IP-Networking
IP-Routing

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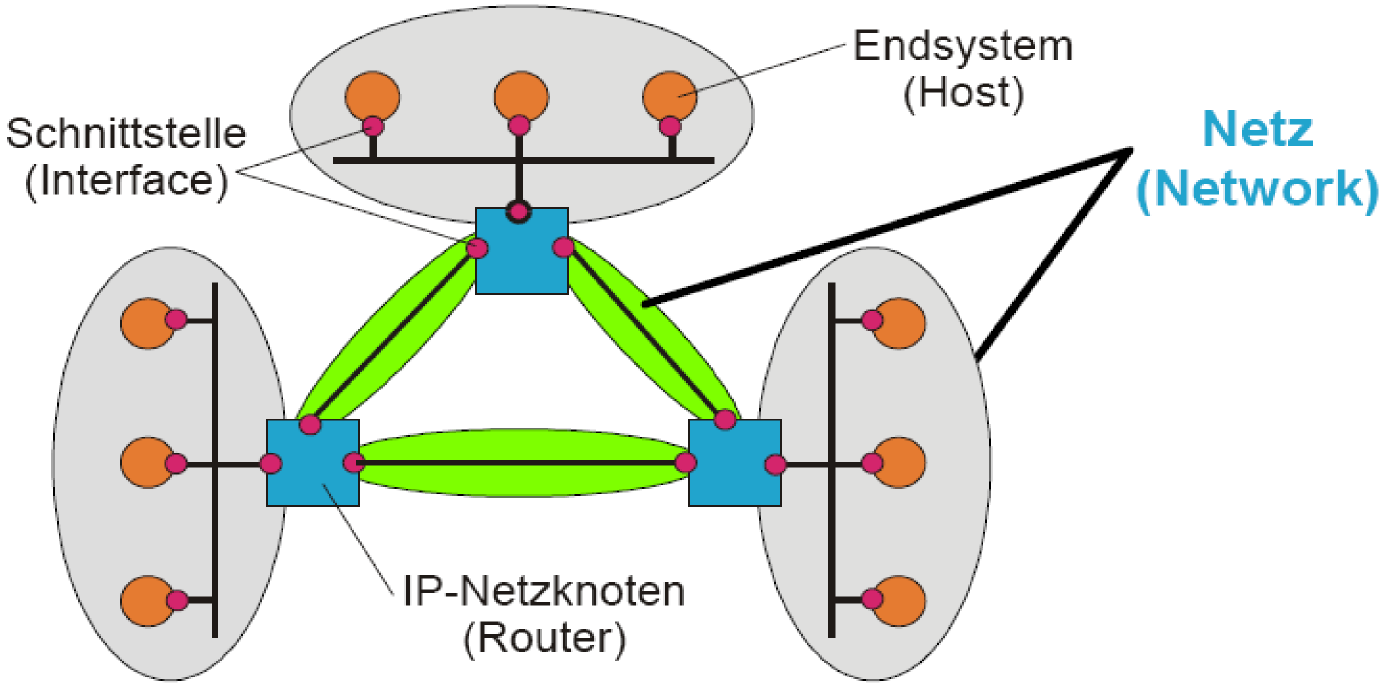
Introduction

Basic IP-Routing Scenario

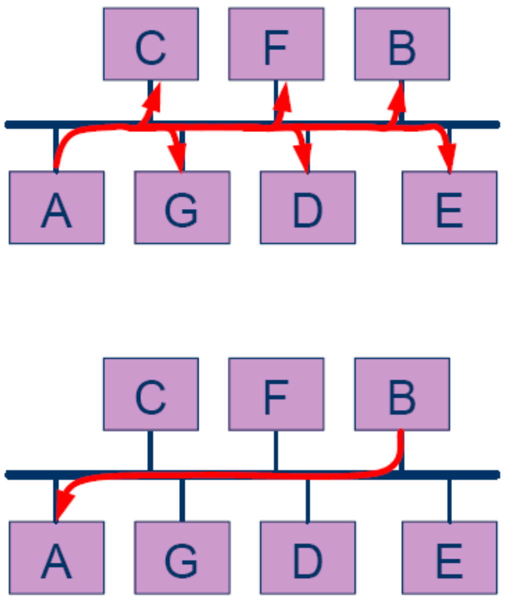


- **Stations (End Systems, Hosts)**
  - own an IP address (per network interface)
  - know a router (in their network) which forwards packets to other networks
  - communicate within their network by means of layer two addresses (for example Ethernet MAC addresses)
- **Routers (Intermediate Systems)**
  - forward packets after evaluation of IP destination addresses (more precisely: the network ID of the destination address): determination of the next hop via the routing table

Packet Forwarding within a Network

Layer 2 forwarding and ARP protocol:

- within a (local) network the packet forwarding is based on a layer 2 address, for example the Ethernet MAC address
- thus the layer 2 address which belongs to a certain IP address (host ID) has to be determined (address resolution)
- for that, the Address Resolution Protocol (ARP) is used:

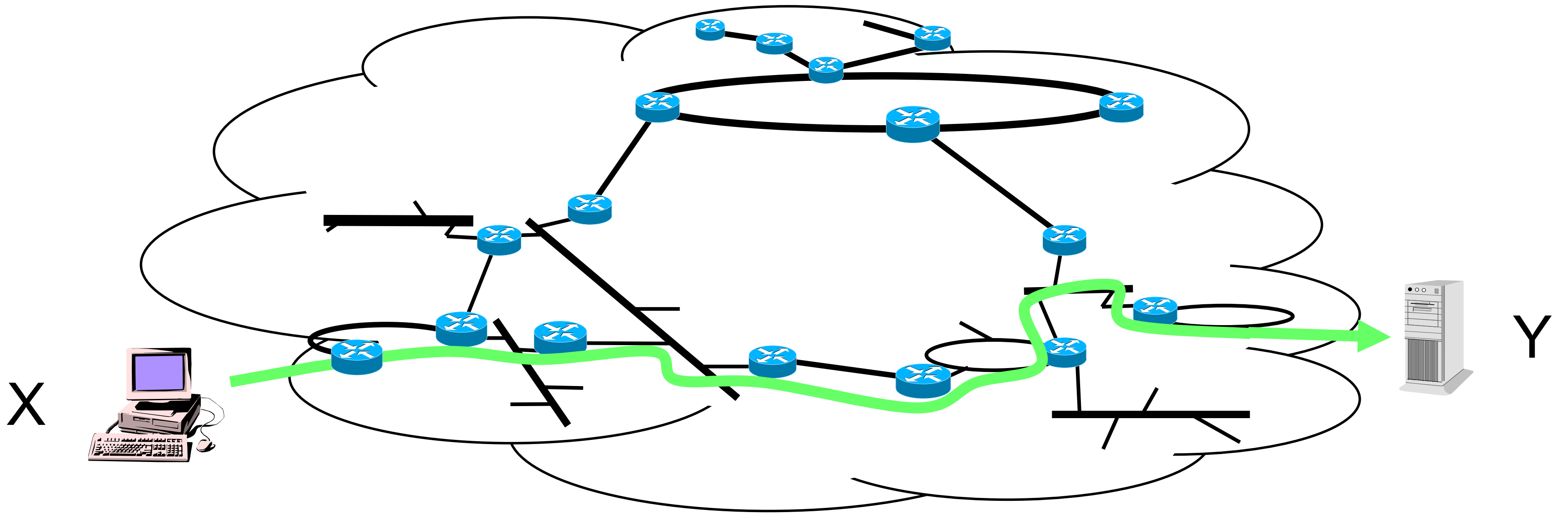


- system A wants to transmit IP packets to system B (with IP address IP_B)
- A transmits an ARP broadcast to all systems within the local network; the ARP broadcast contains the destination IP address IP_B as well as A's IP address and layer 2 address
- B recognises IP_B in the ARP broadcast and answers with its layer 2 address to A; additionally, B updates its ARP cache with the information of A
- A updates after the reception of the response its ARP cache with the information of B

Packet forwarding between Networks

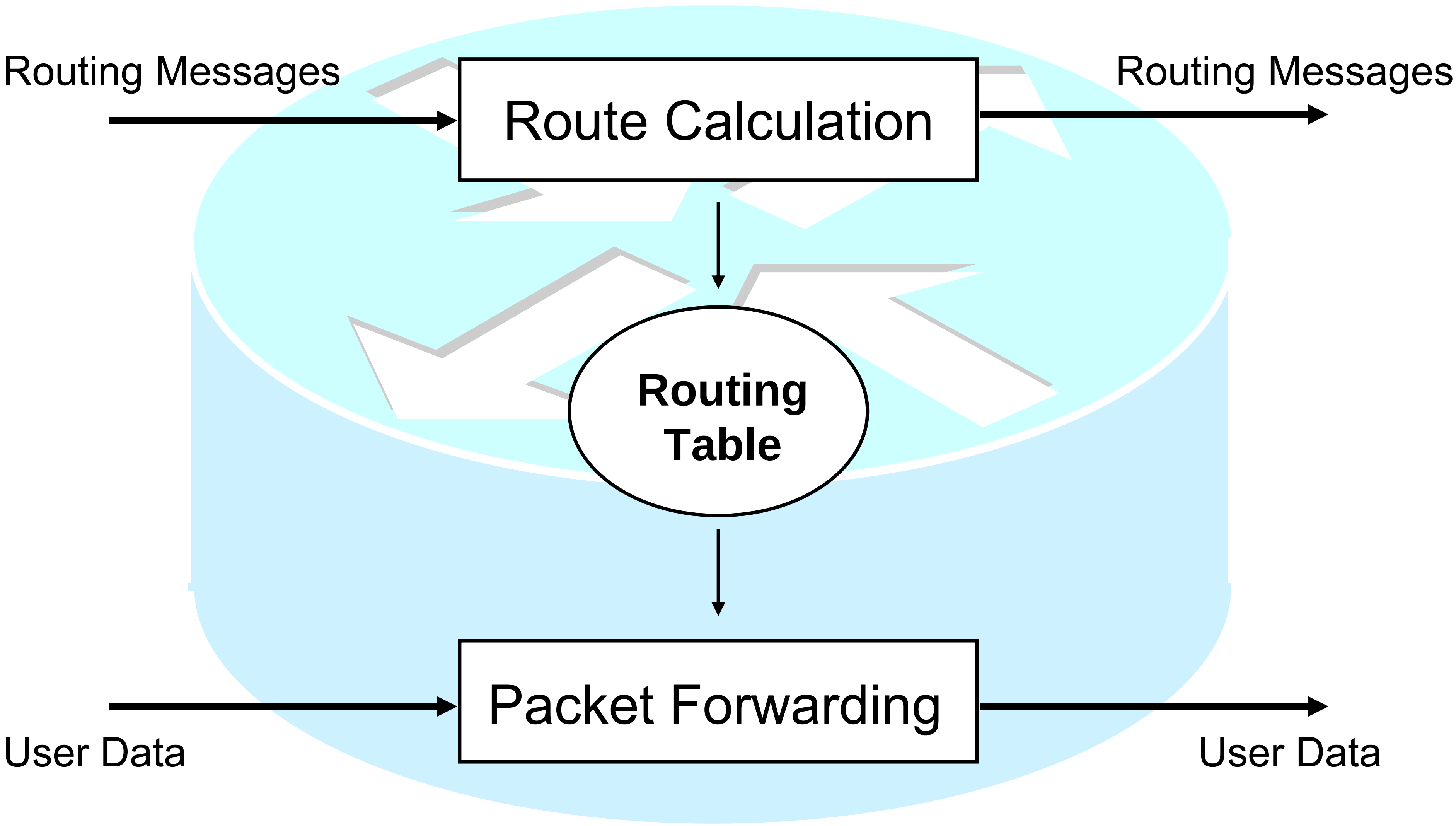
Layer 3 forwarding (IP routing):

- IP packets of an host X with destination Y have to be routed, if X and Y are not in the same (local) network (i.e. the network IDs of their IP addresses are different)
- routing means: provisioning and maintenance of a path (route) between source and destination
- routing is a function of the network layer (OSI layer 3)

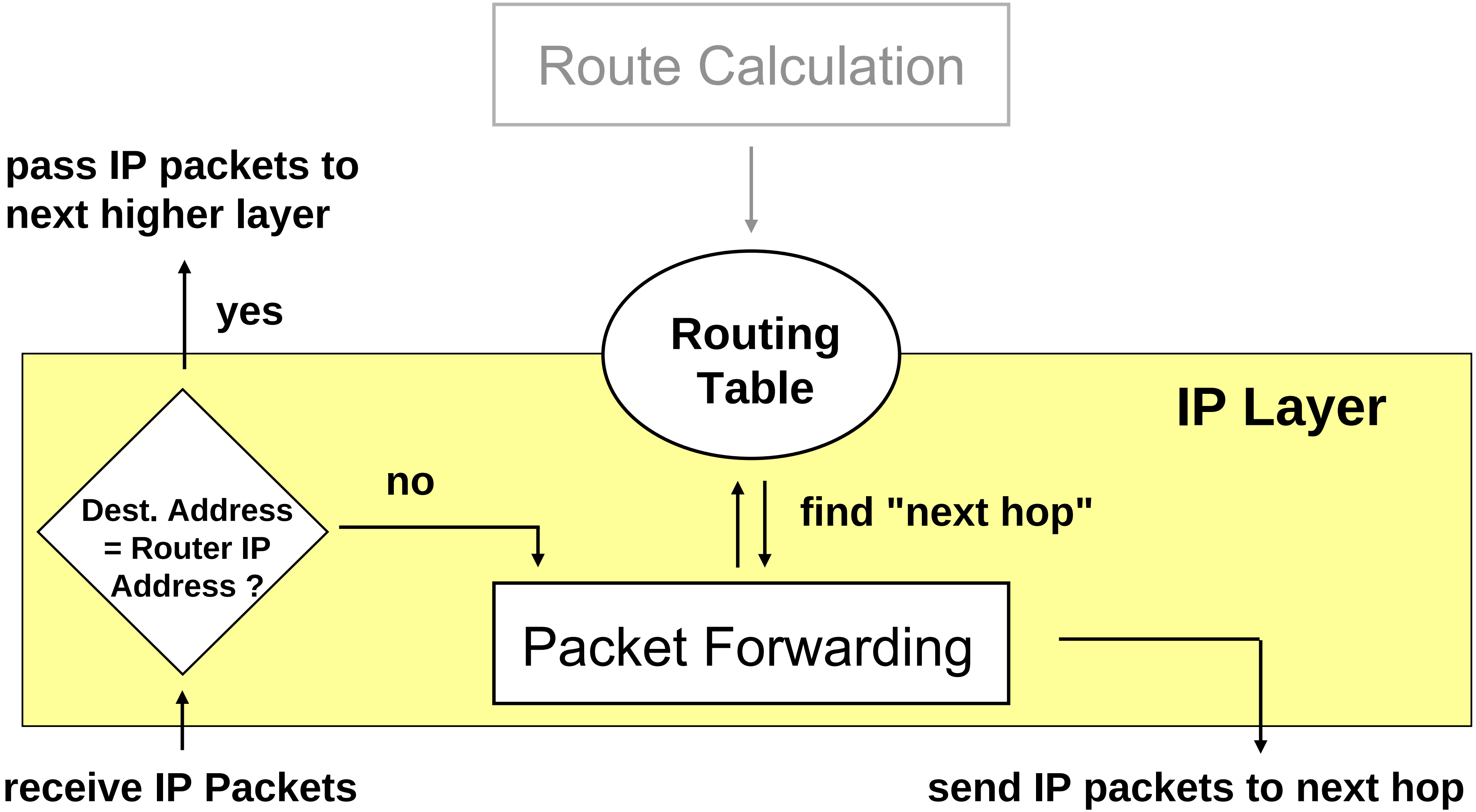


Basic Principles of IP Routing

Basic Operation of an IP Router - Overview



Basic Operation of an IP Router - Packet Forwarding (1)

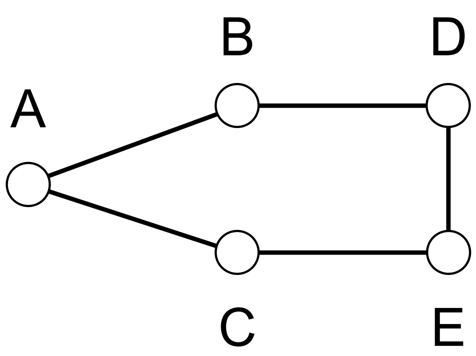


Basic Operation of an IP Router - Packet Forwarding (2)

Principle of destination IP address based packet forwarding:

- the forwarding is only based on the destination address (network ID) of the IP packet
- IP packets will be forwarded to the next hop router (which is determined from the routing table)
- every router performs its forwarding decision independently of other routers

Network example



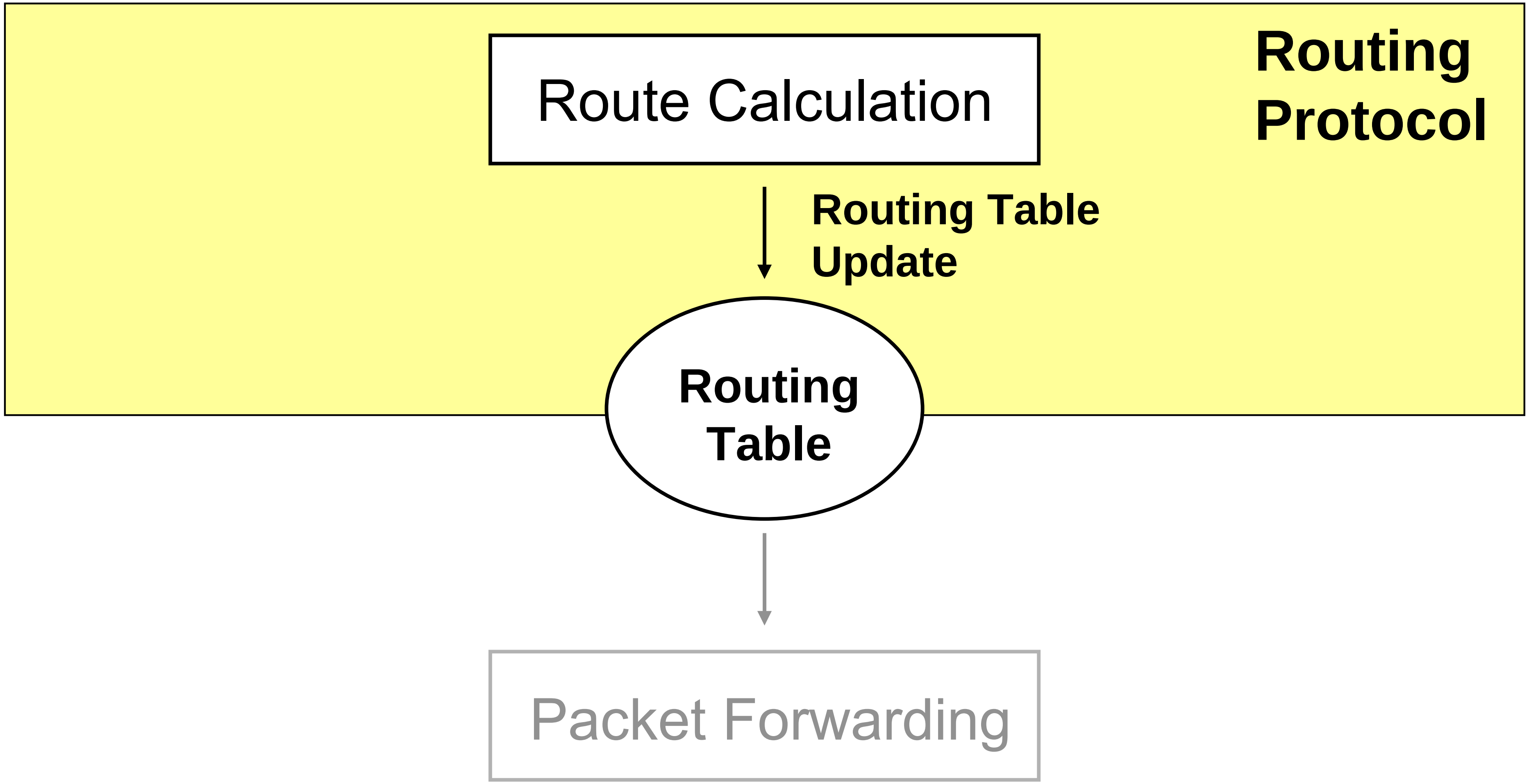
Routing table (Router A)

dest. net.	next hop
B	B
C	C
D	B
E	C

Routing table (Router B)

dest. net.	next hop
A	A
C	A
D	D
E	D

Basic Operation of an IP Router - Route Calculation (1)

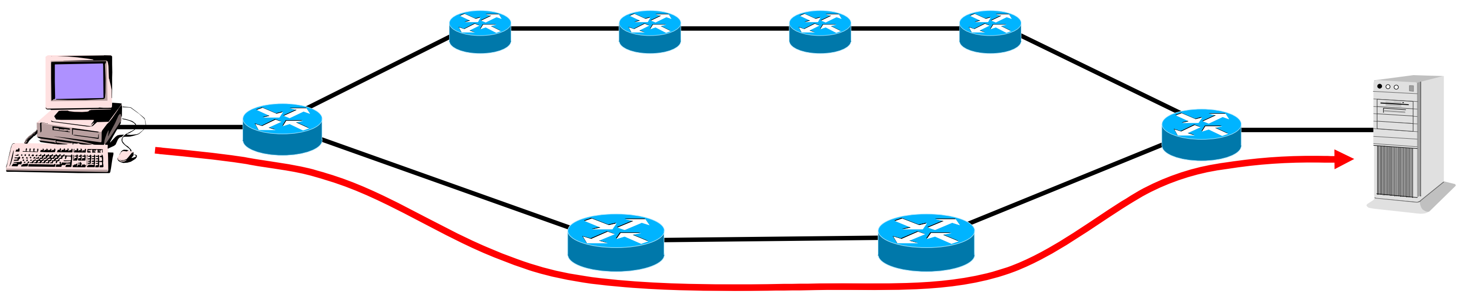


Basic Operation of an IP Router - Route Calculation (2)

Tasks of the routing protocol:

- exploring the network: finding reachable destinations
- observing the network: identification of topology changes
- route calculation: shortest path principle

Shortest path routing principle: if more than one route is available, the shortest route will be chosen (based on a predefined cost metric)



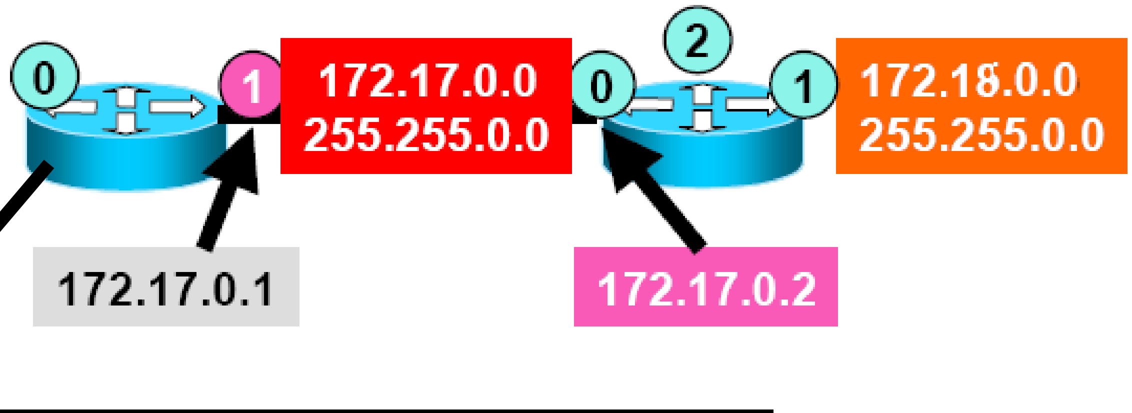
Routing Metrics

- Routing protocols use metrics for every path in the network
  - the lowest sum metric indicates the optimal path
  - after a topology change the optimal path is recalculated based on the updated metrics (which are exchanged between the routers)
- Examples for metrics:
  - number of traversed networks towards the destination (hop count)
    - simplest metric
    - different capacities of alternative paths are not considered
  - capacity, delay, load, reliability, maximum packet size on the links
  - arbitrarily defined link costs
- Often combinations of weighted metrics are used
  - default values (vendor recommendations) for link metrics and their weights
  - link metrics and weights can be changed manually to perform path optimization (traffic engineering)

Routing Tables - Variants of Routing Table Entries

- Static routes
  - routing tables entries are added manually
  - high effort, since every network has to be configured in every router
  - for changes every affected router has to be reconfigured manually
  - full control of the paths in the network
- Special case: default routes
  - for networks with only one exit point to the Internet (stub network)
  - default routes are used if no routing table entry exists for an (external) destination address - all packets (with external destination) are send to this border router (default gateway)
- Dynamic routing
  - routers exchange routing information via routing protocols
  - advantage: automatic route configuration, thus less configuration effort
  - disadvantage: high CPU load of routers due to routing protocol processing and overhead in the network due to exchange of routing information
  - usually applied in large networks

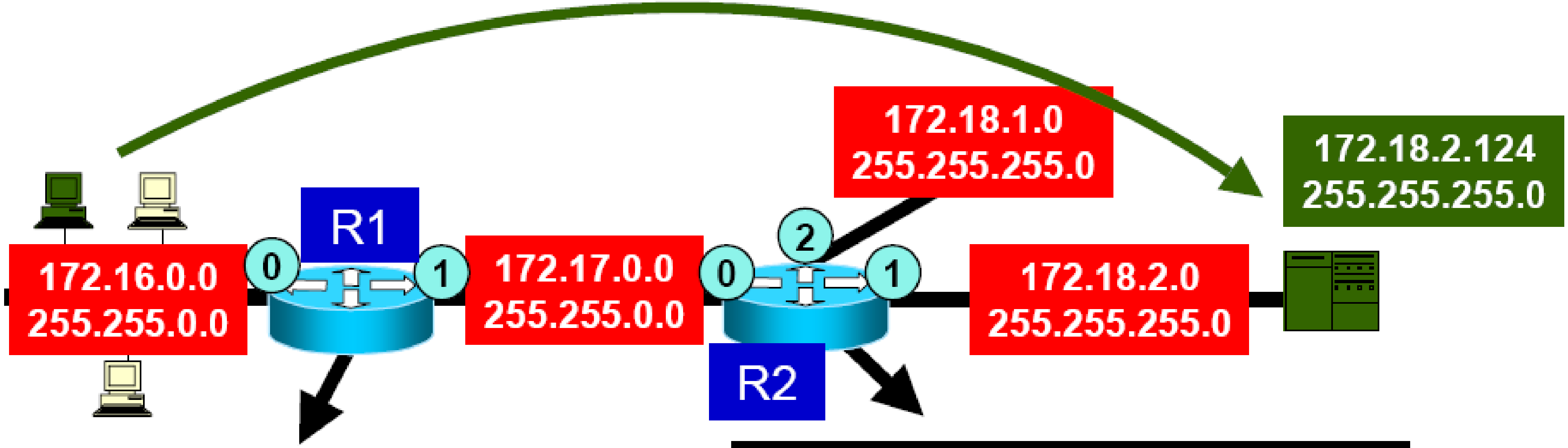
Routing Tables - Structure of Routing Tables



Dest. Net.	Mask	Next Hop	If.	Hops
...	...		...	...
172.17.0.0	255.255.0.0	----	1	1
172.18.0.0	255.255.0.0	172.17.0.2	1	2

- **Identification of a next hop in case of point-to-point links:**
  - either: through specification of an egress interface (explicit, since only one router could be reached through this interface), for example interface 1
  - or: through specification of the IP address of the interface of the next router which is connected at the other end of the link, e.g. 172.17.0.2
- **Identification of a next hop in case of multipoint connections (LAN):**
  - through explicit specification of the IP address of the interface of the next hop router which is connected to the LAN

Routing Tables - Examples of Routing Table Entries



Dest. net.	Mask	If.	Hops
172.16.0.0	255.255.0.0	0	1
172.17.0.0	255.255.0.0	1	1
172.18.0.0	255.255.0.0	1	2

Dest. net.	Mask	If.	Hops
172.16.0.0	255.255.0.0	0	2
172.17.0.0	255.255.0.0	0	1
172.18.1.0	255.255.255.0	2	1
172.18.2.0	255.255.255.0	1	1

Classification of Routing Protocols

IP Routing Protocols

- **Intra-domain Routing Protocols**
  - Distance Vector Principle

    Examples:

    RIP
    IGRP
    EIGRP
  - Link State Principle

    Examples:

    OSPF
    IS-IS
- **Inter-domain Routing Protocols**
  - Preference & Policy Principle

    Example:

    EGP
  - Path Vector Principle

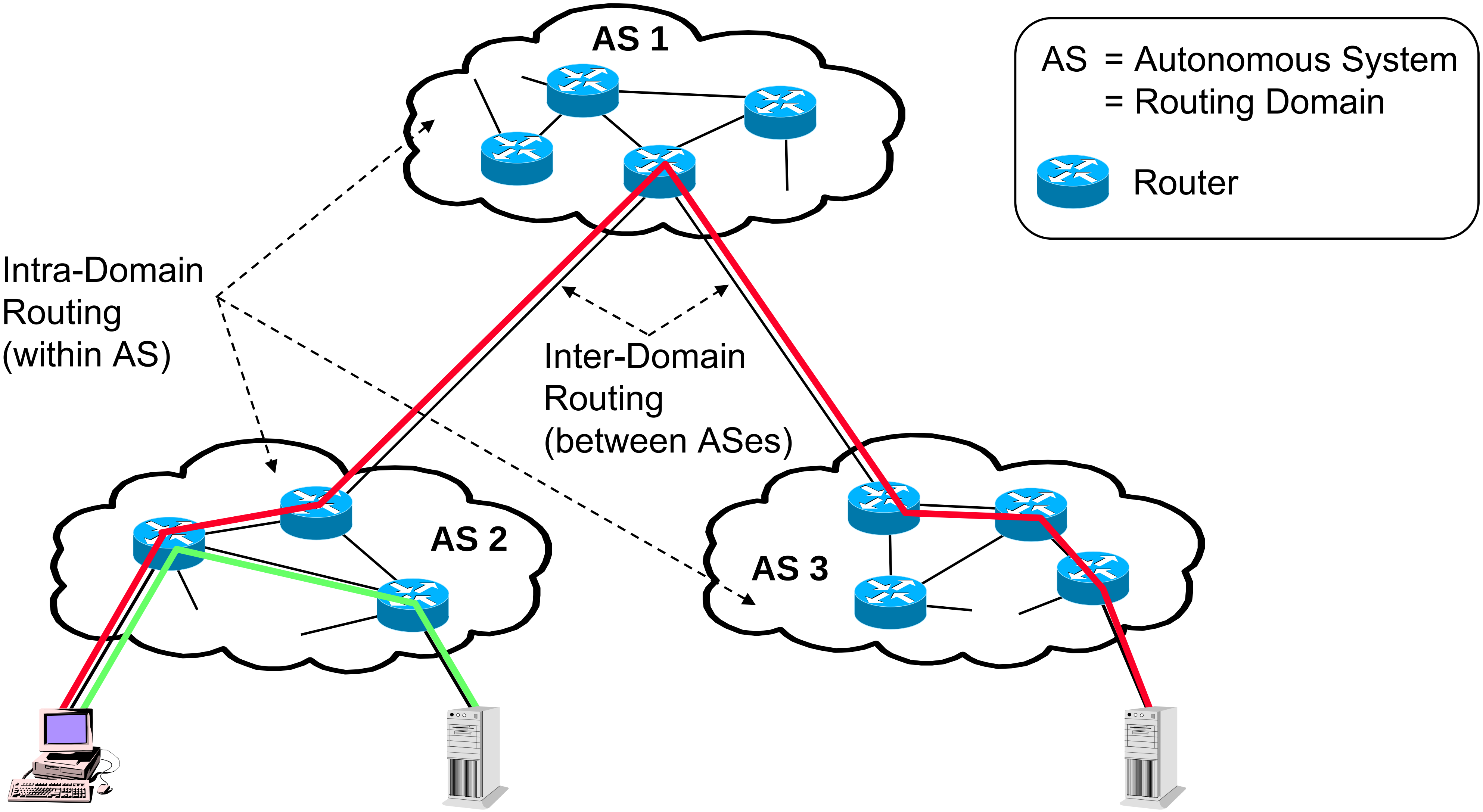
    Example:

    BGP-4

Classification of Routing Protocols

- Routing protocols are part of the different protocol suites
  - e.g. RIP, OSPF in case of TCP/IP; IPX-RIP in case of Novell
- Besides these standard protocols also proprietary protocols exists
  - e.g. IGRP from Cisco
- Different routing concepts exist
  - distance vector routing (e.g. RIP)
  - link state routing (e.g. OSPF)
  - hybrid versions
- Different routing protocols for different use cases are available
  - interior gateway protocols = intra-domain routing protocols
    - routing within a network of an operator (e.g. RIP, OSPF)
  - exterior gateway protocols = inter-domain routing protocols
    - routing between networks of different operators (e.g. BGP)
    - allow the definition of policies

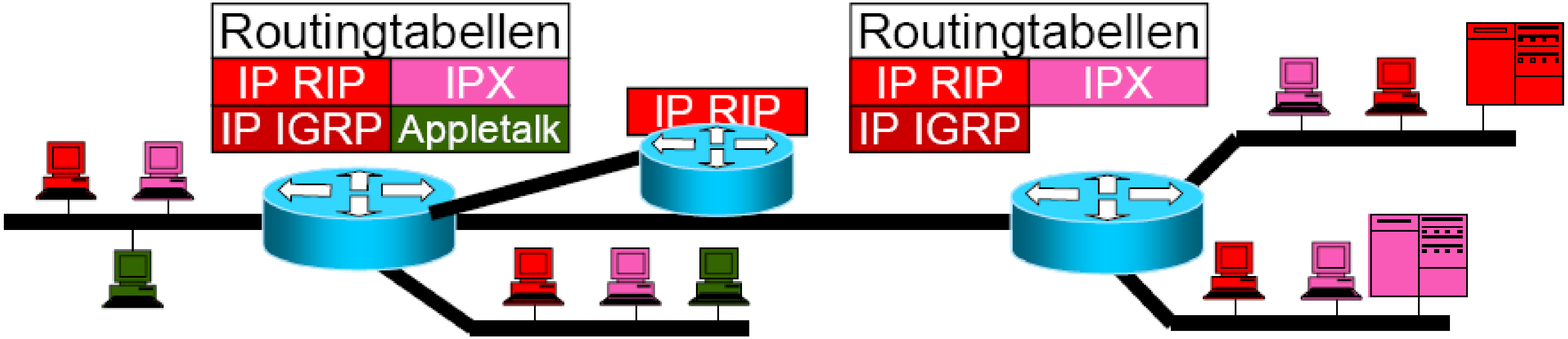
Intra-Domain vs. Inter-Domain Routing



Distance Vector vs. Link State Routing

- Distance vector routing protocols (Bellman-Ford algorithm)
  - routers send the complete content of their routing tables to all neighbours - by that the metrics are incremented
  - frequent periodic updates (large overhead)
  - low CPU load of the router, but extra capacity required in the network
  - it can take a long time until the routing tables are stable (convergence) after a topology change
  - suitable for small networks (e.g. RIP routing)
- Link state routing protocols (Shortest Path First algorithm)
  - routers send information about their links to all routers in the network
  - every router has the complete view on the topology and calculates the optimal paths to all destination networks (e.g. with a shortest path algorithm)
  - updates are only sent in case of topology changes, normally only a small amount of data incurs per update
  - high CPU load of the router, but low capacity requirement in the network
  - fast convergence
  - suitable for larger networks (e.g. OSPF routing)

Multi Protocol Routing, Ships in the Night



- A router can use several routing protocols simultaneously
  - separated routing tables have to be administrated → higher CPU load, more network capacity needed
  - routing protocols usually don't exchange information among each other → „Ships in the Night" routing; however, some implementations allow for an exchange
- Several routing protocols (e.g. RIP and IGRP) might be applied to one routed protocol (e.g. IP)
  - only the informations of the most trustworthy routing protocol are used; the relative trustability is defined by the so called administrative distance