Network Layer (8): Routing Protocols

Required reading:
Kurose 5.3, 5.4

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Autonomous Systems

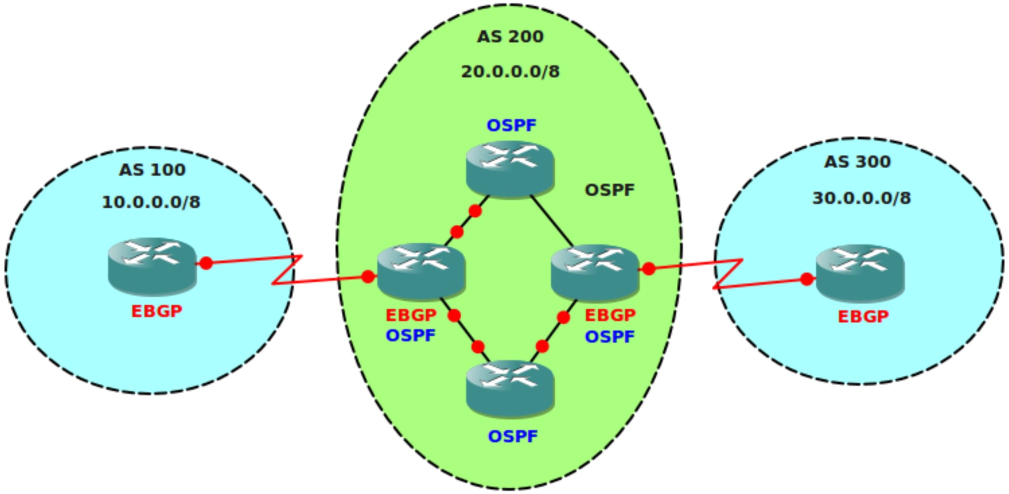
Autonomous System (AS) – set of routers or networks <u>administered by a single organization</u> such as

- corporate network
- campus network
- ISP network

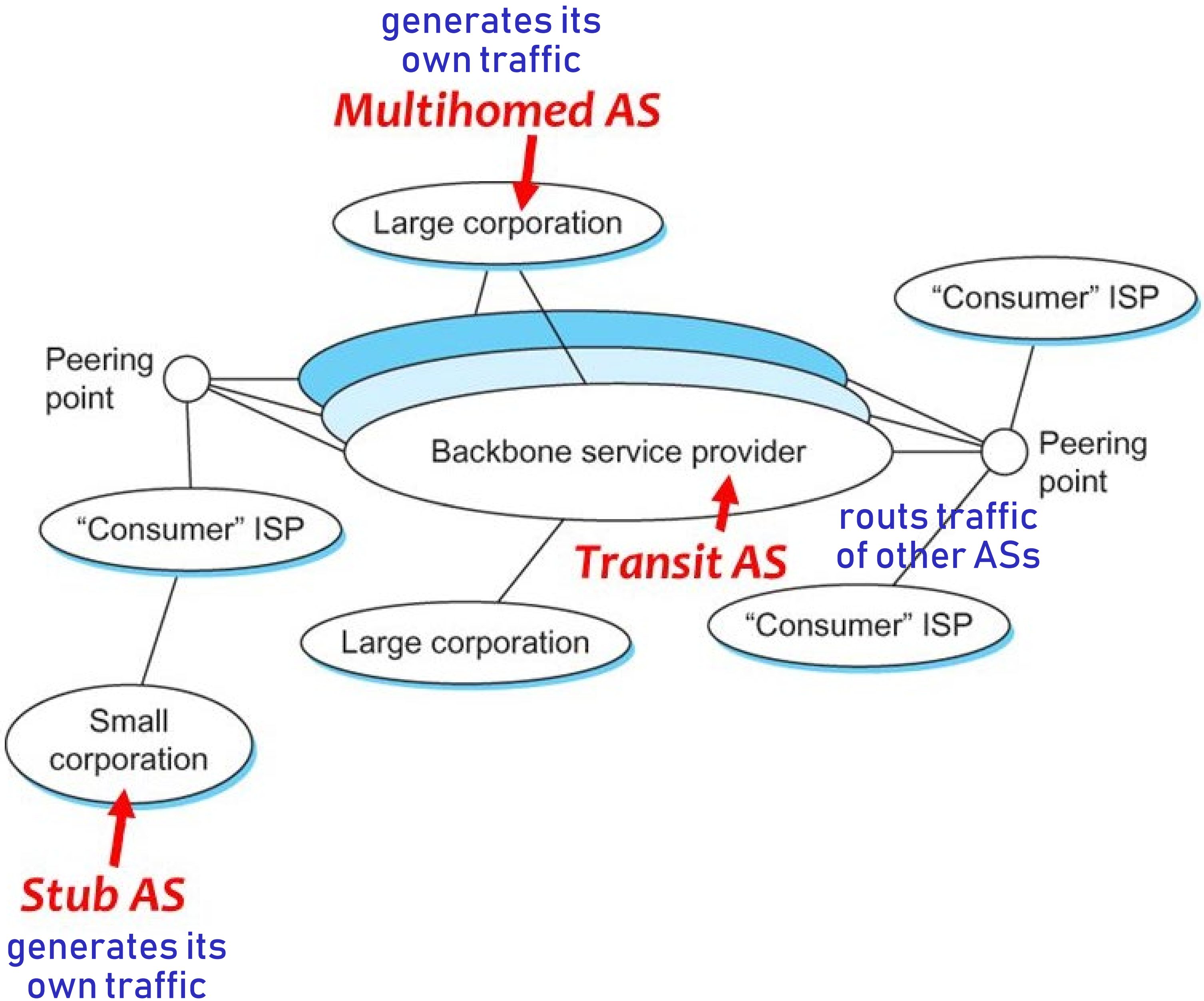
➢ alternate definition: unit of routing policy
  - all routers communicate with / use the same protocol (OSPF, RIP, …)

➢ routing inside an AS: intra-domain routing

➢ routing between ASs: inter-domain routing



Autonomous Systems (cont.)



Autonomous Systems (cont.)

AS Taxonomy

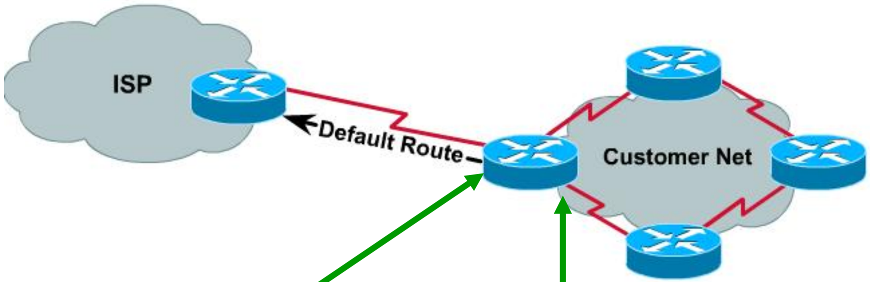
1) **Stub AS**: has only a single connection to the outside AS-s (e.g. a small corporations that connects only to one regional ISP)
   - stub is either a traffic ‘source’ or a traffic ‘sink’

2) **Multihomed AS**: has multiple connections to the outside world but refuses to carry transit traffic - carries only local traffic (e.g. large corporations that connects to more than one regional/national ISP)
   - still only a traffic ‘source’ or a traffic ‘sink’

3) **Transit AS**: has multiple connections to the outside world and carries both transit and local traffic (e.g. national and international ISP-s)

Autonomous Systems (cont.)

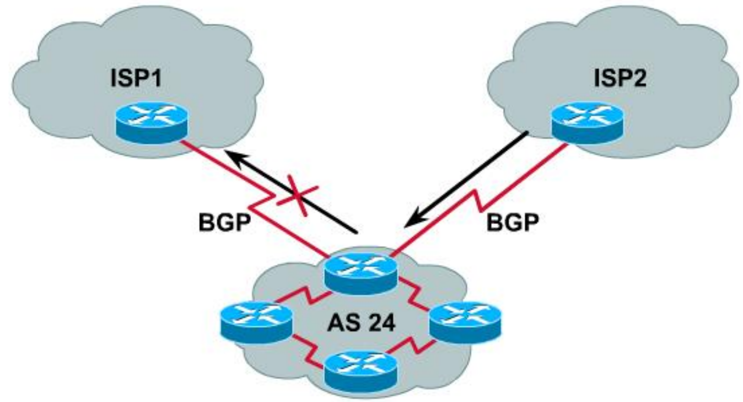
Stub AS:



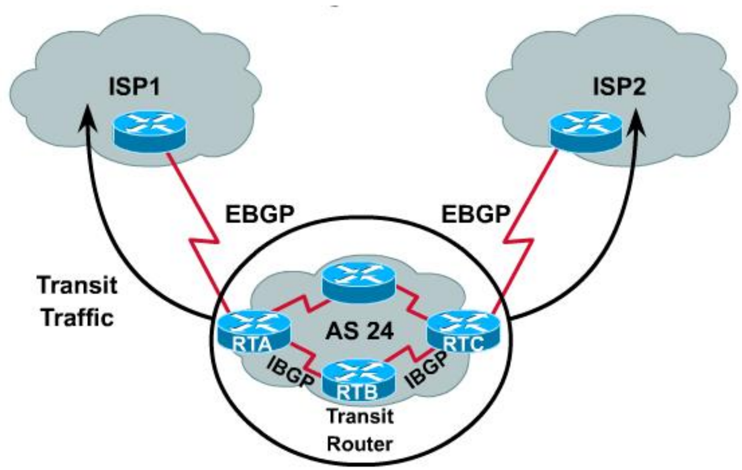
one intra-domain routing protocol

one inter-domain routing protocol

Multihomed AS:



Transit AS:



http://www.networkeducator.com/autonomous-system.htm

Routing Protocols

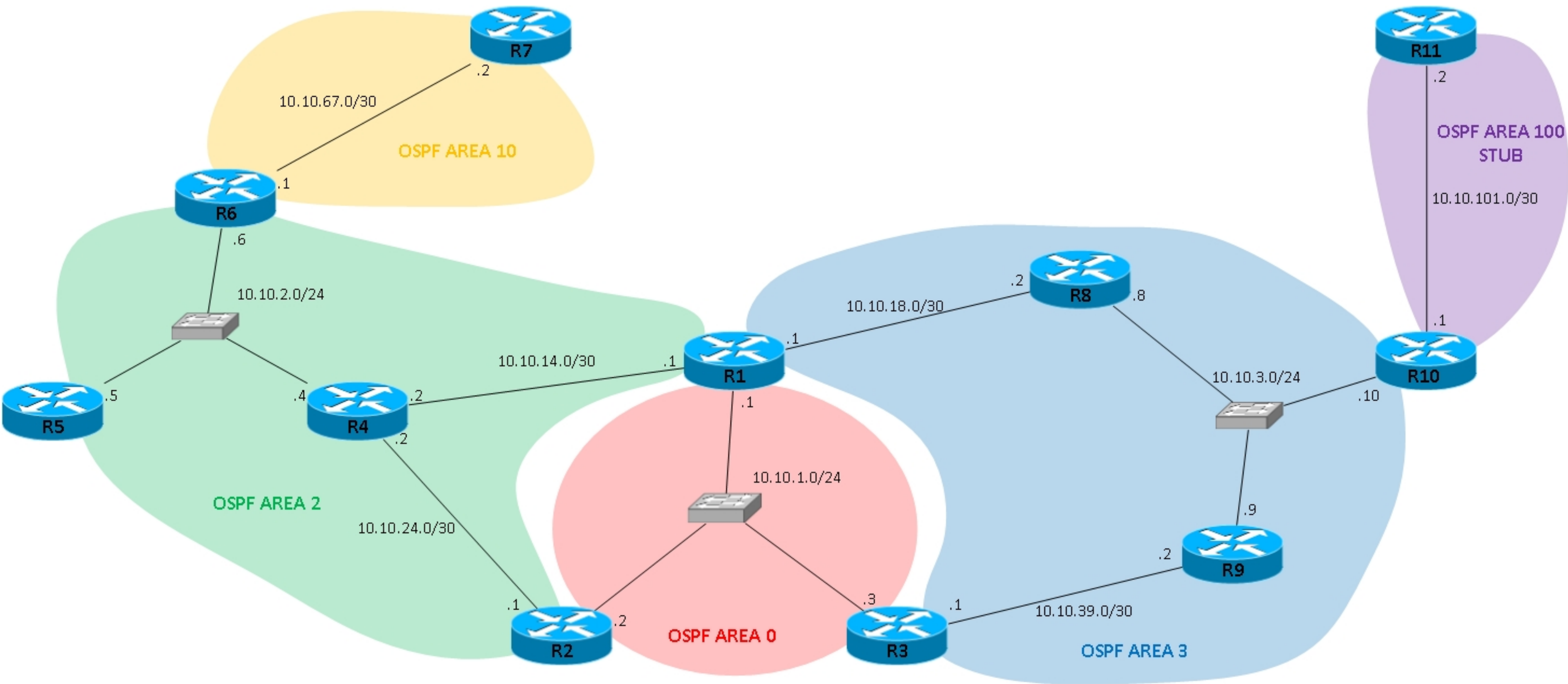
Open Shortest Path First – intra-AS routing protocol (OSPF Protocol)

flooding is costly !!!

- link state protocol based on Dijkstra shortest-path algorithm
- routers broadcasts routing information to all other routers in their AS, not only to the neighbours, at least once every 30 min
- each router constructs a complete topological map of the entire AS
- OSPF advertisements are carried directly by IP
  - on a broadcast network the IP-OSPF packet contains a standard multicast IP address of 224.0.0.5, which refers to OSPF routers
- enables routing using multiple metrics!!! - OSPF does not mandate a policy on how link weights are set (that is the job of system administrator); instead provides mechanisms for determining least-cost path routing for given set of link weights
  - administrator might choose to set all link costs to 1, thus achieving minimum-hop routing
  - administrator might choose to set all link costs to be inversely proportional to link capacity in order to discourage traffic from using low-bandwidth links, etc.
- an OSPF autonomous system can be configured into “areas”, with each area running its own OSPF algorithm, with a different metric …

Routing Protocols (cont.)

Example [OSPF – multiple areas, multiple metrics]



W = hop or bandwidth or current congestion level or etc.

Routing Protocols (cont.)

Routing Information Protocol (RIP Protocol) – one of the earliest intra-AS routing protocols still in widespread use today

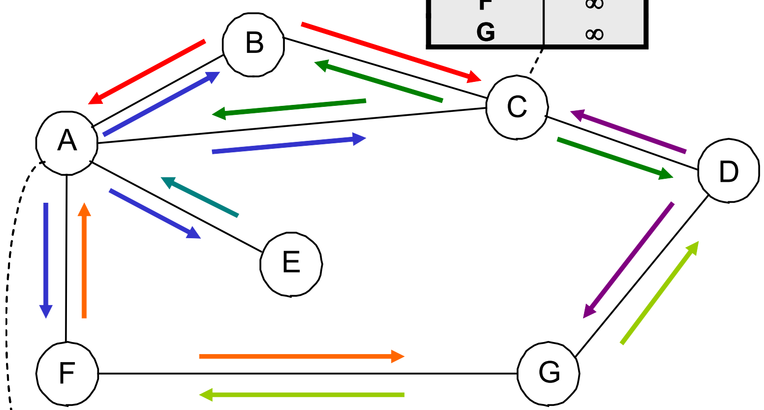
- distance vector protocol based on distributed Bellman-Ford algorithm
- most common distance metric: # of hop – each hop has a cost of 1
- max cost of a path = 15 ⇒ RIP is used in autonomous systems with fewer than 15 hops in diameter (path = 16 hops ⇒ host unreachable)
- routing updates are exchanged between neighbours approximately every 30 sec using so-called RIP response messages
- if a router does not hear from its neighbour at least once every 180 sec, that neighbour is considered unreachable
  - either the neighbour has died or the connecting link has failed
- … when this happens, RIP modifies the local routing table & then propagates this information to other neighbouring routers
  - such triggered updates can be sent before 30 sec
- routers send RIP update messages to each other over UDP using port 520

NOTE: RIP is implemented as an application-layer process, therefore it can run over UDP (transport-layer protocol), even though it is a network-layer protocol

Routing Protocols (cont.)

Example [RIP – single metrics]

Dest.	Cost
A	1
B	1
D	1
E	∞
F	∞
G	∞



Dest.	Cost
B	1
C	1
D	∞
E	1
F	1
G	∞

Destination	Cost	Next Hop
A	1	A
C	1	C
D	2	C
E	2	A
F	2	A
G	∞	–

All nodes must use the same (single) cost metric.

Routing Protocols (cont.)

Link-State (OSPF) for Inter-AS Routing

1) each router advertises its link metrics to all other routers
2) each router builds up a picture of complete network topology and then performs a routing calculation

Problem 1: flooding of link-state information to all routers across multiple AS-s may be unmanageable

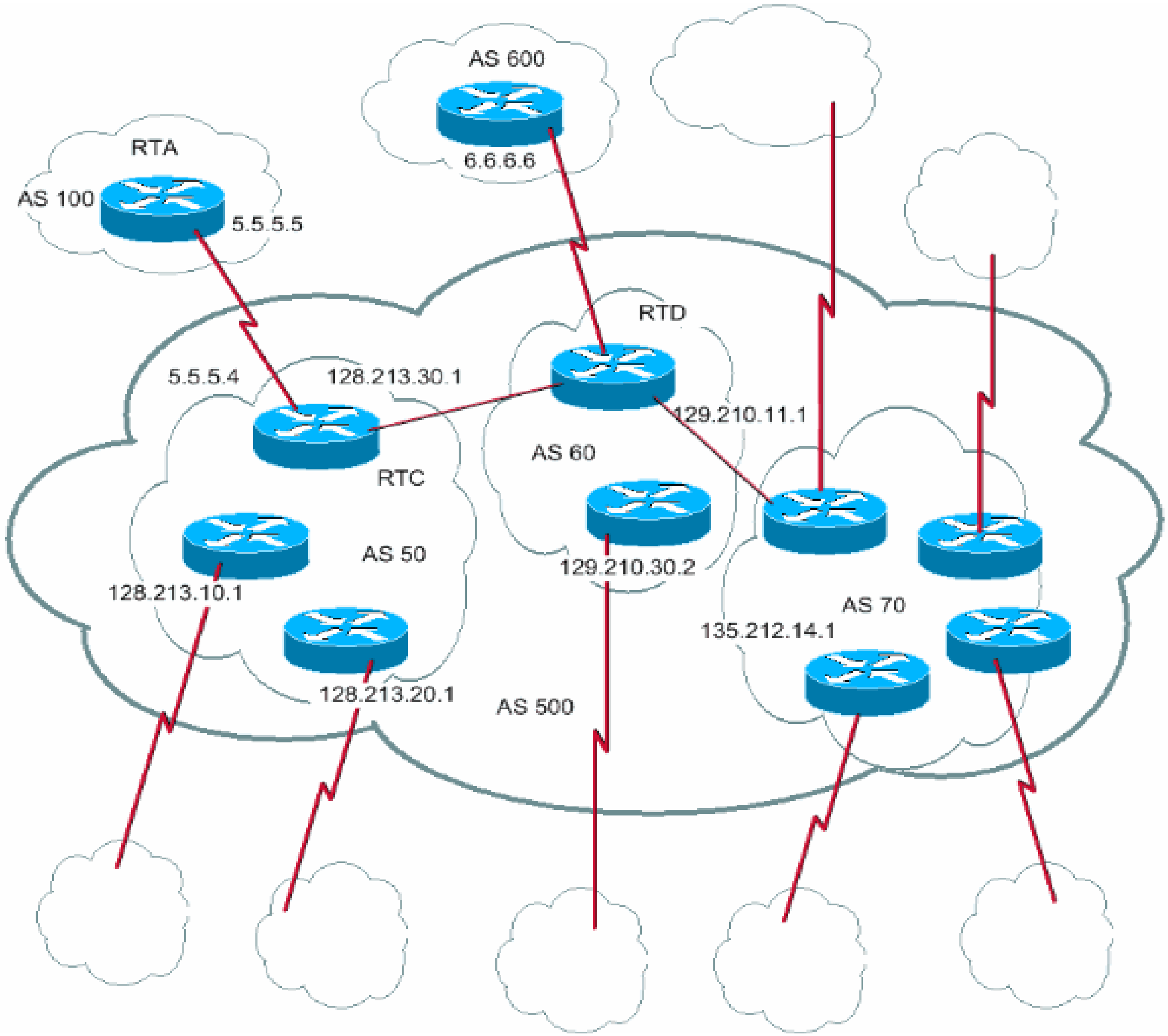
Problem 2: each router may be have to maintain a huge link-state database

Distance-Vector (RIP) for Inter-AS Routing

1) each router advertises to its neighbours a listing of each network it can reach together with an associated distance metric
2) each router builds up a routing database on the bases of these updates, without knowing the identity of intermediate networks/routers on any particular path

Problem 1: cost-metric may vary from one AS to another

Problem 2: DV algorithm gives no information about the AS-s that will be visited along a route

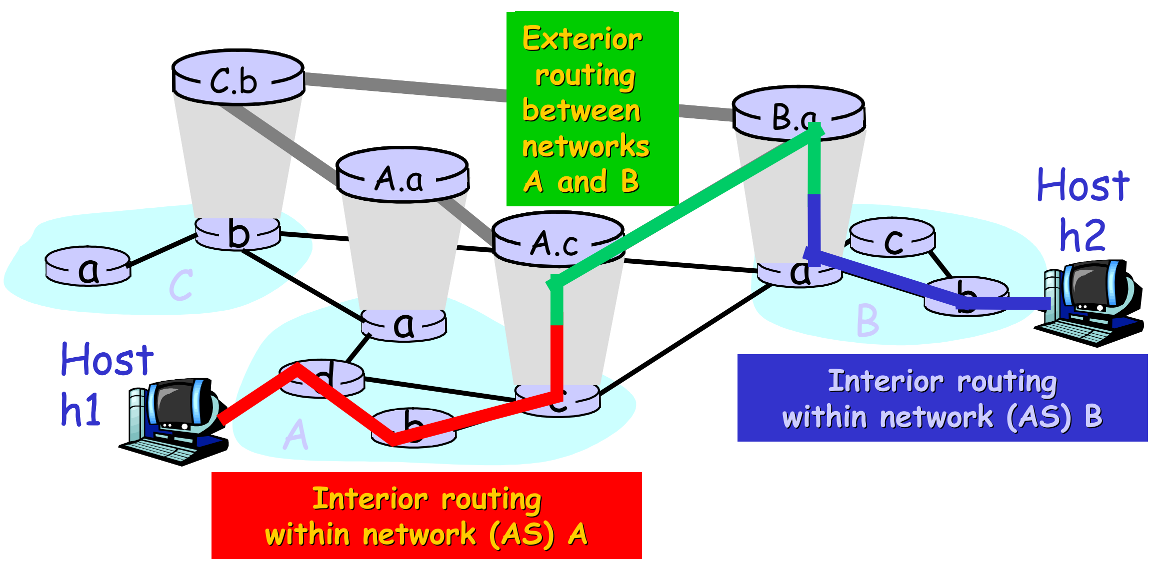

AS 600
6.6.6.6
RTA
AS 100
5.5.5.5
RTD
5.5.5.4
128.213.30.1
129.210.11.1
AS 60
RTC
AS 50
129.210.30.2
128.213.10.1
AS 70
135.212.14.1
128.213.20.1
AS 500

Intra-AS vs. Inter-AS Routing

Hierarchical (2-level) Routing

1) **Intra-AS Routing**: routing within an AS - can be **custom tailored to specific requirements and applications** - network administrator responsible for choice of routing algorithm, cost metric, etc. (RIP, OSPF, IGRP)

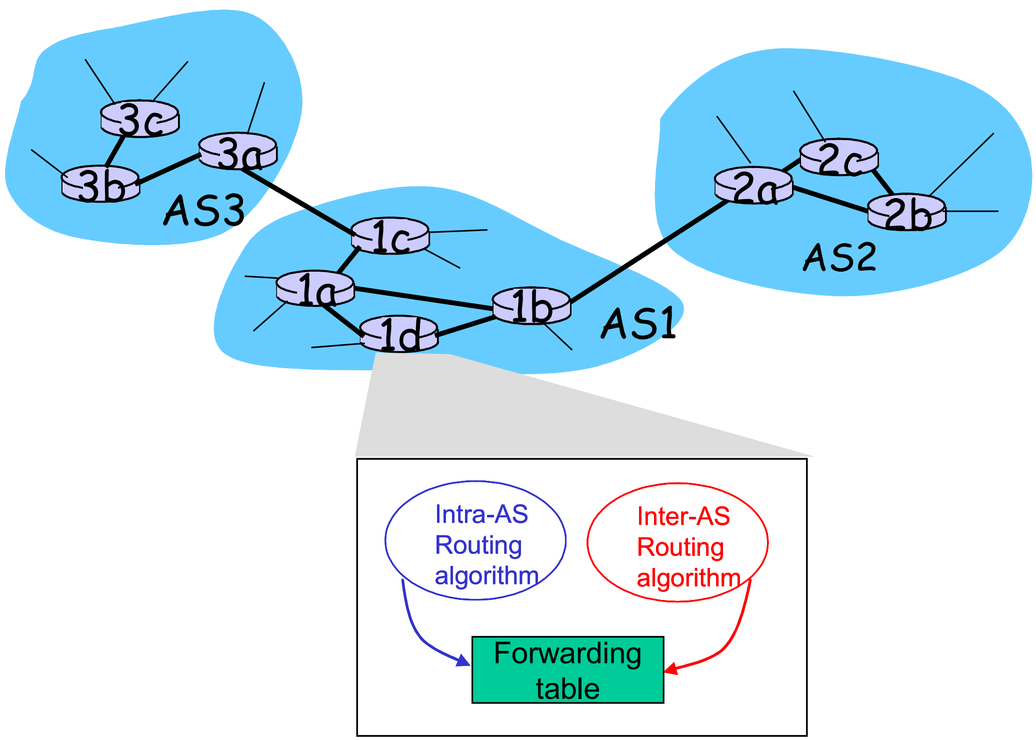
2) **Inter-AS Routing**: routing between AS-s - **policy dominates performance** - network administrator can control where traffic goes, and who can route through the net (BGP, IDRP)



Intra-AS vs. Inter-AS Routing (cont.)

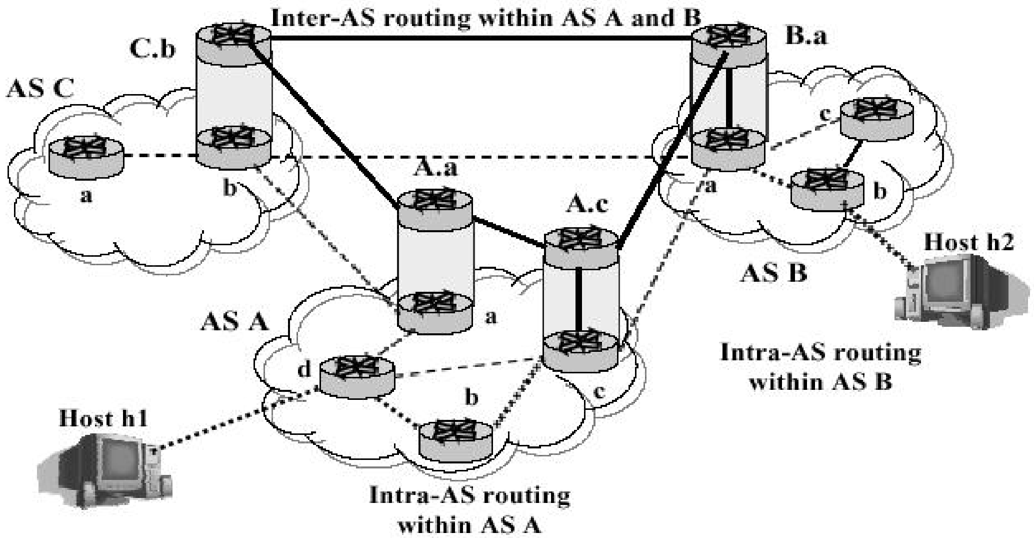
Gateway Routers (aka Border Router) – routers in an AS responsible for forwarding packets to destinations outside the AS

- **run at least one inter- & one intra- AS routing protocol**
- **perform inter-AS routing among themselves**
- **perform intra-AS with other routers in their AS**



Intra-AS vs. Inter-AS Routing (cont.)

Example [Inter-AS routing]

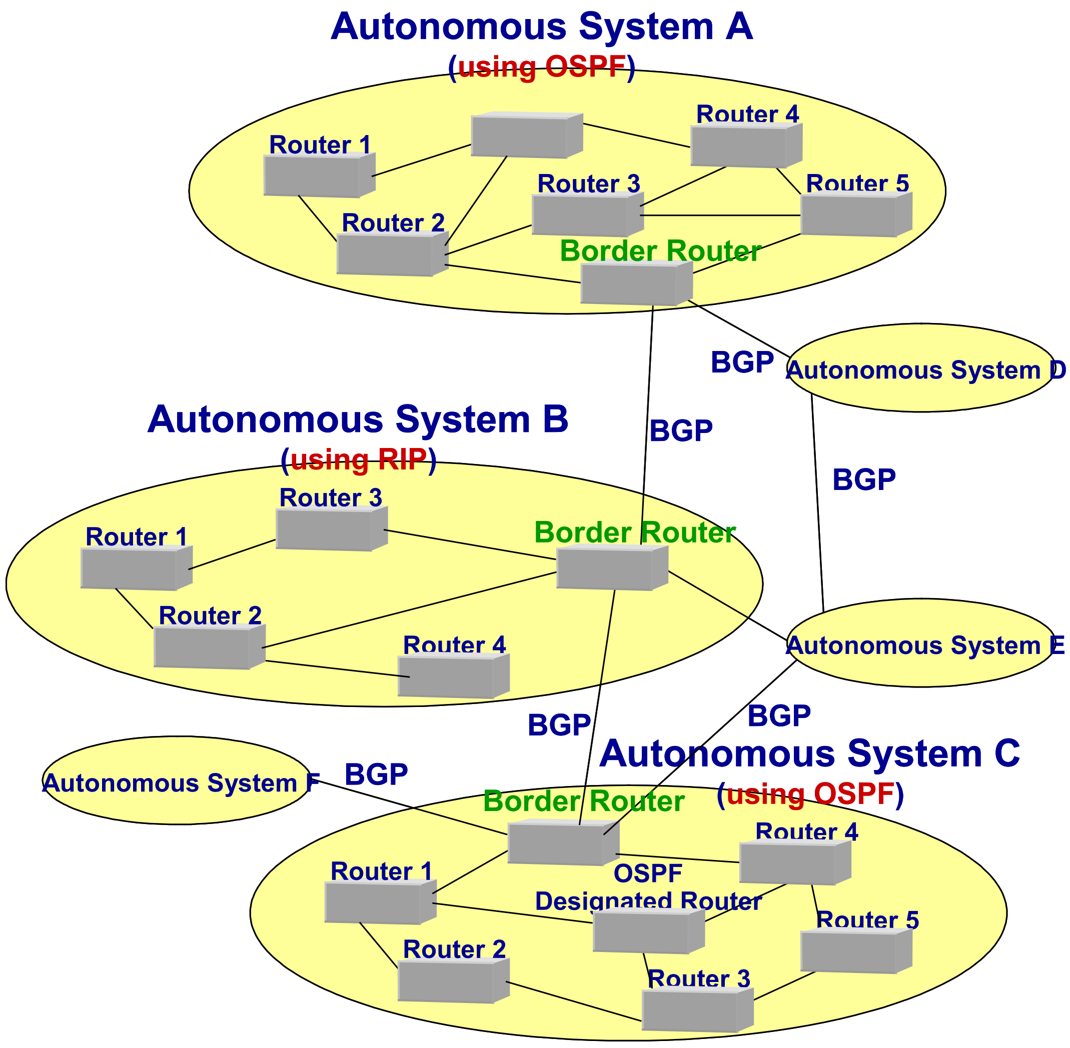


Which routing steps should be performed if host h1 needs to send a packet to h2?

- **The packet is first routed on the link connecting A.d to A.c using A's table built using intra-AS routing protocol. Router A.c will receive the packet and see that it is destined to an AS outside of A.**
- **A.c's routing table for the inter-AS protocol would indicate that a packet destined to AS B should be routed along the A.c to B.a link.**
- **When the packet arrives at B.a, B.a's inter-AS routing sees that the packet is destined for AS B.**
- **The packet is then "handed over" to the intra-AS routing protocol within B, which routes the packet to its final destination (h2) through router B.b.**

Intra-AS vs. Inter-AS Routing (cont.)

Example [hierarchical routing]

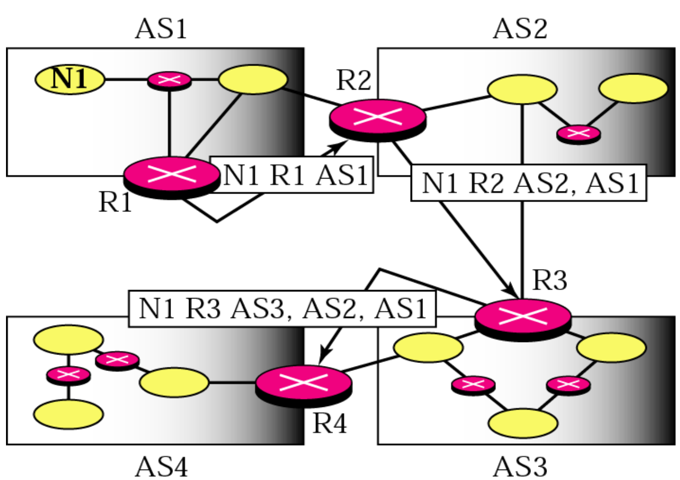


Inter-AS Routing: BGR

Border Gateway Routing (BGR) Protocol – inter-AS routing protocol based on path-vector routing principle (extended distance-vector)

Path-Vector Routing – routers exchange detailed path information rather than cost information

- each entry in a routing table (update message) contains:
  1) destination network
  2) next router (i.e., router's own ID)
  3) AS-s path to reach the destination



path vectors advertising the reachability of N1

Inter-AS Routing: BGR (cont.)

Path-Vector (BGR) Principles

1) **Policy Routing**
   - when a router receives an update message, it checks the path; if one of AS-s listed is against its policy, the router can ignore that path (i.e. update message)

2) **Loop Prevention**
   - when a router receives an update message, it checks if its AS is in the path – if it is, looping is involved and message is ignored

3) **Path-Vector Messages**
   - upon receiving a valid update message, the router updates its routing table and modifies the message before sending it to the next neighbour by adding its AS number to the path and replacing the next router entry with its own identification

BGR Router Communication – BGR peers exchange messages over TCP on port 179, so to ensure reliability and congestion control