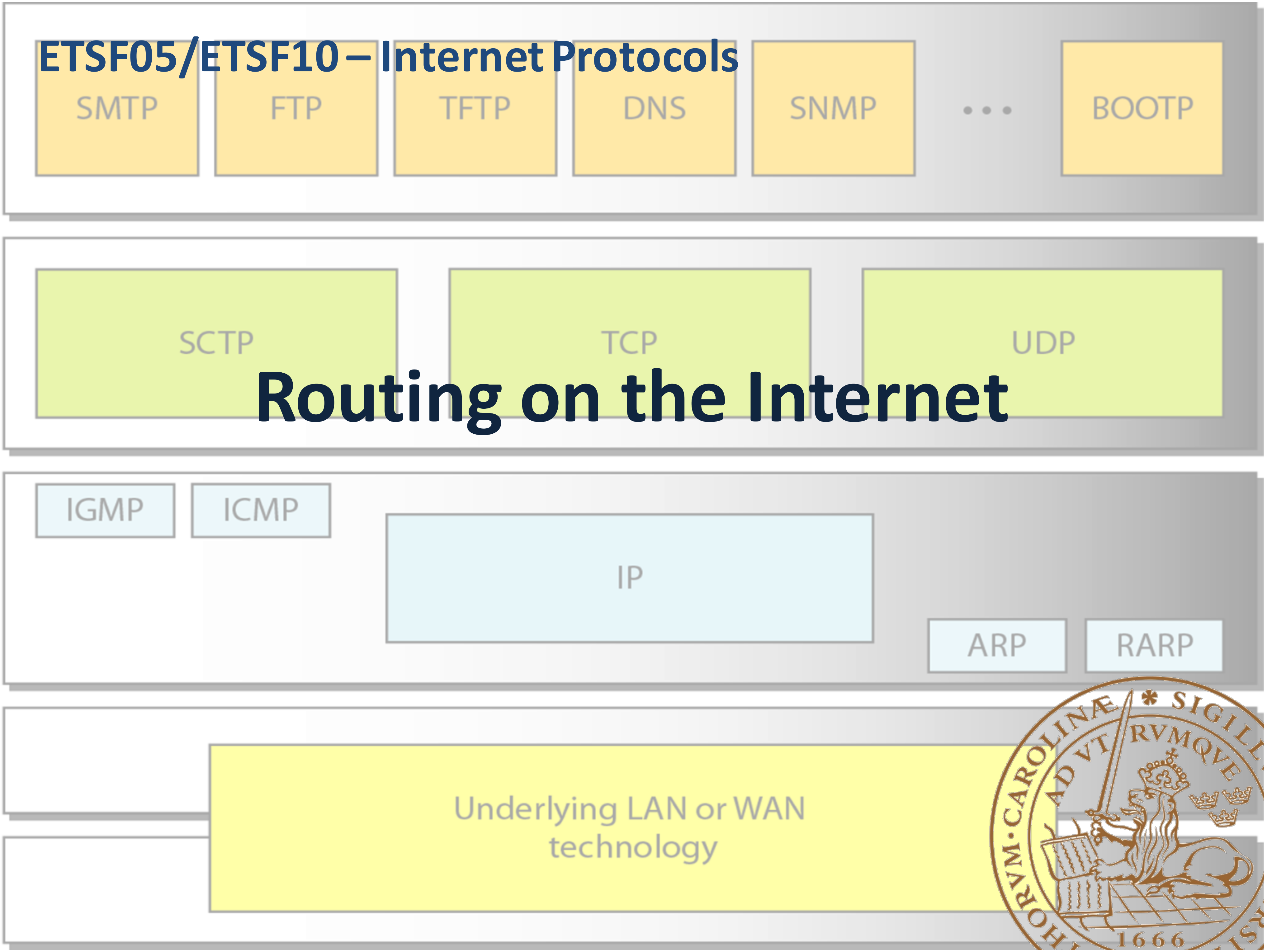
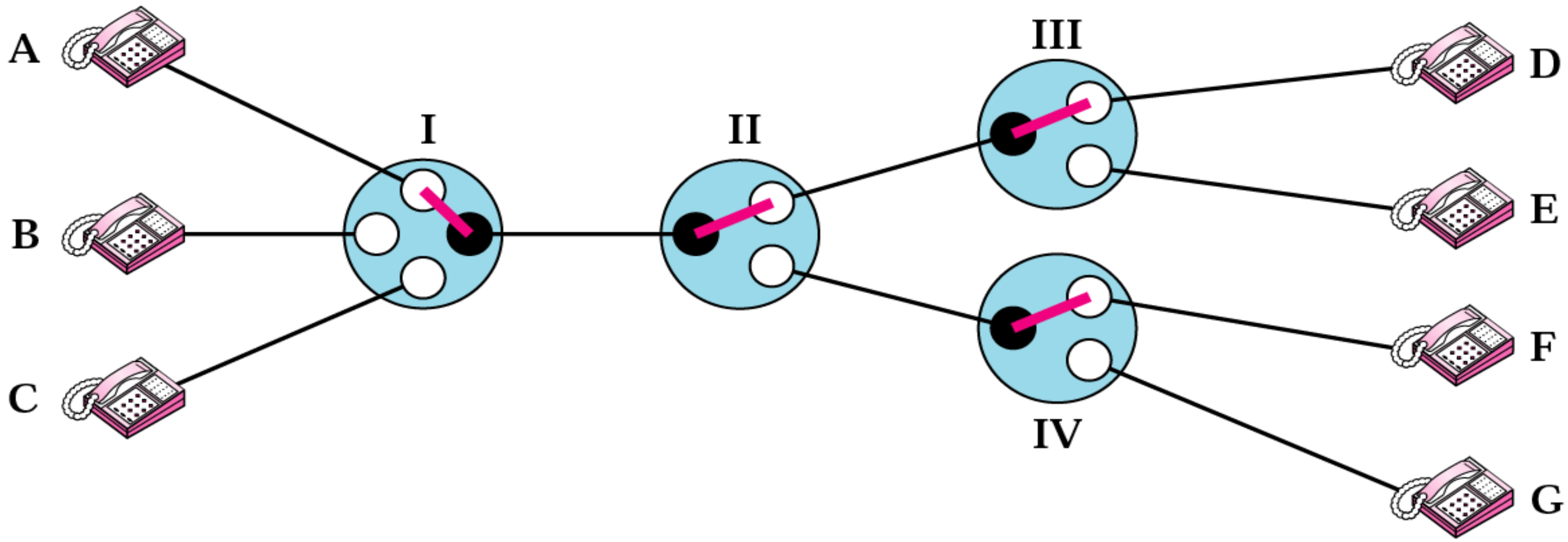
ETSF05/ETSF10 – Internet Protocols

Routing on the Internet



Circuit switched routing



Routing in Packet Switching Networks

- Key design issue for (packet) switched networks
- Select route across network between end nodes
- Characteristics required:
  - Correctness
  - Simplicity (Scalable)
  - Robustness vs Stability
  - Fairness vs Optimality
  - Efficiency (overhead)

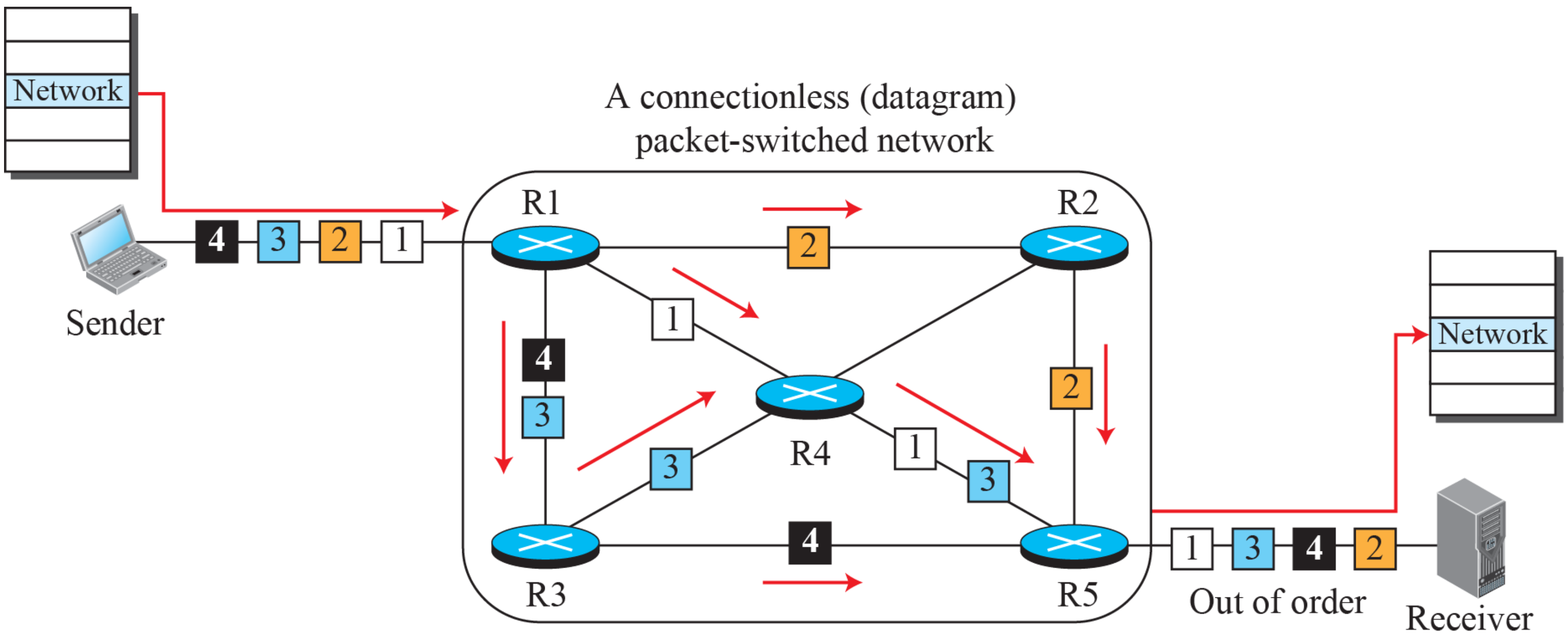
Routing Strategies - Flooding

- Packet sent by node to every neighbor
- Eventually multiple copies arrive at destination
- No network information required
- Each packet is uniquely numbered so duplicates can be discarded
- Need to limit infinite retransmission of packets
  - Can include a hop count in packets
  - Nodes can remember identity of packets retra

Packet-switched Routing

Choosing an optimal path

- According to a cost metric
- Decentralised: each router has full/necessary information

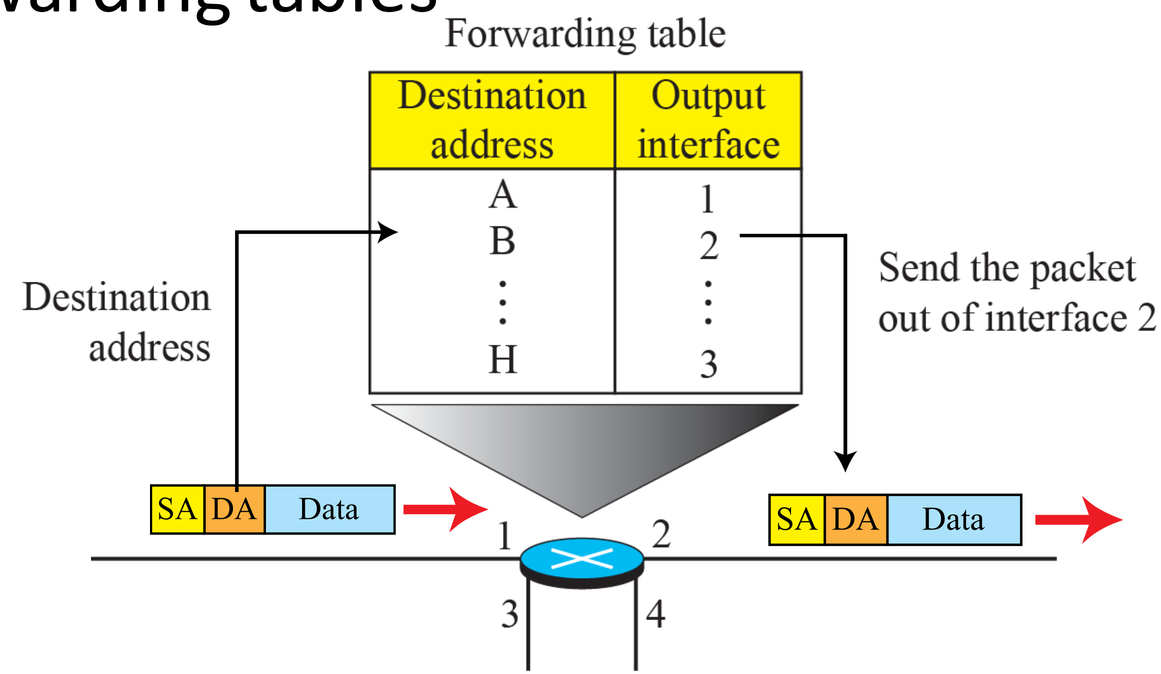


Router

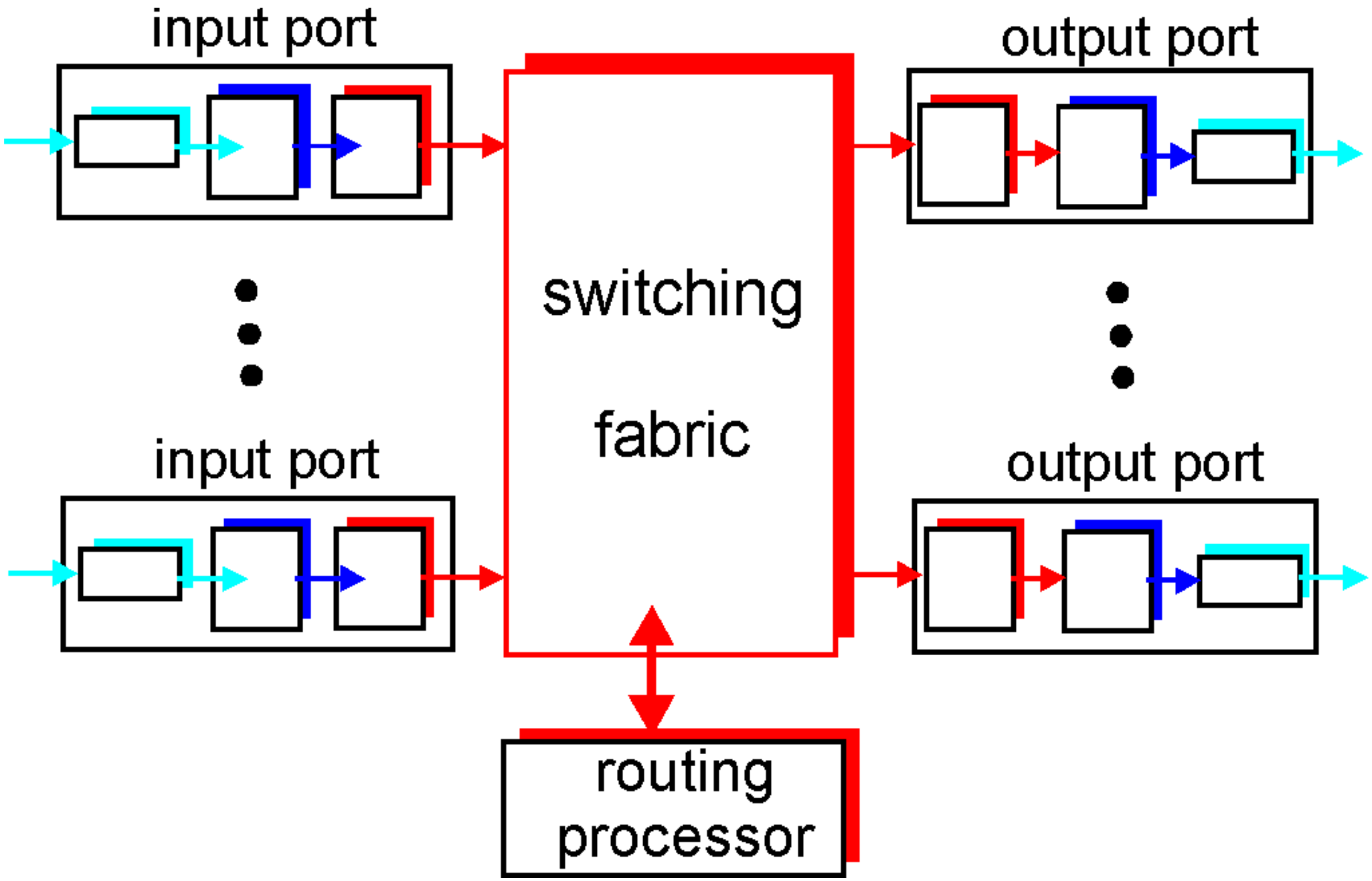
- Internetworking device
  - Passes data packets between networks
  - Checks ***Network Layer*** addresses
  - Uses Routing/forwarding tables

Two functions:

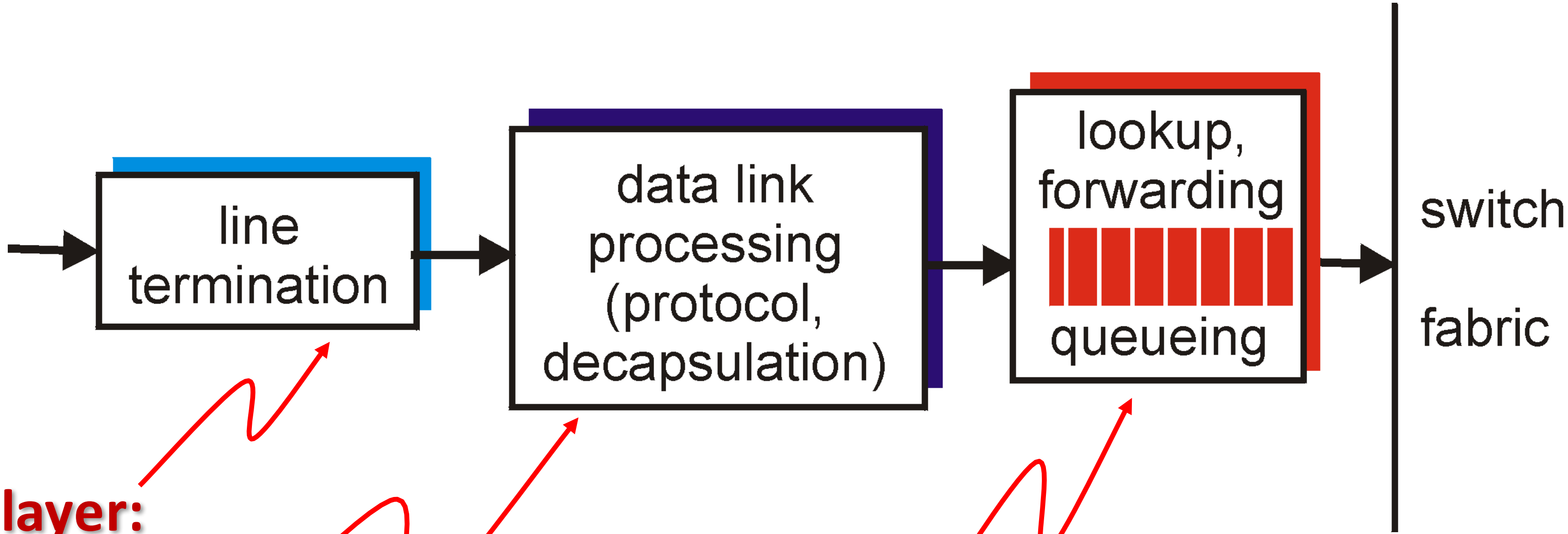
1. Routing
2. Forwarding



Router Architecture Overview



Input Port



Physical layer:
bit-level reception

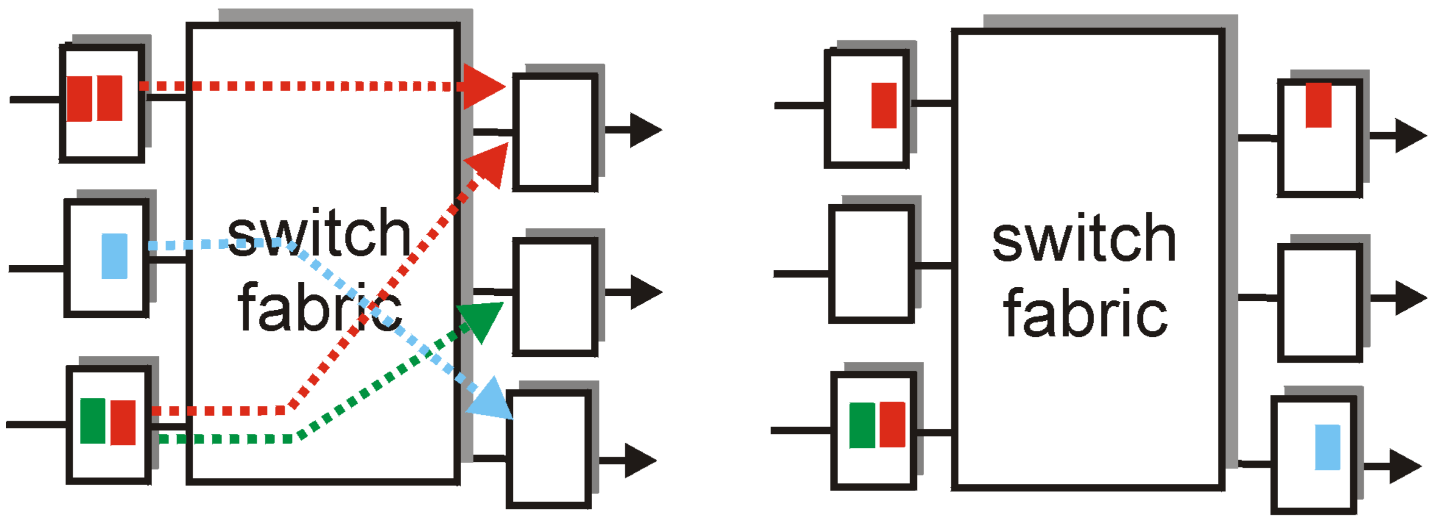
Data link layer:
e.g., Ethernet

Decentralized switching:

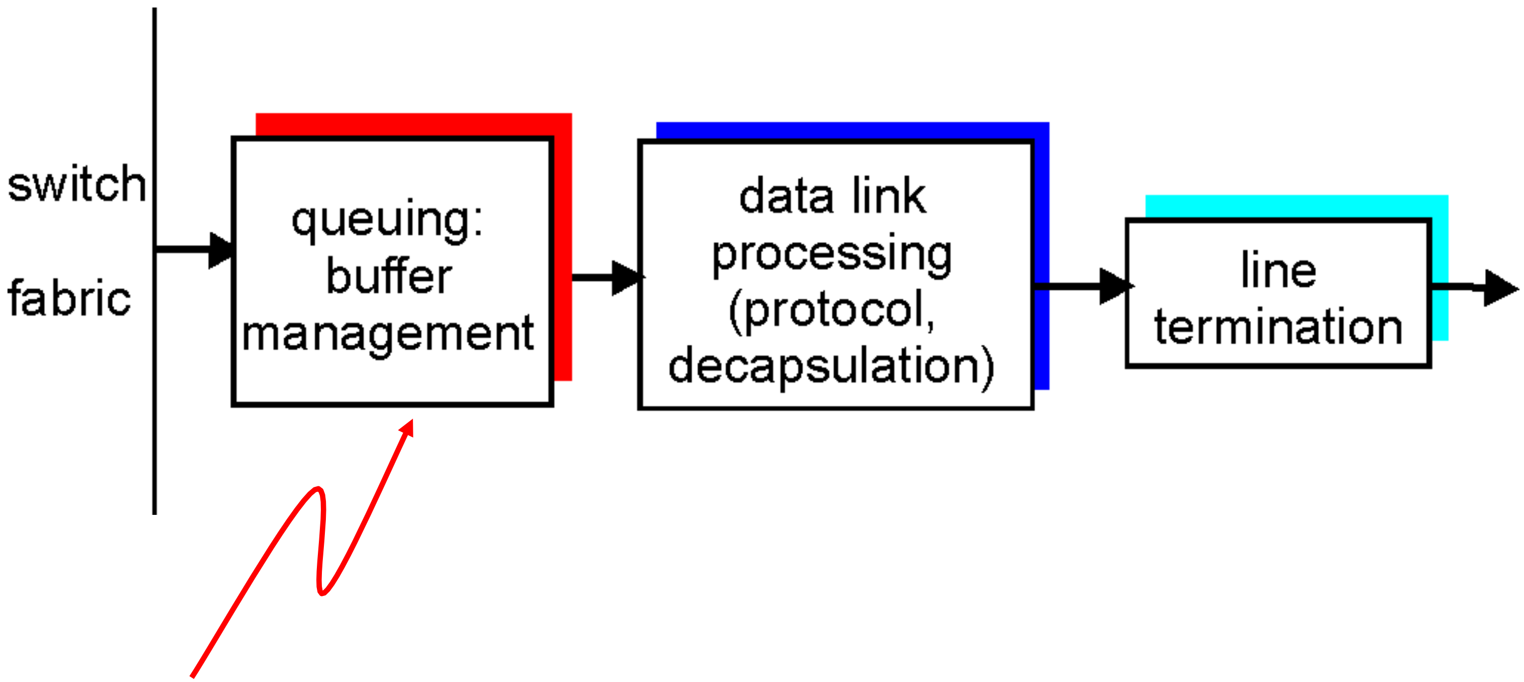
- Given destination, lookup output port using routing table in input port memory
- Goal: complete input port processing at ‘line speed’

Input Port Queuing

- Fabric slower than sum of input ports → **queuing**
- **Delay and loss** due to input buffer overflow
- **Head-of-the-Line (HOL) blocking**: Datagram at front of queue prevents others in queue from proceeding



Output Port

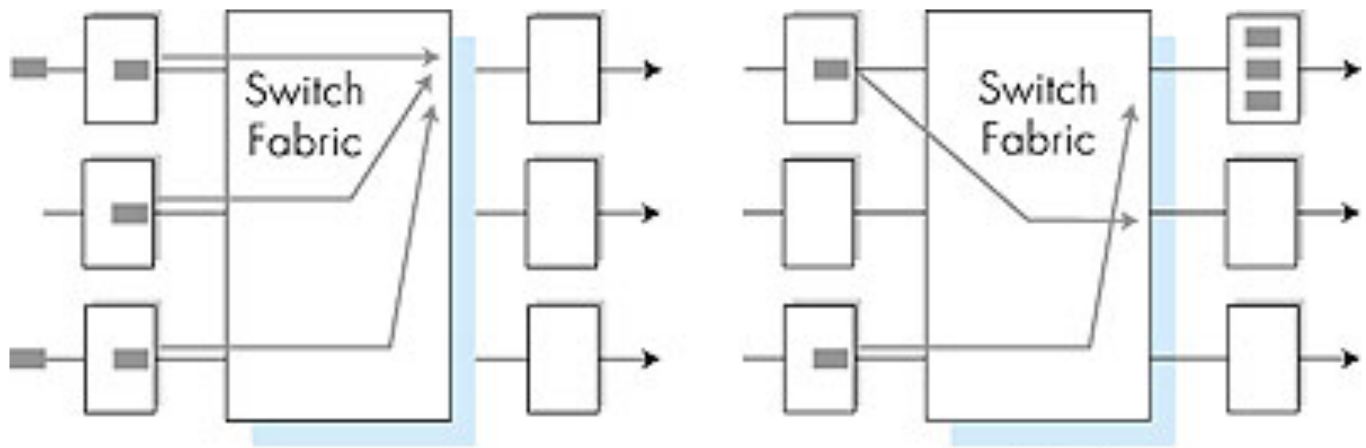


Priority Scheduling:

Scheduling discipline may choose among queued datagrams for transmission

Output Port Queuing

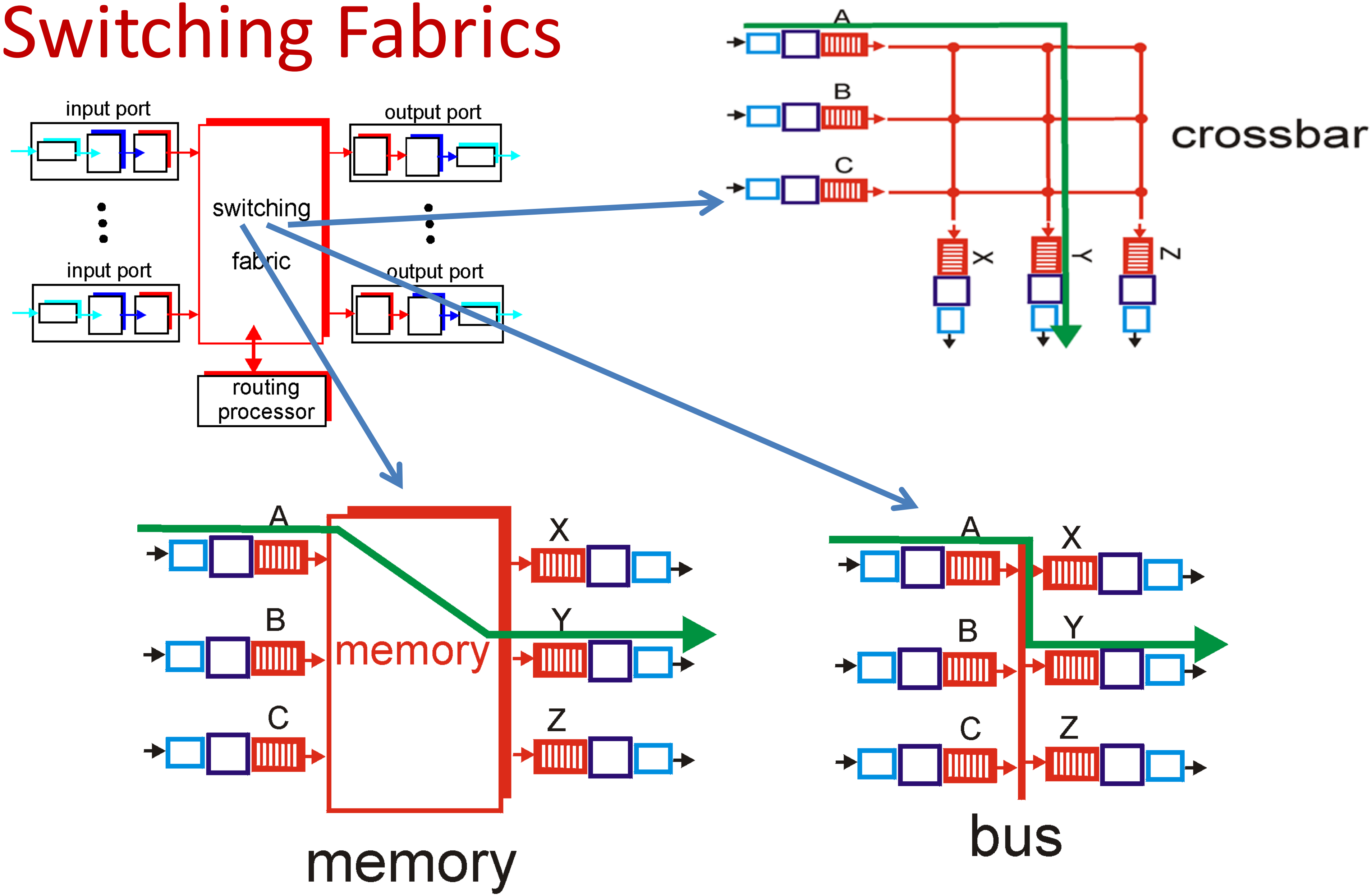
- Datagrams' arrival rate through the switch exceeds the transmission rate of the output line → buffering
- Delay and loss due to output port buffer overflow



Output Port Contention at Time *t*

One Packet Time Later

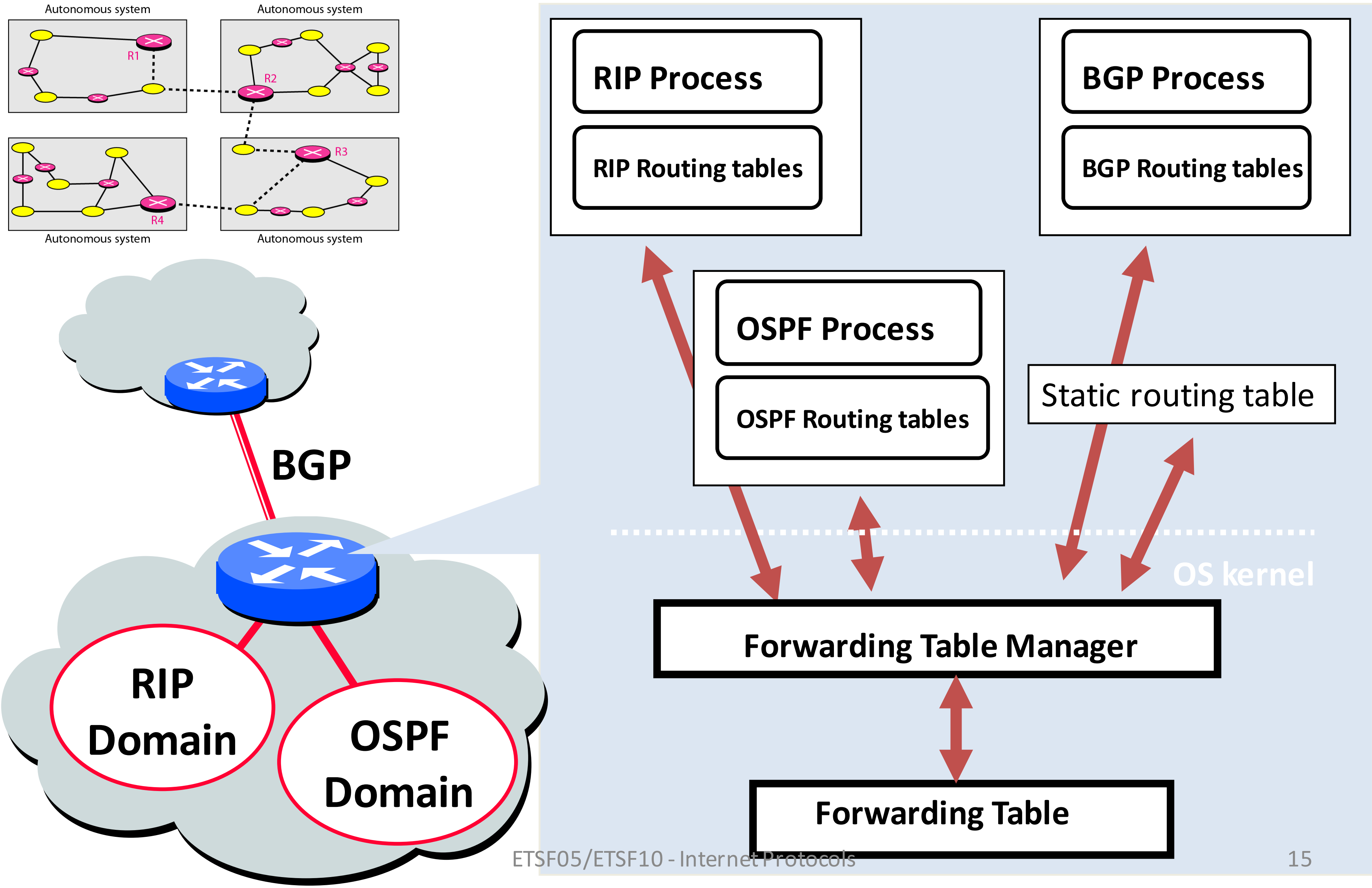
Switching Fabrics



Router cache

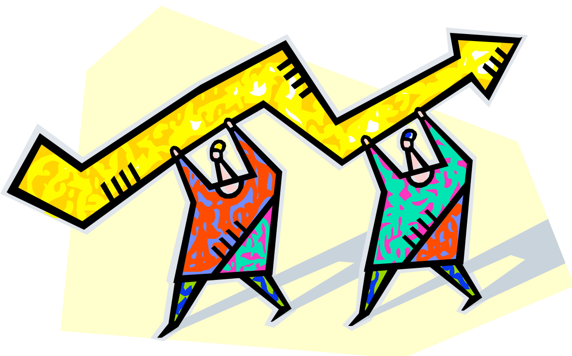
- Save next hop for packet type (addr and TOS)
  - Keep packets within a session on the same path
  - Prohibits reordering
  - decreases delay variations
- Works in both directions
  - Reply take the same path as request
- Drawback: for long sessions (e.g. video) session continuity might be broken
- Typical for user networks

Routing Tables and Forwarding Table



Performance Criteria

- Used for selection of route
- Simplest is to choose "**minimum hop**"
- Can be generalized as "**least cost**" routing
- Since "least cost" is more flexible it is more common than "minimum hop"



Best Path: Decision Time and Place

Decision time (when?)

- Packet or virtual circuit (session) basis
- Fixed or dynamically changing

Decision place (where?)

- Distributed - made by each node
  - More complex, but more robust
- Centralized – made by a designated node
- Source – made by source station

Network Information Source and Update Timing

- Routing decisions usually based on knowledge of network, traffic load, and link cost
  - Distributed routing
    - Using local knowledge, information from adjacent nodes, information from all nodes on a potential route
  - Central routing
    - Collect information from all nodes

Issue of update timing

- Depends on routing strategy
- Fixed - never updated
- Adaptive - regular updates

Routing Strategies - Fixed Routing

- Use a **single permanent** route for each source to destination pair of nodes
- Determined using a least cost algorithm
- **Route is fixed**
  - Until a change in network topology
  - Based on expected traffic or capacity
- Advantage is **simplicity**
- Disadvantage is **lack of flexibility**
  - Does not react to network failure or congestion

Routing Strategies - Adaptive Routing

- Used by almost all packet switching networks
- **Routing decisions change as conditions on the network change due to failure or congestion**
- **Requires information about network**

- More complex
- Tradeoff between quality and overhead
- Too quick updates may lead to oscillations
- Too slow updates may lead to outdates information

Classification of Adaptive Routing Strategies

A convenient way to classify is on the basis of information source

Local (isolated)

- Route to outgoing link with shortest queue
- Can include bias for each destination
- Rarely used - does not make use of available information

Adjacent nodes

- Takes advantage of delay and outage information
- Distributed or centralized

All nodes

- Like adjacent

ARPANET Routing Strategies 1st Generation

Distance Vector Routing

- **1969**
- Distributed adaptive using **estimated delay**
  - Queue length used as estimate of delay
- Version of **Bellman-Ford** algorithm
- **Node exchanges delay vector with neighbors**
- **Update routing table based on incoming information**
- **Doesn't consider line speed**, just queue length and responds slowly to congestion

ARPANET Routing Strategies
2nd Generation

Link-State Routing

- **1979**
- Distributed adaptive using **delay** criterion
  - Using timestamps of arrival, departure and ACK times
- Re-computes average delays every 10 seconds
- **Any changes are flooded to all other nodes**
- Re-computes routing using **Dijkstra's algorithm**
- Good under light and medium loads
- Under heavy loads, little correlation between reported delays and those experienced

ARPANET Routing Strategies 3rd Generation

- **1987**
- Link cost calculation changed
  - Dampen routing oscillations
  - Reduce routing overhead
- Measure average delay over last 10 seconds and transform into link utilization estimate
- Calculate average utilization based on current value and previous average

$$U(n+1) = \frac{1}{2}\rho(n) + \frac{1}{2}U(n)$$

- Use as link cost a function based on the average utilization

Autonomous Systems (AS)

- Exhibits the following characteristics:
  - Is a set of routers and networks managed by a single organization
  - Consists of a group of routers exchanging information via a common routing protocol
  - Except in times of failure, is connected (in a graph-theoretic sense); there is a path between any pair of nodes

Interior Router Protocol (IRP)
Interior Gateway Protocol (IGP)

- A shared routing protocol which passes information between routers **within an AS**
- Custom tailored to specific applications and requirements

Examples

- Routing Information Protocol (RIP)
- Open Shortest Path First (OSPF)

Exterior Router Protocol (ERP) Exterior Gateway Protocol (EGP)

- Pass information **between routers in different ASs**
- Will need to pass less information than an IRP for the following reason:
  - To transfer a datagram from a host in one AS to a host in another AS, a router in the first system need only determine the target AS and devise a route to get into that target system
  - Once the datagram enters the target AS, the routers within that system can cooperate to deliver the datagram
  - The ERP is not concerned with, and does not know about, the details of the route within the target AS

Examples

- Border Gateway Protocol (BGP)
- Open Shortest Path First (OSPF)

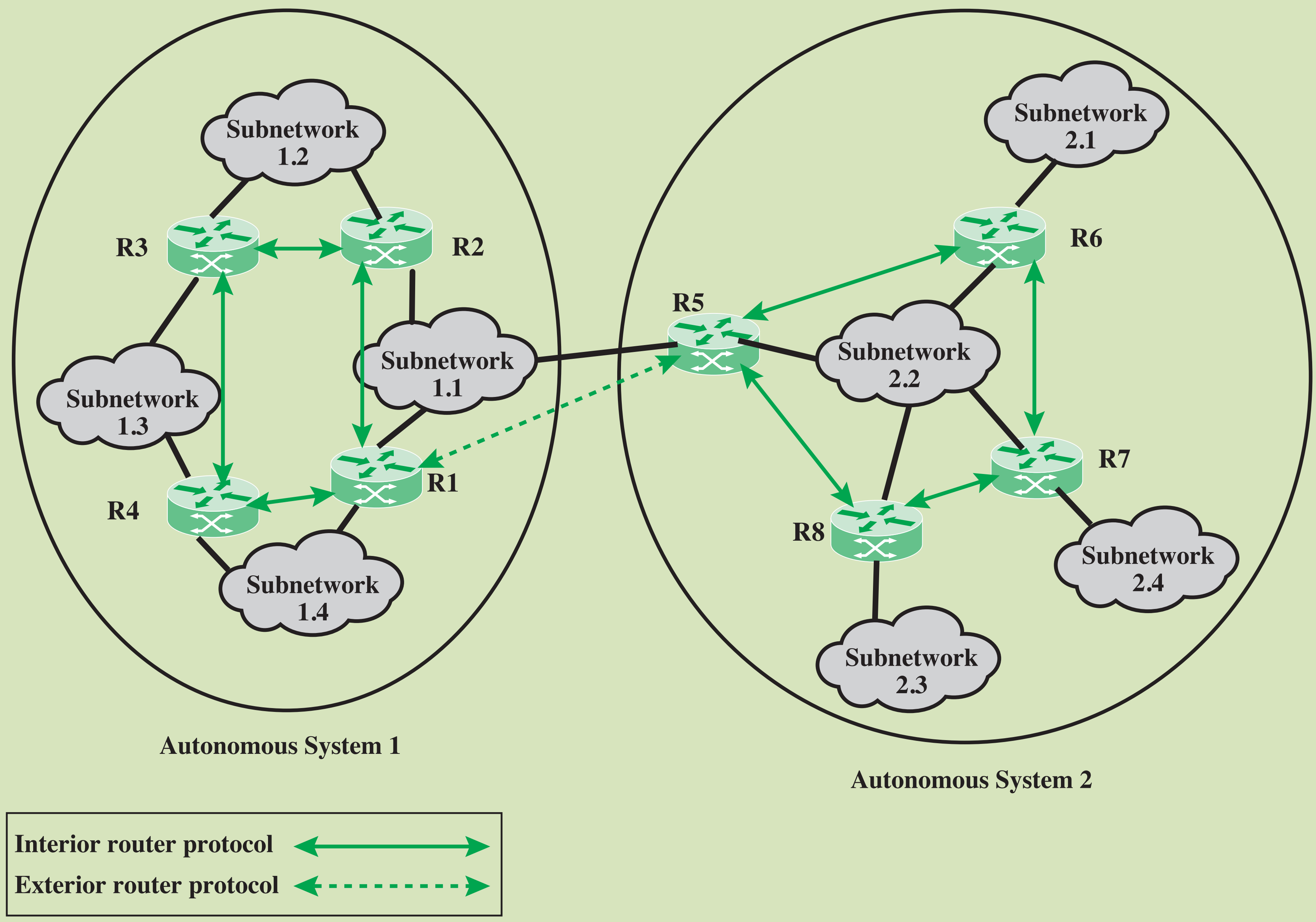
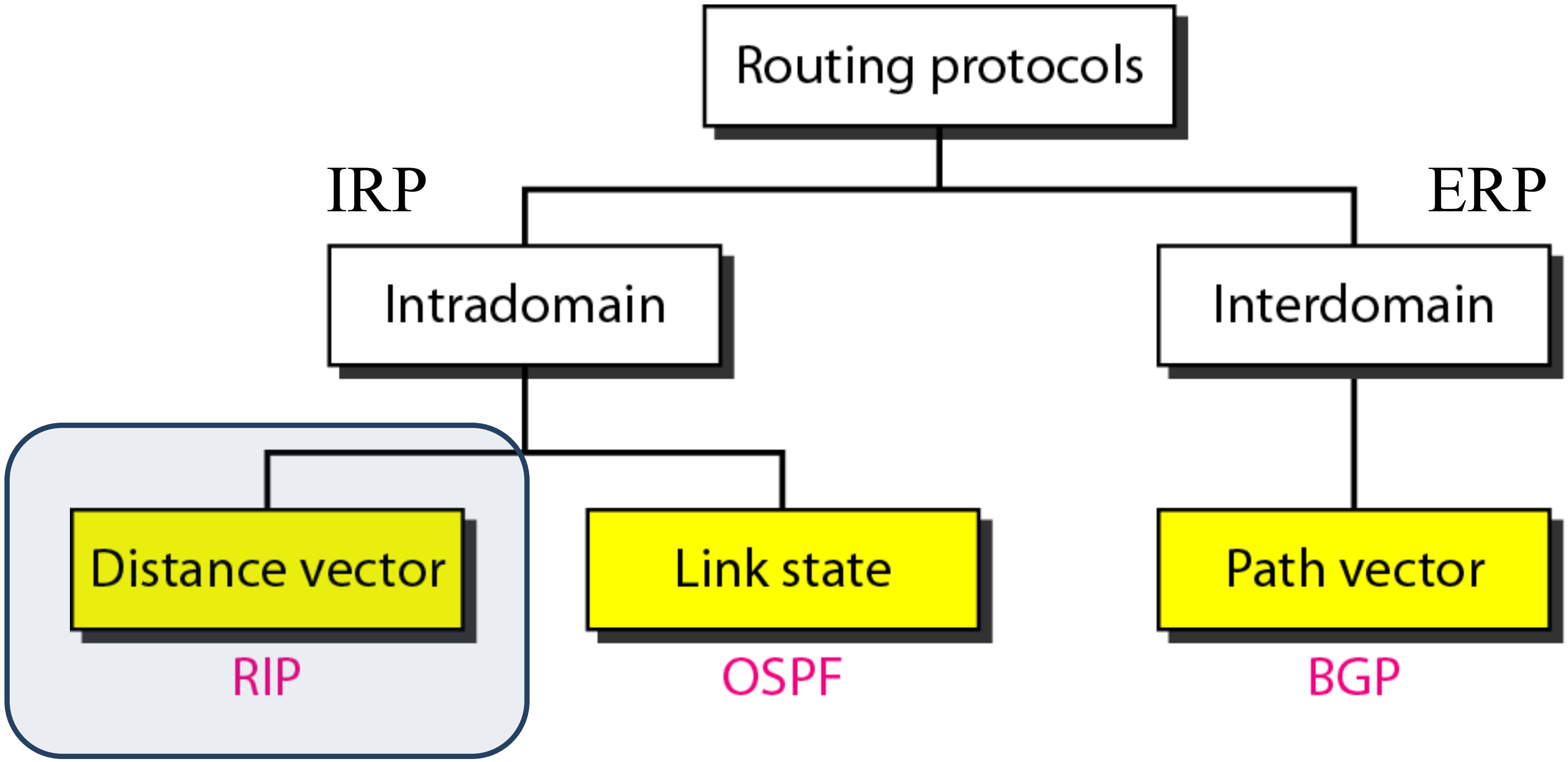


Figure 19.9 Application of Exterior and Interior Routing Protocols

Routing Algorithms and Protocols



Distance-Vector Routing

- Routing Information Protocol (RIP)
- Requires that each node exchange information with its neighboring nodes
  - Two nodes are said to be neighbors if they are both directly connected to the same network
- Used in the first-generation routing algorithm for ARPANET
- Each node maintains a vector of link costs for each directly attached network and distance and next-hop vectors for each destination

RIP (Routing Information Protocol)

- Included in BSD-UNIX Distribution in 1982
- Distance metric:
  - **# of hops** (max 15) to destination network
- Distance vectors:
  - exchanged among neighbours every 30” via Response Message (advertisement)
- Implementation:
  - Application layer protocol, uses UDP/IP

A RIP Forwarding/Routing Table

Destination=net	Cost	Next hop=router
123	3	A
32	5	D
16	3	A
7	2	-

RIP update message

- Contains the whole forwarding table
- Action on reception:
  - Add 1 to cost in received message
  - Change next hop to sending router
  - Apply RIP updating algorithm

- Received update msgs identify neighbours!

RIP Updating Algorithm (Bellman-Ford)

```
if (advertised destination not in table)
   {
   add new entry // rule #1
   }
else if (adv. next hop = next hop in table)
   {
   update cost // rule #2
   }
else if (adv. cost < cost in table)
   {
   replace old entry // rule #3
   }
```

RIP Example

New R1

Des.	N. R.	Cost
N1	—	1
N2	—	1
N3	—	1
N4	R2	2
N5	R2	2

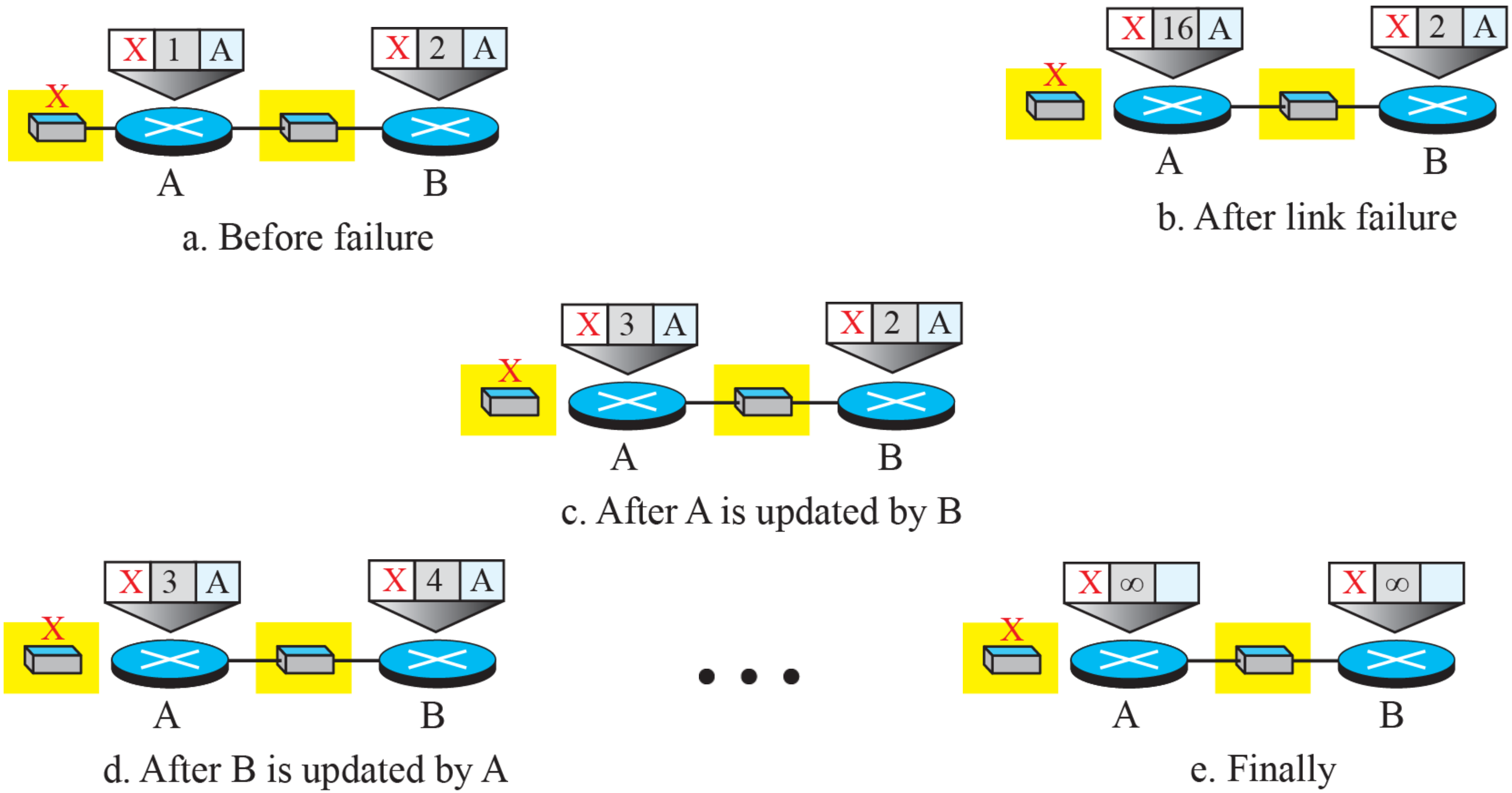
Old R1

Des.	N. R.	Cost
N1	—	1
N2	—	1
N3	—	1

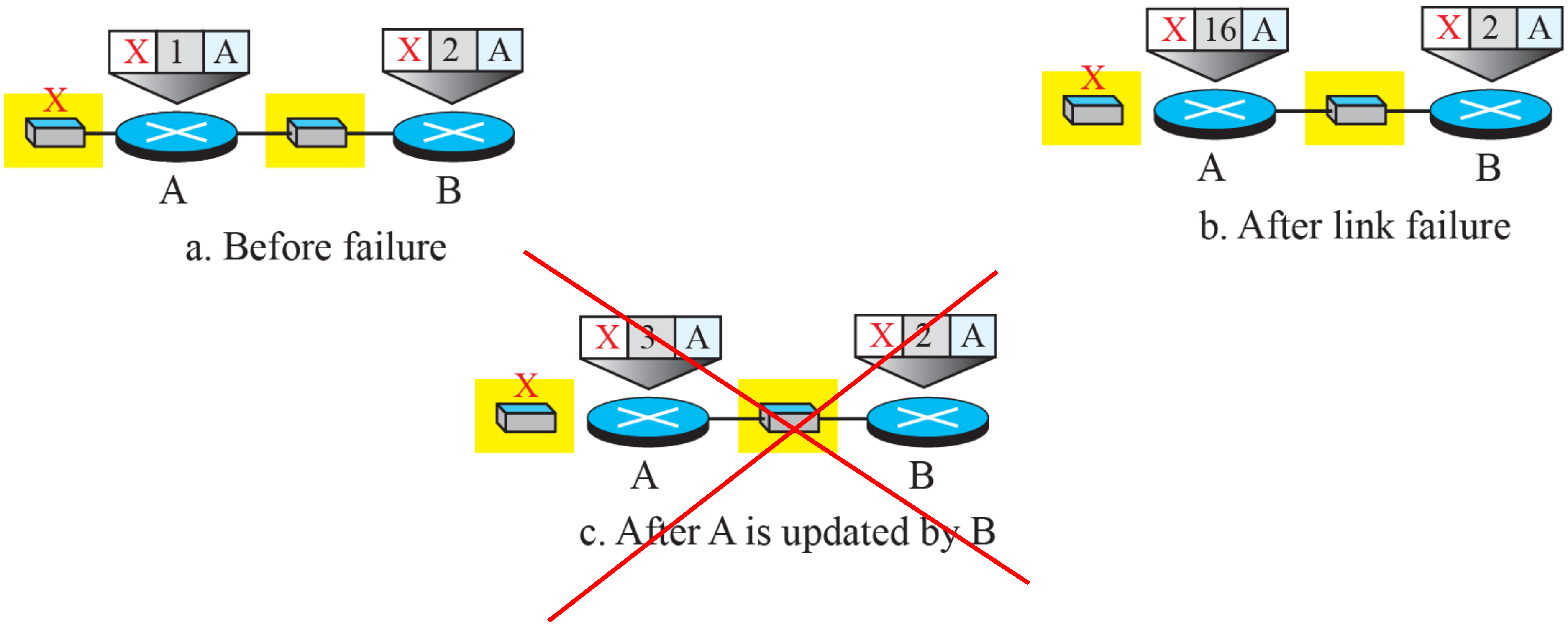
R2 Seen by R1

Des.	N. R.	Cost
N3	R2	2
N4	R2	2
N5	R2	2

Two node instability/Count to inifinity



Split Horizon breaks Count to inifinity

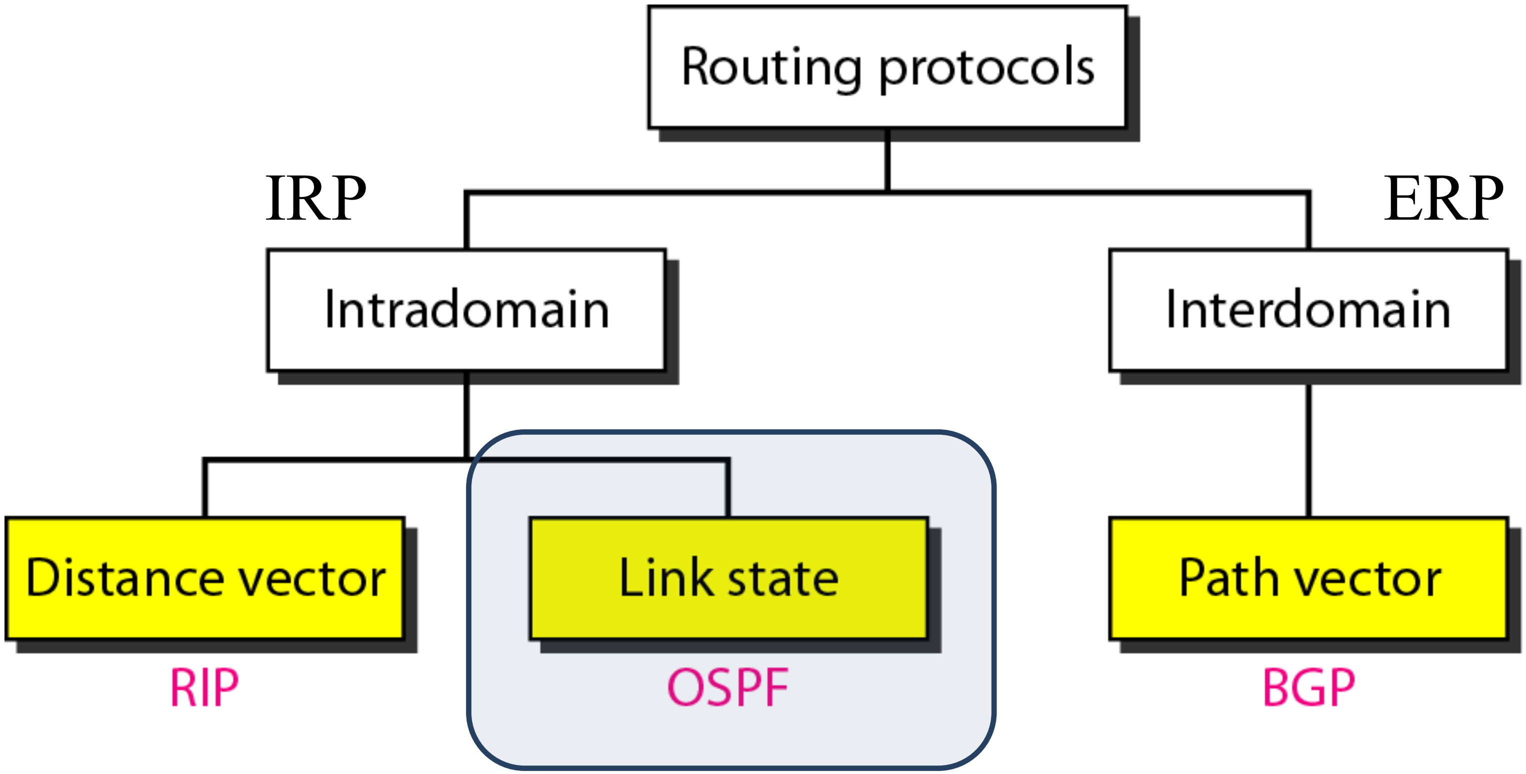


I have a route to X, but I got it from A so I won’t tell A about it!

RIP: Link Failure and Recovery

- If no advertisement heard after 180”
  - Neighbour/link declared dead
  - Routes via neighbour invalidated (infinite distance = 16 hops)
  - New advertisements sent to neighbours (triggering a chain reaction if tables changed)
  - “Poison reverse” – break split horizon for ‘infity routes’ - for to prevent count to infinity loops
  - “Good news travel fast, bad news travel slow”

Routing Algorithms and Protocols



Link-State Routing

- Designed to overcome the drawbacks of distance-vector routing
- When a router is initialized, it determines the link cost on each of its network interfaces
- The router then advertises this set of link costs to all other routers in the internet topology, not just neighboring routers
- From then on, the router monitors its link costs
- Whenever there is a significant change the router again advertises its set of link costs to all other routers in the configuration
- The OSPF protocol is an example
- The second-generation routing algorithm for ARPANET also uses this approach

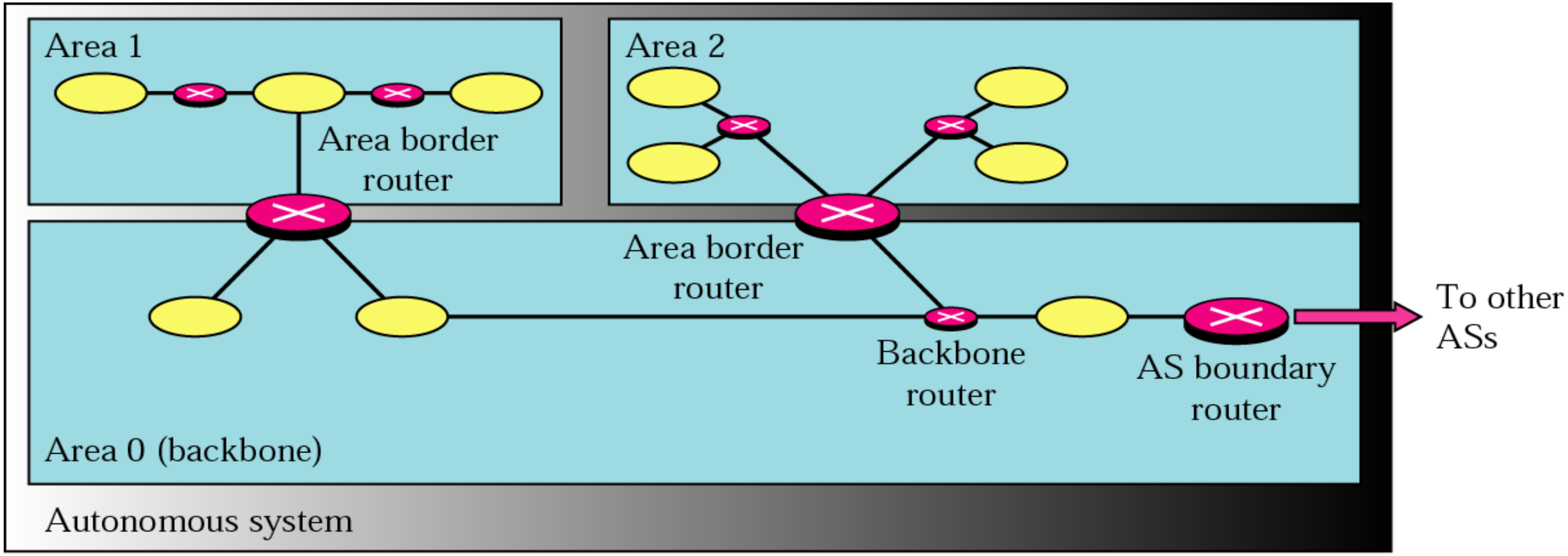
Open Shortest Path First (OSPF)

- RFC 2328 (Request For Comments)
- Used as the interior router protocol in TCP/IP networks
- Computes a route through the internet that incurs the least cost based on a user-configurable metric of cost
- Is able to equalize loads over multiple equal-cost paths

OSPF (Open Shortest Path First)

- Divides domain into areas
  - Limits flooding for efficiency
  - One ”backbone” area connects all
- Distance metric:
  - Cost to destination network

Areas, Router and Link Types



Graph

Network topology expressed as a graph

- Nodes
  - Routers
  - Networks
    - Transit, passing data through
    - Stub, end network (not transit)
- Edges
  - Direct, router to router
  - Indirect, router to network

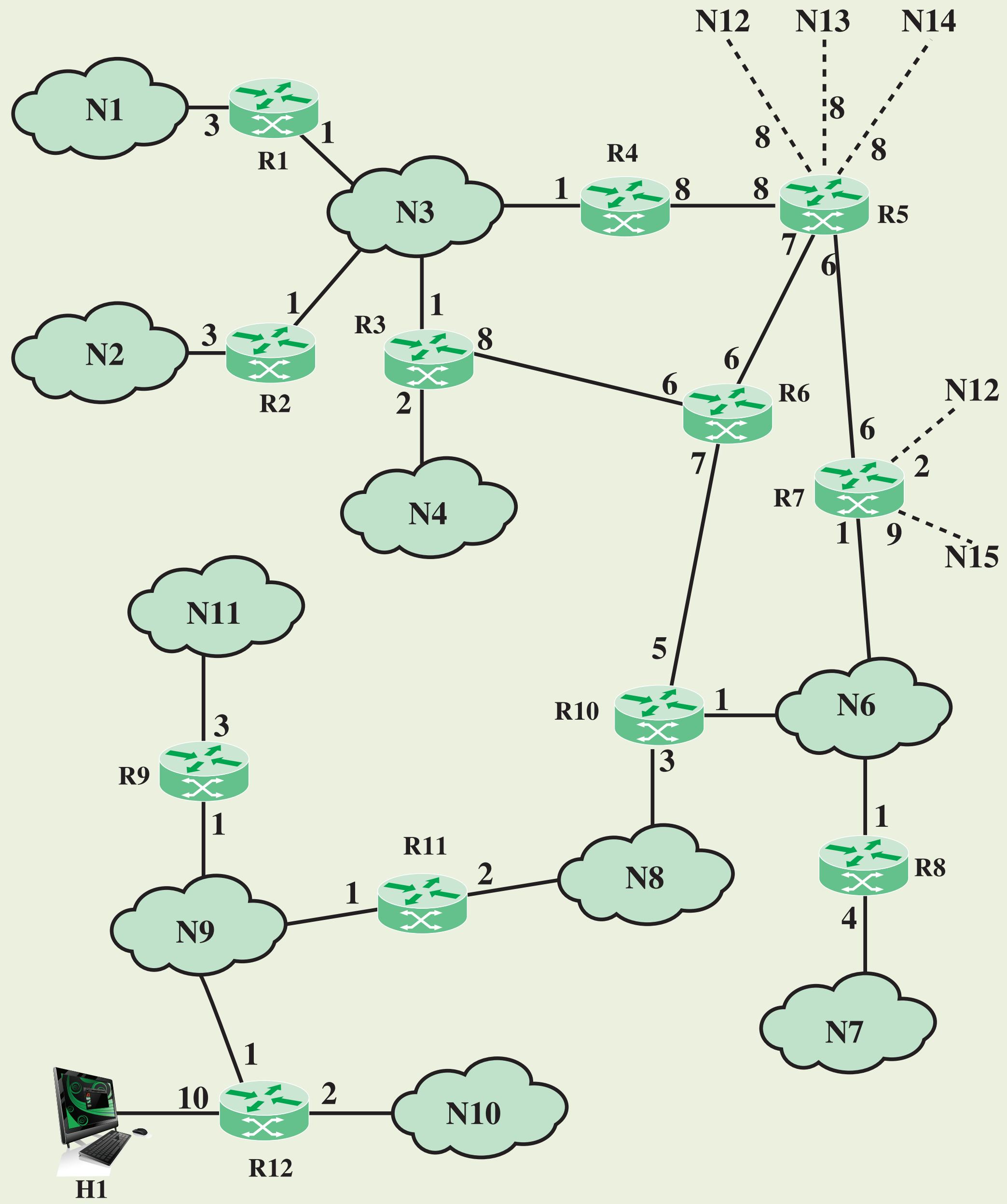


Figure 19.11 A Sample Autonomous System

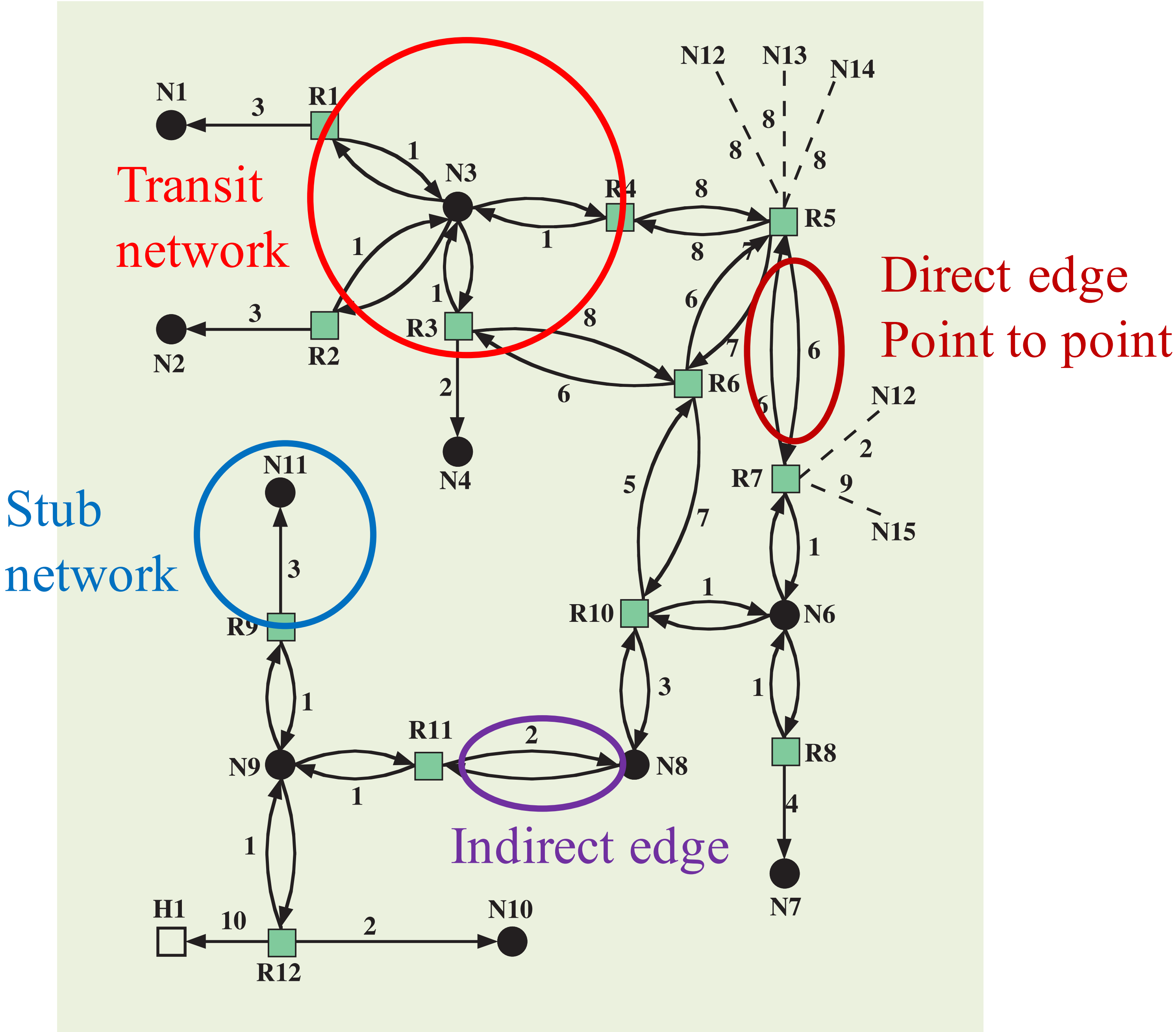
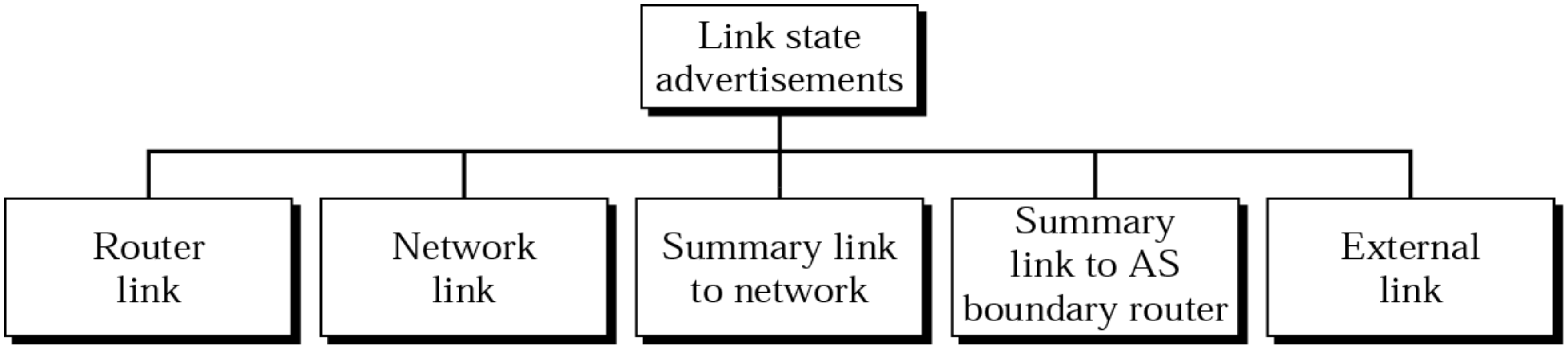


Figure 19.12 Directed Graph of Autonomous System of Figure 19.11

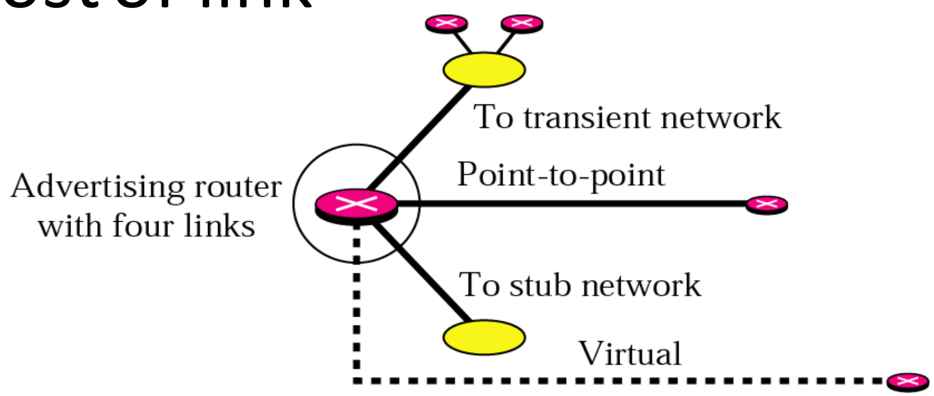
Link State Advertisements

- What to advertise?
  - Different entities as nodes
  - Different link types as connections
  - Different types of cost



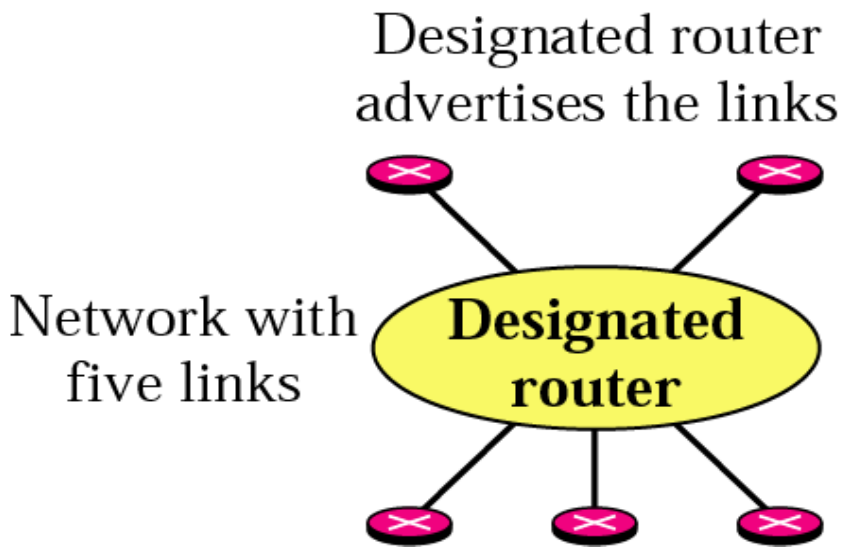
Router Link Advertisement

- Advertise the router as a node
  - Address
- Transient link (connection to transient network)
  - Address to network and cost of link
- Stub link (connection to stub network)
  - Address to network and cost of link
- Point-to-point link
  - Address to other router and cost for link



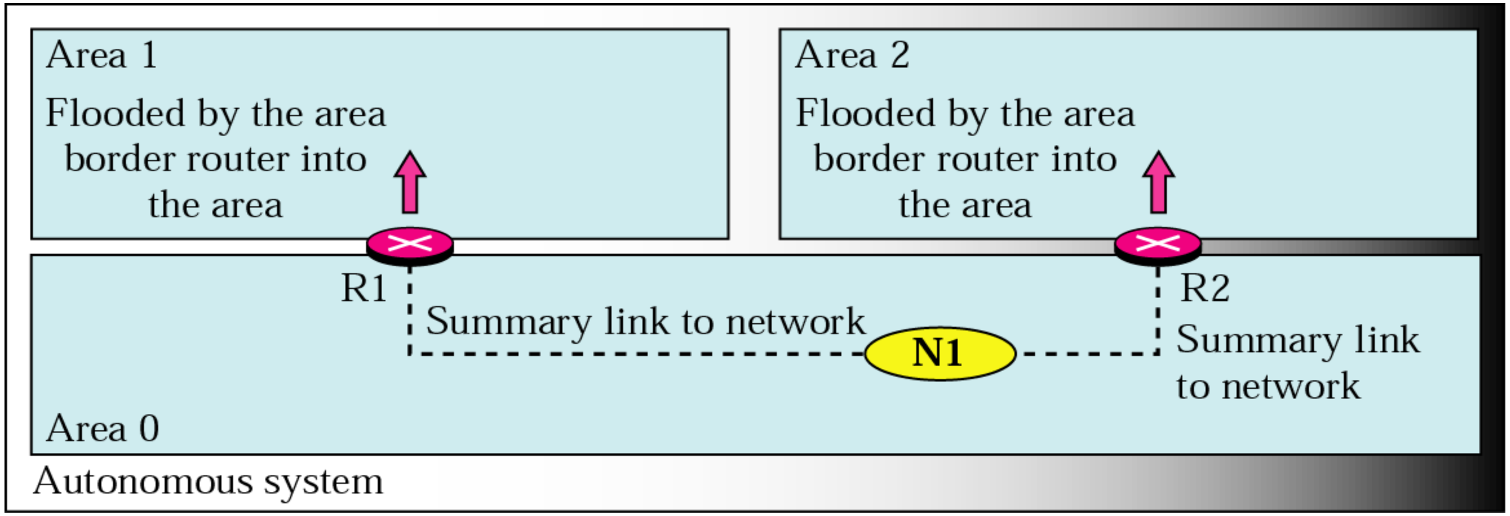
Network Link Advertisement

- A network is a passive entity and cannot advertise itself
  - A designated router does the announcement
  - Addresses to all connected routers (no costs)



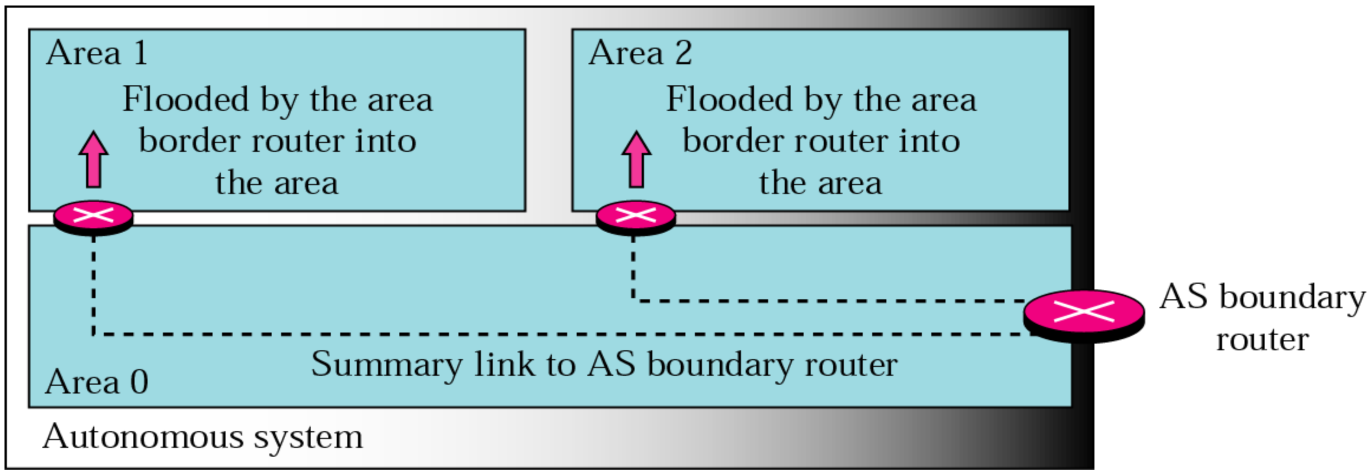
Summary Link to Network

- Done by area border routers
  - Advertise links between area and backbone
    - Viewed from backbone to area
    - Viewed from area to backbone



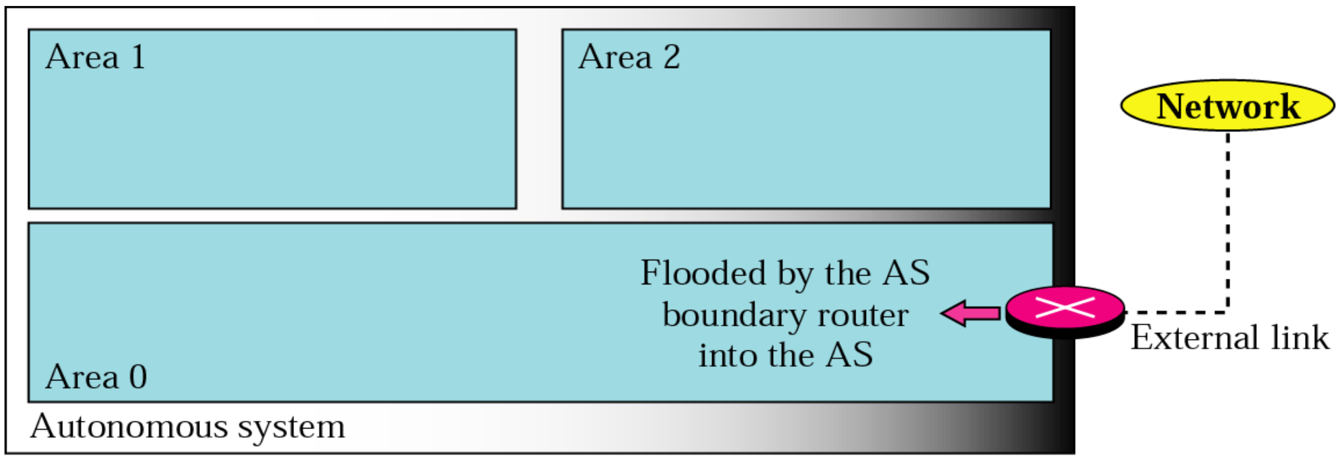
Summary Link to AS Boundary Router

- Done by AS border router
  - Links to other AS
  - Advertised in to the AS



External Link Advertisement

- Done by AS border router
  - Link to a single network outside the domain
  - Advertise in to the AS



Hello message

- Find neighbours
- Keep contact with neighbours: I am still alive!
- Sent out periodically (typically every 10th second)
- If no hellos received during holdtime (typically 30 seconds), neighbour declared dead.

- Compare RIP update messages

Dijkstra’s Algorithm

- Finds shortest paths from given source node to all other nodes
- Develop paths in order of increasing path length
- Algorithm runs in stages
  - Each time adding node with next shortest path
  - Algorithm terminates when all nodes have been added to T

Comparison

- Bellman-Ford
  - Calculation for node n needs link cost to neighbouring nodes plus total cost to each neighbour
  - Each node can maintain set of costs and paths for every other node
  - Can exchange information with direct neighbours
  - Can update costs and paths based on information from neighbours and knowledge of link costs

- Dijkstra
  - Each node needs complete topology
  - Must know link costs of all links in network
  - Must exchange information with all other nodes