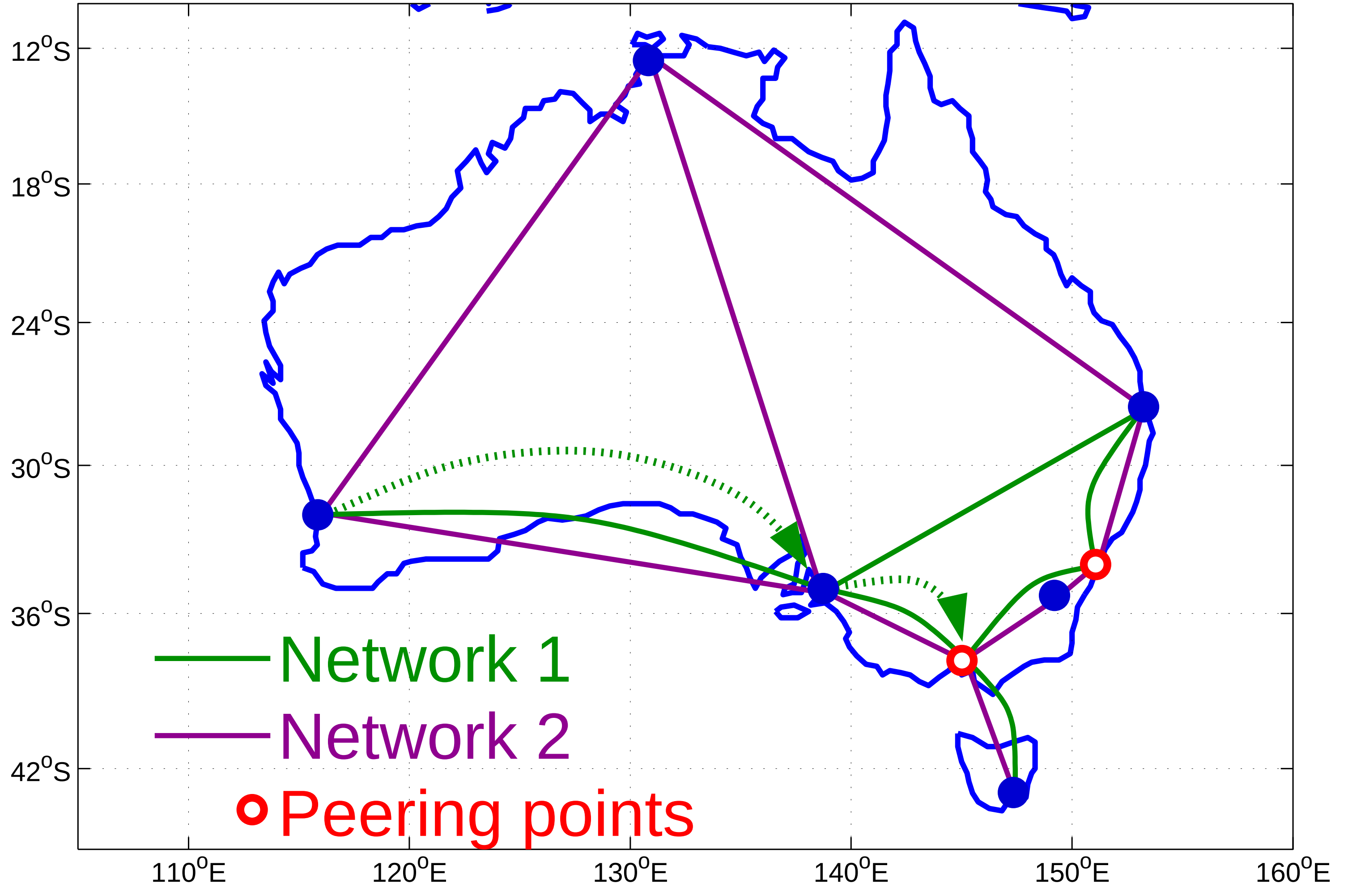

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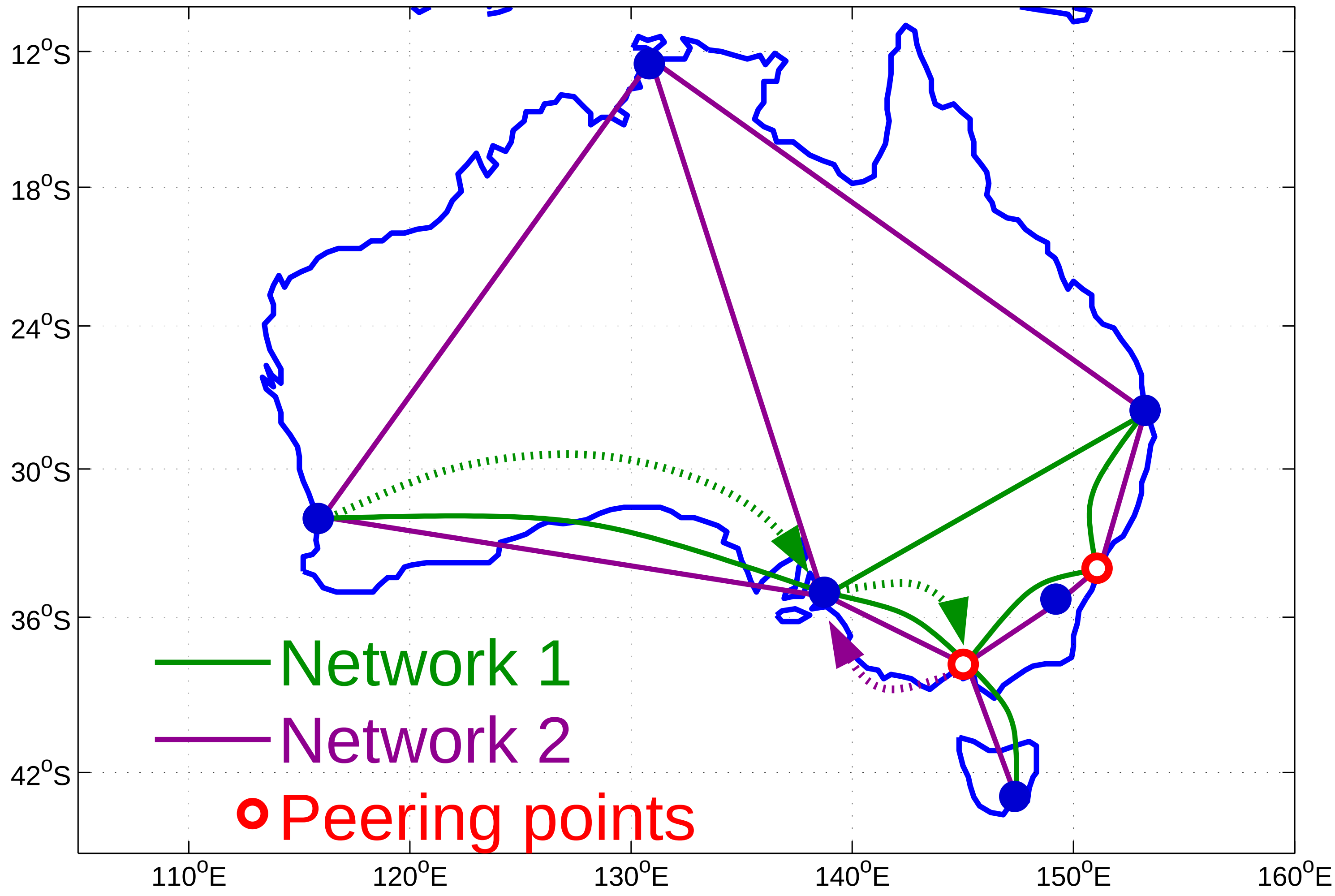

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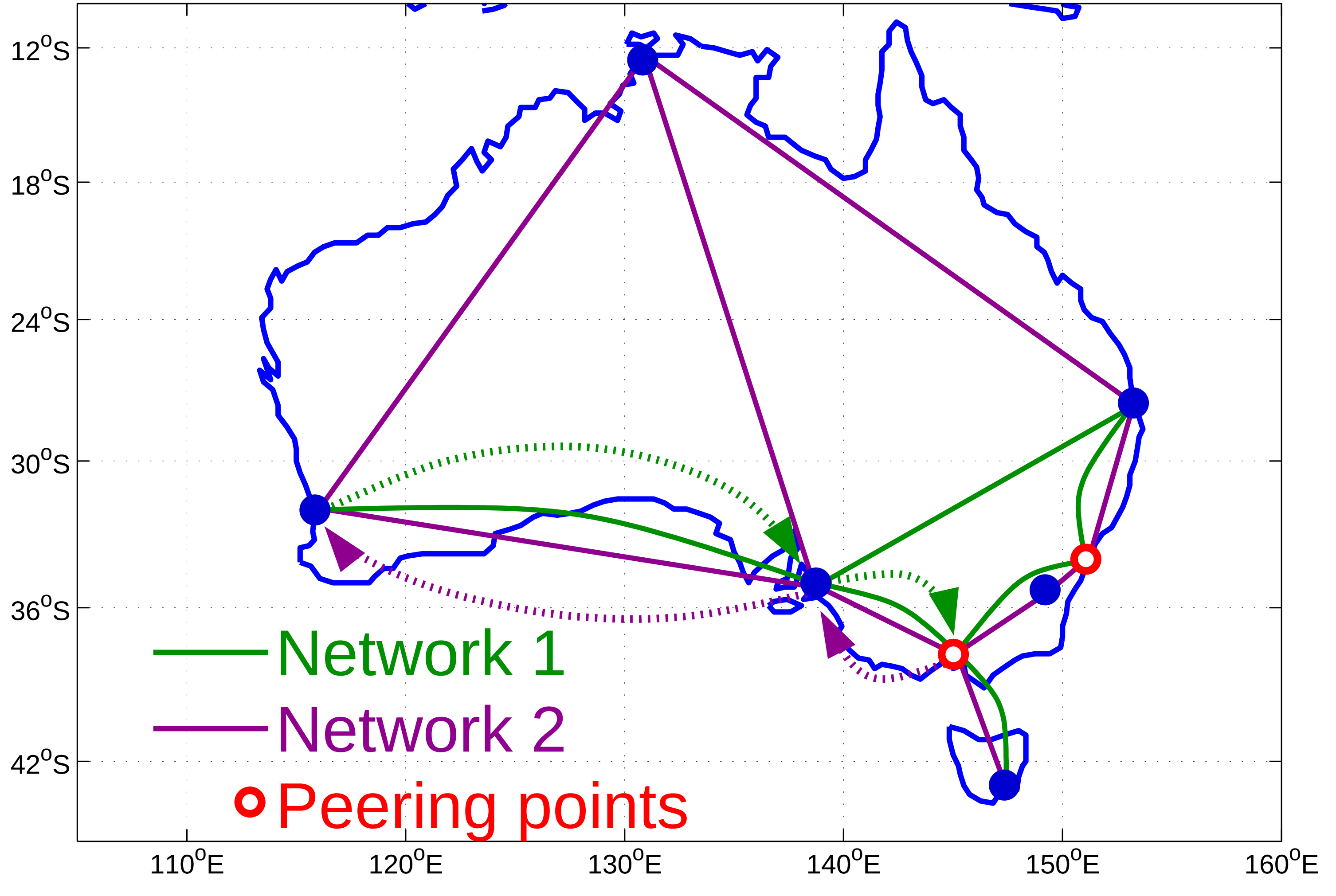

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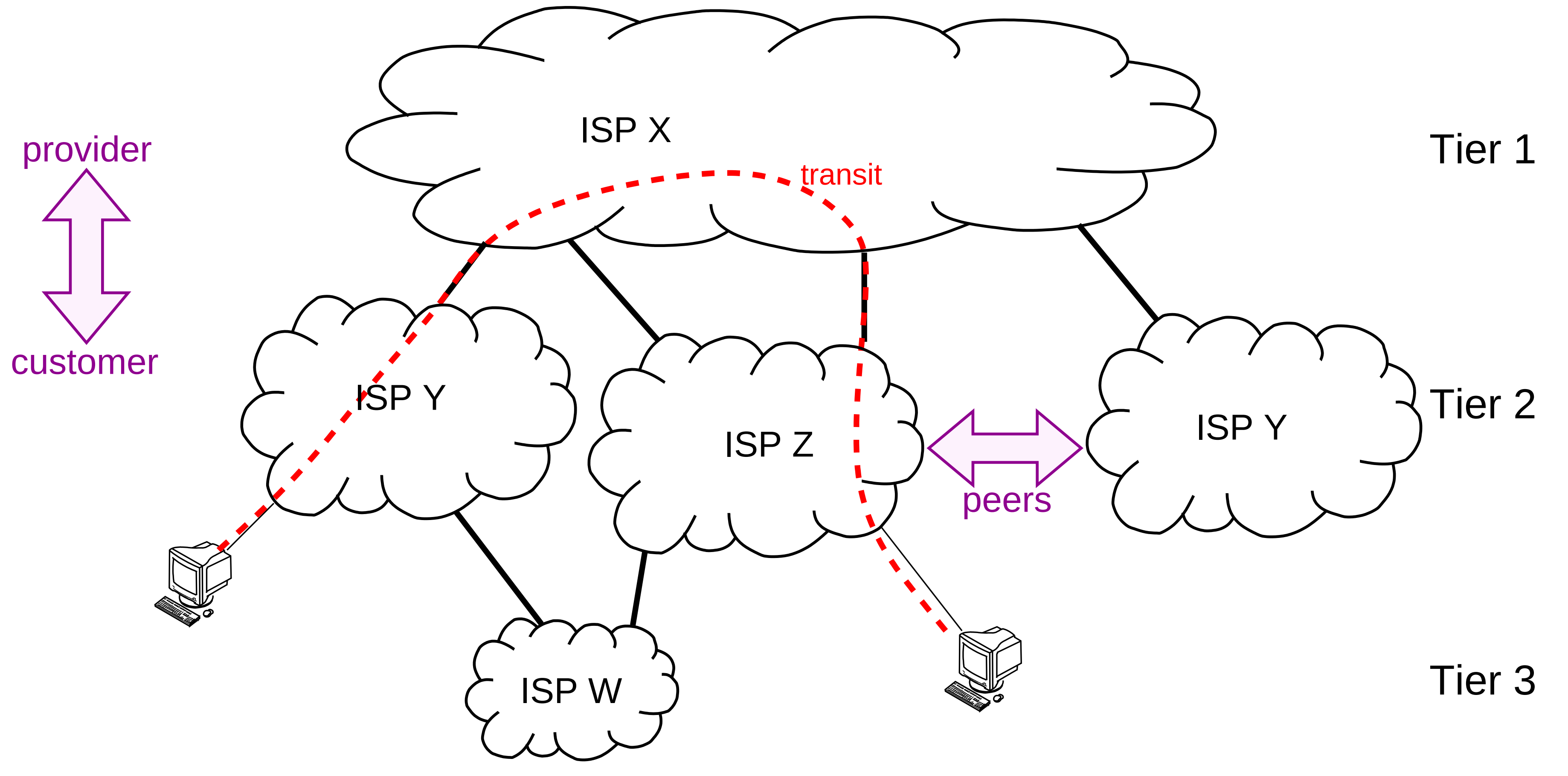
Tiering and Peering

Peering between tier-1's is **needed**



- peering makes sense for lower tier peers as well
- avoid transit charges from providers

Tiering and Peering

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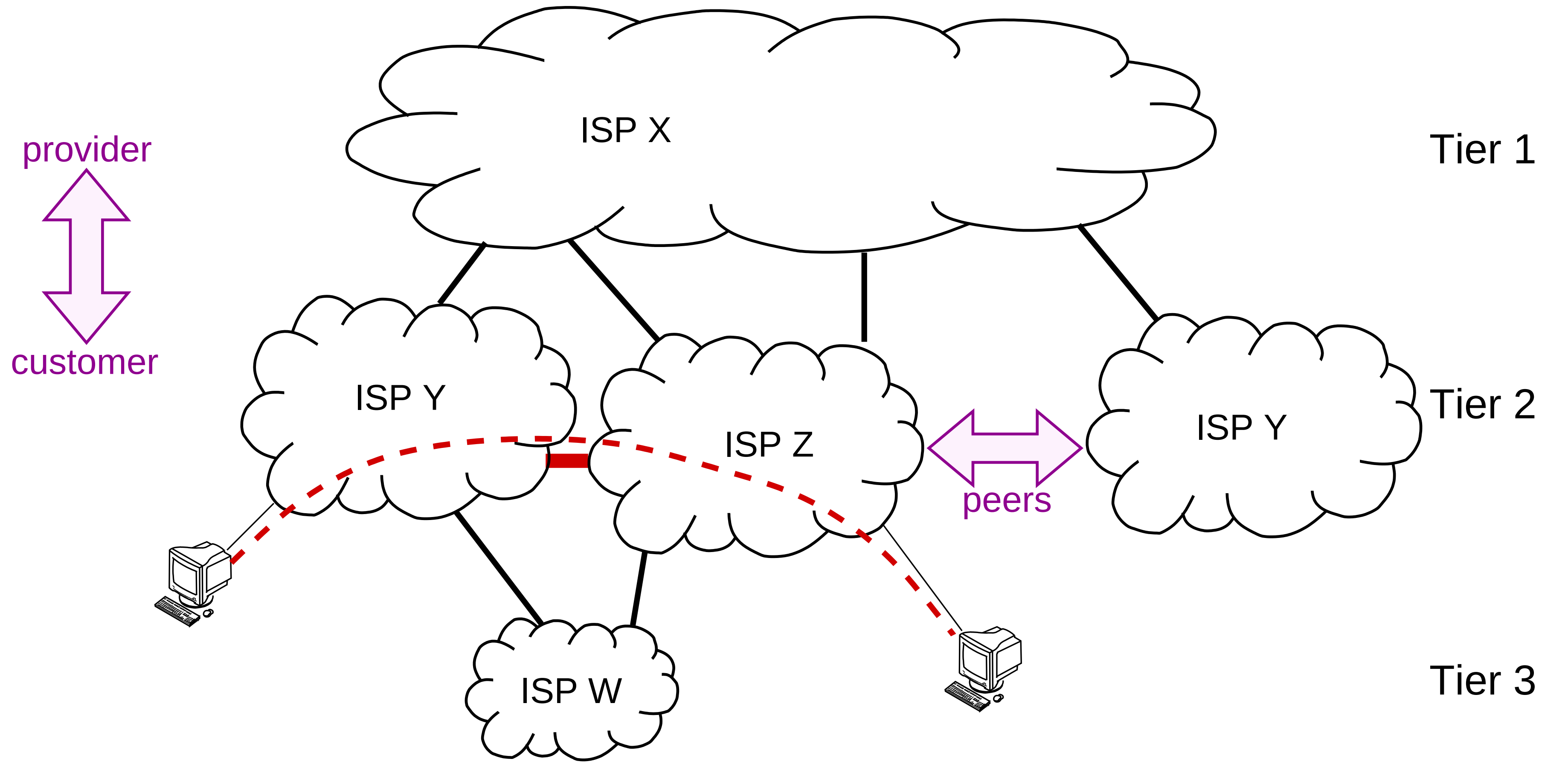


- peering makes sense for lower tier peers as well
- avoid transit charges from providers

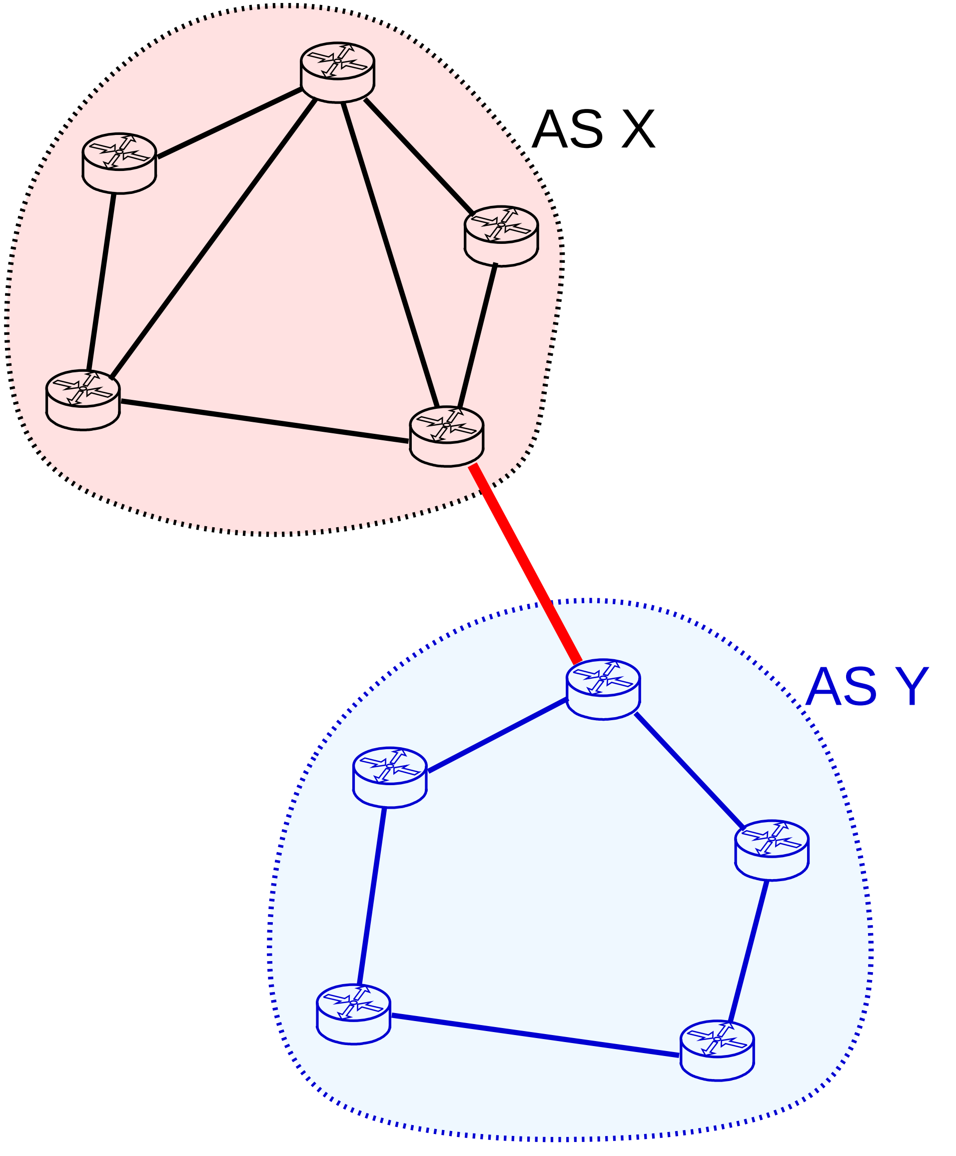
Peering Connections

What are the physical connections between ASes

- private peering
  - a point-to-point connection between a gateway router on each network
  - usually a WAN link
- Internet Exchange Point (IXP)
  - third party runs a router or switch or network
  - ISPs connect to the switch
  - similar concept Network Access Point (NAP)
- co-location facility
  - third party provides premises (and power etc)
  - multiple ISPs maintain routers in the premises
  - create local connection between their routers
  - e.g. carrier hotel

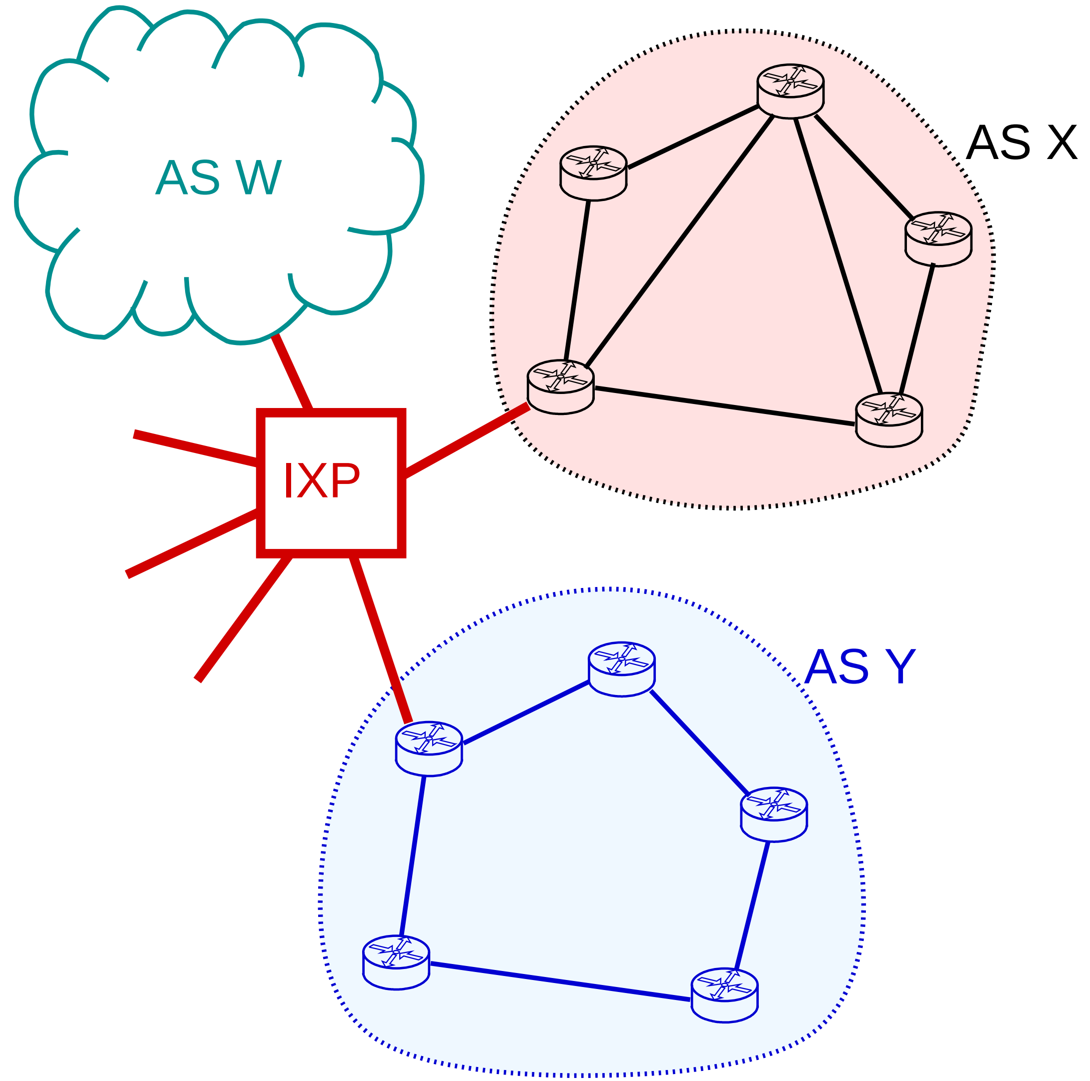
Private Peering Connections

- advantage:
  - high capacity
  - only two parties involved
- disadvantages:
  - not very flexible
  - e.g. can't change peers easily



Exchange points

- advantage:
  - multiple parties
  - very flexible
- disadvantages:
  - connection to a single PoP
  - lower capacity
  - subject to a third party



Exchange points

Some US Exchange points

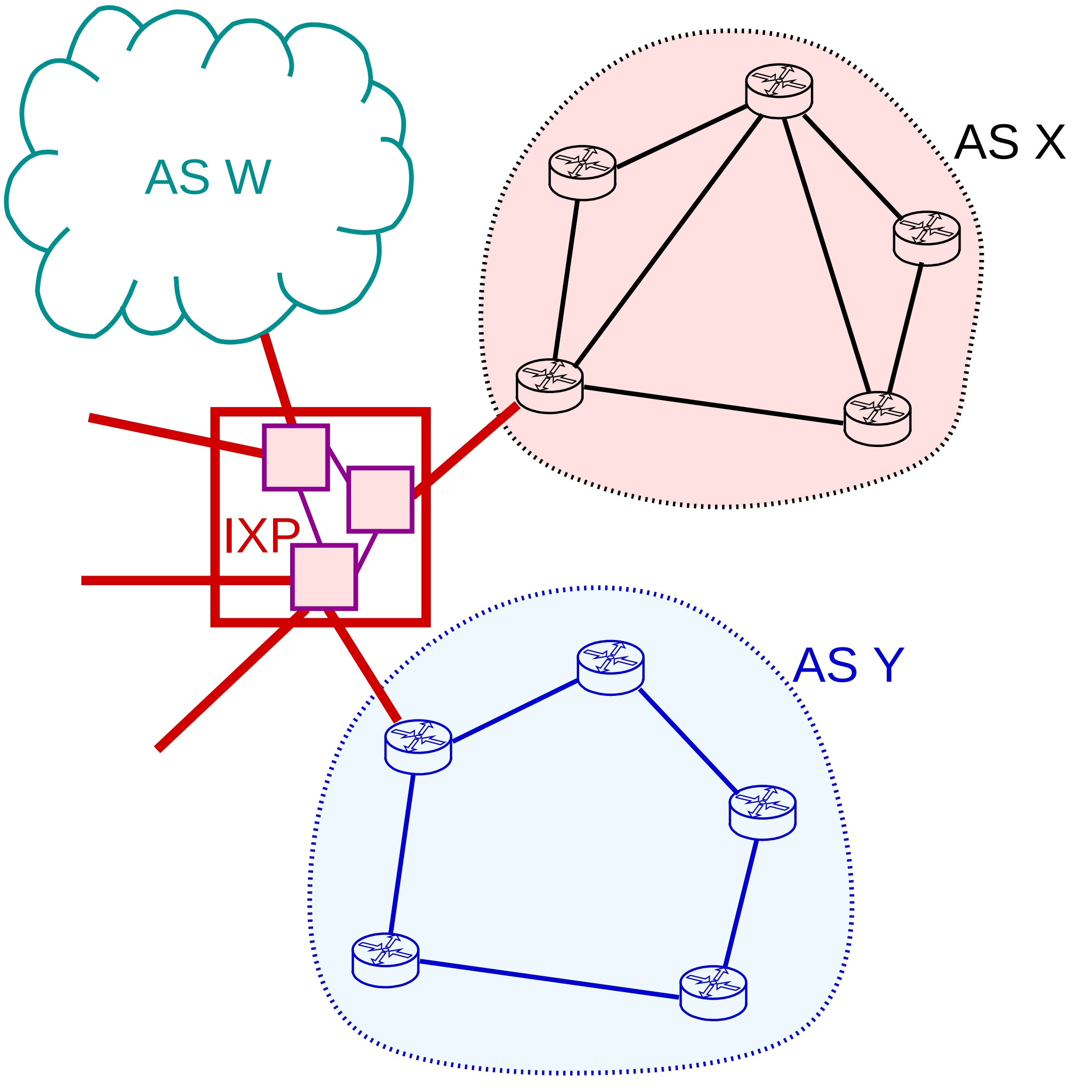
- MAE East (N VA)
- Sprint NAP (NJ)
- PAIX
- MAE West

Australian exchange points

- AUSIX.NET - Sydney
- Melbourne NAPette
- VIX - Victorian Internet Exchange (Melbourne)
- SAIX - Southern Australian Internet Exchange
- WAIX - Western Australia Internet Exchange

Distributed Exchange points

- advantage:
  - multiple parties
  - very flexible
- disadvantages:
  - subject to a third party



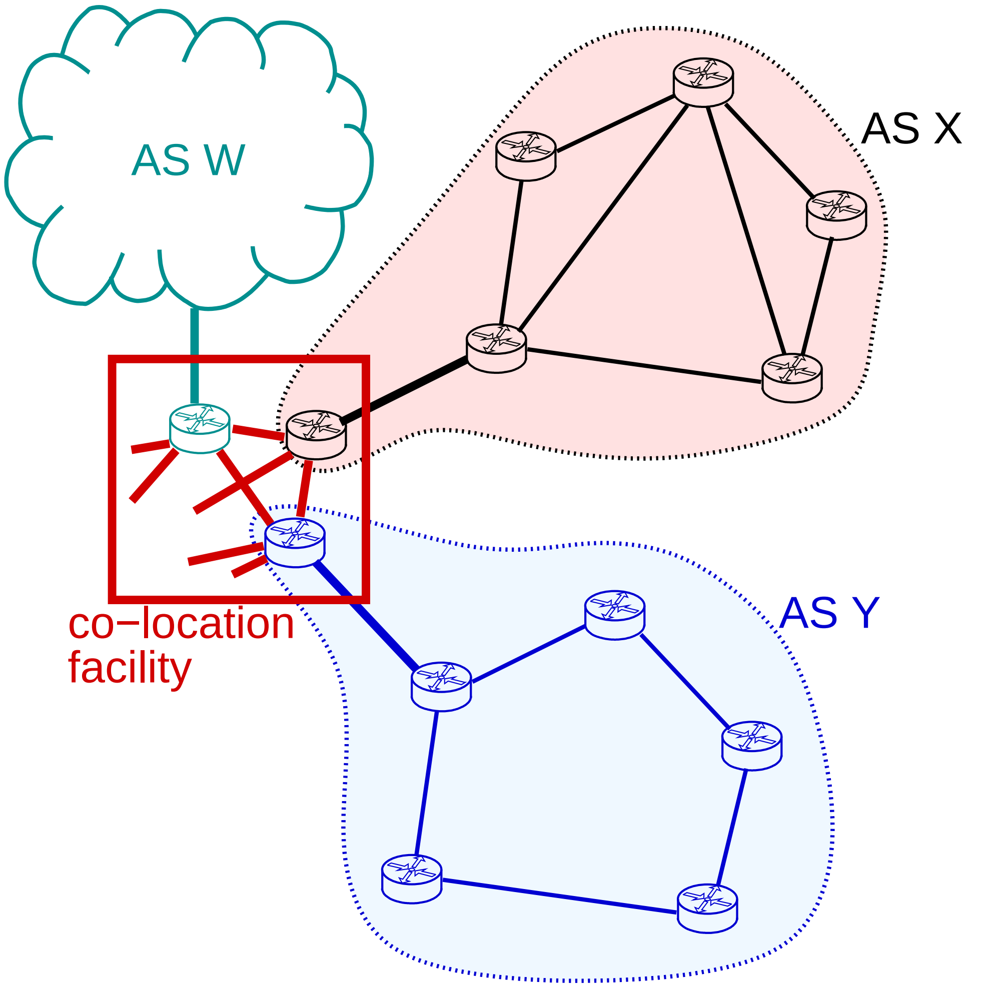
Distributed Exchange points

Some distributed exchange points

- LoNAP, London http://www.lonap.net/
  see their peering matrix at
  http://stats.lonap.net/cgi-bin/matrix.cgi
- LYNX, London http://www.linx.net/
  http://www.nanog.org/mtg-9901/ppt/linx/sld001.htm

Co-Location

- advantage:
  - best of private peering and NAPs
- disadvantages:
  - extra expense
- example:
  - Internap



http://www.internap.com/products/preferredcollo.html

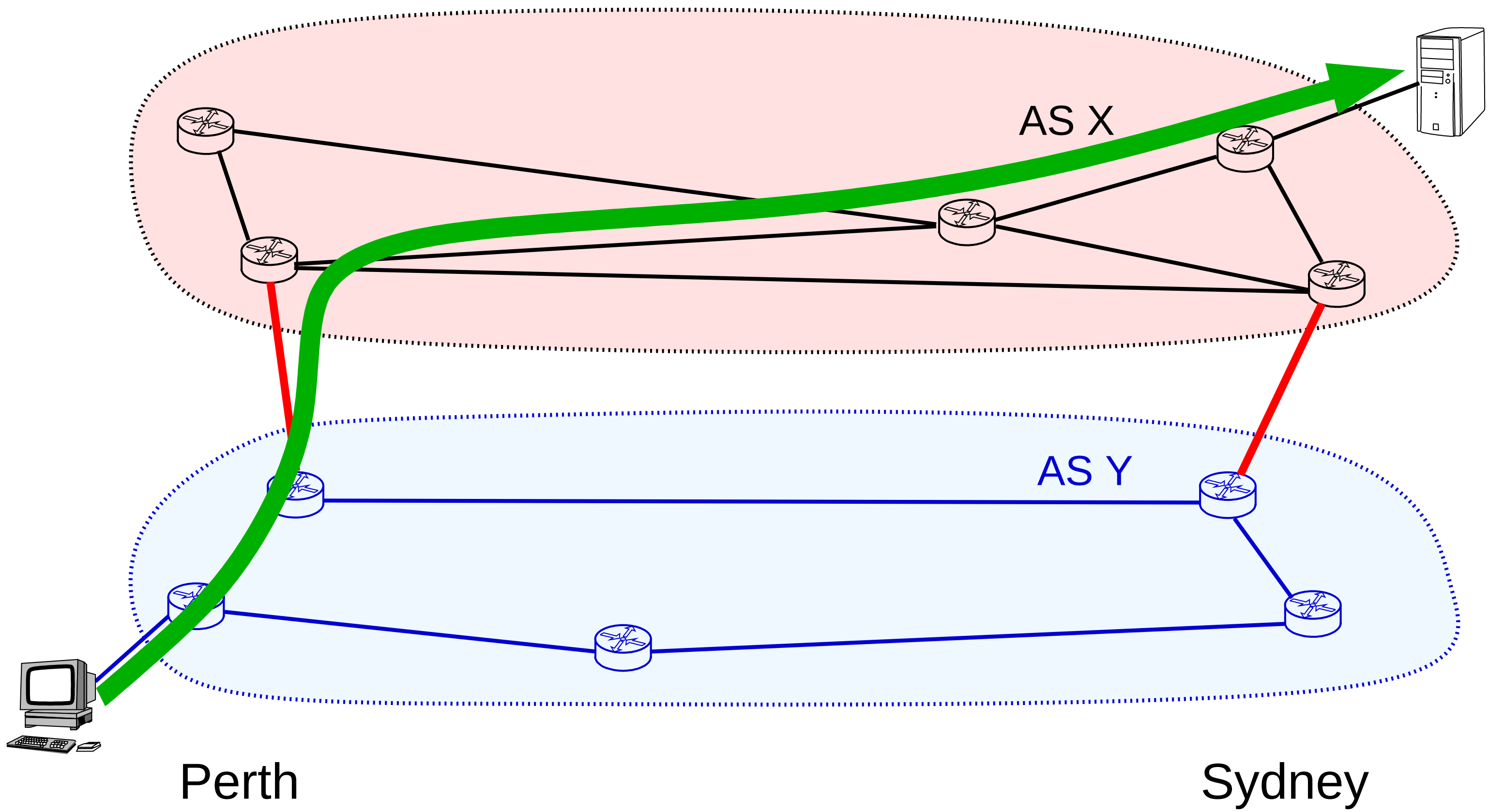
http://www.internap.com/products/locationmap.html

Routing Policy

- policy is a set of arbitrary rules for routing
- examples
  - we prefer to route to **peers** rather than **providers**
    - providers charge us money
    - traffic exchanged with peers for free
  - we prefer to route to route traffic with X
    - maybe X provides better QoS
    - maybe X's network is more secure
  - hot-potato routing
    - reduce cost of carrying traffic on our network by dumping onto someone else's as soon as possible

Hot Potato routing

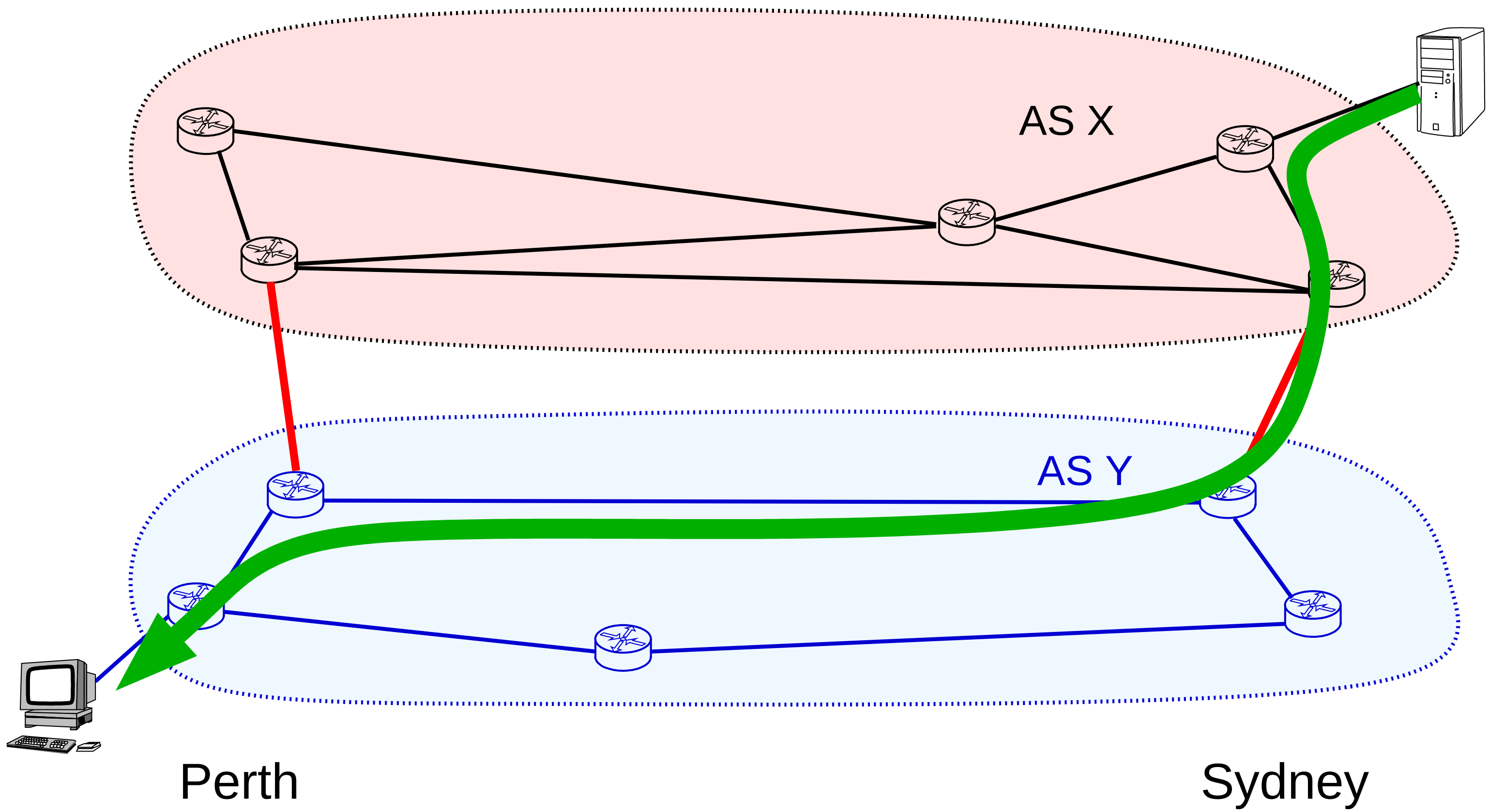
- dump traffic off your network as fast as possible



- traffic from Perth on AS Y to Sydney on AS X

Hot Potato routing

- dump traffic off your network as fast as possible

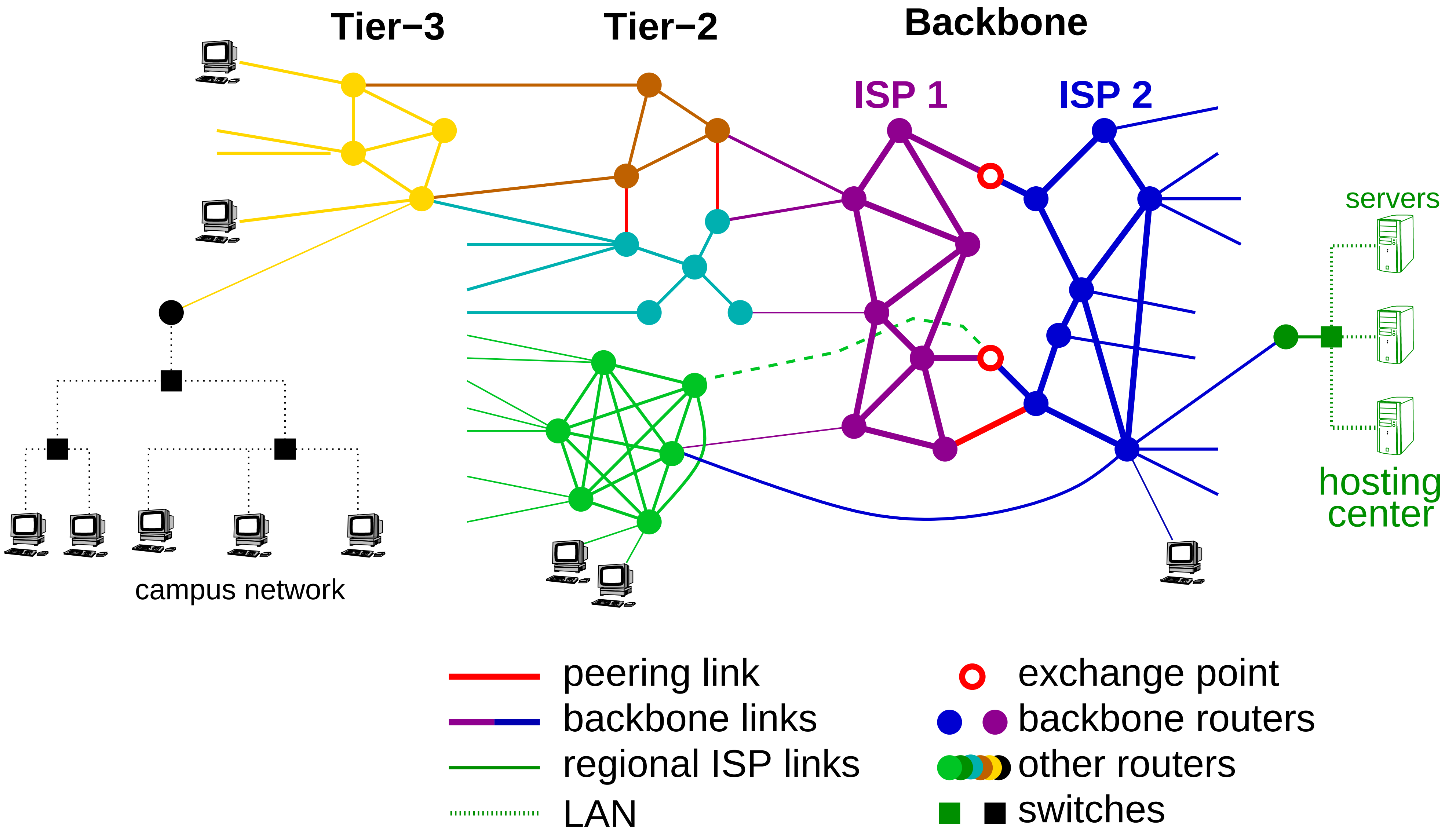


- results in **intrinsic** asymmetry in routing
- only fair if traffic is balanced

Complexities multiply

- no hard and fast rules about tiering
  - companies would like to be called tier-1
  - companies operate multiple networks
  - regional coverages overlap, but aren't equal
- peering between lower tiers to avoid transit fees
- relationships are more than just
  - customer-provider
  - peer-peer
- physical layers add complexity
  - two IP networks (layer 3)
  - relate as peers (so they are competing at level 3)
  - but both buy layer-1 physical transport from same company

A Picture of the Internet



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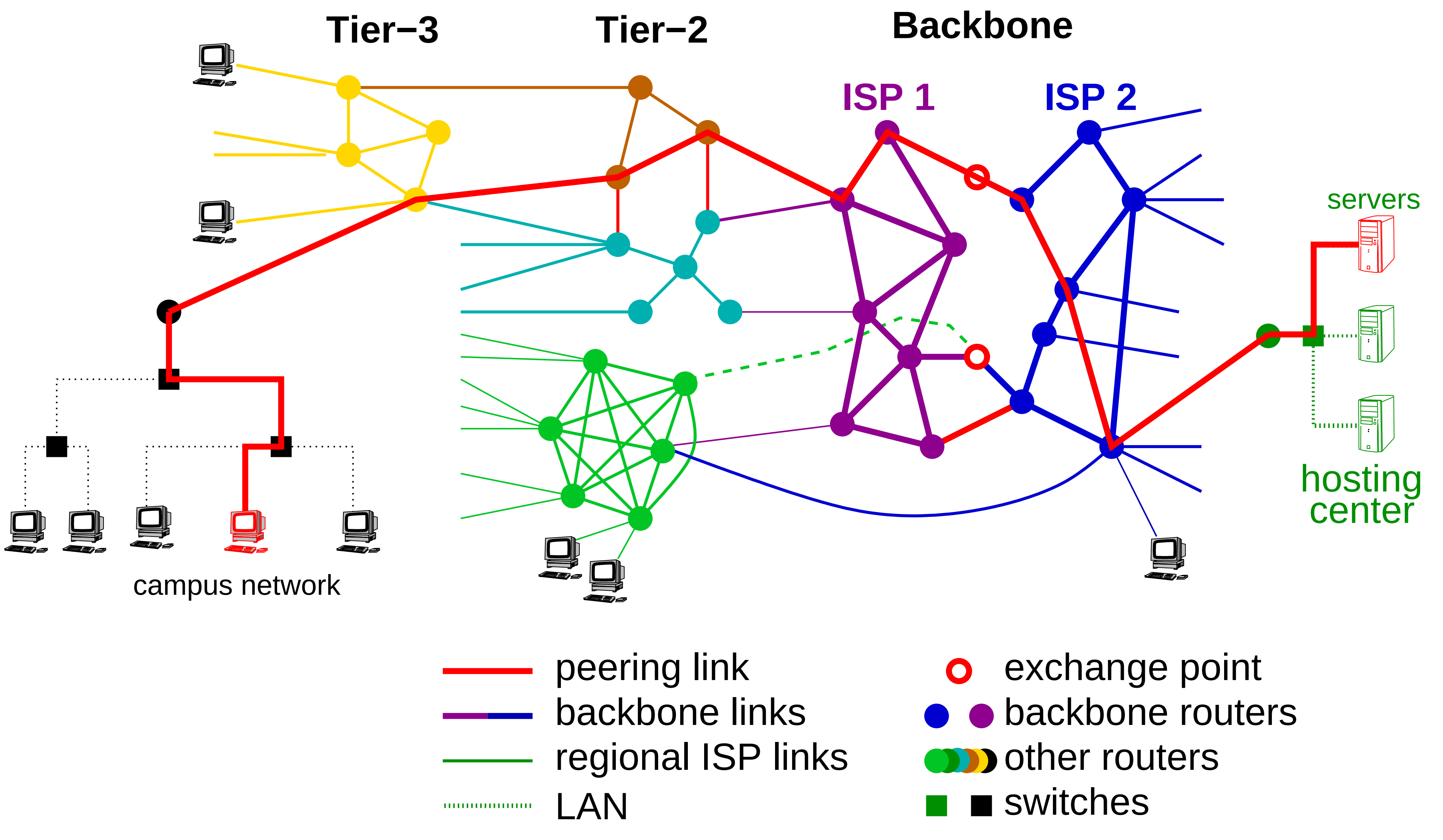

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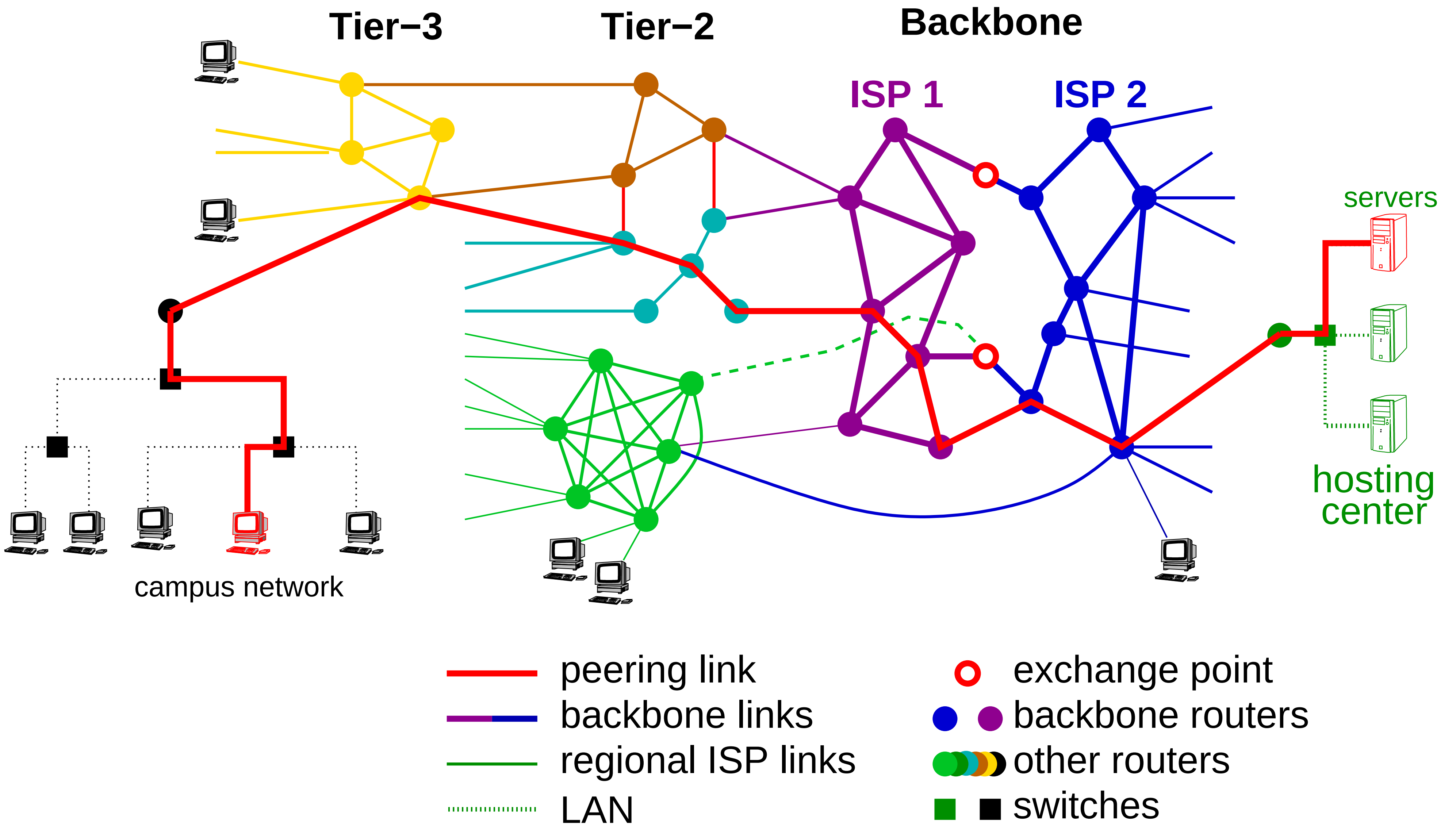

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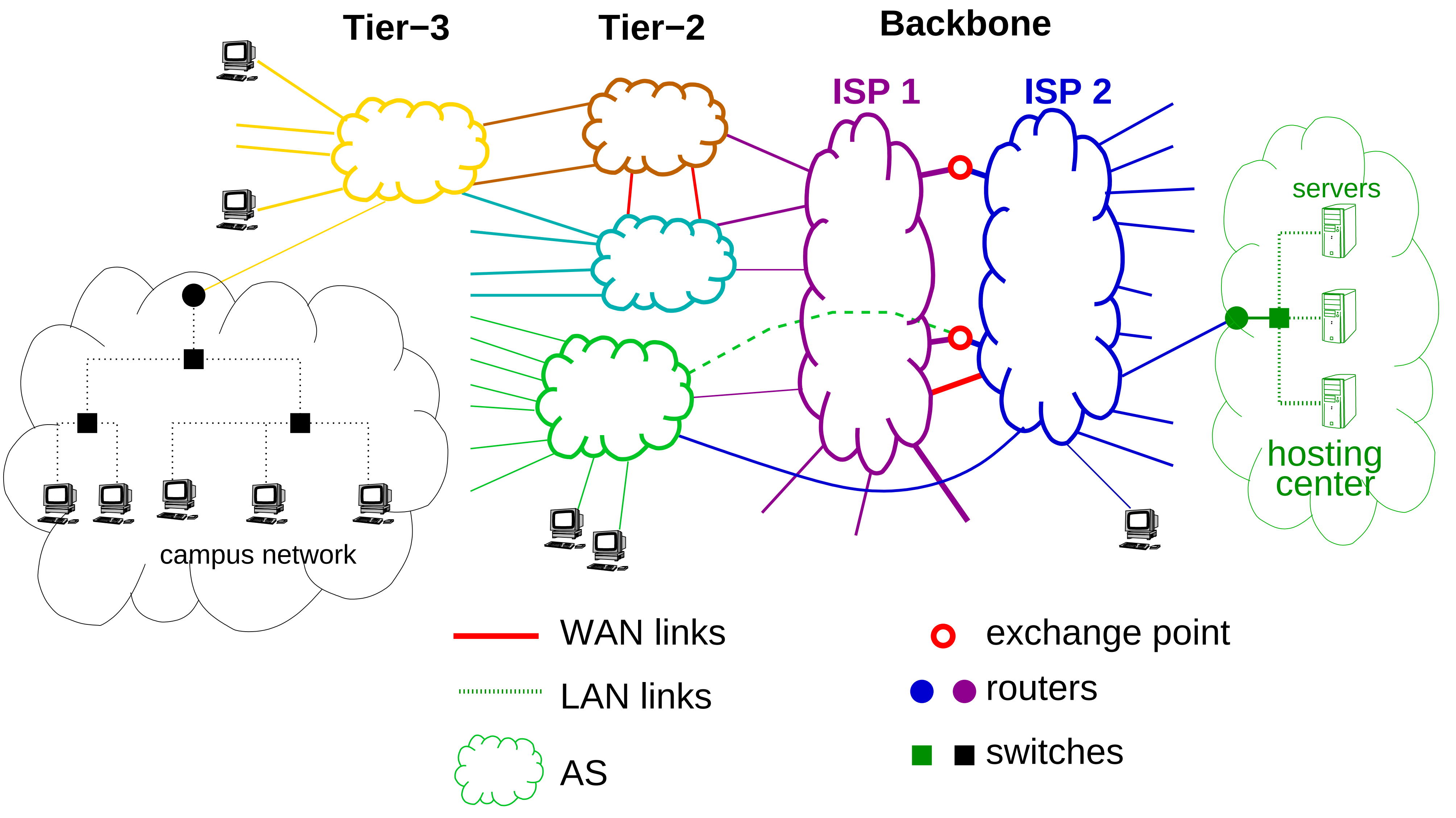
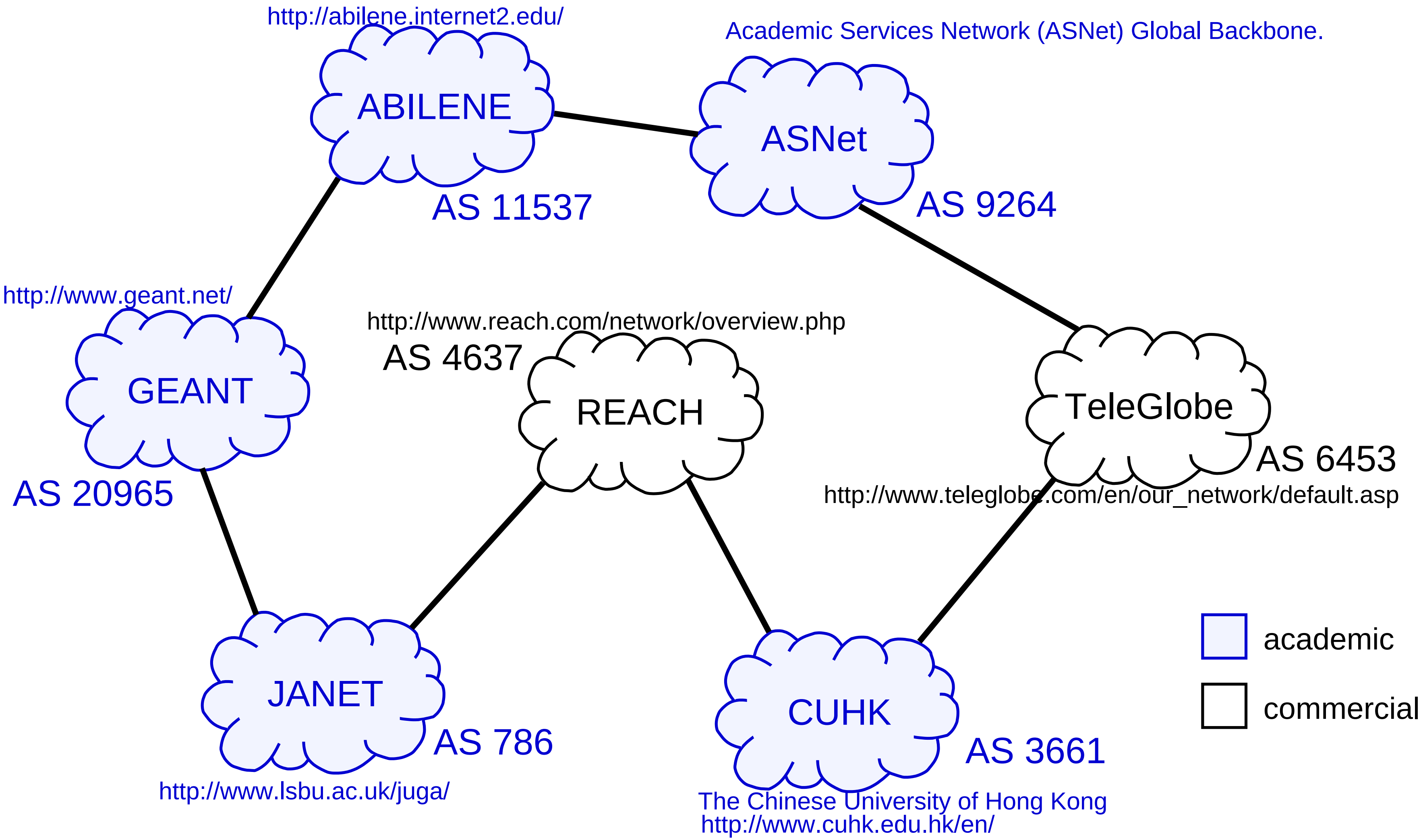


A Real Example

A real example from [3]



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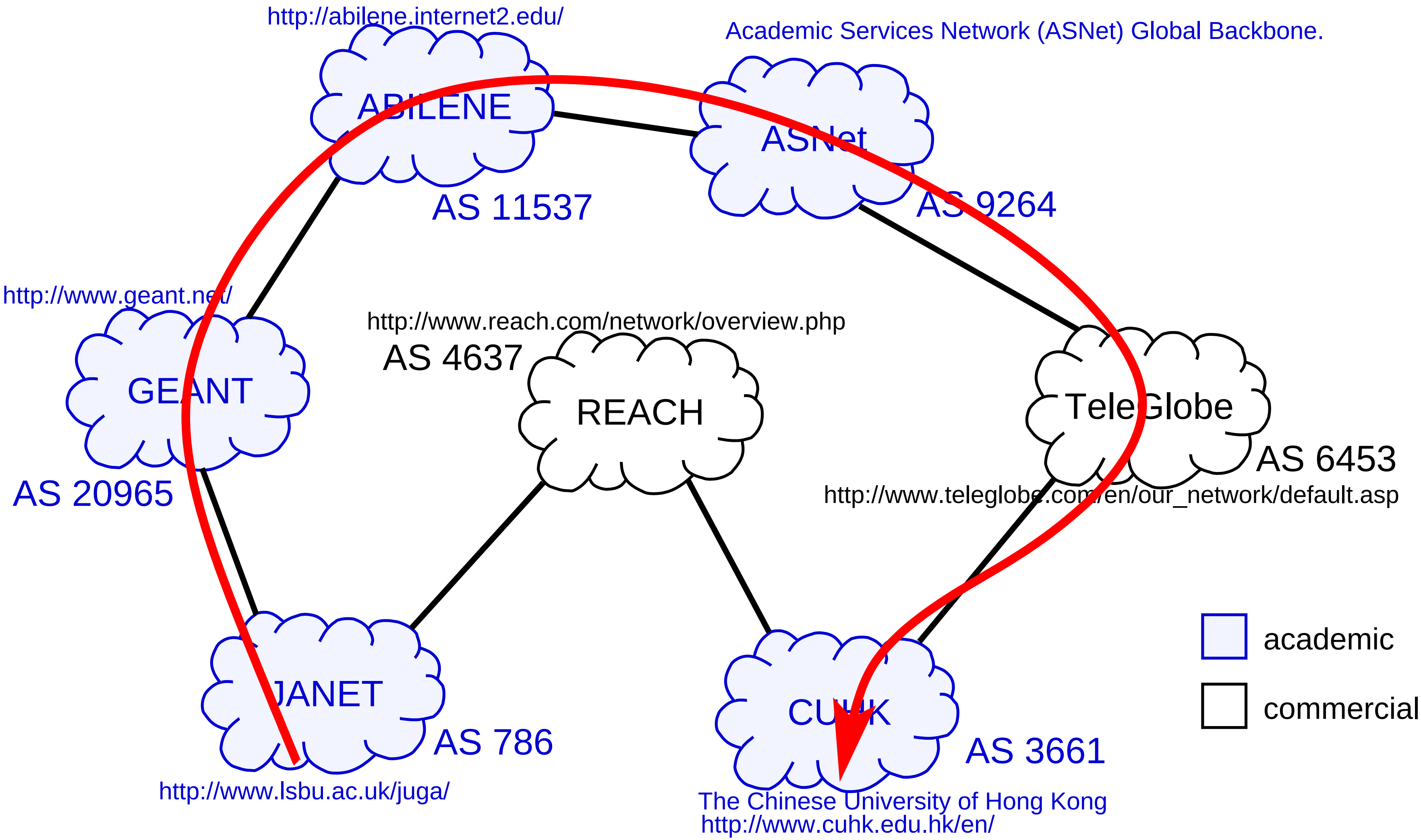

Rule: academic networks prefer to use academic networks

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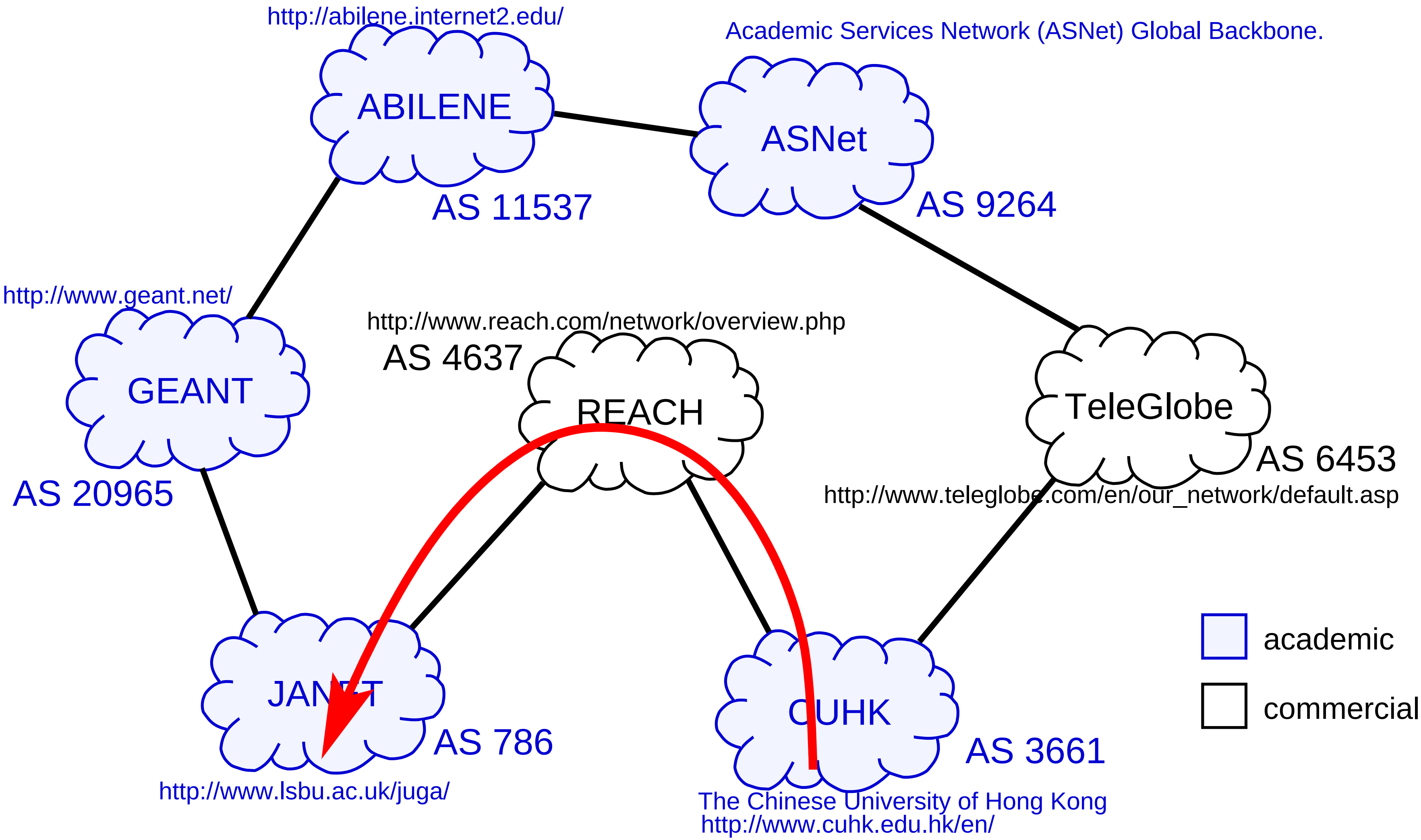

Rule: all else being equal use the shortest path

Inter-domain optimization

- network design: e.g., where should peering links go?
- traffic engineering: balancing loads on peering links
- routing: optimize WRT policies (BGP)

To work with any of these, we need to know more about how BGP works.

References

[1] G. Huston, "Peering and settlements - part I," The Internet Protocol Journal, vol. 2, March 1999.

[2] G. Huston, "Peering and settlements - part II," The Internet Protocol Journal, vol. 2, June 1999.

[3] H. Zheng, E. K. Lua, M. Pias, and T. Griffin, "Internet routing policies and round-trip-times," in Passive and Active Measurements Workshop, (Boston, MA, USA), 2005.

[4] J. Stewart III, BGP4: Inter-domain Routing in the Internet. Addison-Wesley, Boston, 1999.

[5] T. Griffin, "Does BGP Solve the Shortest Paths Problem?," in The North American Network Operators' Group (NANOG) 18, (San Jose, CA, USA), February 2000. http://www.nanog.org/mtg-0002/ppt/griffin/.

[6] T. Griffin, F.Shepherd, and G.Wilfong, "The stable paths problem and interdomain routing," IEEE/ACM Transactions on Networking, vol. 10, no. 2, pp. 232–243, 2002.