IP Networking
IP Addressing

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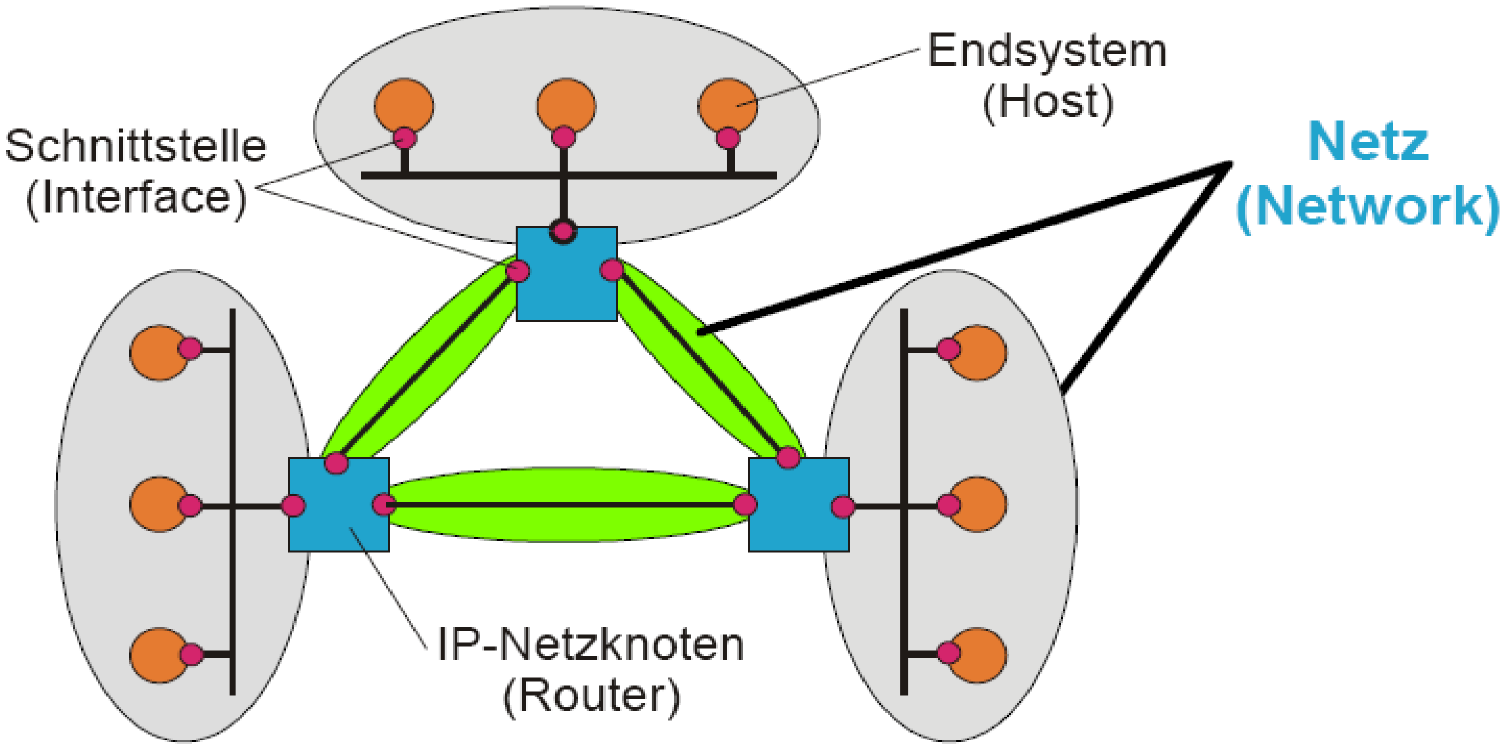
Fundamentals

Basic Scenario



- an IP address is assigned to each interface
- each interface is assigned to a network
  - a host uniquely belongs to a network
  - a router connects one or more networks

IPv4 Address Format

- IPv4 addresses are 32 Bit (4 Byte) long
- IPv6 addresses are 128 Bit (16 Byte) long
- For better readability the octet notation with decimal numbers is used in IPv4 instead of the binary notation ("dotted decimal notation"):
  – each octet of the IP address corresponds to a decimal number [0..255]
  – example:

132	●	252	●	150	●	2
10000100		11111100		10010110		00000010

10000100 : $1 \times 2^7 + 0 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$
$128 + 0 + 0 + 0 + 0 + 4 + 0 + 0 = 132$

11111100 : $1 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$
$128 + 64 + 32 + 16 + 8 + 4 + 0 + 0 = 252$

10010110 : $1 \times 2^7 + 0 \times 2^6 + 0 \times 2^5 + 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$
$128 + 0 + 0 + 16 + 0 + 4 + 2 + 0 = 150$

00000010 : $0 \times 2^7 + 0 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$
$0 + 0 + 0 + 0 + 0 + 0 + 2 + 0 = 2$

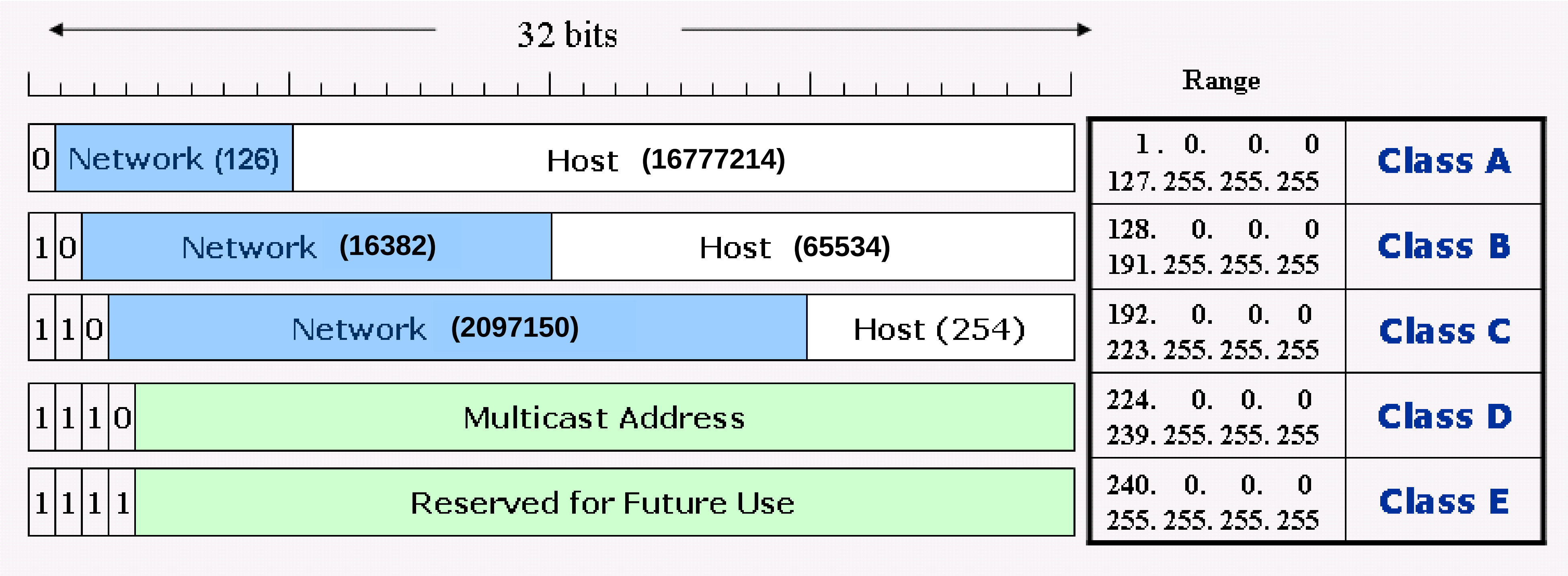
IPv4 Address Format

- The IP address consists of 2 parts:
  - **Network ID**
  - **Host ID**

Netz ID	Host ID

- The network ID addresses the network the host is connected to; the Host ID addresses the host within the network
- Routers base their forwarding decision only on the network ID
- The length of the different parts is not common for all IP addresses:
  - the traditional addressing scheme distinguishes 4 classes of IP addresses (**class-based addressing**)
  - the class is defined by the first 4 bits of the address
  - motivation for class-based addressing: the size of the network (i.e. the number of hosts) can be taken into account during the address assignment

Traditional IP Addressing Scheme (class-based)



Special IP Addresses (1)

- Reserved addresses for special use cases
  - destination addresses:

111111 111111		broadcast within the own network (local broadcast)
Network ID	111 … 111	directed broadcast to a certain (distant) network (directed broadcast)
127	(arbitrary)	loopback to local host

  - source addresses:

000000 000000		default address of a host that has not been assigned an IP address yet (used on startup before dynamic address assignment)
00 … 00	Host ID	host in this network (only at startup)

  - network addresses:

Network ID	000 ... 000	network address (must not be used by hosts)

Special IP Addresses (2)

- Address range reserved for private use (RFCs 1597,1918):
  - simultaneous use in different private networks possible
  - IP packets with these addresses are not forwarded by public routers

Von	Bis	
10.0.0.1	10.255.25.254	(1 private class A network)
172.16.0.1	172.31.255.254	(16 private class B networks)
192.168.0.1	192.168.255.254	(256 private class C networks)

IP Address Ranges - Overview

0.0.0.0	00000000.00000000.00000000.00000000	ganzes Netz, Defaultroute
1.0.0.0	00000001.00000000.00000000.00000000	erstes Class A Netz
10.0.0.0	00001010.00000000.00000000.00000000	private Nutzung
126.0.0.0	01111110.00000000.00000000.00000000	letztes Class A Netz
127.0.0.0	01111111.00000000.00000000.00000000	Diagnose (Loopback)
128.0.0.0	10000000.00000000.00000000.00000000	erstes Class B Netz
172.16.0.0	10101100.00010000.00000000.00000000	private Nutzung (Anfang)
172.31.0.0	10101100.00011111.00000000.00000000	private Nutzung (Ende)
191.255.0.0	10111111.11111111.00000000.00000000	letztes Class B Netz
192.0.0.0	11000000.00000000.00000000.00000000	erstes Class C Netz
192.168.0.0	11000000.10101000.00000000.00000000	private Nutzung (Anfang)
192.168.255.0	11000000.10101000.11111111.00000000	private Nutzung (Ende)
223.255.255.0	11011111.11111111.11111111.00000000	letztes Class C Netz
255.255.255.255	11111111.11111111.11111111.11111111	Broadcast an alle Knoten

IP Addressing - Valid Host Addresses (Example)

- Example: private class B network 172.17.0.0

172.16.255.255	10101100.00010000.11111111.11111111	Broadcastadresse für 172.16.0.0
172.17.0.0	10101100.00010001.00000000.00000000	**Netzwerkadresse für 172.17.0.0**
172.17.0.1	10101100.00010001.00000000.00000001	**Erster gültiger Host für 172.17.0.0**
...	...	**Gültige Hostadressen für 172.17.0.0**
172.17.255.254	10101100.00010001.11111111.11111110	**Letzter gültiger Host für 172.17.0.0**
172.17.255.255	10101100.00010001.11111111.11111111	**Broadcastadresse für 172.17.0.0**
172.18.0.0	10101100.00010010.00000000.00000000	Netzwerkadresse für 172.18.0.0
172.18.0.1	10101100.00010010.00000000.00000001	Erster gültiger Host für 172.18.0.0

Number of valid host addresses: $2^{(\text{number of hostbits})} - 2$

Subnetting and Supernetting

Subnetting - Principle

- Problems of class-based addressing:
  - the classes do not adapt to the real demand: there are few class A/B addresses (designed for a large number of hosts) and many class C addresses (designed for only few hosts)
  - the use of class A/B addresses for networks with more than 254 Hosts (where a class C address is just a bit too small) leads to a waste of addresses; example: assignment of 15 class B addresses for an IP network of an organization consisting of 15 networks with 300 hosts each
- Solution: sub-dividing of class A/B networks - **Subnetting**
  - use of class-based addresses (i.e. class A or B) for multiple networks; the networks are distinguished by **subnet ID** for which a part of the original host ID field is used:

network ID	subnet ID	Host ID

  - the subnet ID is used for routing of IP packets within an organization (between subnets); the network ID is used for the routing outside of the organization (in the public Internet) (i.e. in the Internet only the class A/B network of the organization is visible)

Subnetting - Subnet Mask

- The distinction between the network address (i.e. the network ID in class-based addressing plus the subnet ID) and the remaining host part of the address is given by the **subnet mask**
- Similar to the IP address, the subnet mask consists of 32 bits; all bits of the network and subnet ID are marked by "1" and all host ID bits are marked by "0"
- Using a logic AND operation of IP address and subnet mask the subnet ID can be extracted easily; subsequently, organization-internal routers must know the subnet mask for all connected networks
- Example:

class B address	Network ID	Host ID	
subnet mask (255.255.255.0)	111111111111111111111111		00000000
subnet address	Network ID	Subnet ID	Host ID

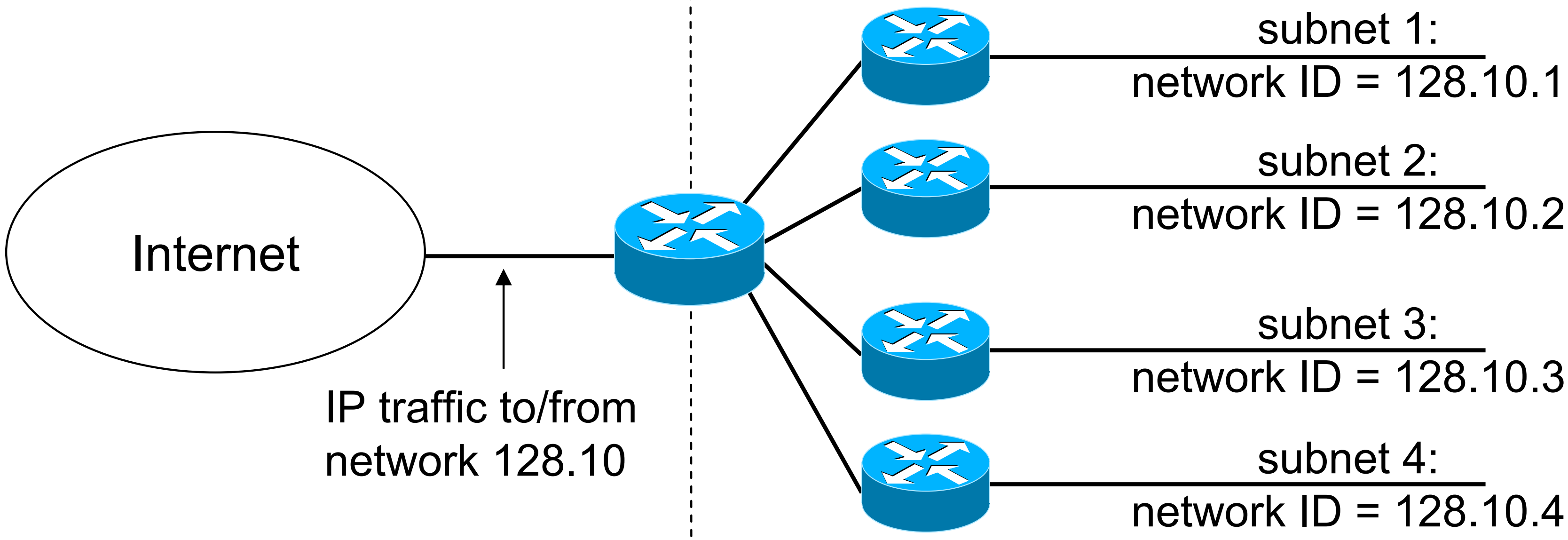
Subnetting - Representation of the Subnet Mask

- Binary representation:
  - example: 11111111111111111111111100000000

- Octet representation using decimal numbers ("dotted decimal notation"):
  - example: 255.255.255.0

- Prefix notation:
  - "/x" is appended to the IP address (**Prefix length**), where x represents the number of bits of the network and subnet ID
  - example: 134.109.4.102/24

Subnetting - Example



128	10	1	1	IP address
255	255	0	0	subn.mask

→ network ID = 128.10
→ Host ID = 1.1

128	10	1	1	IP address
255	255	255	0	subn.mask

→ network ID = 128.10
→ subnet ID = 1
→ host ID = 1

Subnetting - Rules for the Subnet Mask

- Valid values for subnet mask bytes

Bitmuster	Dezimalnotation	Anzahl Subnetbits
10000000	128	1
11000000	192	2
11100000	224	3
11110000	240	4
11111000	248	5
11111100	252	6
11111110	254	7
11111111	255	8

Dezimalwert:

$$256 - 2^{(8-n)}$$

n: Anzahl der Subnetbits

- only one byte of the mask may contain both subnet and host bits
- the first (most significant) byte of the mask is always 255

Subnetting - Subnet Table

Prefix	Subnet Mask	Number of Host IDs
/12	255.240.0.0	1M
/14	255.252.0.0	256K
/16	255.255.0.0	64K
/18	255.255.192.0	16K
/20	255.255.240.0	4K
/22	255.255.252.0	1K
/24	255.255.255.0	256
/26	255.255.255.192	64
/28	255.255.255.240	16
/30	255.255.255.252	4
/32	255.255.255.255	1 (host-specific route)

Supernetting

- Problem: also in Subnetting addresses may be wasted
  - in case of only a few hundred hosts the use of a class B address with Subnetting is inefficient; for example in case of a class B address (65534 hosts max.) with Subnetting for an organization's IP network consisting of 15 subnets with 300 hosts each, only 15·300=4500 host addresses are required
- Possible solution: use of multiple class C addresses
  - example: for 4500 host addresses a minimum of 18 class C addresses is required
- Further problem: many class C network ID entries in Internet routers
  - external (Internet) routers now have to store many class C network IDs in their routing tables instead of only one class B network ID (per organization)
- Problem solution: **Supernetting and CIDR**
  - aggregation of multiple consecutive (usually class C) addresses to a long **aggregated address** with common network ID (**Supernetting**); network ID and host ID are distinguished via the network mask (like in Subnetting)
  - fully flexible border between network ID and subnet ID (aligned to the host address requirement of an organization) → **class-less addressing (Classless Interdomain Routing, CIDR**); makes the traditional class-based addressing obsolete
  - drawback: class-less addressing requires network masks also in the Internet (which have to be distributed by routing protocols)

Supernetting - Example

- Example: Supernetting with 4 consecutive class C addresses

	network ID			host ID
220.100.16.x	1101 1100	0110 0100	0001 0000	xxxx xxxx
220.100.17.x	1101 1100	0110 0100	0001 0001	xxxx xxxx
220.100.18.x	1101 1100	0110 0100	0001 0010	xxxx xxxx
220.100.19.x	1101 1100	0110 0100	0001 0011	xxxx xxxx

4 x 254 hosts

1 Supernet	network ID			host ID
220.100.16	1101 1100	0110 0100	001 00xx	xxxx xxxx

1022 hosts

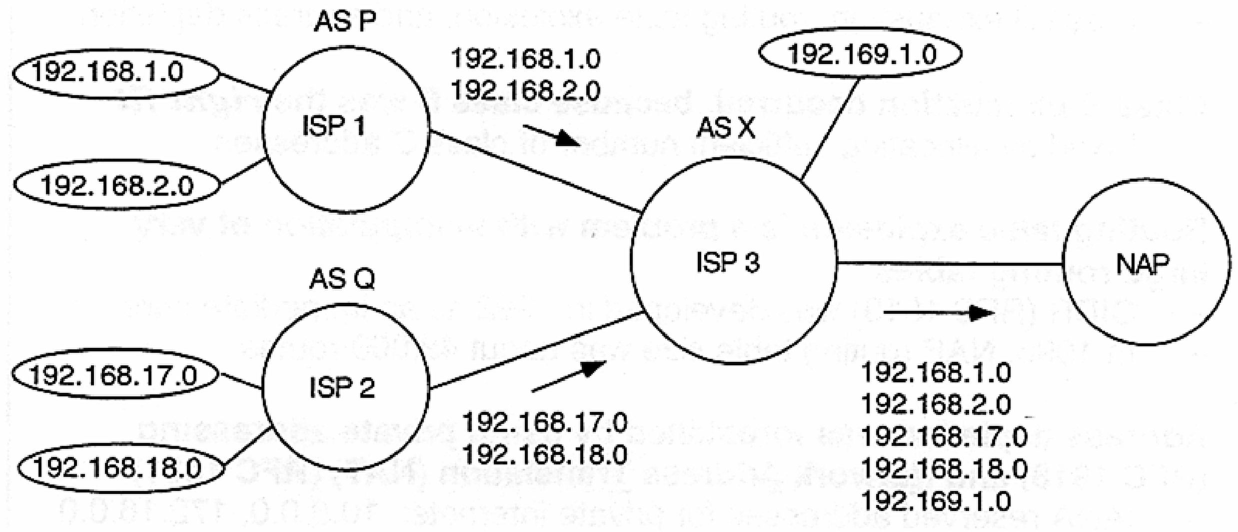
subnet mask → 1111 1111 1111 1111 1111 1100 0000 0000

Supernetting - Remarks

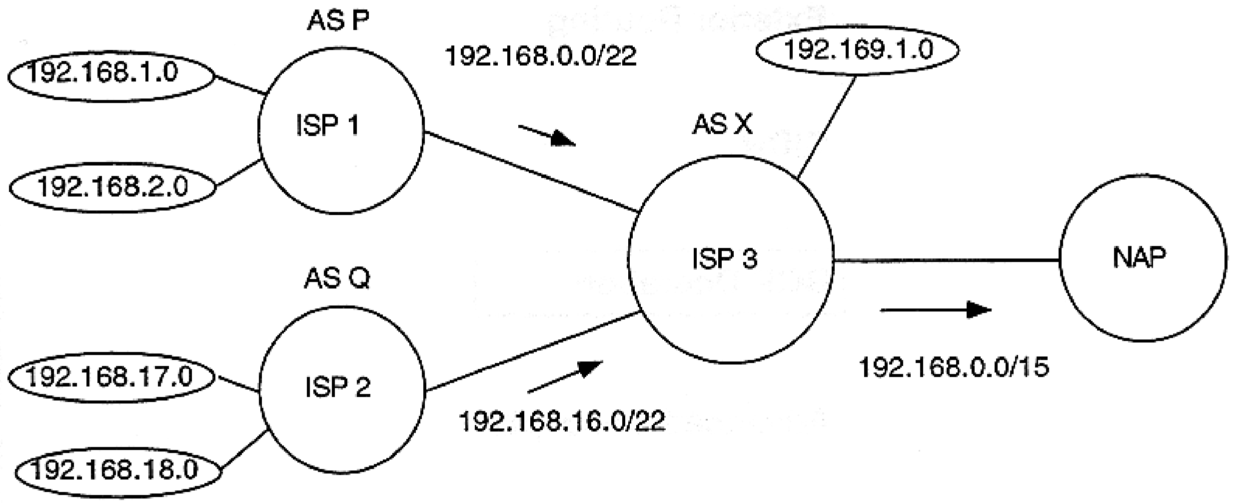
- Representations of the subnet mask in case of Supernetting:
  - binary
  - octet-wise
  - prefix notation (most common)
- Supernetting (and the address aggregation) might be performed hierarchically; example:
  - an Internet Service Provider (ISP) is assigned an address with /18 prefix (i.e. with an 18 Bit network ID); this corresponds to 64 consecutive class C addresses
  - the ISP might assign addresses with /20 prefix to its customers; it can assign a maximum of 4 addresses with /20 prefix and each of these addresses corresponds to 16 consecutive class C networks
- The address aggregation with Supernetting/CIDR also leads to an aggregation of routing table entries (**Route Aggregation**)
  - example: externally (in the Internet) the mentioned ISP and all its customers are known via a /18 network ID - from the outside the sub-divisioning of the /18 address is not visible; in class-based addressing all class C networks would have to be communicated to the outside

Supernetting - Route Aggregation (Example)

routing in class-based addressing:



routing in class-less addressing (CIDR):



Examples: Class-based vs. Class-less Addressing

- Class-based addressing

IP address	class	network address	broadcast address
203.24.8.3	C	203.24.8.0	203.24.8.255
23.1.0.4	A	23.0.0.0	23.255.255.255
129.69.170.1	B	129.69.0.0	129.69.255.255

- Class-less addressing

IP address	prefix	network address	broadcast address
203.78.5.34	/24	203.78.5.0 (203.78.5.0 /24)	203.78.5.255
203.78.5.34	/22	203.78.4.0 (203.78.4.0 /22)	203.78.7.255
203.78.5.34	/27	203.78.5.32 (203.78.5.32 /27)	203.78.5.63

Examples: Interpretation of IP Addresses

1)	`10101100.00010010.00101000.11111111`	172.18.40.255
	`11111111.11111111.11110000.00000000`	255.255.240.0
	→ host address (not all host bits are 0 or 1)	
2)	`10101100.00010010.00100000.00000000`	172.18.32.0
	`11111111.11111111.11110000.00000000`	255.255.240.0
	→ sub-net address	
3)	`10101100.00010010.00101111.11111111`	172.18.47.255
	`11111111.11111111.11110000.00000000`	255.255.240.0
	→ broadcast address	