L30 - IP Technology Basics

IP Technology Basics

TCP/IP Protocol Suite, RFC,
IP Addresses, IP Forwarding

Agenda

- **Introduction**
- **IP Address**
  - Address Classes
  - Subnetting
- **IP Forwarding**
  - Routing Basics
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

IP Technology

- **packet switching technology**
  - packet switch is called router or gateway (IETF terminology)
  - end system is called IP host
  - structured layer 3 address (IP address)
- **datagram service**
  - connectionless
    - datagrams are sent without establishing a connection in advance
  - best effort delivery
    - datagrams may be discarded due to transmission errors or network congestion

TCP Technology

- **shared responsibility between network and end systems**
  - routers responsible for delivering datagrams to remote networks based on structured IP address
  - IP hosts responsible for end-to-end control
- **end to end control**
  - is implemented in upper layers of IP hosts
  - TCP (Transmission Control Protocol)
    - connection oriented
    - sequencing, windowing
    - error recovery by retransmission
    - flow control

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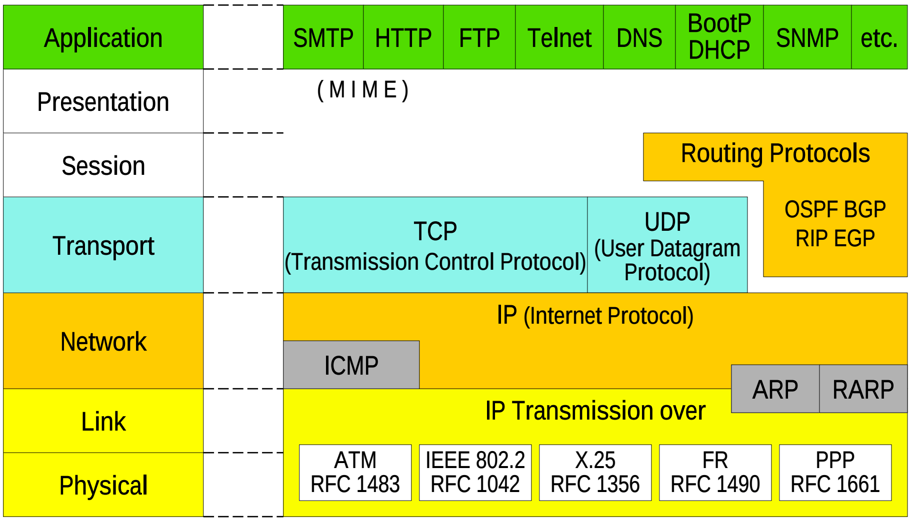
TCP/IP Protocol Suite



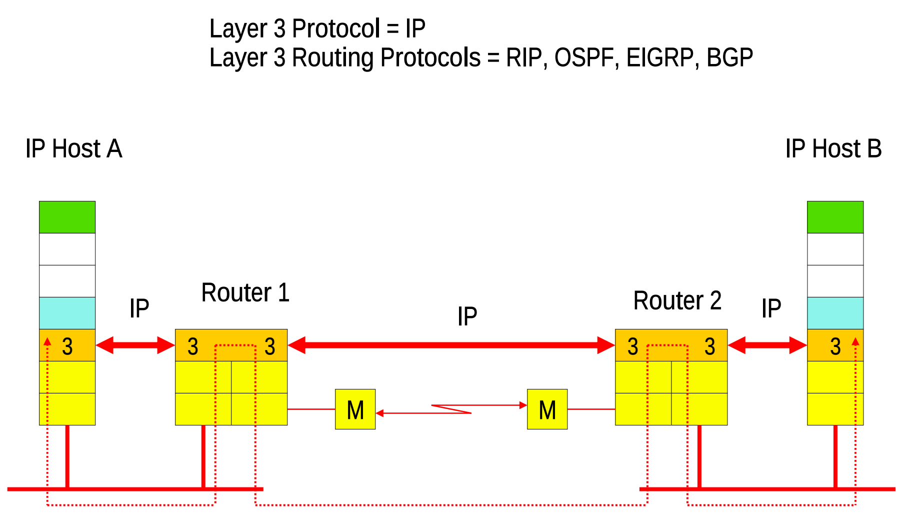
TCP/IP Story of Success

- **IP over everything**
  - technology independent
  - internetwork is built by layering a unique IP protocol on top of various network technologies
    - overlay technique
  - it is easy to adopt new network technologies
    - define how to transfer IP datagrams and how to use the possible switching capability of the new network
- **end-to-end principle**
  - avoids sophisticated tasks to be performed by network infrastructure (routers)
  - TCP takes care of reliability

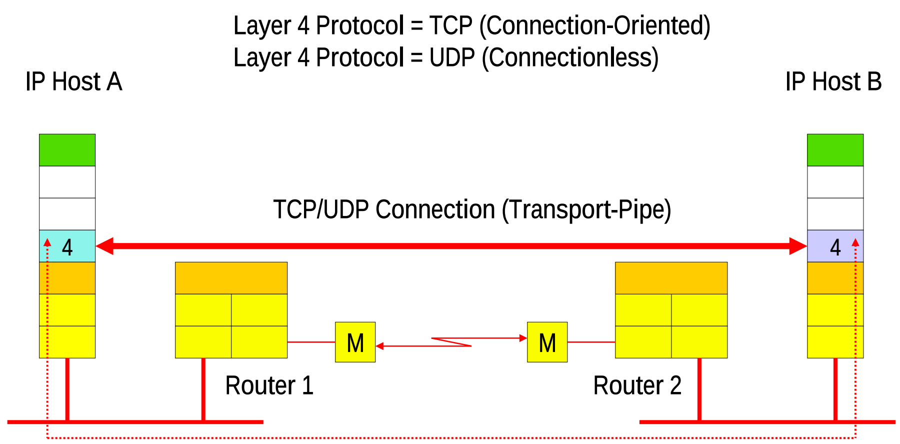
TCP/IP Story of Success

- **TCP**
  - tolerant and adaptive to network operational conditions
    - robust against network failures
    - adapts to varying network delays
    - adapts to varying network load
- **right functionality partition between**
  - IP
    - knows nothing about end systems applications
    - makes best effort to route packets through the network
  - and TCP
    - takes care of end-to-end issues
    - end users know nothing about network internals
- **WWW**

IP and OSI Network Layer 3



TCP/UDP and OSI Transport Layer 4



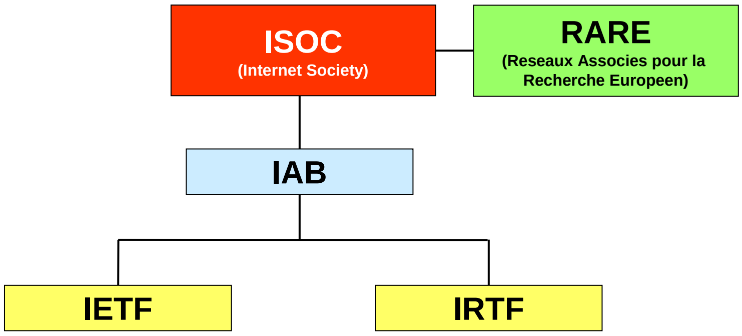
Key Players of Internet Technology

- **IAB (Internet Architecture Board)**
  - responsible for technical directions, coordination and standardization of the TCP/IP technology
  - the "Board" is highest authority and controls IETF, IRTF
- **IETF (Internet Engineering Task Force)**
  - provides solutions and extensions for TCP/IP
    - working groups organized in areas
    - area manager and IETF chairman form the IESG (Internet Engineering Steering Group)
- **IRTF (Internet Research Task Force)**
  - coordinates and prioritize research
    - research groups controlled by the IRSG (Internet Research Steering Group)

Key Players of Internet Technology

- **ISOC (Internet Society)**
  - highest Internet organization founded in 1992
- **RARE (Reseaux Associes pour la Recherche Europeen)**
  - founded 1986 to build and maintain a European high speed data network infrastructure
  - EBONE initiated by RARE
  - member of ISOC and ETSI (European Telecommunications Standards Institute)
  - close cooperation with RIPE (Reseaux IP Europeen)

Internet Organizations



Internet in Europe

- **RIPE NCC (Reséaux IP Européens Network Coordination Center)**
  - Internet Registry
    - assigning IP addresses
    - assigning AS numbers
  - Routing Registry
    - coordinating policies between Internet Service Providers (ISP)
  - how to contact?
    - RIPE NCC
    - Singel 258
    - 1016 AB Amsterdam
    - The Netherlands
    - Phone: +31 20 535 4444 , Fax: +31 20 535 4445
    - E-Mail: <ncc@ripe.net>, WWW: <http://www.ripe.net>

Standardization by RFCs

- **all documentation, standards, proposals for new protocols and enhancements for the Internet**
  - are published as "Requests for Comments" (RFC)
  - RFCs were the initial approach of engineers to discuss questions, suggestions via e-mail to speed up development
    - part of the success story of TCP/IP
  - IETF (Internet Engineering Task Force) decides, which RFCs will be adopted as a standard after rigorous review (e.g. two different implementations have to exist)
  - RFCs are numbered in sequence of publishing
  - adopted enhancements or changes to a protocol will result in a new RFC number

Standardization by RFCs

- **today's standardization process is best described**
  - in RFC-2026
    - The Internet Standards Process Revision3
- **not every RFC is an Internet Standard**
  - categories
    - Informational, Experimental, Historic
    - Proposed Standard
    - Draft Standard
    - Standard
- **IAB (Internet Architecture Board) publishes periodically a status list of all protocols:**
  - Official Protocol Standard RFC (currently RFC 3300).

How to get RFCs ?

- **RFCs can be ordered from the NIC (Network Information Center) or retrieved through "anonymous FTP":**
  - ftp://ds.internic.net/rfc/
  - ftp://ftp.univie.ac.at/netinfo/rfc/

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  - Address Classes
  - Subnetting
- IP Forwarding
  - Routing Basics
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

IP Address

- IP address
  - 32 bit , dotted decimal notation
  - identifies access to a network (network interface)
  - basic structure
    - network number (net-id)
    - host number (host-id)
  - two level hierarchy
  - net-id must be unique when a physical network with IP hosts is connected to the Internet
    - assignment controlled by Internet Registry
  - host-id is assigned by each local network manager

Address notation

IP address (example):

1 0 0 0 0 0 0 0	1 1 1 1 0 0 0 0	0 0 0 0 0 0 0 1	0 1 1 0 1 1 0 1
0x80	0xF0	0x01	0x6D

each octet of an IP address is written as the decimal equivalent:

128	240	1	109

The resulting four numbers are delimited with dots (dotted decimal notation):

128.240.1.109

Binary vs Decimal Notation

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
1	0	0	0	0	0	0	0	128
0	1	0	0	0	0	0	0	64
0	0	1	0	0	0	0	0	32
0	0	0	1	0	0	0	0	16
0	0	0	0	1	0	0	0	8
0	0	0	0	0	1	0	0	4
0	0	0	0	0	0	1	0	2
0	0	0	0	0	0	0	1	1
1	1	1	1	1	1	1	1	255

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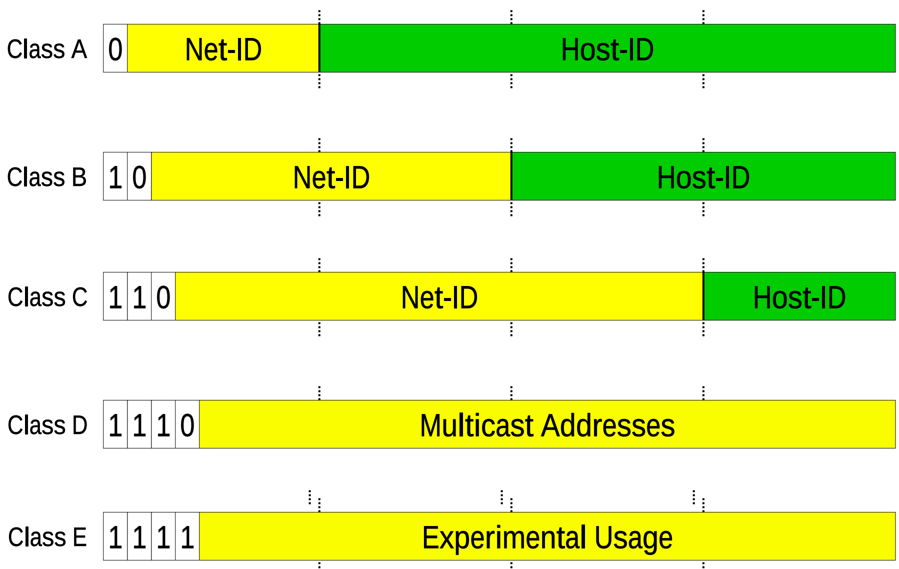
Classes

- **several classes of IP addresses**
  - A, B, C (unicast), D (multicast), E (experimental)
  - class defines numbers of address-bits to be used for net-id
    - class A 7 bits of net-id, 24 bits of host-id
      126 nets / 16.777.214 hosts
    - class B 14 bits of net-id, 16 bits of host-id
      16.384 nets / 65.534 hosts
    - class C 21 bits of net-id, 8 bits of host-id
      2.097.512 nets / 254 hosts
    - class D 28 bits multicast group number
  - first octet rule
    - class A range: 1 - 126
    - class B range: 128 - 191
    - class C range: 192 - 223
    - class D range: 224 - 239

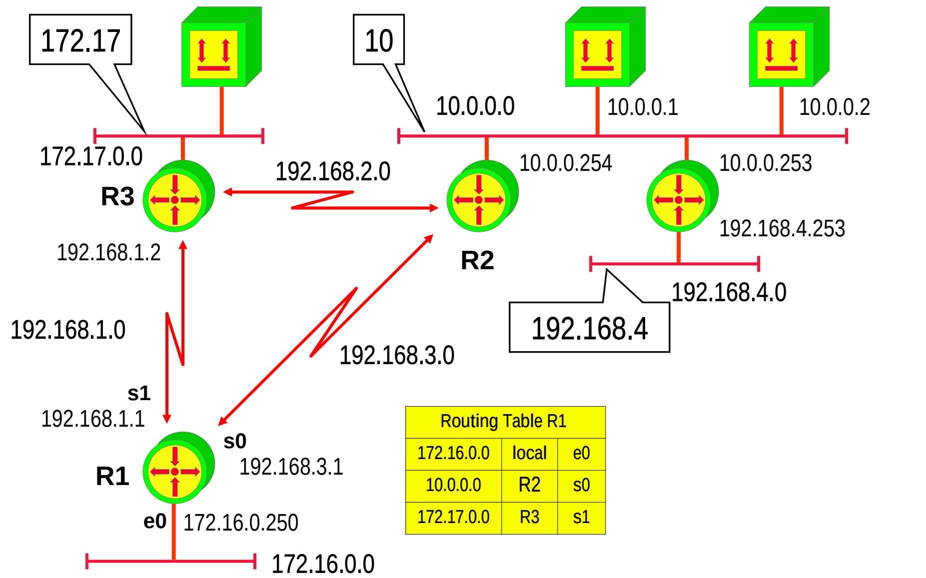
IP Address Classes



IP Address Classes First Octet Rule

Class A	0	1-127
Class B	1 0	128-191
Class C	1 1 0	192-223
Class D	1 1 1 0	224-239
Class E	1 1 1 1	240-255

IP Address (Net-ID) Example

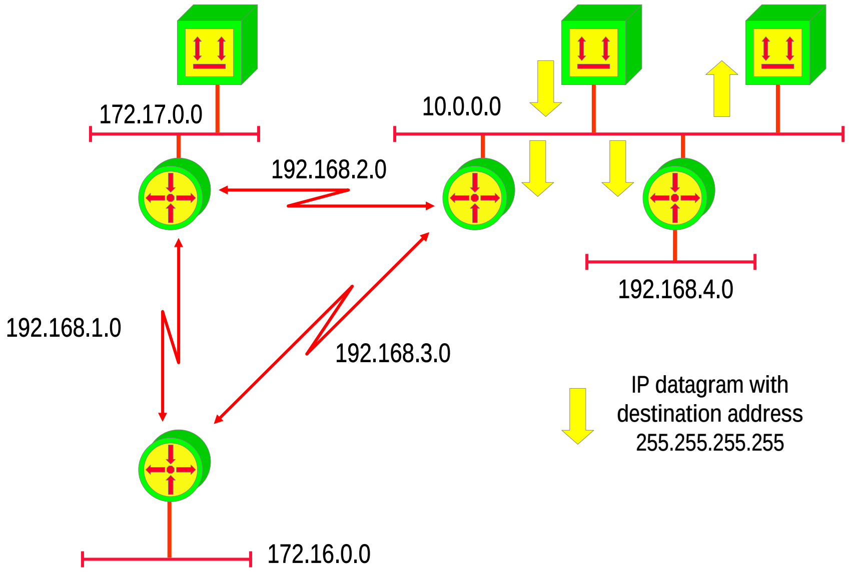


Routing Table R1		
172.16.0.0	local	e0
10.0.0.0	R2	s0
172.17.0.0	R3	s1

Special Addresses

- **basic IP address format**
  - { net-id, host-id }
- **special purpose addresses and rules**
  - { 0, 0 } this host on this network (0.0.0.0)
  - { 0, <host-id> } specified host on this network
  - { <net-id>, -1 } directed broadcast to specified network
  - { -1, -1 } limited broadcast on this network (255.255.255.255)
  - { 127, <any> } loopback address
  - { <net-id>, 0 } never used for a host number, identifies network itself
  - note:
    - 0 … means all corresponding bits = 0
    - -1 … means all corresponding bits = 1

IP Limited Broadcast



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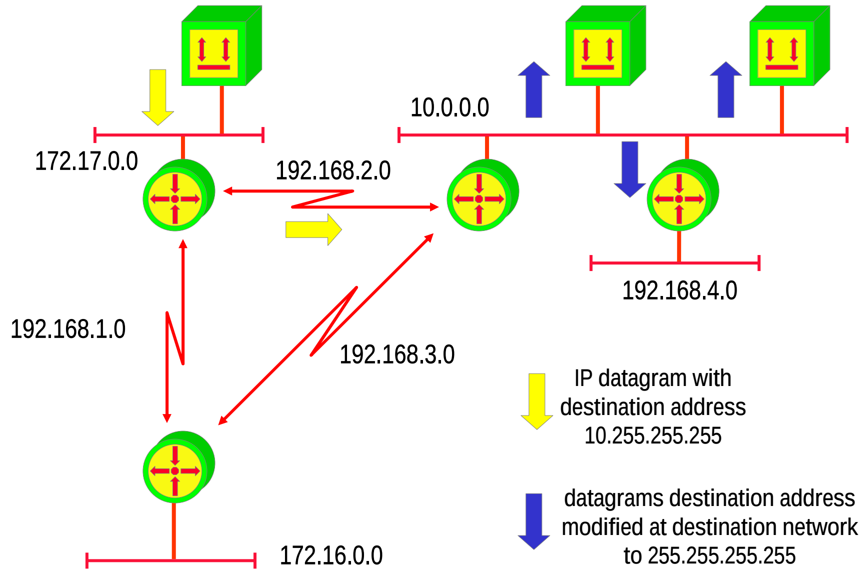
IP Directed Broadcast



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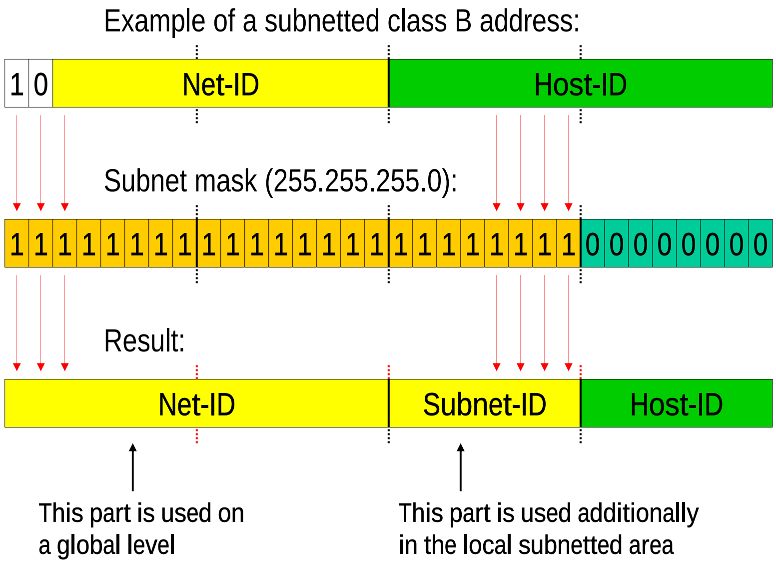
Subnetting

- **two level hierarchy was sufficient in the early days of the Internet**
- **with local area networks a third hierarchical level was introduced by subnetting**
- **subnetting**
  - some bits of the host-id can be used as subnet-id
  - subnet-id extends classful net-id meaning
    - subnet-id bits are only locally interpreted inside subnetted area
    - net-id bits are still globally seen outside the subnetted area
  - number of bits to be used for network identification are specified by subnet mask (written in dotted decimal notation)
    - ones portion represents network part (must be contiguous)
    - zeros portion represent the host part

Subnet addressing



Possible Subnet Mask Values

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
1	0	0	0	0	0	0	0	128
1	1	0	0	0	0	0	0	192
1	1	1	0	0	0	0	0	224
1	1	1	1	0	0	0	0	240
1	1	1	1	1	0	0	0	248
1	1	1	1	1	1	0	0	252
1	1	1	1	1	1	1	0	254
1	1	1	1	1	1	1	1	255

Subnet Mask

- **natural subnet mask**
  - address classes without subnetting
    - class A … 255.0.0.0
    - class B … 255.255.0.0
    - class C … 255.255.255.0
- **old notation of IP addresses**
  - with subnetmask
    - 10.0.0.0 255.0.0.0 (Class A)
    - 176.16.0.0 255.255.0.0 (Class B)
- **new notation of IP addresses**
  - with prefix/length
    - 10.0.0.0 / 8 (Class A)
    - 176.16.0.0 / 16 (Class B)

Rules with Subnetting

- **IP address format with subnetting**
  - { net-id, subnet-id, host-id }
- **additional special purpose addresses and rules**
  - { <net-id>, <subnet-id>, -1 }
    - directed broadcast to specified subnet
  - { <net-id>, -1, -1 }
    - directed broadcast to all subnets of specified subnetted network
  - { <net-id>, 0, <host-id> }
    - subnet zero never used for a subnet number for classful routing (see RFC 950)
  - { <net-id>, -1, <host-id> }
    - subnet broadcast never used for a subnet number for classful routing (see RFC 950)

Subnet Mask Examples 1

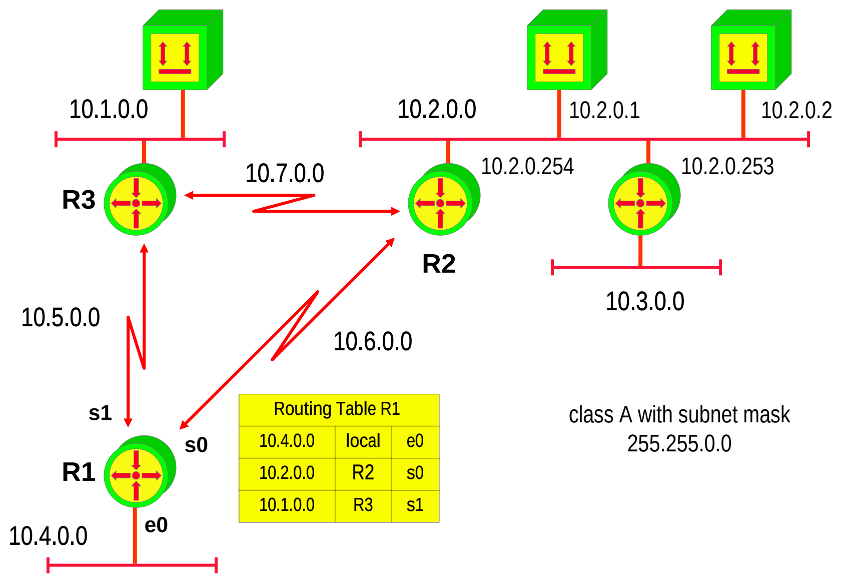
- **class A ⇨ pseudo class B (8 bit subnetting)**
  - 10.0.0.0 with 255.255.0.0 (10.0.0.0 / 16)
  - subnetworks:
    - 10.0.0.0 subnet zero
    - 10.1.0.0
      - 10.1.0.1 first IP host in net 10.1.0.0
      - 10.1.255.254 last IP host in net 10.1.0.0
      - 10.1.255.255 directed broadcast in net 10.1.0.0
    - 10.2.0.0
    - 10.3.0.0

      ……….
    - 10.254.0.0
    - 10.255.0.0 subnet broadcast
  - 254 subnets / 65534 hosts

Subnet Zero / Subnet Broadcast

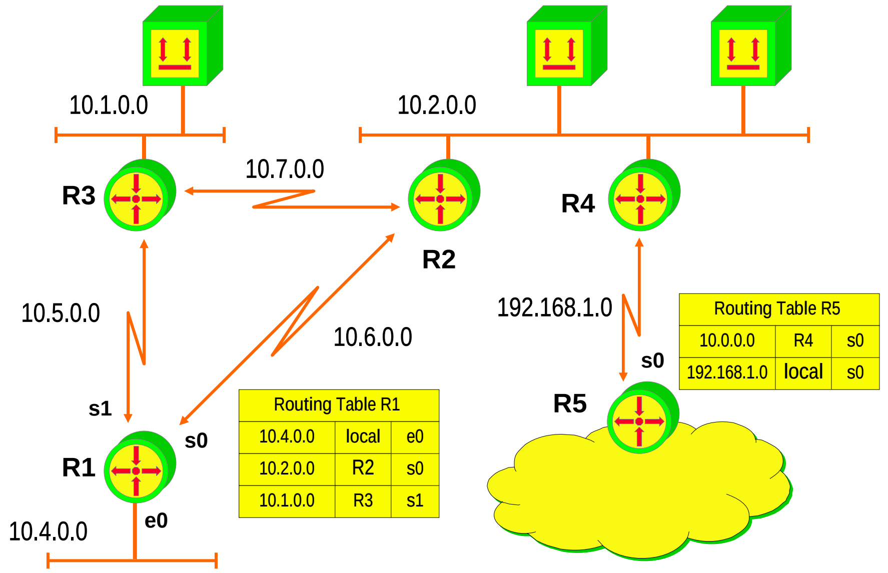
- **What is the problem?**
  - Does 10.0.0.0 mean net-ID
    of net 10
    or
    of subnet 10.0 ?
  - Does 10.255.255.255 mean directed broadcast
    for the whole net 10
    or
    for the subnet 10.255 ?
  - subnet zero and subnet broadcast are ambiguous

IP Address Example with Subnetting



Routing Table R1		
10.4.0.0	local	e0
10.2.0.0	R2	s0
10.1.0.0	R3	s1

Classful Routing



Routing Table R1		
10.4.0.0	local	e0
10.2.0.0	R2	s0
10.1.0.0	R3	s1

Routing Table R5		
10.0.0.0	R4	s0
192.168.1.0	local	s0

Subnet Mask Examples 2

- **class A ⇨ pseudo class C (16 bit subnetting)**
  - 10.0.0.0 with 255.255.255.0 (10.0.0.0 / 24)
  - subnetworks:
    - 10.0.0.0 subnet zero
    - 10.0.1.0
    - 10.0.2.0

      ……….
    - 10.0.255.0
    - 10.1.0.0
    - 10.1.2.0

      ………..
    - 10.255.254.0
    - 10.255.255.0 subnet broadcast
  - 65534 subnets / 254 hosts

Subnet Mask Examples 3

- **class B ⇨ pseudo class C (8 bit subnetting)**
  - 172.16.0.0 with 255.255.255.0 (172.16.0.0 / 24)
  - subnetworks:
    - 172.16.0.0 subnet zero
    - 172.16.1.0
    - 172.16.2.0

      ……….

      ………..
    - 172.16.254.0
    - 172.16.255.0 subnet broadcast
  - 254 subnets / 254 hosts

Subnet Mask -> Net-ID, Host-ID

- **class A address**

subnet mask 255.255.0.0

IP- Address 10.3.49.45

? net-id, ? host-id

net-id = 10.3.0.0

host-id = 0.0.49.45

65534 IP hosts

range: 10.3.0.1 -> 10.3.255.254

10.3.0.0 -> network itself

10.3.255.255 -> directed broadcast for this network

Subnet Mask Examples 4

- **class B address**

subnet mask 255.255.255.192
IP- Address 172.16.3.144
? net-id, ? host-id

address binary	1010 1100 . 0001 0000 . 0000 0011 . 1001 0000
mask (binary)	1111 1111 . 1111 1111 . 1111 1111 . 1100 0000

----

logical AND (bit by bit)

net-id	1010 1100 . 0001 0000 . 0000 0011 . 1000 0000

net-id = 172.16.3.128
host-id = 0.0.0.16

Subnet Mask Examples 5

- **class B ⇨ 10 bit subnetting**
  - 172.16.0.0 with 255.255.255.192 (172.16.0.0 / 26)
  - subnetworks:

	net-ID | host-ID
• 172.16.0.0 subnet zero	172.16.0. 00 | xx xxxx
• 172.16.0.64	172.16.0. 01 | xx xxxx
– 172.16.0.65 first IP host	172.16.0. 01 | 00 0001
– 172.16.0.66 second IP host	172.16.0. 01 | 00 0010
………..	
– 172.16.0.126 last IP host	172.16.0. 01 | 11 1110
– 172.16.0.127 directed broadcast	172.16.0. 01 | 11 1111
• 172.16.0.128	172.16.0. 10 | xx xxxx
• 172.16.0.192	172.16.0. 11 | xx xxxx

Subnet Mask Examples 5

- subnetworks (cont.):
  - 172.16.1.0 172.16.1. 00 | xx xxxx
  - 172.16.1.64 172.16.1. 01 | xx xxxx
  - 172.16.1.128 172.16.1. 10 | xx xxxx
  - 172.16.1.192 172.16.1. 11 | xx xxxx
  - 172.16.2.0 172.16.2. 00 | xx xxxx
  - 172.16.2.64 172.16.2. 01 | xx xxxx

  ………..
  - 172.16.255.0 172.16.255. 00 | xx xxxx
  - 172.16.255.64 172.16.255. 01 | xx xxxx
  - 172.16.255.128 172.16.255. 10 | xx xxxx
  - 172.16.255.192 subnet broadcast 172.16.255. 11 | xx xxxx
- 1022 subnets / 62 hosts

Subnet Mask Examples 6

- **class C ⇨ 2 bit subnetting**
  - 192.168.16.0 with 255.255.255.192 (192.168.16.0 / 26)
  - subnetworks: net-ID host-ID
    - 192.168.16.0 subnet zero 192.168.16. 00 | xxxxxx
    - 192.168.16.64 192.168.16. 01 | xxxxxx
    - 192.168.16.128 192.168.16. 10 | xxxxxx
    - 192.168.16.192 subnet broadcast 192.168.16. 11 | xxxxxx
  - 2 subnets / 62 hosts

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Subnet Mask Examples 7

- **class C ⇨ 3 bit subnetting**
  - 192.168.16.0 with 255.255.255.224 (192.168.16.0 / 27)
  - subnetworks:

subnetwork	net-ID | host-ID
192.168.16.0 subnet zero	192.168.16. 000 | xxxxx
192.168.16.32	192.168.16. 001 | xxxxx
192.168.16.64	192.168.16. 010 | xxxxx
192.168.16.96	192.168.16. 011 | xxxxx
192.168.16.128	192.168.16. 100 | xxxxx
192.168.16.160	192.168.16. 101 | xxxxx
192.168.16.192	192.168.16. 110 | xxxxx
192.168.16.224 subnet broadcast	192.168.16. 111 | xxxxx

  - 6 subnets / 30 hosts

Subnet Mask Examples 8

- **class C ⇨ 4 bit subnetting**
  - 192.168.16.0 with 255.255.255.240 (192.168.16.0 / 28)
  - subnetworks:

subnetwork	net-ID | host-ID
192.168.16.0 subnet zero	192.168.16. 0000 | xxxx
192.168.16.16	192.168.16. 0001 | xxxx
– 192.168.16.17 1st IP host	192.168.16. 0001 | 0001
– 192.168.16.18 2nd IP host	192.168.16. 0001 | 0010
………..	
– 192.168.16.30 14th IP host	192.168.16. 0001 | 1110
– 192.168.16.31 directed broadcast	192.168.16. 0001 | 1111
192.168.16.32	192.168.16. 0010 | xxxx
192.168.16.48	192.168.16. 0011 | xxxx

Subnet Mask Examples 8

- subnetworks (cont.):

	net-ID | host-ID
192.168.16.64	192.168.16. 0100 | xxxx
192.168.16.80	192.168.16. 0101 | xxxx
192.168.16.96	192.168.16. 0110 | xxxx
192.168.16.112	192.168.16. 0111 | xxxx
192.168.16.128	192.168.16. 1000 | xxxx
192.168.16.144	192.168.16. 1001 | xxxx
192.168.16.160	192.168.16. 1010 | xxxx
192.168.16.176	192.168.16. 1011 | xxxx
192.168.16.192	192.168.16. 1100 | xxxx
192.168.16.208	192.168.16. 1101 | xxxx
192.168.16.224	192.168.16. 1110 | xxxx
192.168.16.240 subnet broadcast	192.168.16. 1111 | xxxx

- 14 subnets / 14 hosts

Subnet Mask Examples 9

- **class C ⇨ 5 bit subnetting**
  - 192.168.16.0 with 255.255.255.248 (192.168.16.0 / 29)
  - subnetworks:

	net-ID | host-ID
192.168.16.0 subnet zero	192.168.16. 00000 | xxx
192.168.16.8	192.168.16. 00001 | xxx
192.168.16.16	192.168.16. 00010 | xxx
192.168.16.24	192.168.16. 00011 | xxx
………..	
192.168.16.240	192.168.16. 11110 | xxx
192.168.16.248 subnet broadcast	192.168.16. 11111 | xxx

- 30 subnets / 6 hosts

Subnet Mask Examples 10

- **class C ⇨ 6 bit subnetting**
  - 192.168.16.0 with 255.255.255.252 (192.168.16.0 / 30)
  - subnetworks:

	net-ID	host-ID
• 192.168.16.0 subnet zero	192.168.16. 000000	xx
• 192.168.16.4	192.168.16. 000001	xx
– 192.168.16.5 1st IP host	192.168.16. 000001	01
– 192.168.16.6 2nd IP host	192.168.16. 000001	10
– 192.168.16.7 directed broadcast	192.168.16. 000001	11
• 192.168.16.8	192.168.16. 000010	xx
………..		
• 192.168.16.248	192.168.16. 111110	xx
• 192.168.16.252 subnet broadcast	192.168.16. 111111	xx

  - 62 subnets / 2 hosts

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- **IP Forwarding**
  - Routing Basics
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

IP Routing

- **routing**
  - process of choosing a path over which to send IP datagrams
  - IP hosts and routers take part in this process
    - routers responsible for selecting the best path in a meshed network in case of indirect delivery of IP datagrams
    - IP hosts responsible for direct delivery of IP datagrams
    - IP hosts responsible for choosing a “default” router (default gateway) as next hop in case of indirect delivery of IP datagrams
  - direct versus indirect delivery
    - depends on destination net-ID
    - net-ID equal source net-ID -> direct delivery
    - net-ID unequal source net-ID -> indirect delivery

IP Routing

- **indirect routing of IP datagrams**
  - is done by routers based on routing tables
  - routing table
    - database of known destinations in form of “signposts”
    - contains next hop router, outgoing port (and metric) to every specified (or known) destination network (net-ID, subnet mask)
- **routing can be either**
  - static
    - non-responsive to topology changes
  - or dynamic
    - responsive to topology changes
    - requires special communication protocols among routers (routing protocol)

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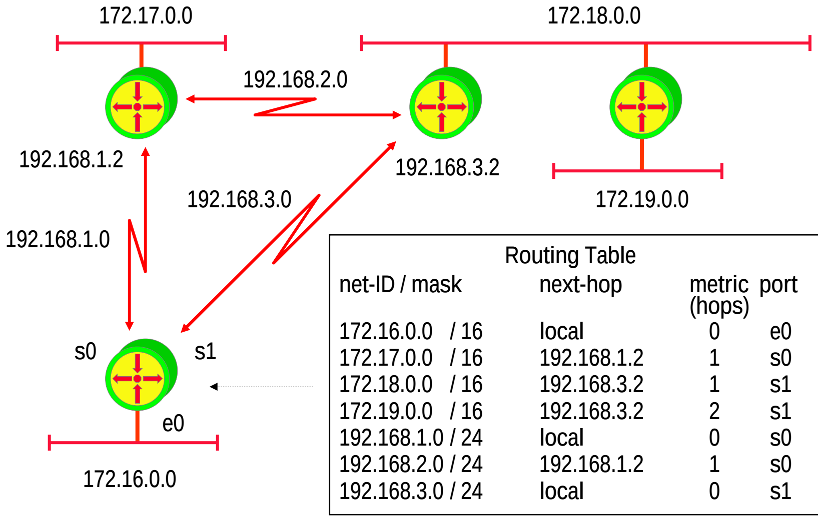
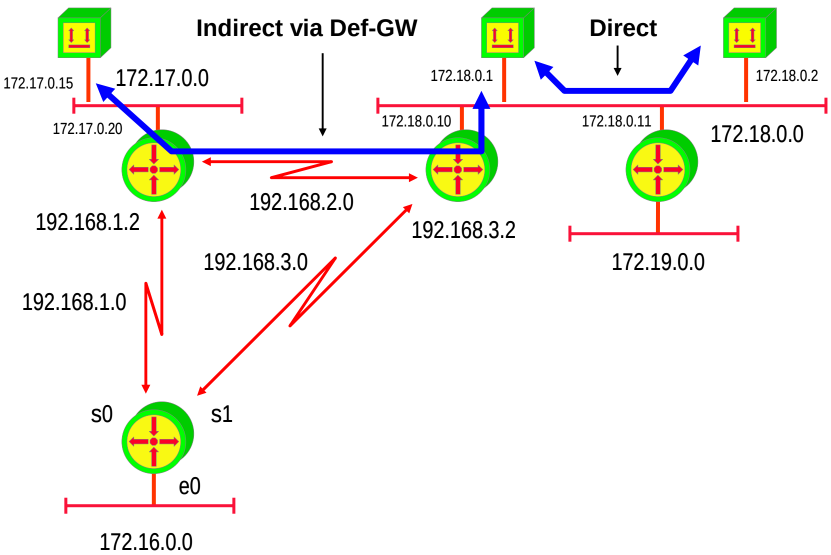
Routing Table Example



Routing Table

net-ID / mask	next-hop	metric (hops)	port
172.16.0.0 / 16	local	0	e0
172.17.0.0 / 16	192.168.1.2	1	s0
172.18.0.0 / 16	192.168.3.2	1	s1
172.19.0.0 / 16	192.168.3.2	2	s1
192.168.1.0 / 24	local	0	s0
192.168.2.0 / 24	192.168.1.2	1	s0
192.168.3.0 / 24	local	0	s1

Direct versus Indirect Delivery



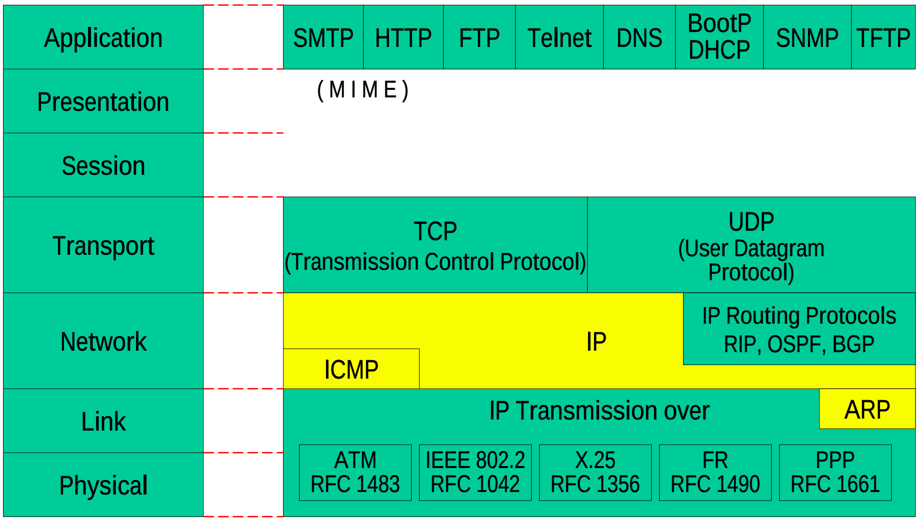
Agenda

- Introduction
- IP Address
  - Address Classes
  - Subnetting
- IP Forwarding
  - Routing Basics
  - Forwarding and ARP
  - Forwarding and ICMP (Error Signaling)

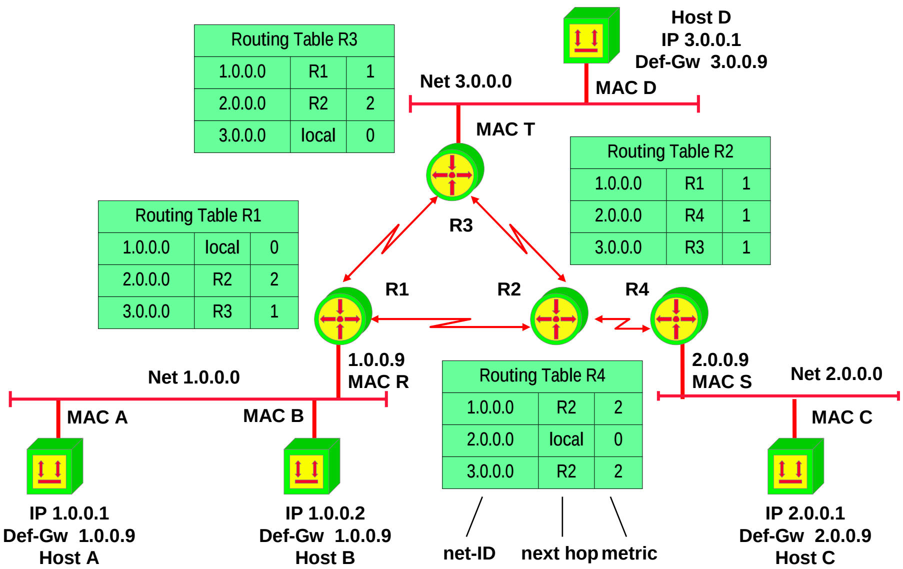
Principle

- **IP Forwarding is done by routers in case of indirect routing**
  - based on the destination address of a given IP datagram
  - following the path to the destination hop by hop
- **routing tables**
  - have information about which next hop router a given destination network can be reached
- **L2 header must be changed hop by hop**
  - if LAN then physical L2 address (MAC addresses) must be adapted for direct communication on LAN
- **mapping between IP and L2 address**
  - is done by Address Resolution Protocol (ARP)

IP Related Protocols



Example Topology



Routing Table R3		
1.0.0.0	R1	1
2.0.0.0	R2	2
3.0.0.0	local	0

Routing Table R2		
1.0.0.0	R1	1
2.0.0.0	R4	1
3.0.0.0	R3	1

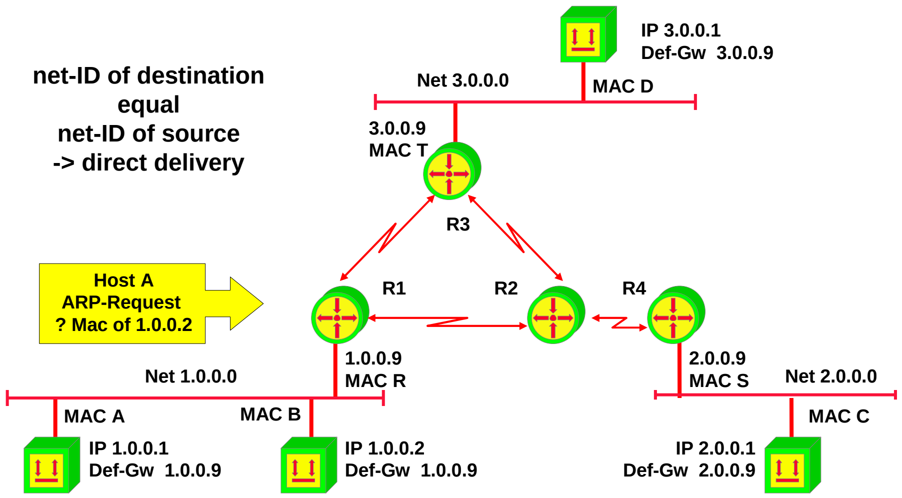
Routing Table R1		
1.0.0.0	local	0
2.0.0.0	R2	2
3.0.0.0	R3	1

Routing Table R4		
1.0.0.0	R2	2
2.0.0.0	local	0
3.0.0.0	R2	2

L30 - IP Technology Basics

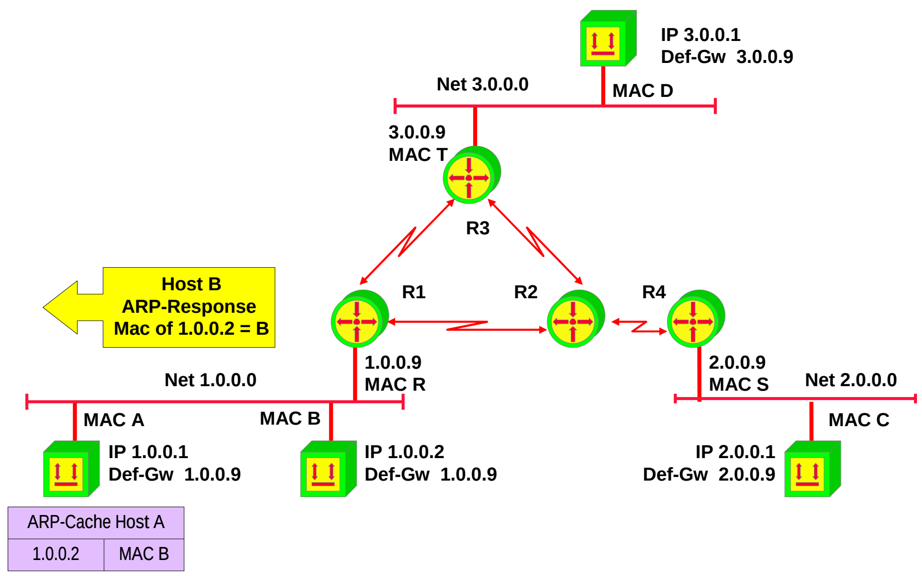
Direct Delivery 1.0.0.1 - > 1.0.0.2

net-ID of destination
equal
net-ID of source
-> direct delivery

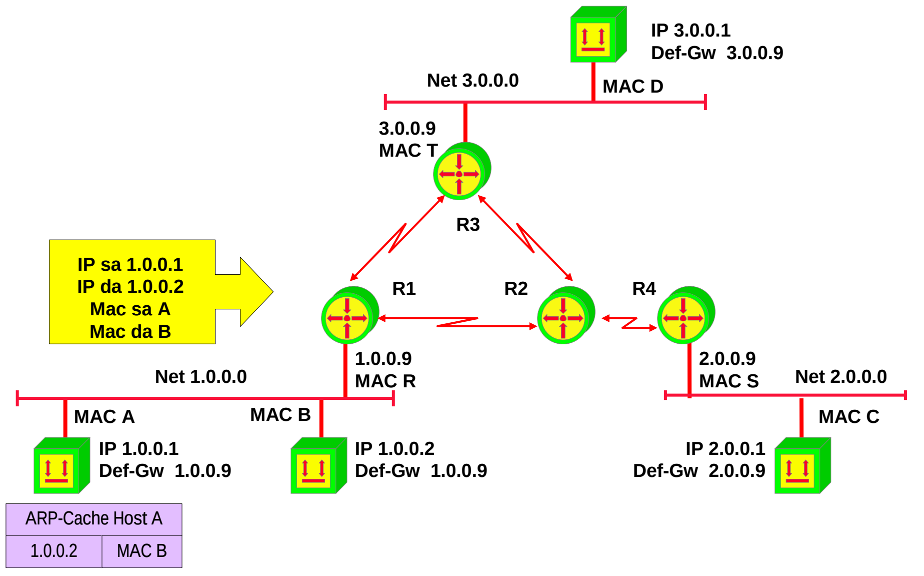


ARP ... Address Resolution Protocol

Direct Delivery 1.0.0.1 - > 1.0.0.2

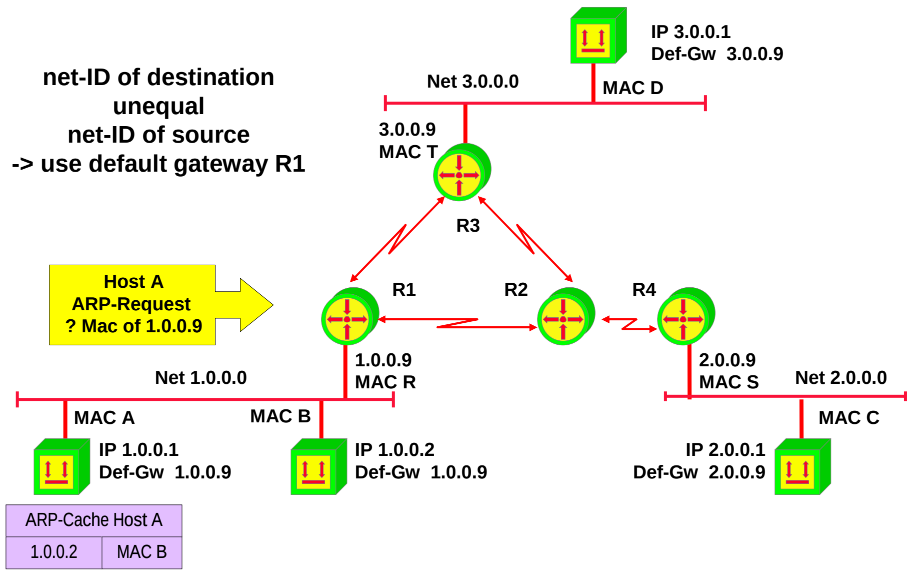


Direct Delivery 1.0.0.1 - > 1.0.0.2



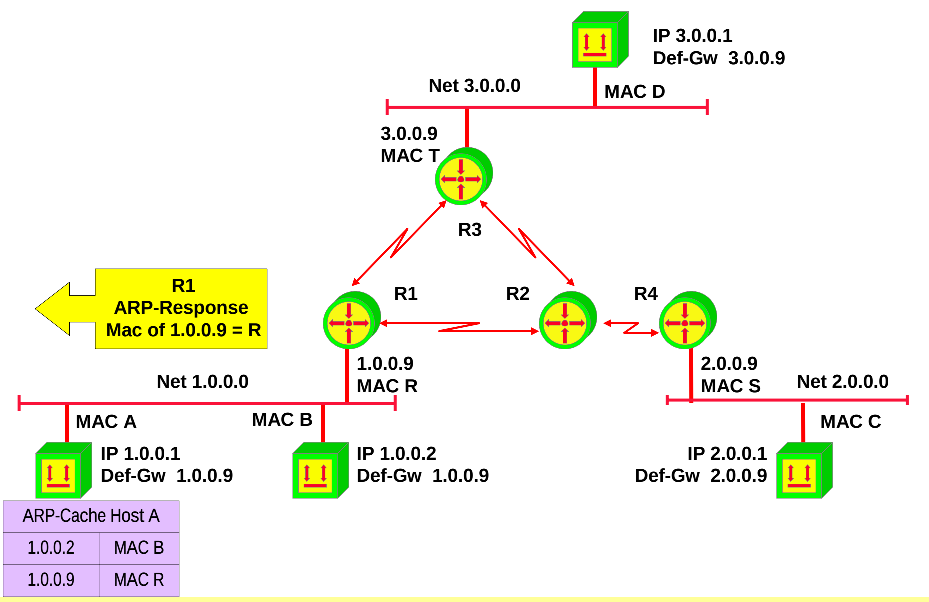
Indirect Delivery 1.0.0.1 - > 2.0.0.1

net-ID of destination
unequal
net-ID of source
-> use default gateway R1



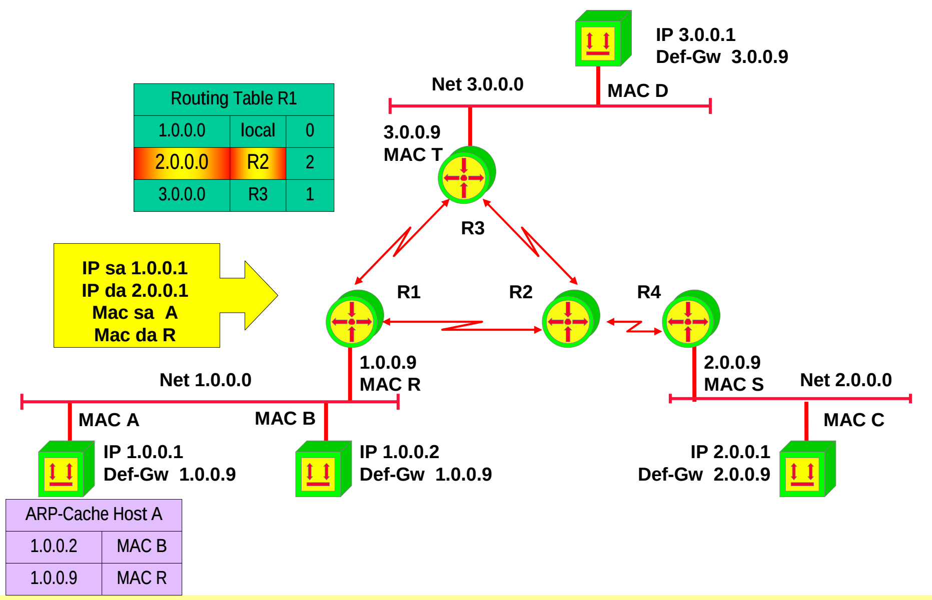
L30 - IP Technology Basics

Indirect Delivery 1.0.0.1 - > 2.0.0.1



ARP-Cache Host A	
1.0.0.2	MAC B
1.0.0.9	MAC R

Indirect Delivery 1.0.0.1 - > 2.0.0.1

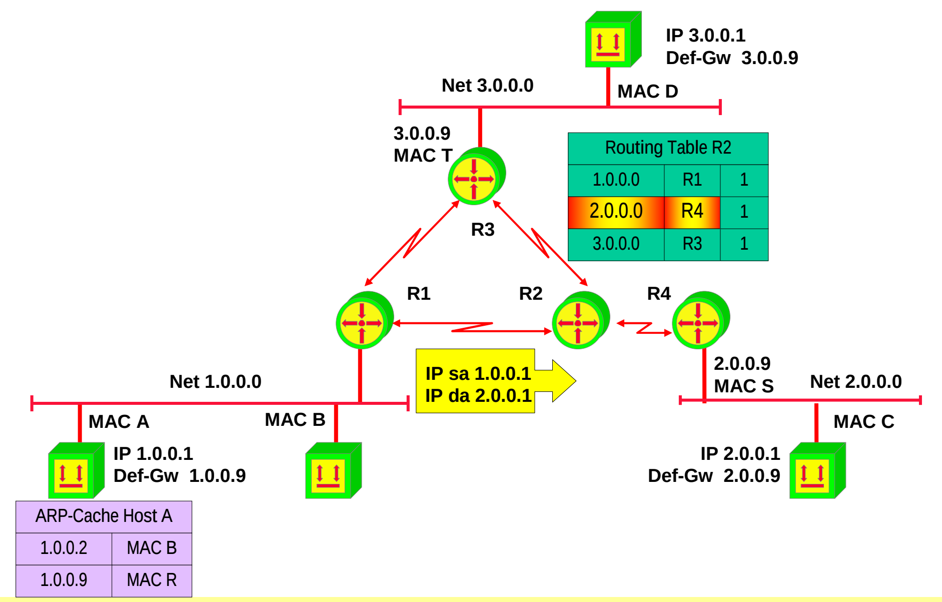


Routing Table R1		
1.0.0.0	local	0
2.0.0.0	R2	2
3.0.0.0	R3	1

ARP-Cache Host A	
1.0.0.2	MAC B
1.0.0.9	MAC R

L30 - IP Technology Basics

Indirect Delivery 1.0.0.1 - > 2.0.0.1



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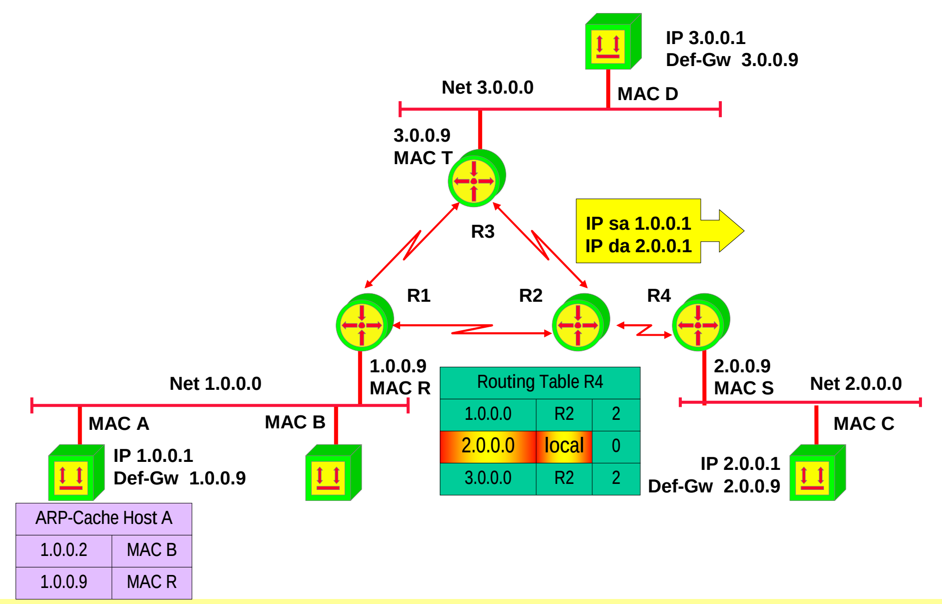
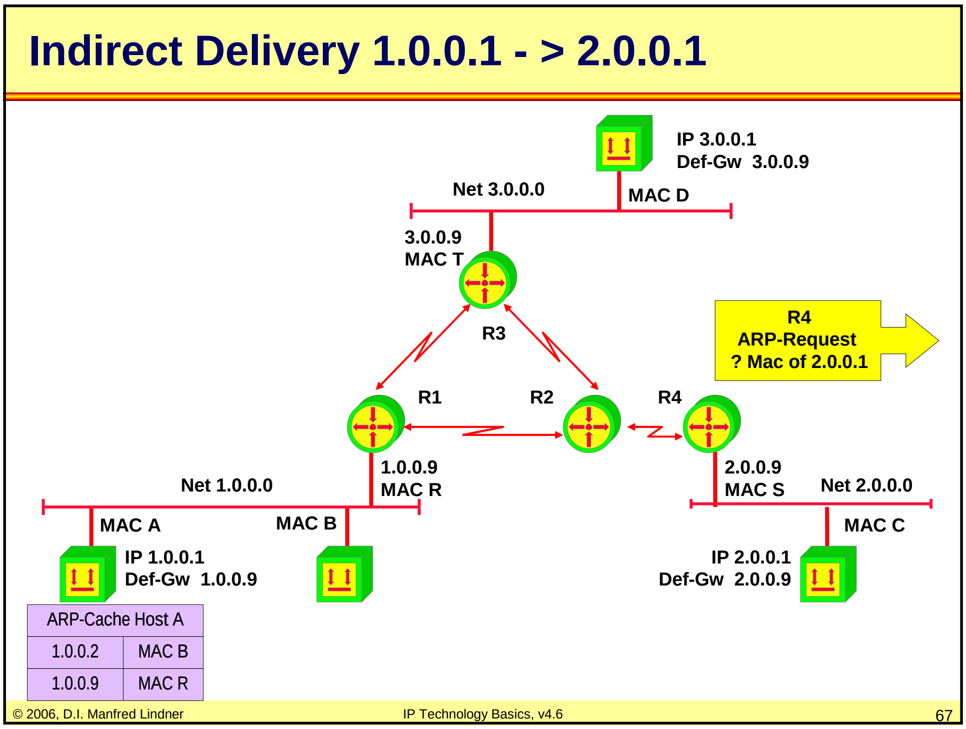
Indirect Delivery 1.0.0.1 - > 2.0.0.1



 IP Technology Basics, v4.6 66


Indirect Delivery 1.0.0.1 - > 2.0.0.1
IP 3.0.0.1
Def-Gw 3.0.0.9
Net 3.0.0.0
MAC D
3.0.0.9
MAC T
R3
R4
ARP-Request
? Mac of 2.0.0.1
R1
R2
R4
1.0.0.9
MAC R
2.0.0.9
MAC S
Net 1.0.0.0
Net 2.0.0.0
MAC A
MAC B
MAC C
IP 1.0.0.1
Def-Gw 1.0.0.9
IP 2.0.0.1
Def-Gw 2.0.0.9
ARP-Cache Host A
1.0.0.2 MAC B
1.0.0.9 MAC R
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IP Technology Basics, v4.6
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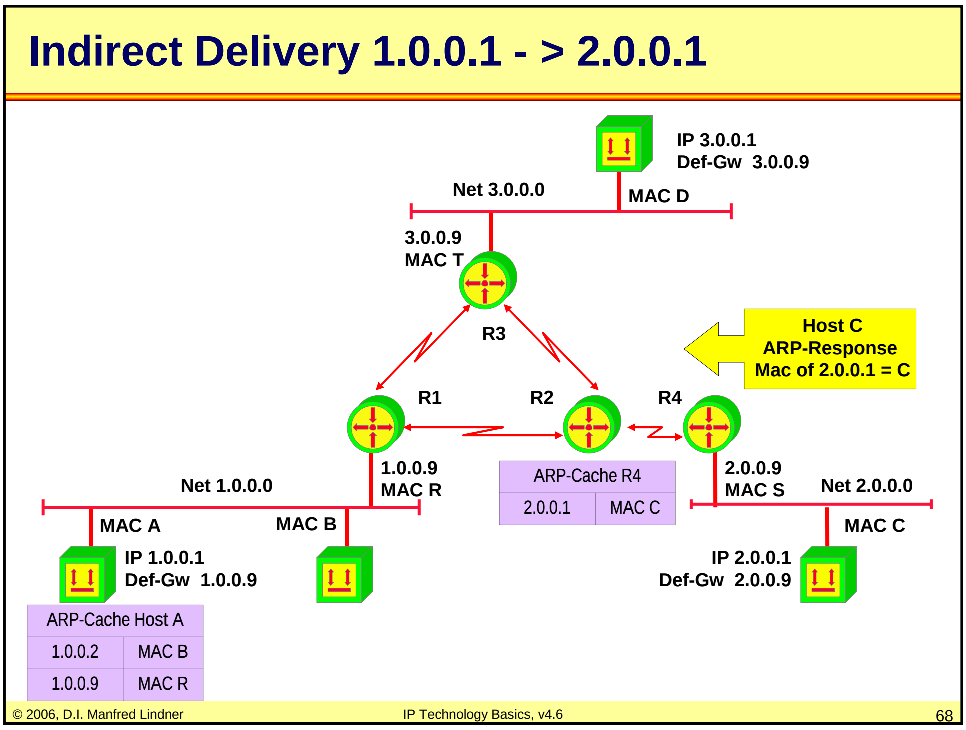
Indirect Delivery 1.0.0.1 - > 2.0.0.1
IP 3.0.0.1
Def-Gw 3.0.0.9
Net 3.0.0.0
MAC D
3.0.0.9
MAC T
R3
Host C
ARP-Response
Mac of 2.0.0.1 = C
R1
R2
R4
1.0.0.9
MAC R
ARP-Cache R4
2.0.0.1 MAC C
2.0.0.9
MAC S
Net 1.0.0.0
Net 2.0.0.0
MAC A
MAC B
MAC C
IP 1.0.0.1
Def-Gw 1.0.0.9
IP 2.0.0.1
Def-Gw 2.0.0.9
ARP-Cache Host A
1.0.0.2 MAC B
1.0.0.9 MAC R
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IP Technology Basics, v4.6
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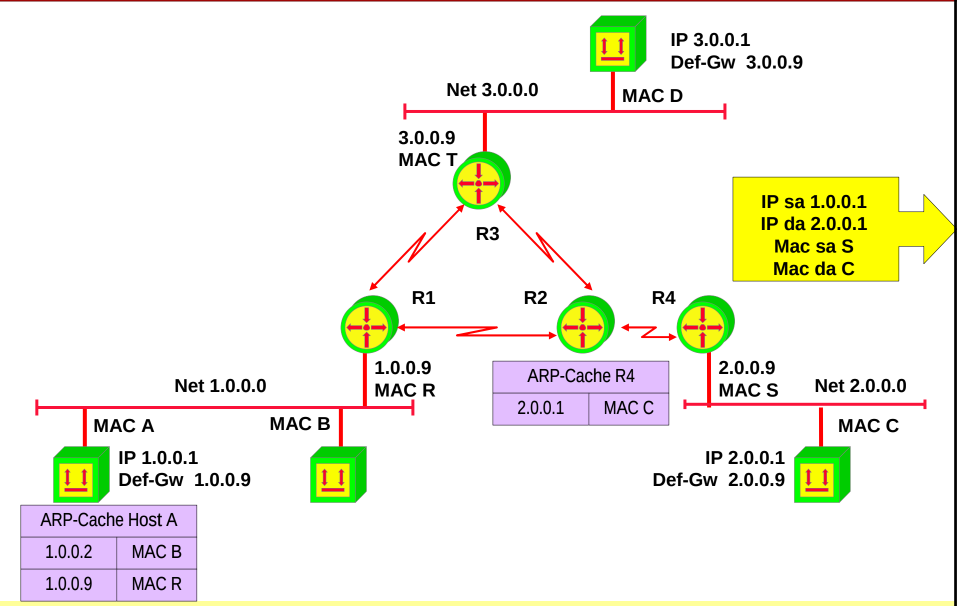
Indirect Delivery 1.0.0.1 - > 2.0.0.1



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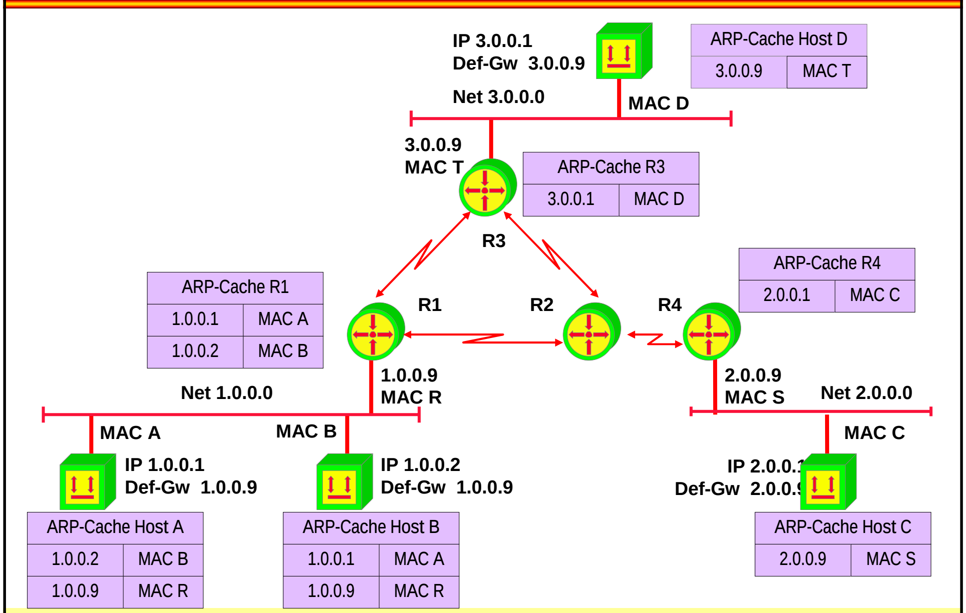
ARP Cache - Final Picture



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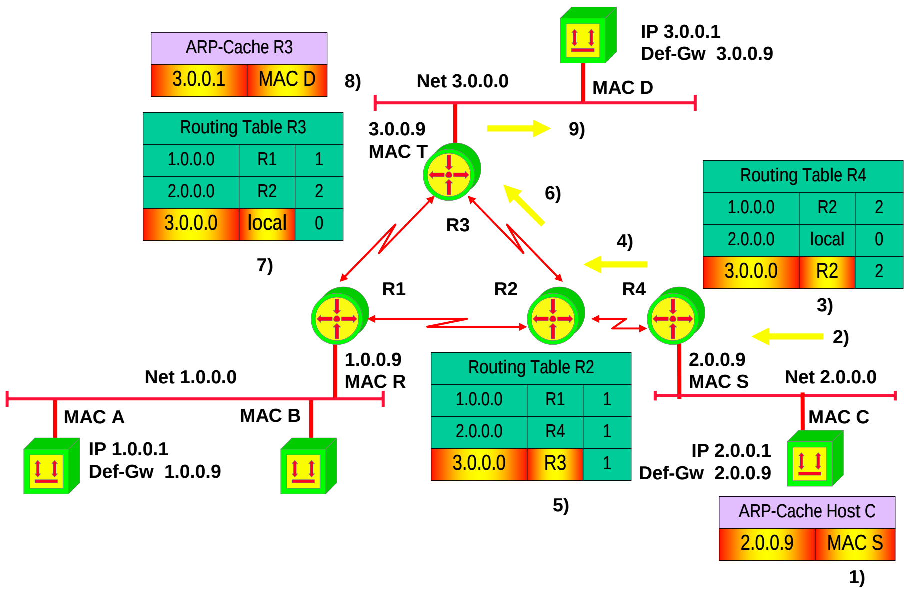
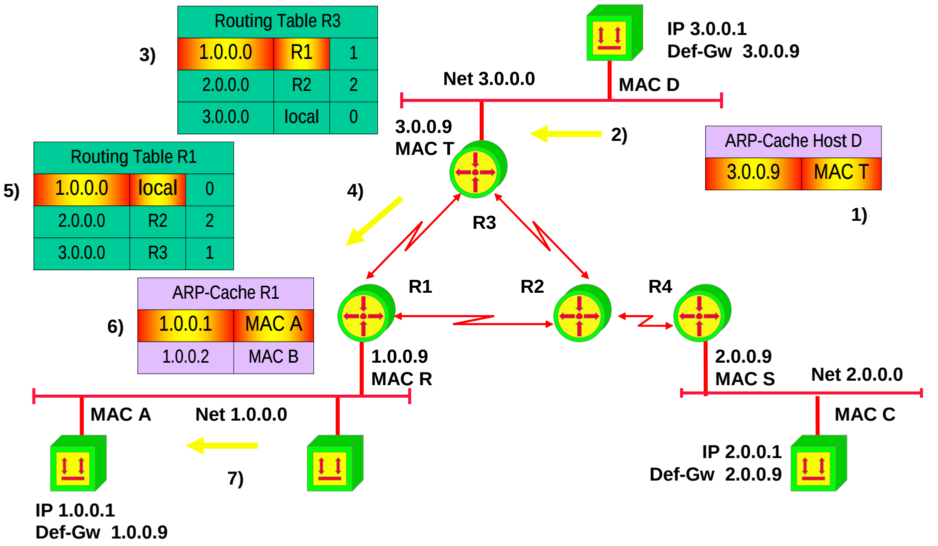
IP Routing Paradigm

- **Destination Based Routing**
  - source address is not taken into account for the forward decision
- **Hop by Hop Routing**
  - IP datagram's follow the path, which is pointed by the current state of the routing tables
- **Least Cost Routing**
  - normally only the best path is considered for forwarding of IP datagram's
  - alternate paths will not be used in order to reach a given destination

Delivery 2.0.0.1 -> 3.0.0.1



Delivery 3.0.0.1 -> 1.0.0.2



Agenda

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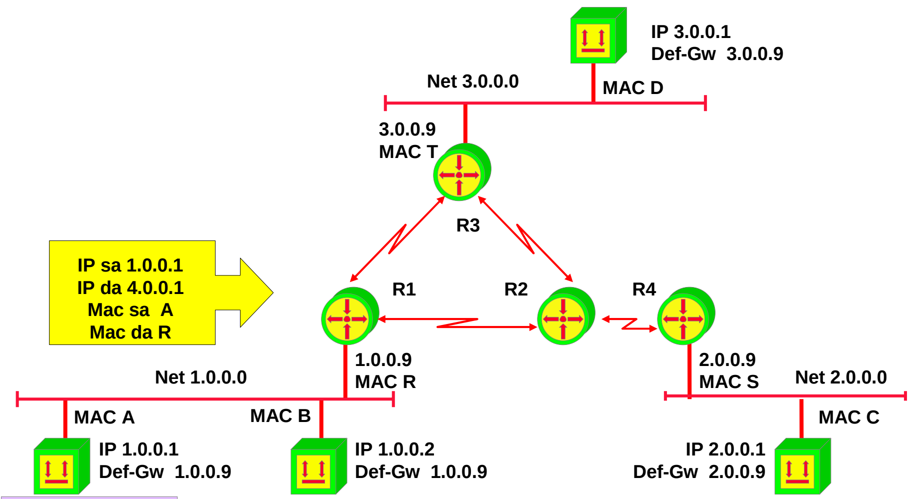
ICMP

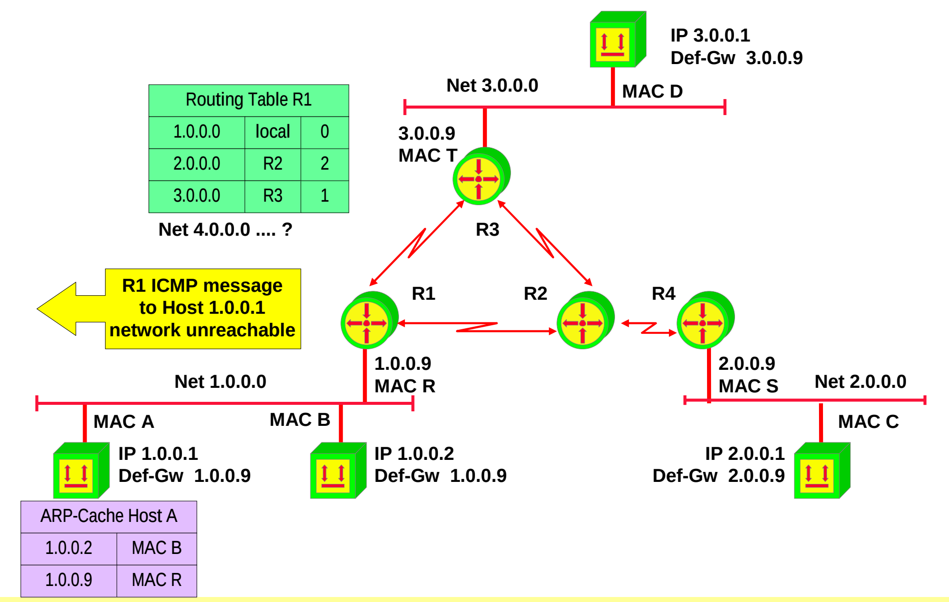
- **datagram service of IP**
  - best effort -> IP datagram's can be lost
- **ICMP**
  - Internet Control Message Protocol generates error messages to enhance the reliability and to provide information about errors and packet loss in the network
- **principle of ICMP operation**
  - IP station (router or destination), which detects any transmission problems, generates an ICMP message
  - ICMP message is addressed to the originating station (sender of the original IP packet)
- **most famous ICMP message: PING**

Delivery 1.0.0.1 - > 4.0.0.1

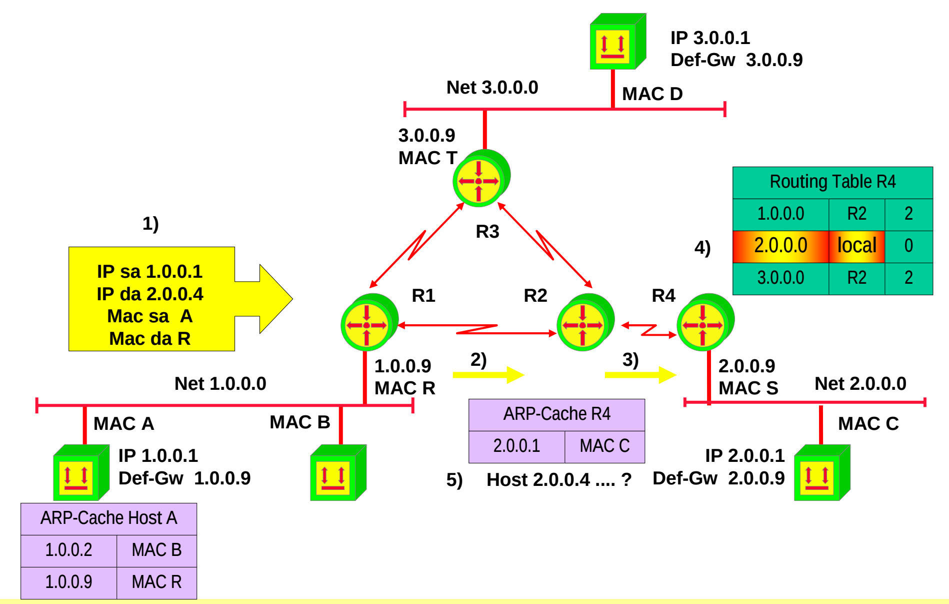


ARP-Cache Host A	
1.0.0.2	MAC B
1.0.0.9	MAC R

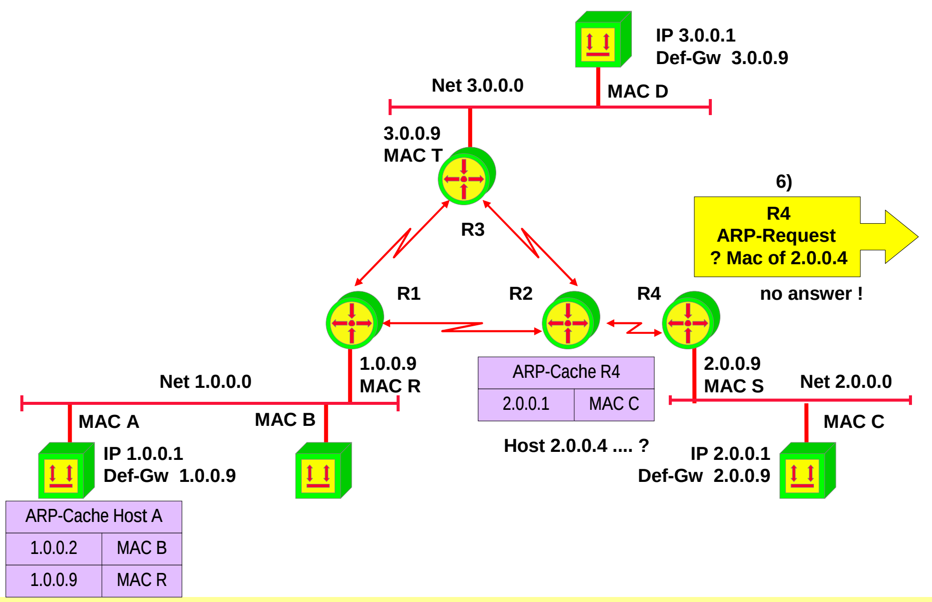
ICMP network unreachable



Delivery 1.0.0.1 - > 2.0.0.4



Delivery 1.0.0.1 - > 2.0.0.4



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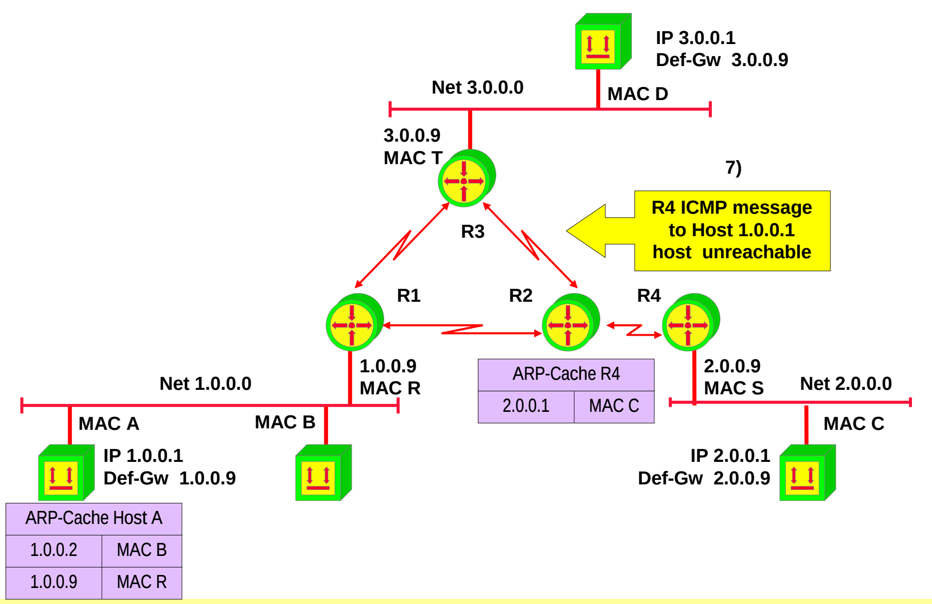
ICMP host unreachable



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