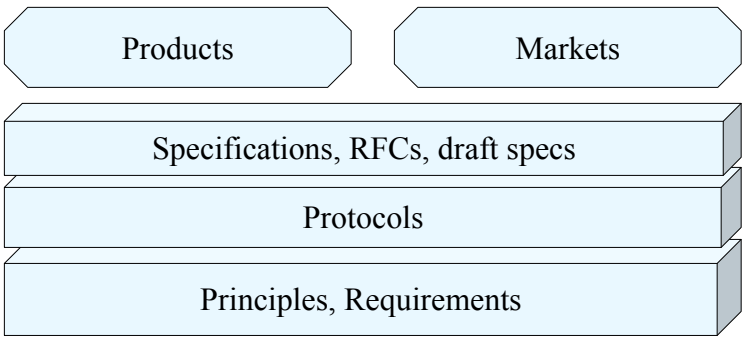
Introduction to routing in the Internet

IPv4, ICMP, ARP
addressing, routing principles

(Chapters 2–3 in Huitema)

Levels of analysis – we deal with principles, protocols and specifications



Internet Architecture Principles

End-to-end principle

- All control in end stations
  - e.g. error and flow control
- The network can not be trusted
- User must in any case check for errors
  - → network control redundant
- Error checking and flow control by TCP
- No state information/connection in the network
  - packets routed independently
  - if a link fails, another route is used
- Same principle as in distributed systems

by Dave Clark

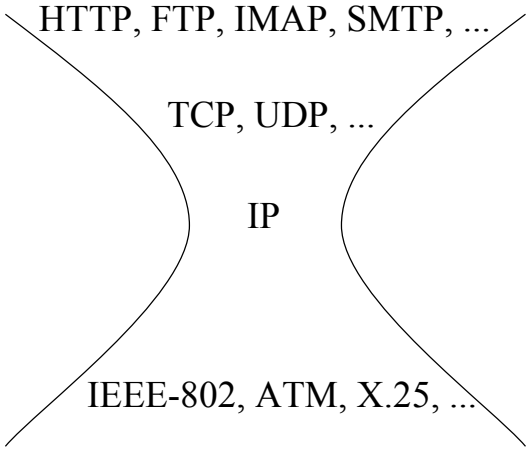
Internet Architecture Principles

IP over everything

- Interconnection based on IP overlay over all kinds of networks:
  - framing or encapsulation
  - address resolution
    - IP-address to network address for each transport technology
  - unique IP-address
  - simple to adapt to new technologies
- Interconnection based on translation:
  - e.g. signaling interworking - imperfect mapping
  - IPv4 to IPv6 mapping!

by Vinston Cerf

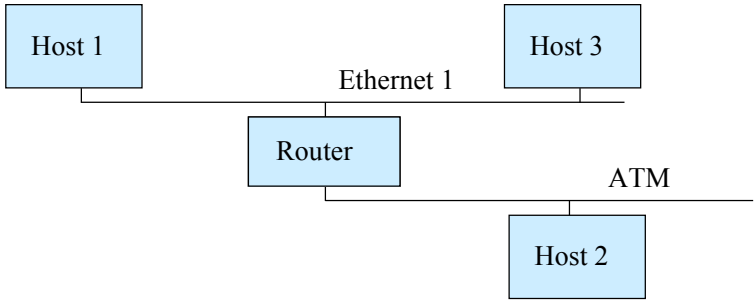
Internet Architecture Principles
IP over everything



Internet Architecture Principles
Connectivity is its own reward

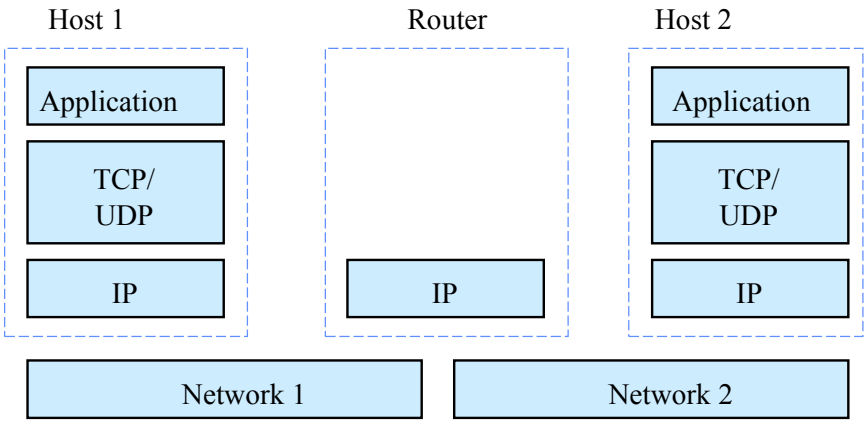
- The value of a network increases in proportion to the square of the number of nodes on the network (Robert Metcalf's law)
- Be liberal with what you receive, conservative with what you send
  - try to make your best to understand what you receive
  - maximum adherance to standard when sending
- Snowballing effect keeps all interested in connectivity thus keeps adhering to standards

By connecting Ethernet segments with routers the traffic of the segments can be separated

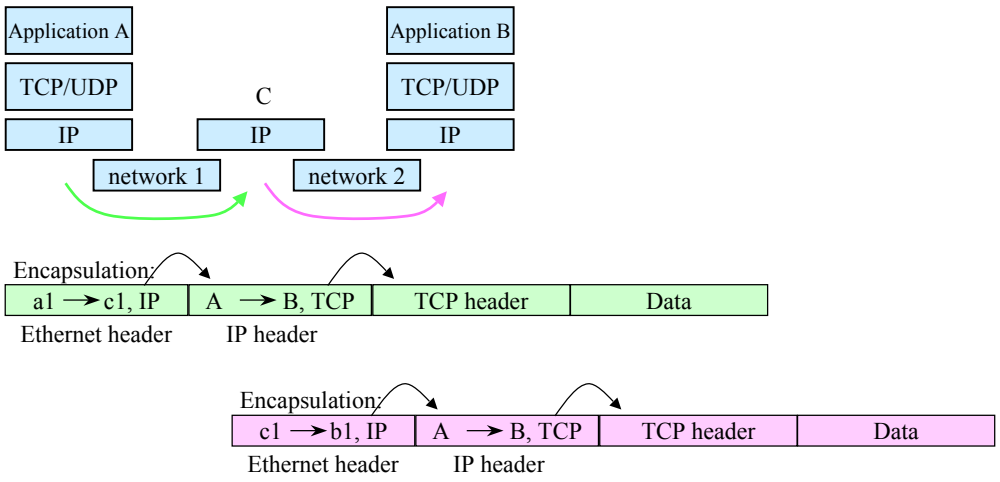


Host 2 does not receive packets sent by Host 1 to other hosts on Ethernet 1

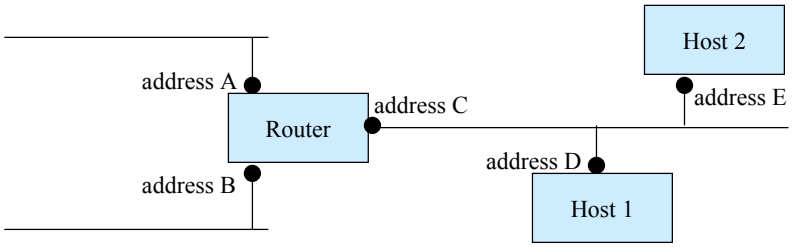
Internet layer model - hosts and routers



Layers and message forwarding



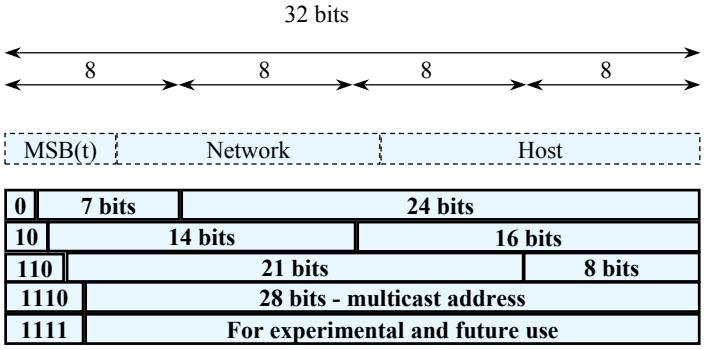
The IP address defines the interface



IPv4 address formats

- Originally a two-level (network, host) hierarchy

1981



IPv4 address formats

1984

- A new level for easier network administration

Network	Subnet	Host

- Examples:

Mask	IP address	Network	Subnet	Host
0xFFFF0000	10.27.32.100	A: 10	27	32.100
0xFFFFFE00	136.27.33.100	B: 136.27	16 (32)	1.100
	136.27.34.141	136.27	17 (34)	0.141
0xFFFFFFC0	193.27.32.197	C: 193.27.32	3 (192)	5

High order bits:
0 ..... 0 - 127. → A-class
10.... 128. - 191. → B-class
110...192. - 223. → C-class

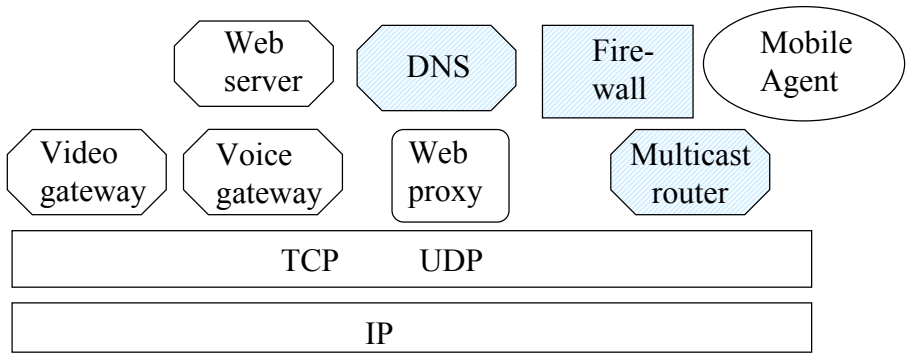
Without right zeroes (and with right zeroes)

Later updated by CIDR (discussed later)

Special addresses

- An unknown network is replaced by 0
  - Only used as source address (e.g. a booting host)
  - 0.0.0.0 = ”this host in this network”
  - 0.X.Y.Z = ”host X.Y.Z in this network”
- Limited broadcast address 255.255.255.255
  - To all host in the local network
- Directed broadcast addresses A.255.255.255, B.B.255.255, C.C.C.255
  - To all hosts in a specified network
- Loopback-address 127.X.X.X (usually 127.0.0.1)
  - Internal in one host
- Multicast-addresses (e.g. 224.0.0.2 = all routers on this subnet)

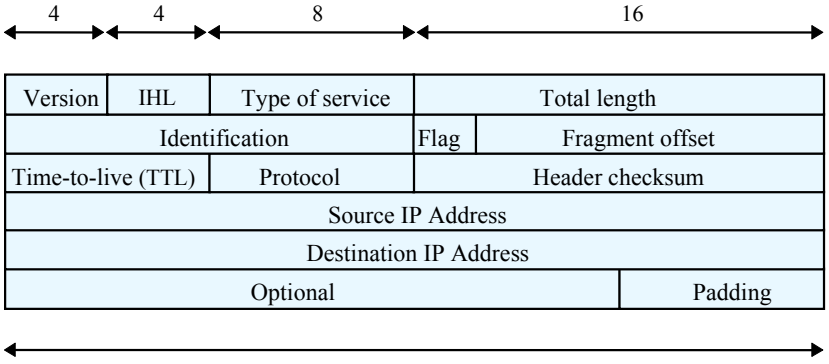
Internet architecture includes a set of service level components on top of TCP/IP



In this course we may touch some of these but only in their relation to routing.

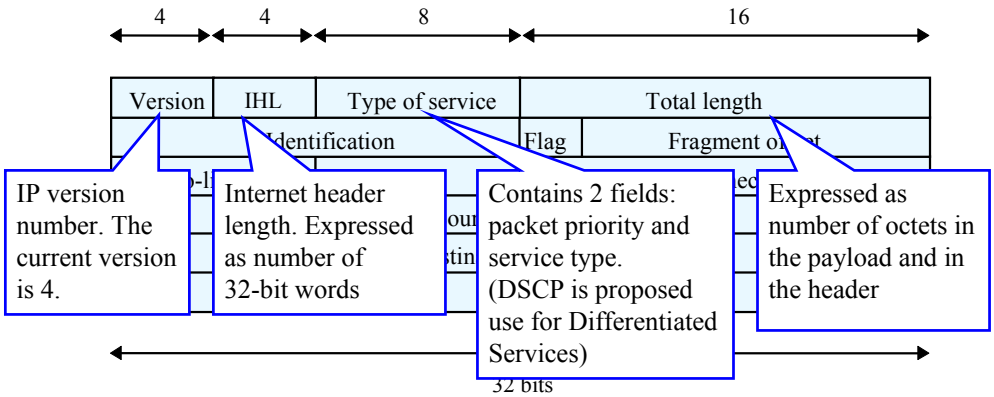
IPv4 packet header

RFC-791

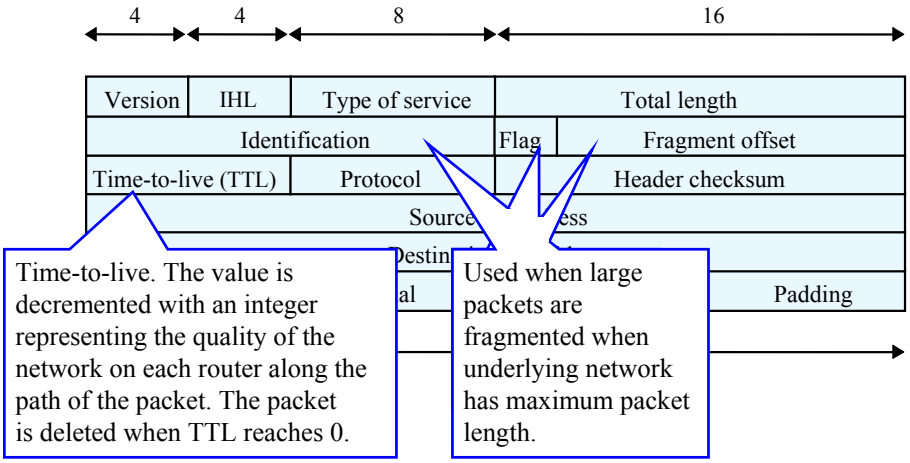


We assume that the sender knows its own IP address.
If not: self configuration protocols such as RARP, BOOTP, DHCP (dynamic host configuration protocol) are used

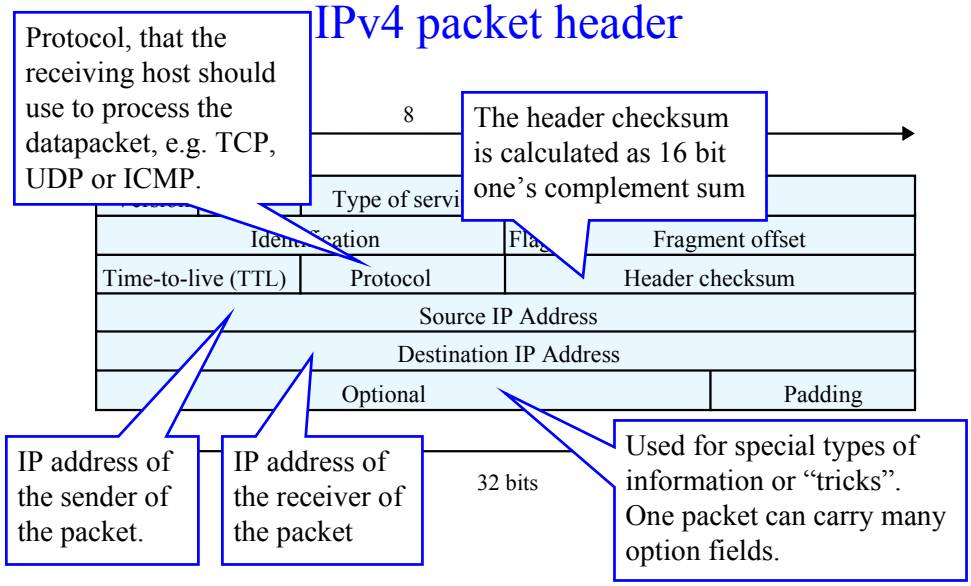
IPv4 packet header



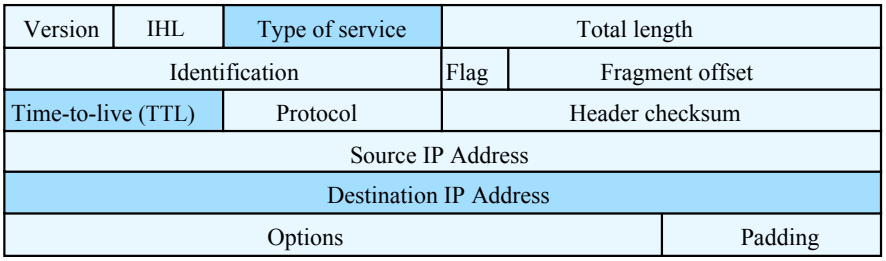
IPv4 packet header



IPv4 packet header

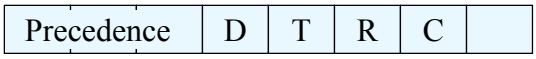


The most important fields in routing are the destination address and the time-to-live



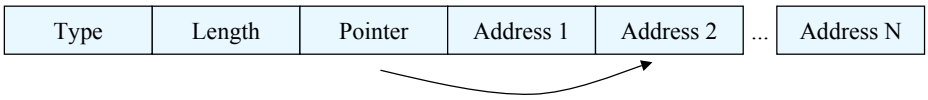
- TTL changes → calculate new checksum
- Options (e.g. source routing)
  - rarely used.

Type of service



- Route selection criteria
  - D – minimization of delay
  - T – maximization of transmission capacity
  - R – maximization of reliability
  - C – minimization of cost
  - Only one can be selected.
- Precedence
  - The largest precedence packet is first taken from the queue to be routed.
- In practise, these are not used
- DiffServ uses the field in another way

Source routing



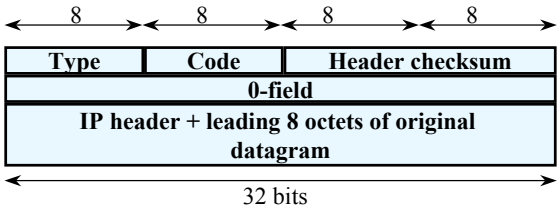
- Implemented with the ”source routing” option
  - Loose source routing (type 131)
    - The packet is sent to the next address in the list using normal routing.
  - Strict source routing (type 137)
    - The packet is sent to the next address in the list. If there is no direct link to the address, the packet is destroyed.
- Rarely used
  - Can be replaced by encapsulation

ICMP - Internet Control Message Protocol

- Gives feedback about the network operation.
- All hosts and routers must support ICMP.
- ICMP messages are transported in IP packets
- ICMP packet is sent backwards if e.g.
  - The receiver is unreachable
  - The router deletes a packet
  - TTL = 0.
- If ICMP message is deleted, a new one is not generated
  - to avoid the “snowballing effect”.

ICMP messages

Type =
- ***0 - Echo reply*** (used for "ping")
- ***3 - Destination unreachable***
- 4 - ~~source quench~~ (not used)
- ***5 - Redirect***
- ***8 - Echo*** (used for "ping")
- ***9 - Router advertisement***
- ***10 - Router solicitation***
- ***11 - Time exceeded***
- 12 - Parameter problem
- 13 - Timestamp
- 14 - Timestamp reply
- 15 - Information request
- 16 - Information reply

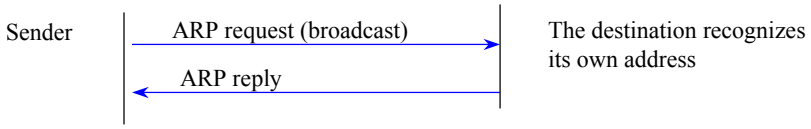


Code =
- **0 - net unreachable**
- **1 - host unreachable**
- **2 - protocol unreachable**
- **3 - port unreachable**
- 4 - fragmentation needed and DF set
- **5 - source route failed**

4 - source quench (="slow down") has been dropped from recommendations

Packet sending – how to determine the next hop

- The sender checks if the destination address in the same sub-network by comparing the masked values of the source and destination address.
  - If same, the destination is in the same subnet (next hop=destination).
  - Otherwise, the packet must be sent to a router (next hop=router).
- It then obtains the media address (MAC-address) of the destination (or router) using the ARP-protocol.



- The media address is stored in the cache.
  - Note: All hosts in the same subnet stores the address in their cache.

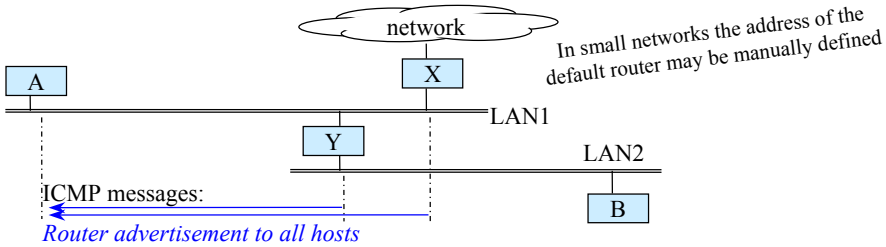
ARP - Address Resolution Protocol

RFC-826

- ARP maps IP to the underlying protocol
- IP-address → MAC-address
- Each network technology requires its own ARP adaptation.
  - Easy if the network supports broadcast or multicast.
    - Ehternet, Token Ring, FDDI
  - ATM requires a special ARP-server
  - Manually defined address for point-to-point links
    - X.25, ISDN, Frame-Relay
- Works on top of Ethernet (not on top of IP)

Router discovery

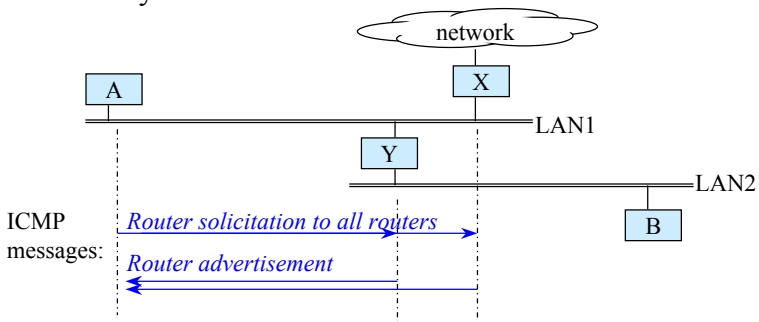
- The routers send *router advertisements* to all hosts periodically (e.g. in 7 minute intervals)



- The advertisement contains
  - a list of the router's addresses.
  - the preference of the addresses, which are used to identify the normal, reserve, etc. router or router address (the preference of the default router is highest)
  - lifetime of the information (e.g. 30 min)

Router discovery

- The host would have to wait max. 7 minutes before it can send packets outside its sub-network.
- Using a *router solicitation*, the host gets the advertisement immediately

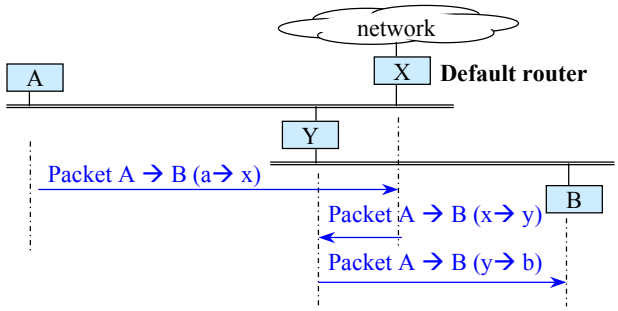


Router discovery

- The host discards advertisements from routers outside its sub-network and chooses the router with the highest priority as its default router.
- All packets for destinations outside the sub-network are sent to the default router.

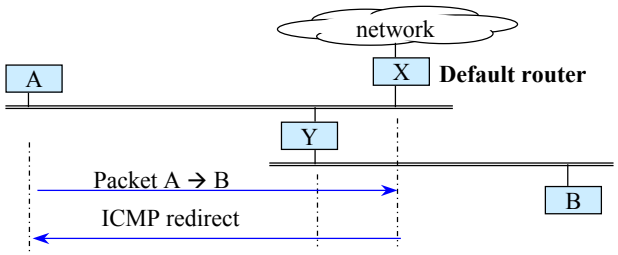
A network may have many routers, the closest to the destination must be found

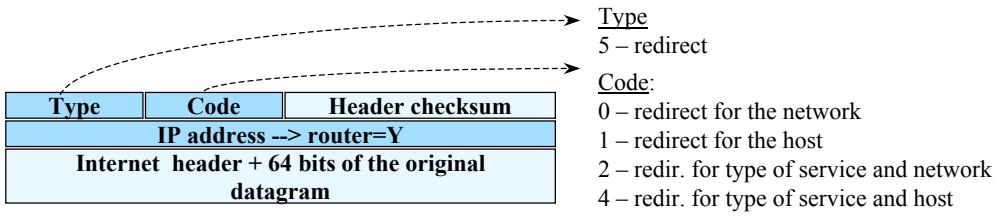
- A packet sent through the default router reaches the destination, but may waste resources



A network may have many routers, the closest to the destination must be found

- The router can send a redirect to indicate a shorter route to the destination





Redirect is a slow mechanism. Hot-standby addressing is an improvement

- Virtual router redundancy protocol (RFC 2338 - 4/98)
  - a router may have a virtual IP address
  - a router can take the IP and MAC addresses of a failed router (in the same segment)
  - After recovery routers negotiate about address assignments
  - Clients are configured with a static (virtual) router address
  - Cisco and DEC have equivalent proprietary protocols
- Host can listen to RIP or OSPF
  - not recommended but used sometimes anyway

Host must have feedback from the first router to avoid sending to a “black hole”

Feedback may be

- TCP acknowledgements
- Router advertisements
- ARP-replies
- ICMP echo reply (ping)

Between routers, routing protocols provide similar feedback and help in detecting failed router neighbors.

DNS – Domain Name Service

- Why DNS?
  - Easier to remember names than addresses
  - The address may change, the name is the same
  - Several addresses per host
- Name → address
- DNS does not affect routing

Routing in the Internet

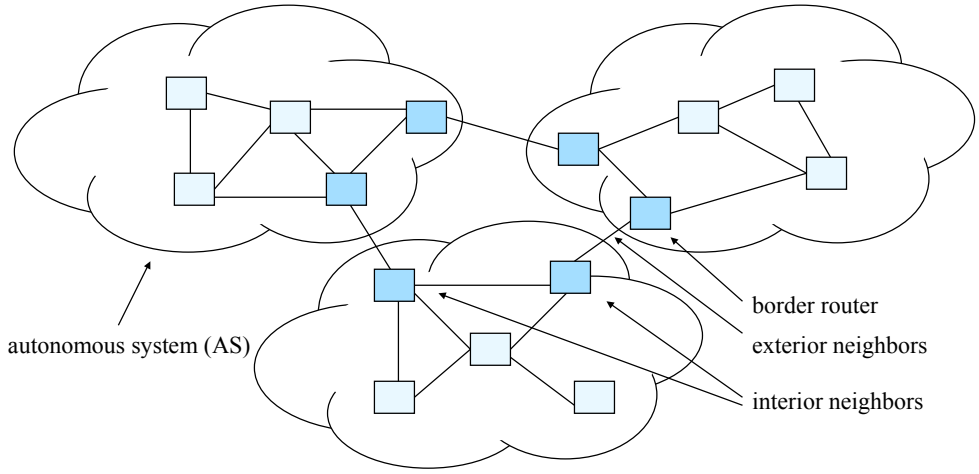
Routing can be static or dynamic

- Static routing is based on manually configured routing tables.
  - Static routing is used when e.g. two peer providers do not trust each other or
  - To connect an organization to a Service Provider with a single connection
  - Static routing is difficult to maintain
- Dynamic routing is based on *routing protocols* which create and maintain the routing tables automatically
  - examples of routing protocols are RIP, OSPF, BGP...
  - E.g. to connect an organization with multiple links to the Internet

Internet routing is based on routing protocols, which collect information

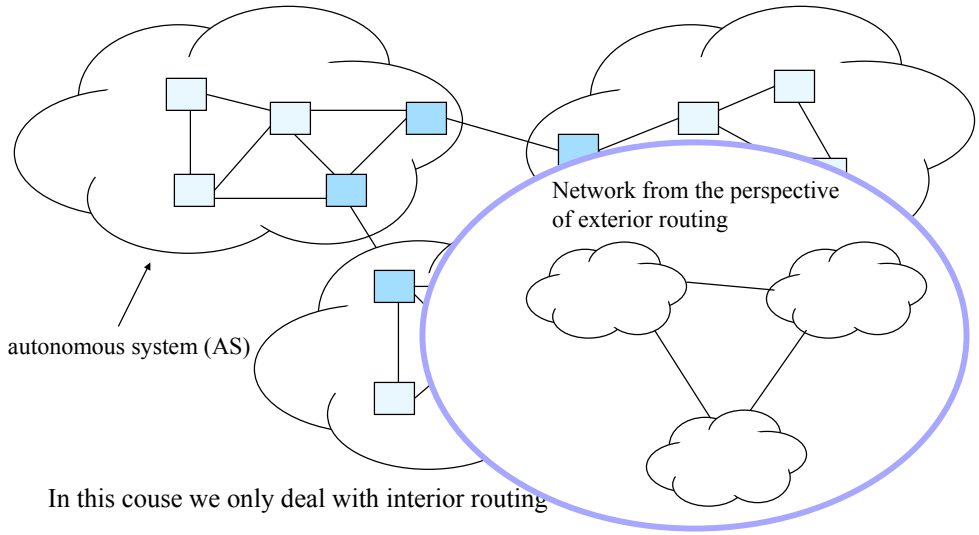
- No off-line route planning
- Routing is completely automatic
- Only dimensioning is made off-line
- The routers communicate with a routing protocol
- The routing algorithm finds the shortest (cheapest) route to every destination

Routing is divided into interior and exterior



In this couse we only deal with interior routing

Routing is divided into interior and exterior



In this couse we only deal with interior routing

Routing is divided into interior and exterior

- Autonomous system, AS
  - Networks operated by a single organization and having a common routing strategy
- Border router
  - At least one neighbor belongs to another autonomous system

Routing is divided into interior and exterior

- Interior routing protocols
  - **Routing Information Protocol (RIP), RIP-2**
  - **Open Shortest Path First (OSPF)**
  - Interior Gateway Routing Protocol (IGRP), EIGRP
  - Intermediate System-to-Intermediate System (IS-IS)
- Exterior routing protocols
  - External Gateway Protocol (EGP)
  - **Border Gateway Protocol version 4 (BGP-4)**

Routing algorithms

- Distance vector
  - Distance vectors are sent, until the state of the network is stable
  - The routers cooperate to generate the routes
  - Example: RIP
- Link state
  - Topology descriptions are sent periodically and nodes generate a map over the network
  - Every router generates the routes independently of the other routers
  - Example: OSPF

Properties of the routing algorithms

Distance vector	Link state
+ Simple and lightweight	- Complex and heavy
- Slow convergence	+ Fast convergence
- Only one route per destination	+ Several routes per destination
- Only one metric	+ Supports different metrics