Computer Networks

(SCC.203)

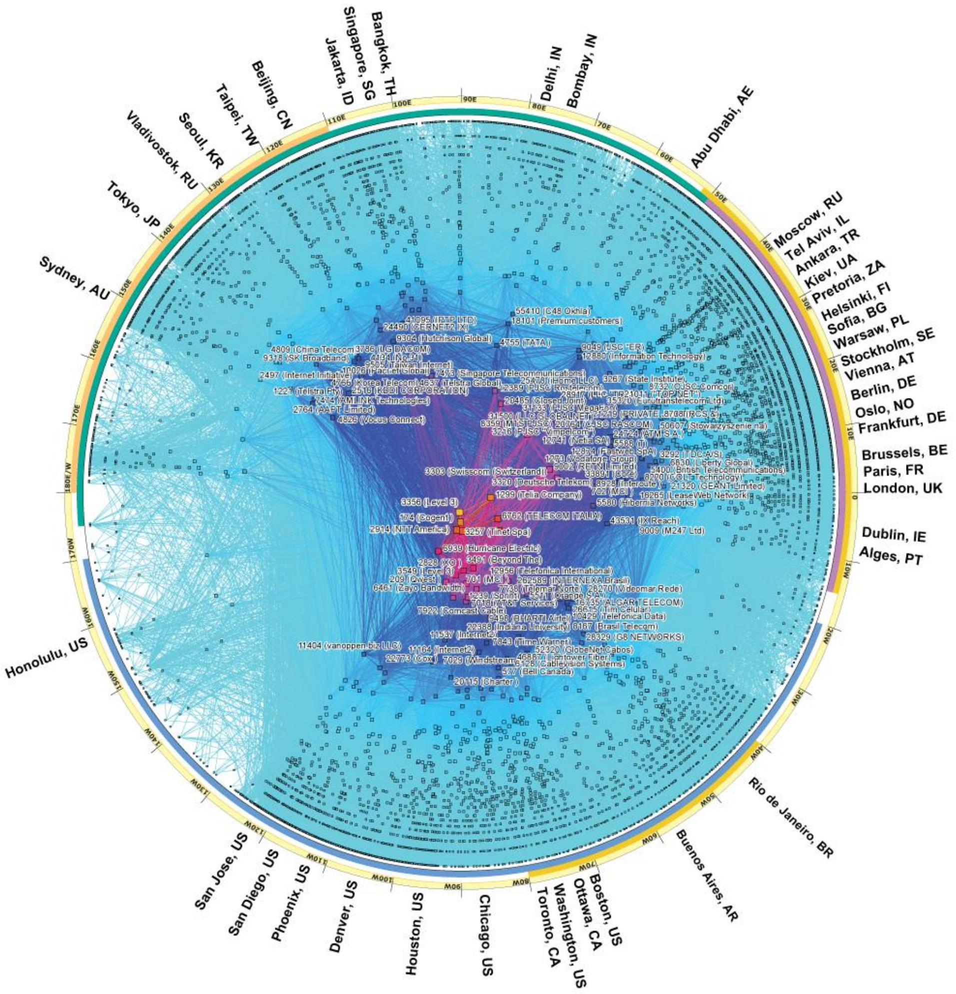
Autonomous Systems and Interdomain Routing

Muhammad Bilal

Autonomous Systems

Inter and Intra domain routing

The scale of the Internet is massive for routing algorithms



- With billions of destinations can't store all destinations in routing tables
- Routing table exchange will swamp links
- Each network admin may want to control routing in its own network

Inter-AS routing: routing within an AS

most common intra-AS routing protocols:

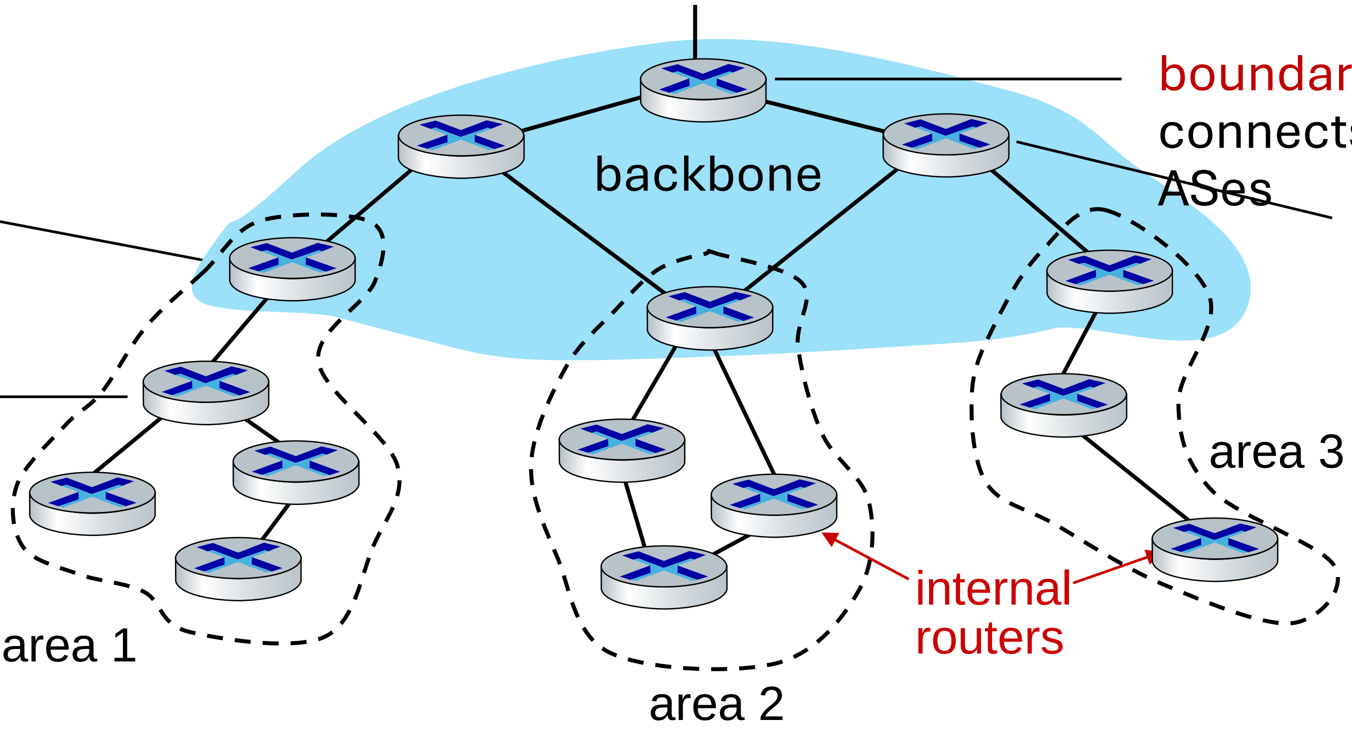
- RIP: Routing Information Protocol [RFC 1723]
  - classic DV: DVs exchanged every 30 secs
  - no longer widely used
- EIGRP: Enhanced Interior Gateway Routing Protocol
  - DV based
  - formerly Cisco-proprietary for decades (became open in 2013 [RFC 7868])
- OSPF: Open Shortest Path First [RFC 2328]
  - link-state routing
  - IS-IS protocol (ISO standard, not RFC standard) essentially same as OSPF

Coping with scale using intra-domain Hierarchy

- OSPF two-level hierarchy: local area, backbone.
  - link-state advertisements flooded only in area, or backbone
  - each node has detailed area topology; only knows direction to reach other destinations

area border routers: "summarize" distances to destinations in own area, advertise in backbone

local routers:
- flood LS in area only
- compute routing within area
- forward packets to outside via area border router



boundary router: connects to other ASes

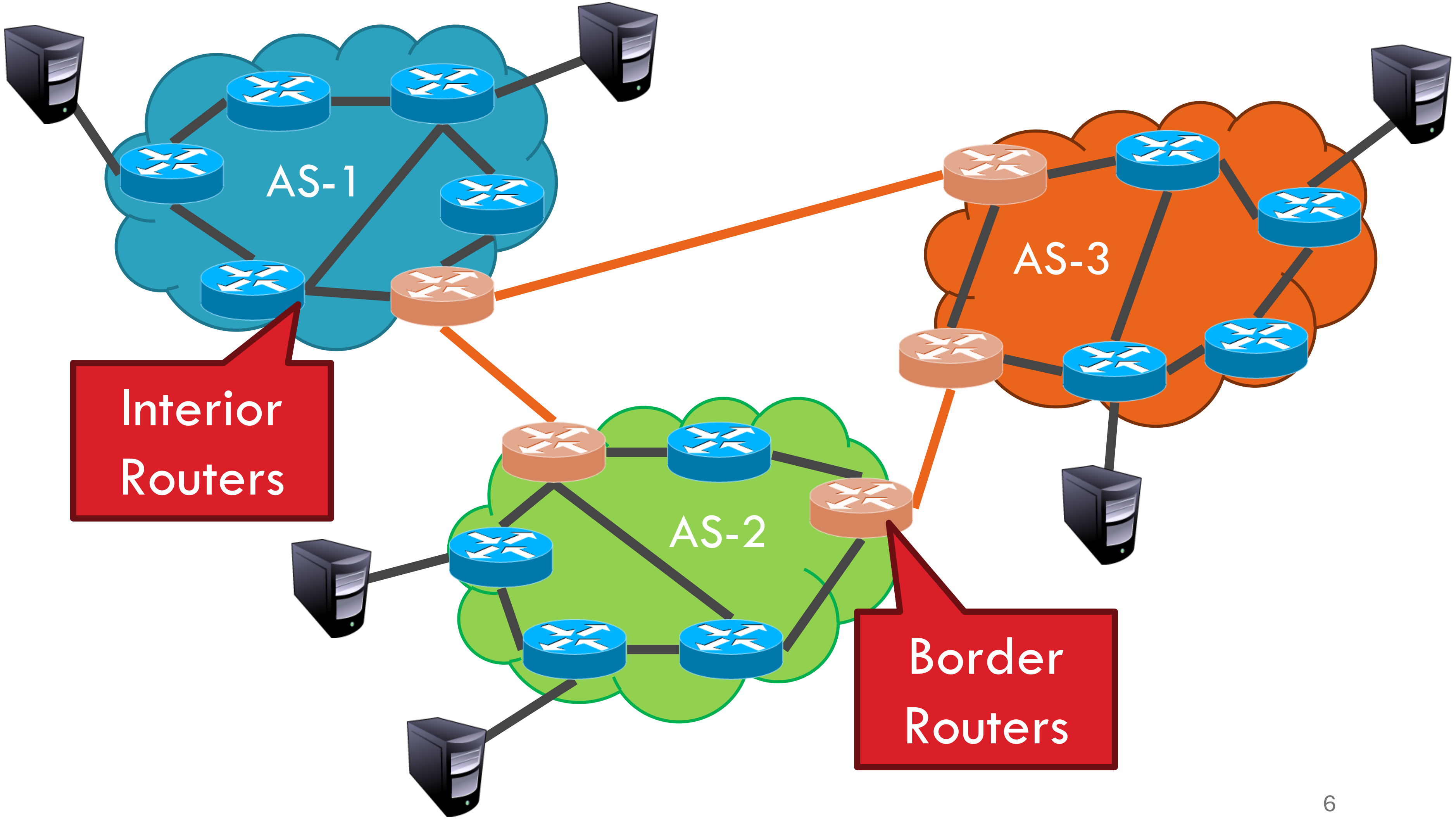
backbone router: runs OSPF limited to backbone

Internet approach to scalable routing

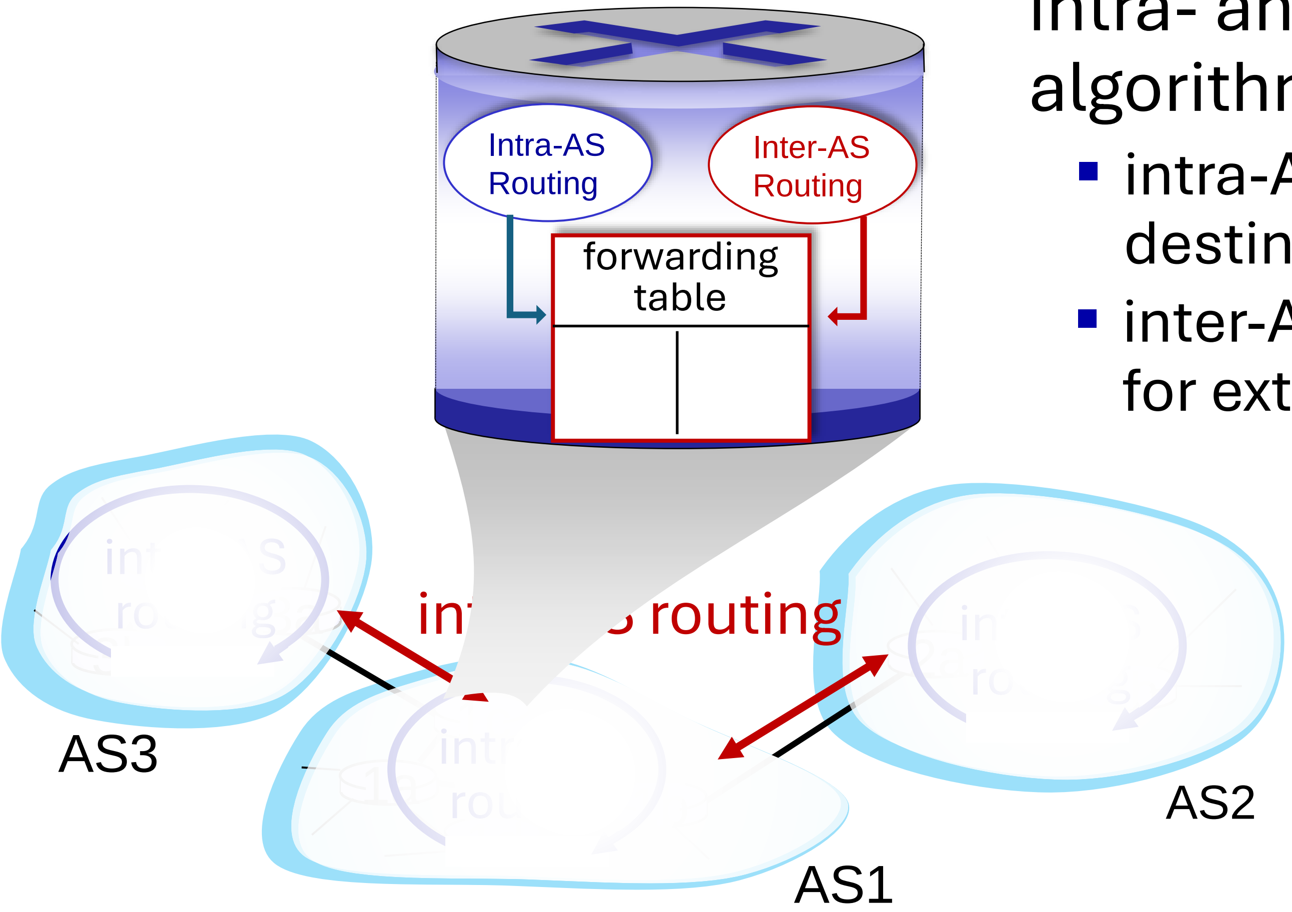
aggregate routers into regions known as "autonomous systems" (AS) (a.k.a. "domains")

All routers in AS must run same intra-domain protocol

Gateways perform inter-domain routing (as well as intra-domain routing)



Interconnected ASes



forwarding table configured by intra- and inter-AS routing algorithms

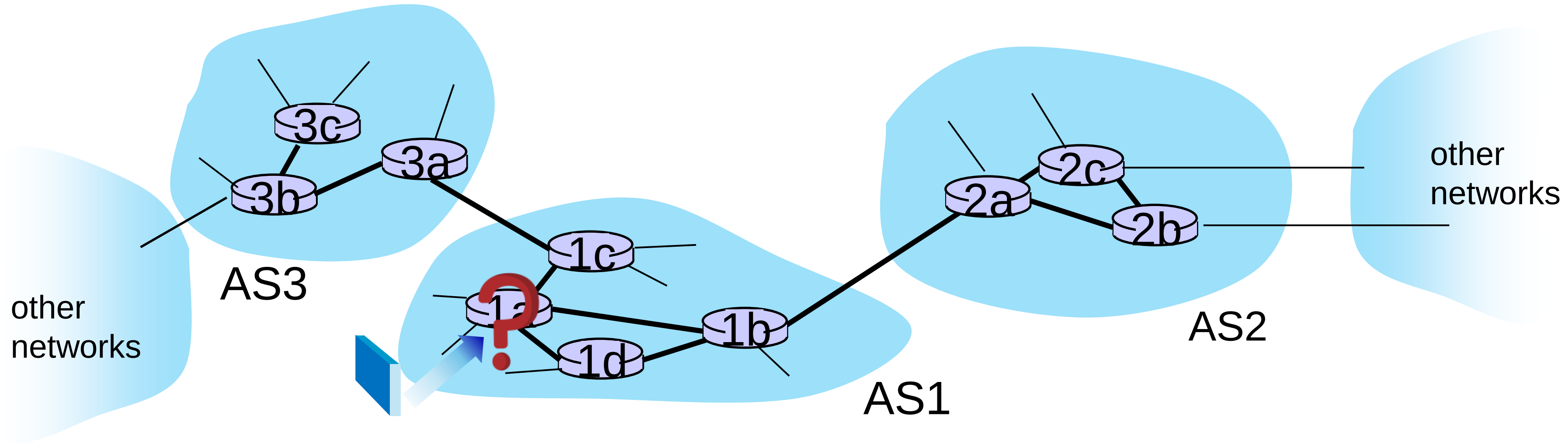
- intra-AS routing determine entries for destinations within AS
- inter-AS & intra-AS determine entries for external destinations

Inter-AS routing: a role in intradomain forwarding

- suppose router in AS1 receives datagram destined outside of AS1:
  - router should forward packet to gateway router in AS1, but which one?

AS1 inter-domain routing must:

1. learn which destinations reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1



AS Numbers

- Each AS identified by an ASN number
  - 32-bit values (original protocol supports only 16-bit ones)
  - 64512 – 65535 are reserved
- Currently, there are ~ 70000 ASNs
  - AT&T: 5074, 6341, 7018, …
  - Sprint: 1239, 1240, 6211, 6242, …
  - Google 15169, 36561 (formerly YT), + others
  - Facebook 32934
  - Lancaster University: 786, 30847
  - https://bgp.he.net/net/148.88.0.0/16

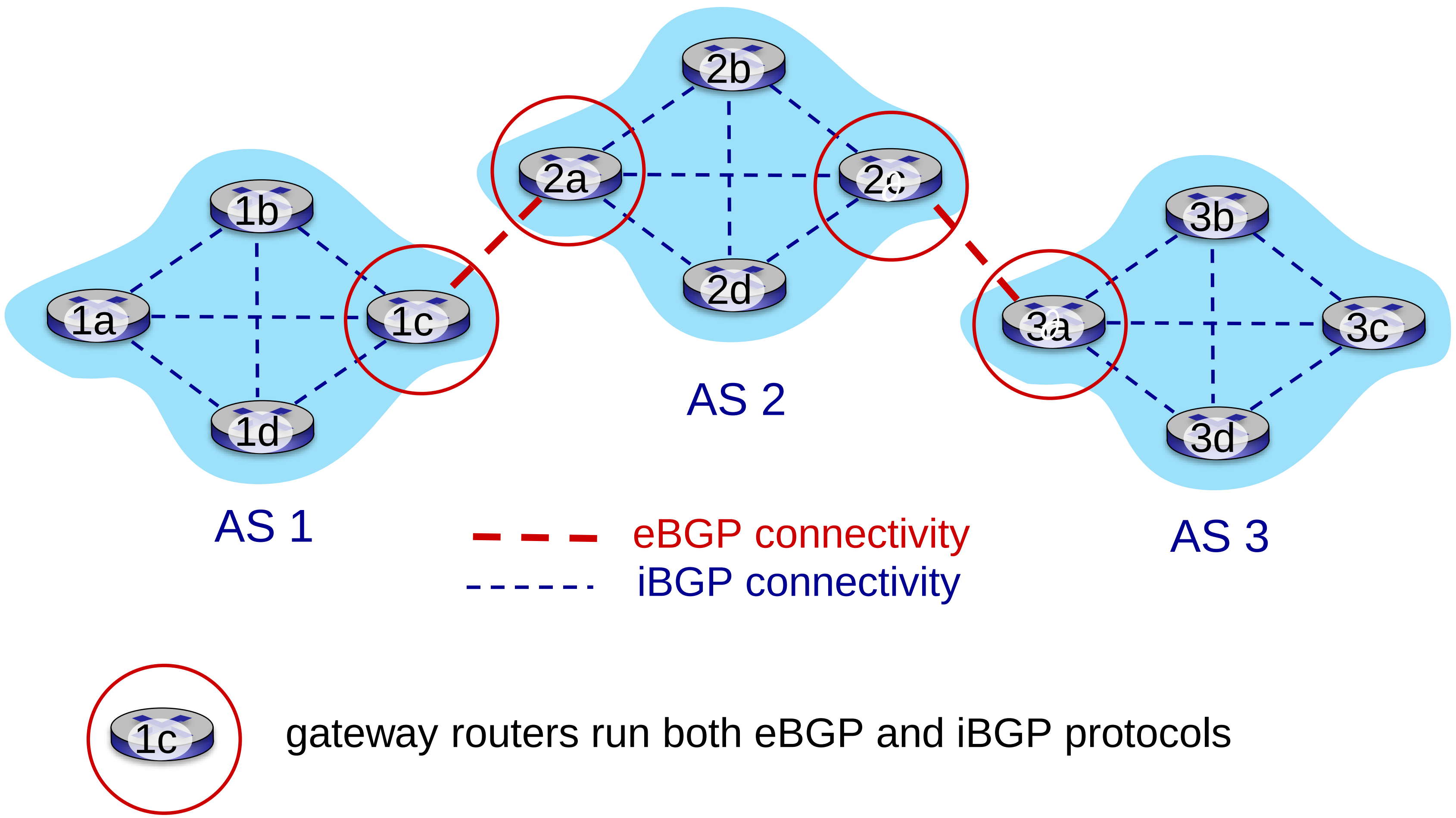
Inter-domain Routing

- What are the requirements?
  - Scalability
  - Flexibility in choosing routes
    - Cost
    - Routing around failures
- BGP (Border Gateway Protocol): the de facto inter-domain routing protocol
  - “glue that holds the Internet together”

Internet inter-AS routing: BGP

- Border Gateway Protocol (BGP)
  - Policy based routing protocol
  - Uses a path vector protocol
- allows subnet (AS) to advertise its existence, and the destinations it can reach, to rest of Internet: "I am here, here is who I can reach, and how"
- Relatively simple protocol, but...
  - Entire world sees advertisements
    - Errors can screw up traffic globally
  - Policies driven by economics
    - How much $$$ does it cost to route along a given path?
    - Not by performance (e.g. shortest paths)
- BGP provides each AS a means to:
  - eBGP: obtain subnet reachability information from neighboring ASes
  - iBGP: propagate reachability information to all AS-internal routers.
  - determine "good" routes to other networks based on reachability information and policy

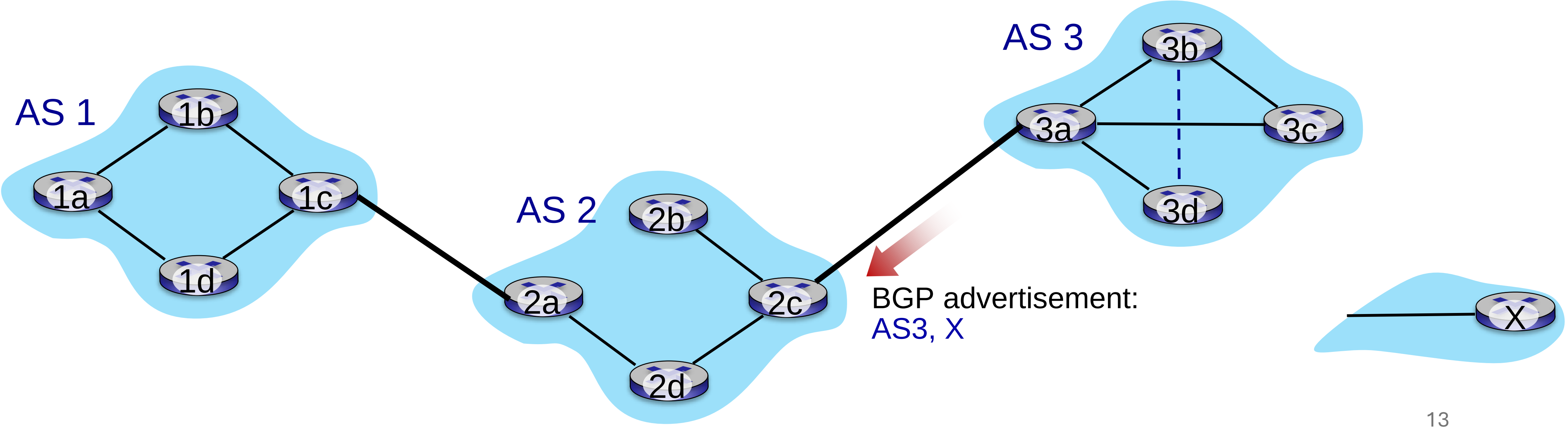
eBGP, iBGP connections



gateway routers run both eBGP and iBGP protocols

BGP basics

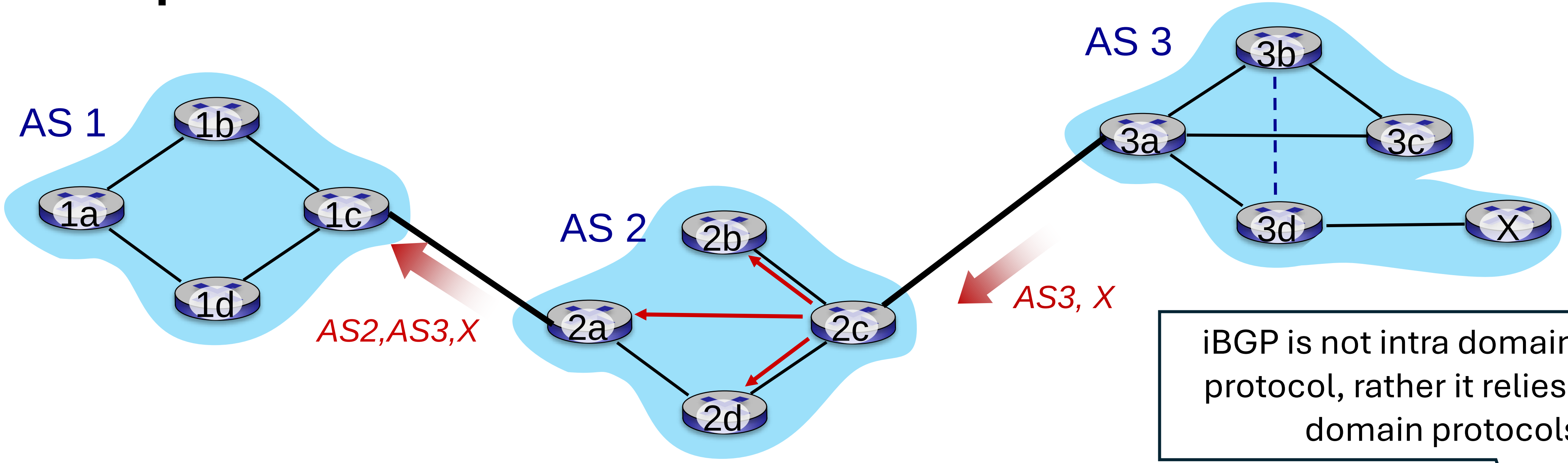
- **BGP session:** two BGP routers ("peers") exchange BGP messages over semi-permanent TCP connection:
  - advertising *paths* to different destination network prefixes (BGP is a "path vector" protocol)
- when AS3 gateway 3a advertises path AS3,X to AS2 gateway 2c:
  - AS3 *promises* to AS2 it will forward datagrams towards X



Path attributes and BGP routes

- BGP advertised route: prefix + attributes
  - prefix: destination being advertised
  - two important attributes:
    - AS-PATH: list of ASes through which prefix advertisement has passed
    - NEXT-HOP: indicates specific internal-AS router to next-hop AS
- policy-based routing:
  - gateway receiving route advertisement uses *import policy* to accept/decline path (e.g., never route through AS Y).
  - AS policy also determines whether to *advertise* path to other other neighboring ASes

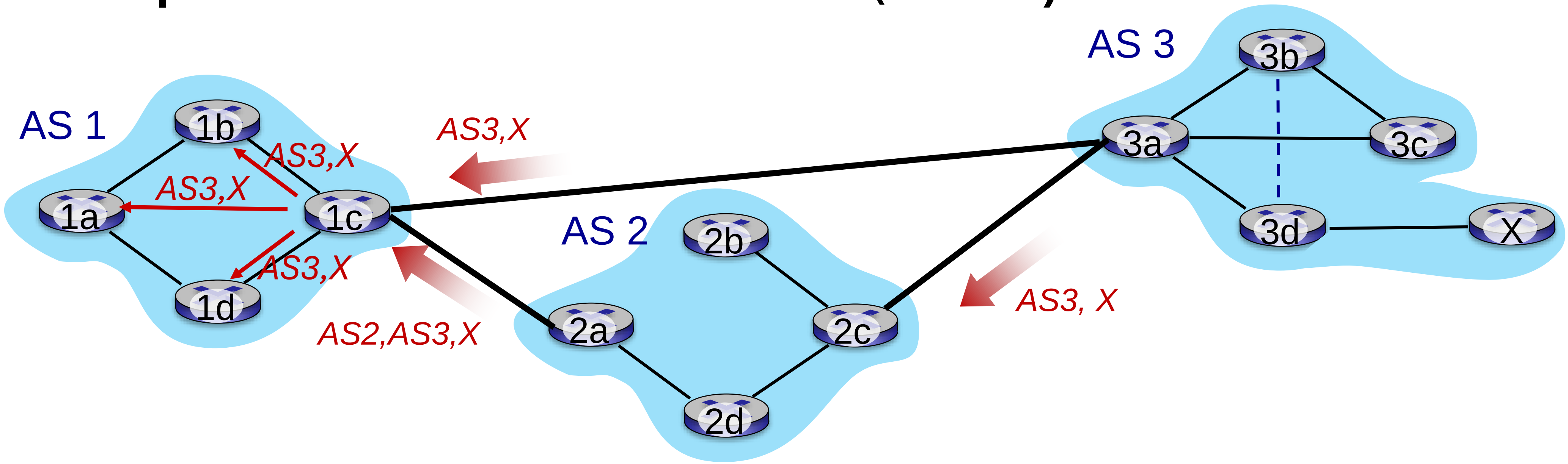
BGP path advertisement



iBGP is not intra domain routing protocol, rather it relies on intra domain protocols.

- AS2 router 2c receives path advertisement AS3,X (via eBGP) from AS3 router 3a
- based on AS2 policy, AS2 router 2c accepts path AS3,X, propagates (via iBGP) to all AS2 routers
- based on AS2 policy, AS2 router 2a advertises (via eBGP) path AS2, AS3, X to AS1 router 1c

BGP path advertisement (more)



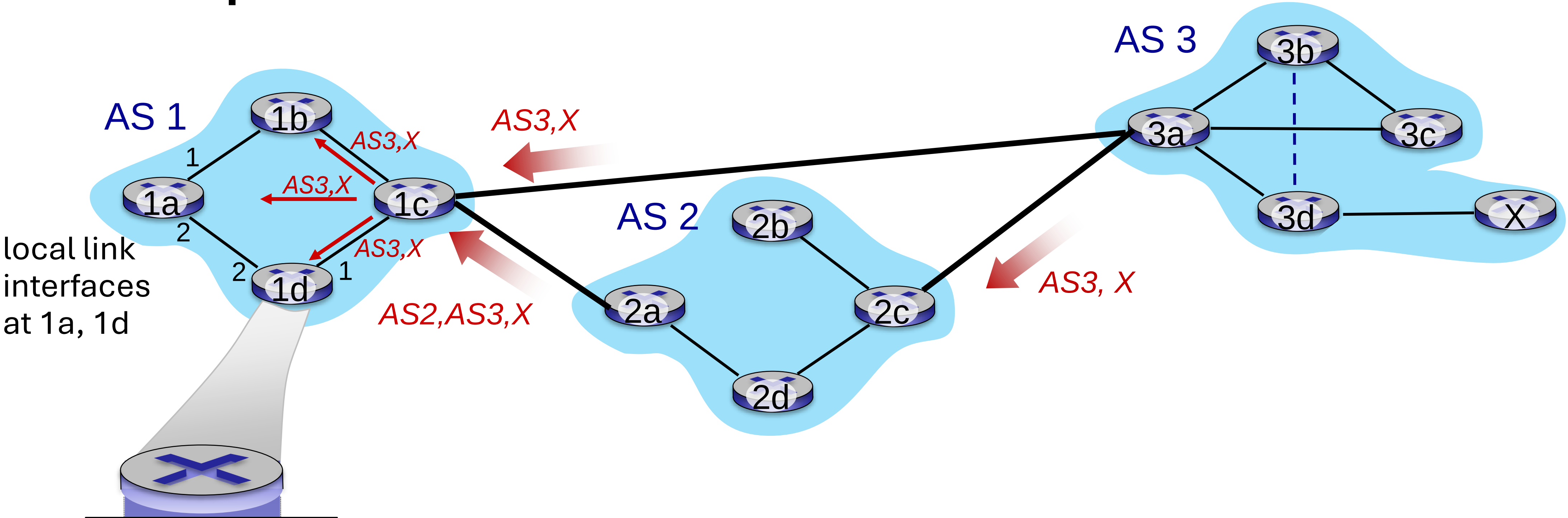
gateway router may learn about multiple paths to destination:

- AS1 gateway router 1c learns path *AS2,AS3,X* from 2a
- AS1 gateway router 1c learns path *AS3,X* from 3a
- based on *policy,* AS1 gateway router 1c chooses path *AS3,X* and advertises path within AS1 via iBGP, if policy states otherwise, it will choose *AS2,AS3,X*

BGP messages

- BGP messages exchanged between peers over TCP connection
- BGP messages:
  - OPEN: opens TCP connection to remote BGP peer and authenticates sending BGP peer
  - UPDATE: advertises new path (or withdraws old)
  - KEEPALIVE: keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - NOTIFICATION: reports errors in previous msg; also used to close connection
- iBGP relies on the IGP (Interior Gateway Protocol) metrics (such as OSPF cost or RIP hop count) for path selection within the AS.

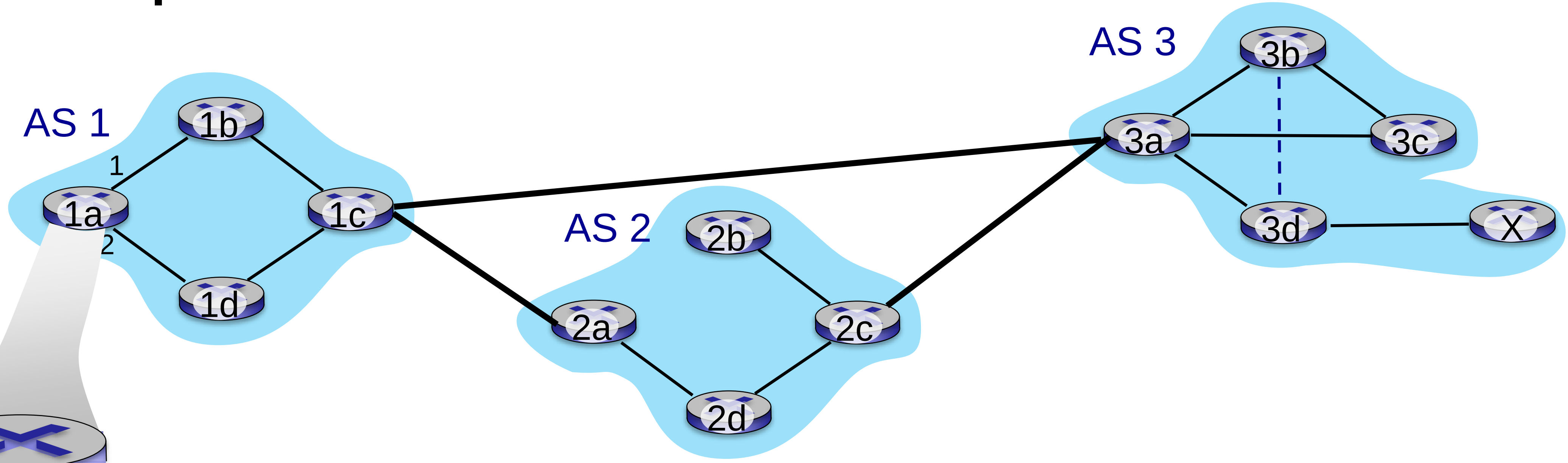
BGP path advertisement

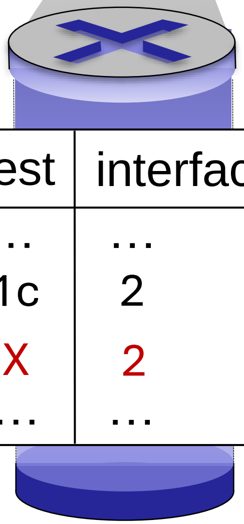


dest	interface
…	…
1c	1
X	1
…	…

- recall: 1a, 1b, 1d learn via iBGP from 1c: “path to X goes through 1c”
- at 1d: OSPF intra-domain routing: to get to 1c, use interface 1
- at 1d: to get to X, use interface 1

BGP path advertisement





dest	interface
…	…
1c	2
X	2
…	…

- recall: 1a, 1b, 1d learn via iBGP from 1c: “path to X goes through 1c”
- at 1d: OSPF intra-domain routing: to get to 1c, use interface 1
- at 1d: to get to X, use interface 1
- at 1a: OSPF intra-domain routing: to get to 1c, use interface 2
- at 1a: to get to X, use interface 2

Why different Intra-, Inter-AS routing ?

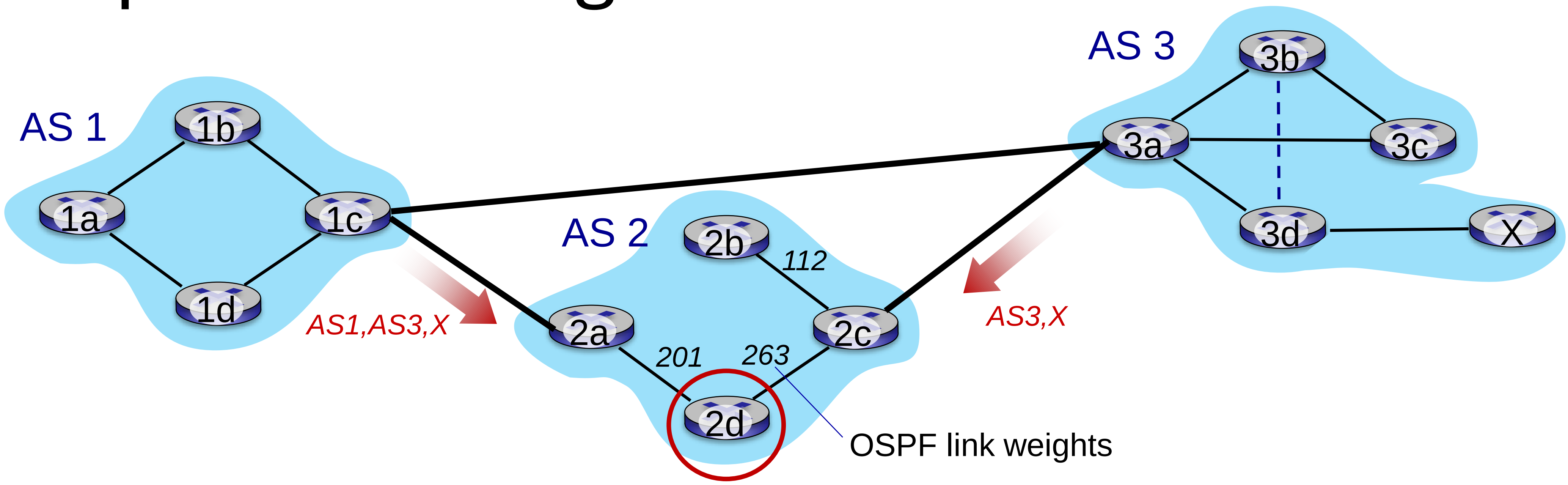
scale:

- hierarchical routing saves table size, reduced update traffic

performance:

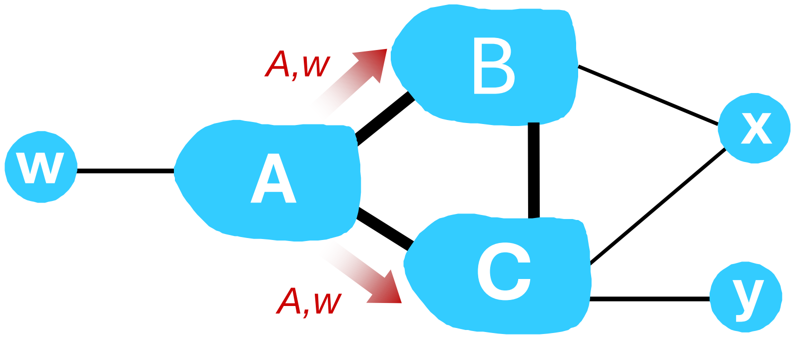
- intra-AS: can focus on performance
- inter-AS: policy dominates over performance

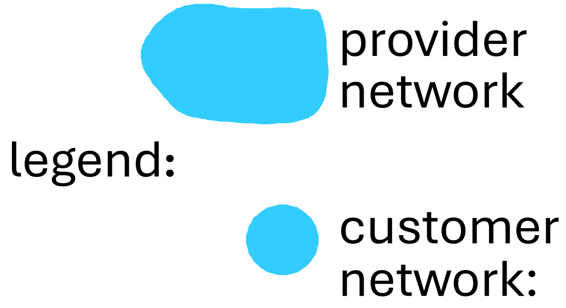
Hot potato routing



- 2d learns (via iBGP) it can route to X via 2a or 2c
- hot potato routing: choose local gateway that has least *intra-domain* cost (e.g., 2d chooses 2a, even though more AS hops to *X*): don't worry about inter-domain cost!

BGP: achieving policy via advertisements

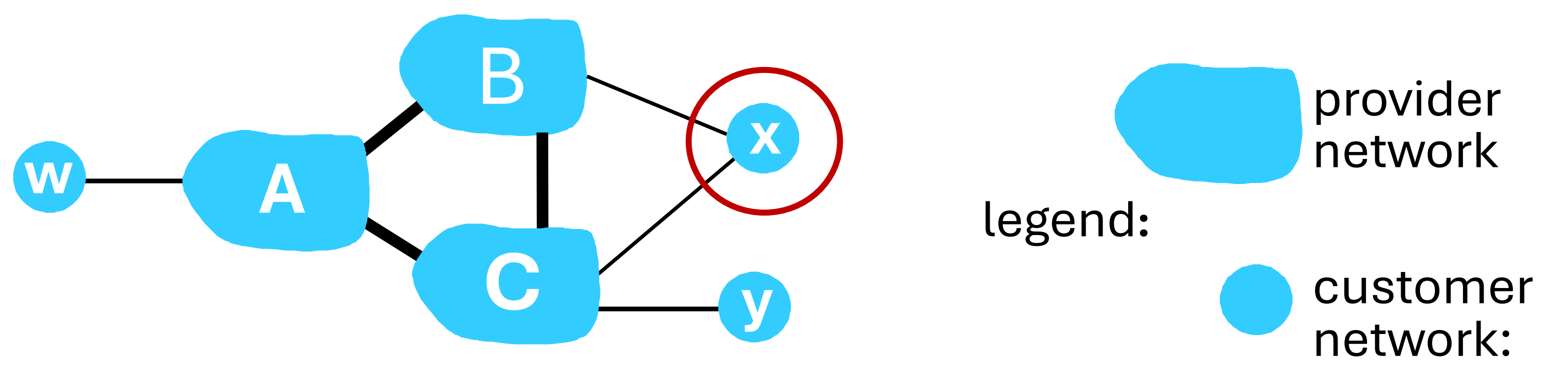




ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs – a typical "real world" policy)

- A advertises path Aw to B and to C
- B *chooses not to advertise* BAw to C!
  - B gets no "revenue" for routing CBAw, since none of C, A, w are B's customers
  - C does *not* learn about CBAw path
- C will route CAw (not using B) to get to w

BGP: achieving policy via advertisements (more)



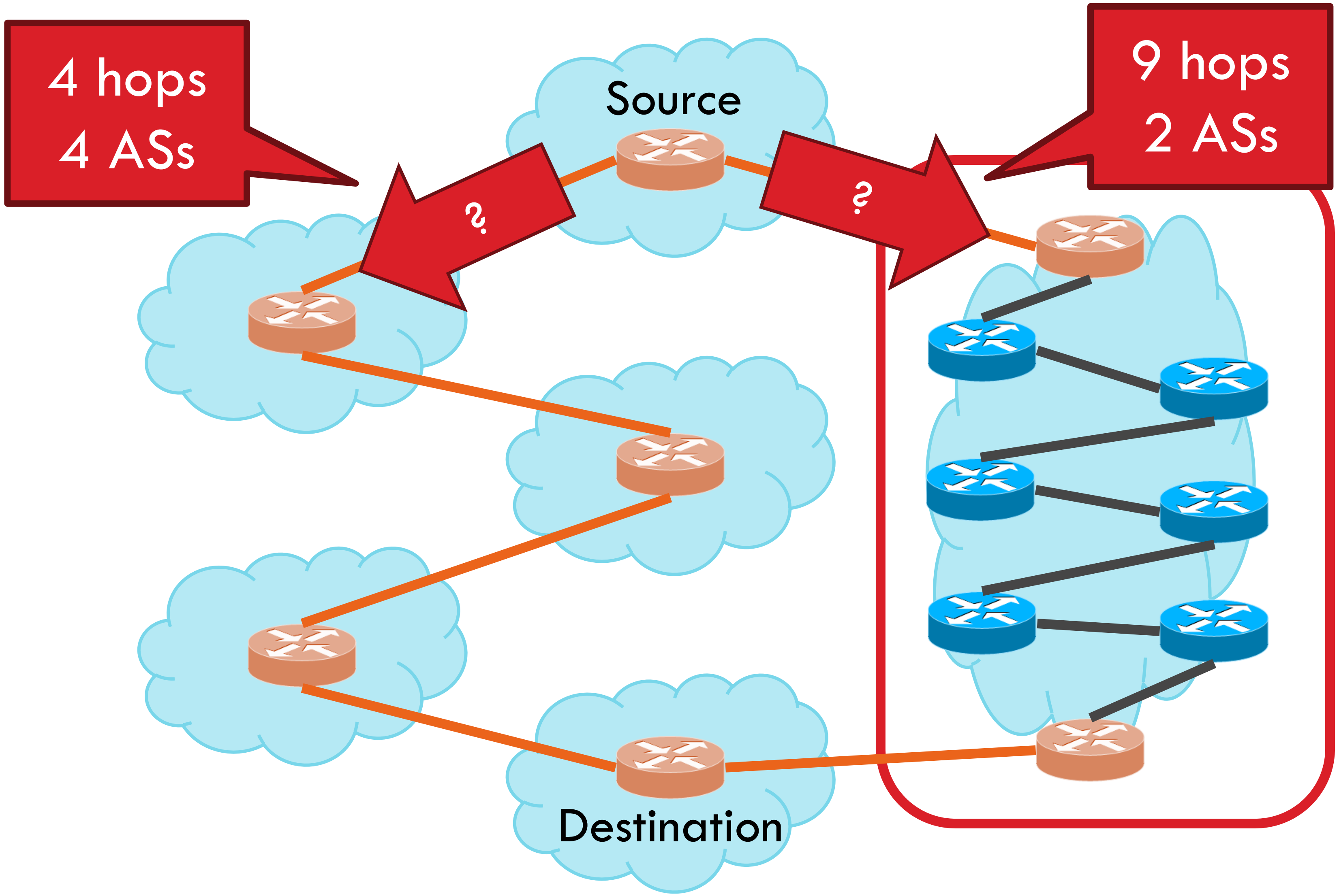
ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs – a typical "real world" policy)

- A,B,C are provider networks
- x,w,y are customer (of provider networks)
- x is dual-homed: attached to two networks
- *policy to enforce:* x does not want to route from B to C via x
  - .. so x will not advertise to B a route to C

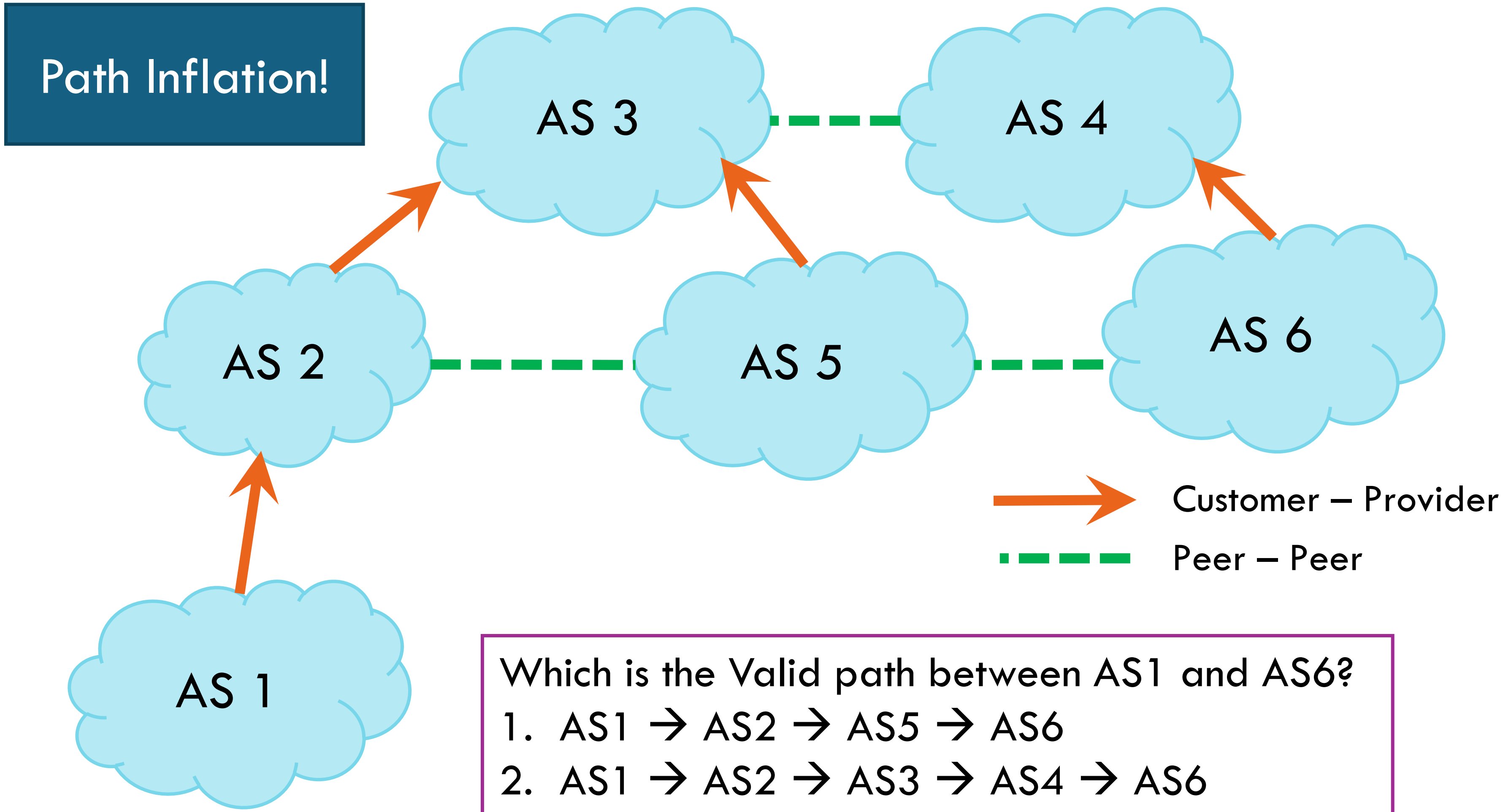
BGP route selection

- router may learn about more than one route to destination AS, selects route based on:
    1. local preference value attribute: policy decision
    2. shortest AS-PATH
    3. closest NEXT-HOP router: hot potato routing
    4. additional criteria

Remember: Shortest AS Path != Shortest Path

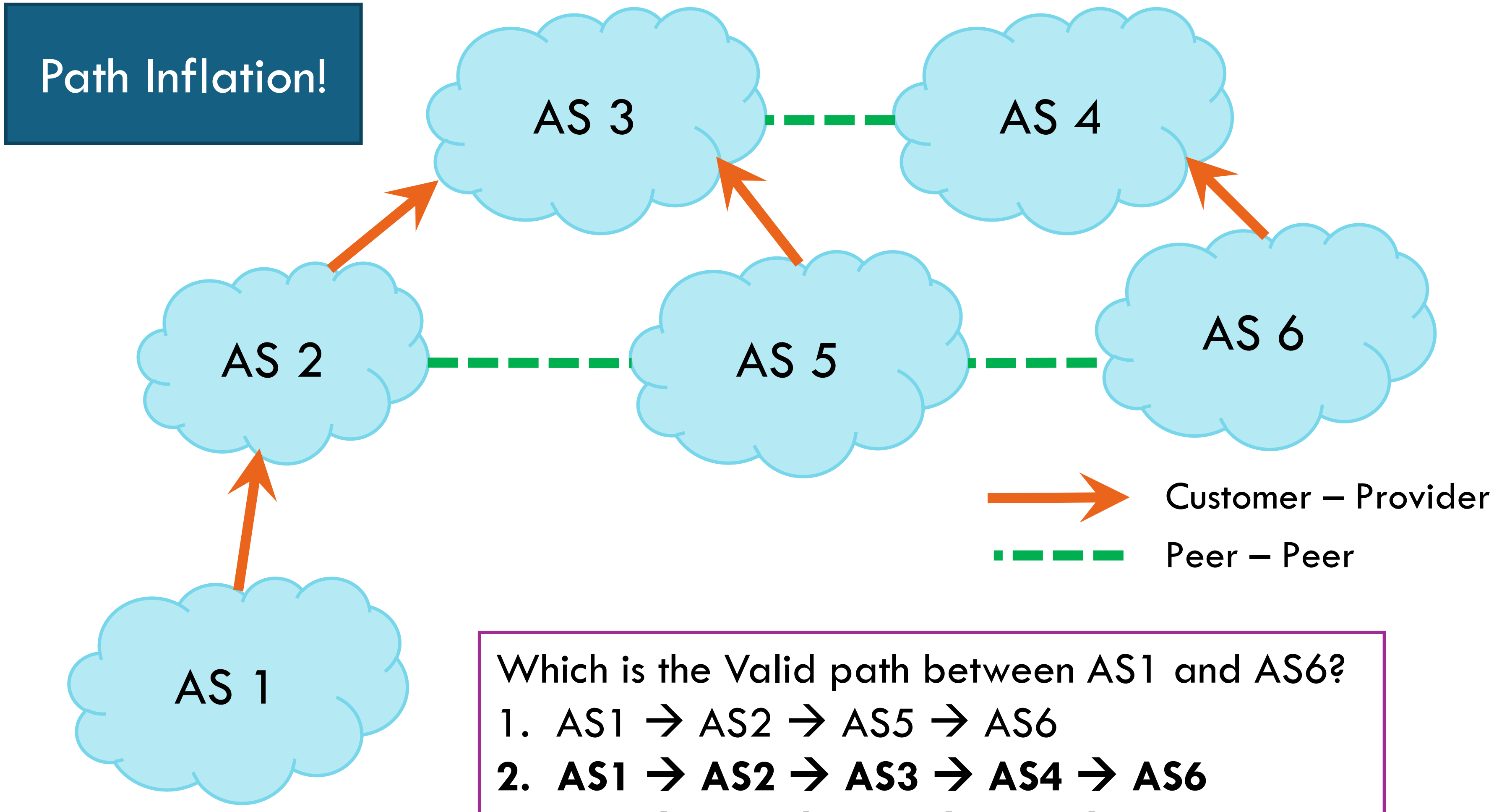


BGP Path Selection!



Which is the Valid path between AS1 and AS6?
1. AS1 → AS2 → AS5 → AS6
2. AS1 → AS2 → AS3 → AS4 → AS6
3. AS1 → AS2 → AS3 → AS5 → AS6

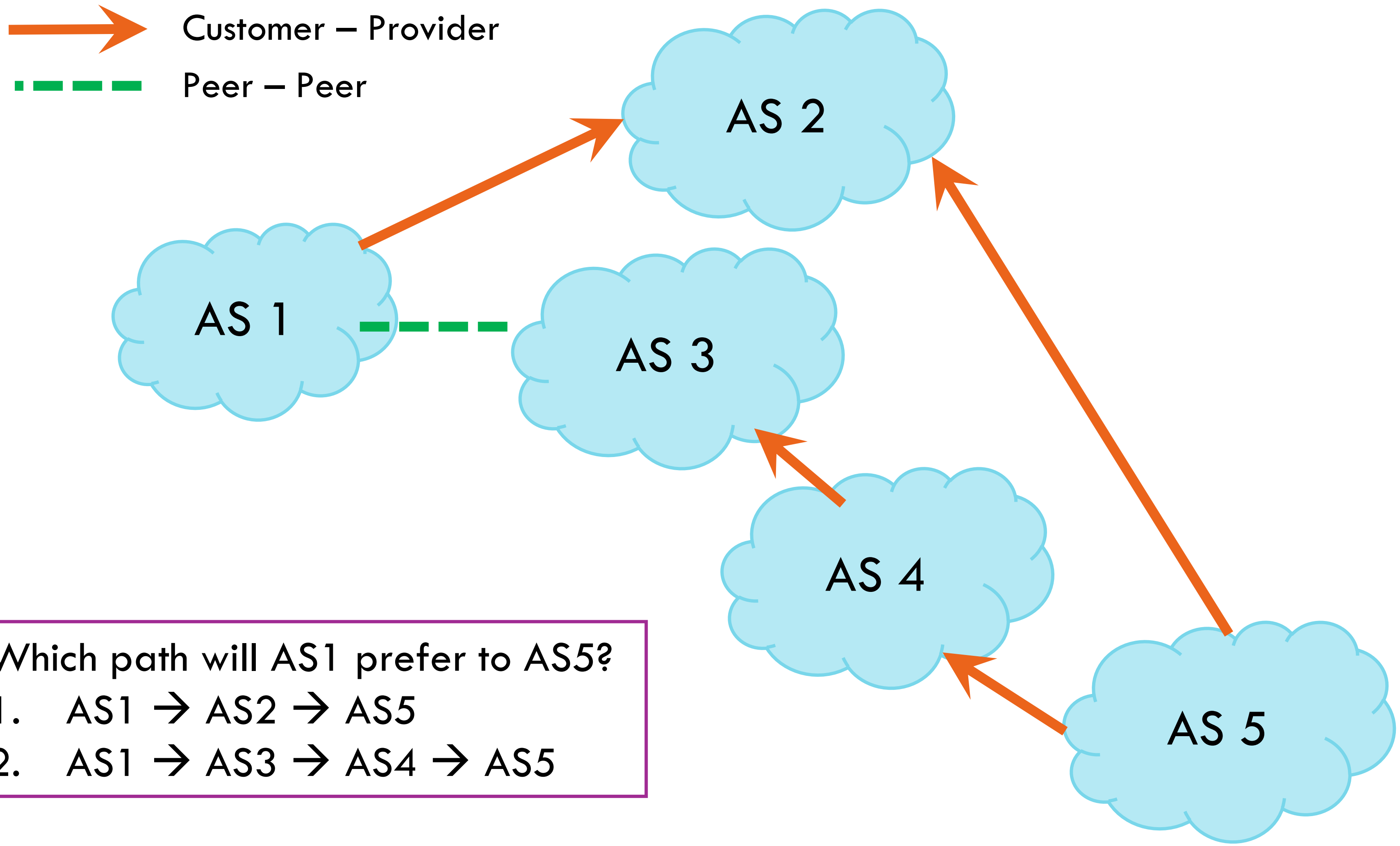
BGP Path Selection!



Which is the Valid path between AS1 and AS6?

1. AS1 → AS2 → AS5 → AS6
2. **AS1 → AS2 → AS3 → AS4 → AS6**
3. AS1 → AS2 → AS3 → AS5 → AS6

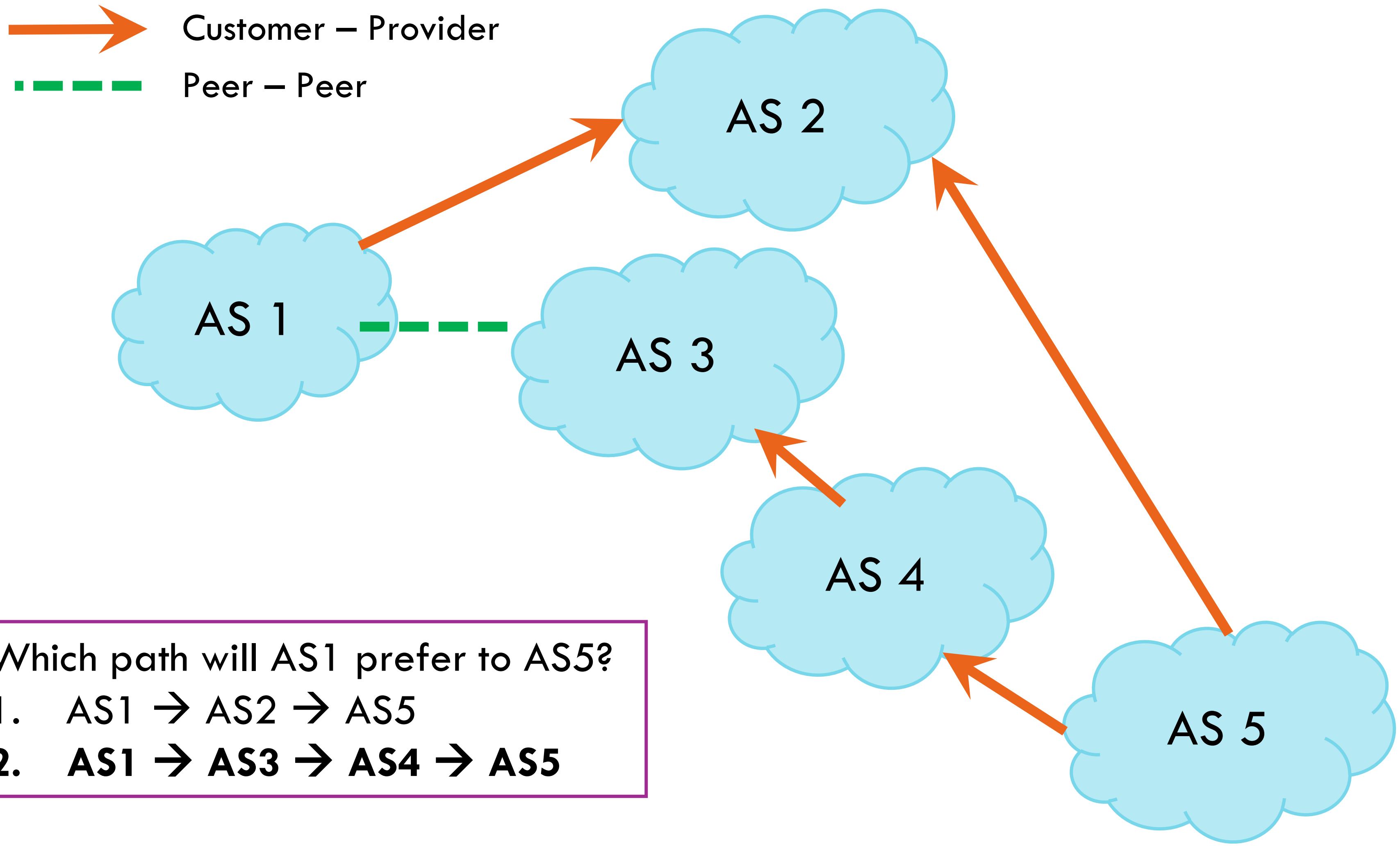
BGP Path Selection!



Which path will AS1 prefer to AS5?

1. AS1 → AS2 → AS5
2. AS1 → AS3 → AS4 → AS5

BGP Path Selection!



Which path will AS1 prefer to AS5?

1. AS1 → AS2 → AS5
2. **AS1 → AS3 → AS4 → AS5**

Network layer: Summary

we've learned a lot!

- approaches to network control plane
  - per-router control (traditional)
  - logically centralized control (software defined networking)
- traditional routing algorithms
  - implementation in Internet: OSPF , BGP
- SDN controllers
  - implementation in practice: ODL, ONOS
- Internet Control Message Protocol
- network management

next stop: link layer!

Thanks for listening!
Any questions?

Acknowledgment

- James F. Kurose University of Massachusetts, Amherst
- Keith W. Ross NYU and NYU Shanghai