

## Solution of Exercise Sheet 4

### Exercise 1 (Routers, Layer-3-Switches, Gateways)

1. What is the purpose of **Routers** in computer networks?  
(Also explain the difference to Layer-3-Switches.)

*They forward packets between networks with different logical address ranges and provide a WAN interface.*

2. What is the purpose of **Layer-3-Switches** in computer networks?  
(Also explain the difference to Routers.)

*They are Routers too which means they forward packets between networks with different logical address ranges but they do not provide a WAN interface.*

3. What is the purpose of **Gateways** in computer networks?

*They enable communication between networks, which base on different protocols.*

4. Why are **Gateways** in the network layer of computer networks seldom required nowadays?

*Modern computer networks operate almost exclusively with the Internet Protocol (IP). For this reason, a protocol conversion at the Network Layer is mostly not required.*

### Exercise 2 (Collision Domain, Broadcast Domain)

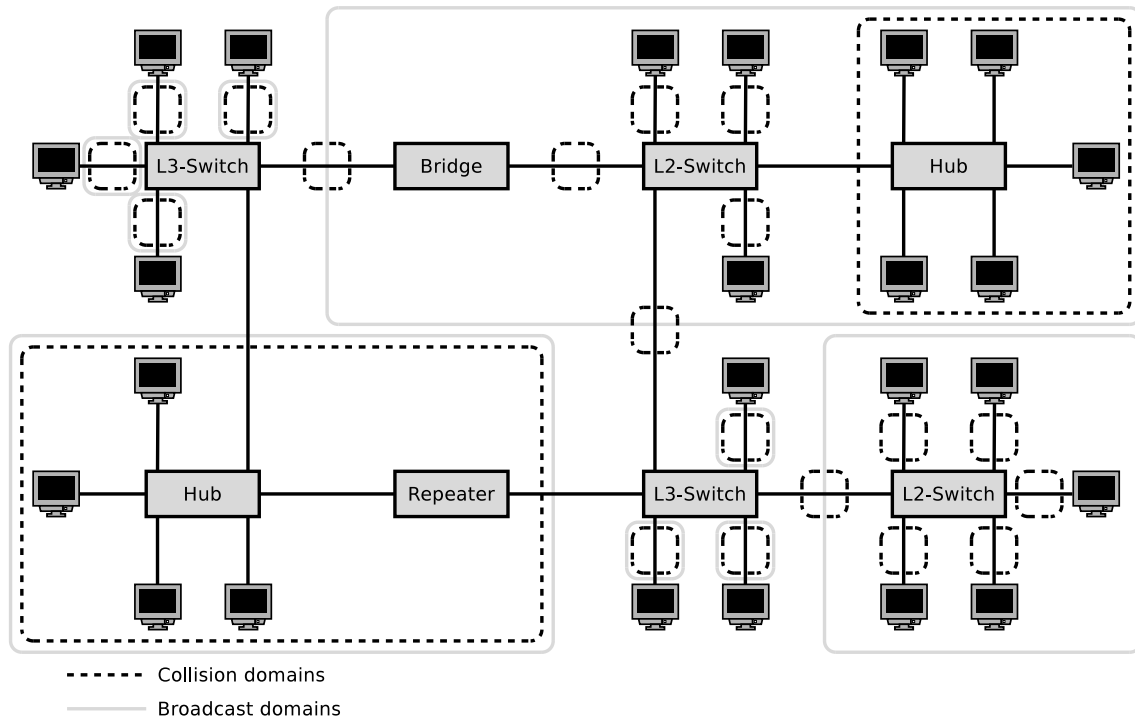
1. Which devices **divide the collision domain**?

|                                   |  |  |
|-----------------------------------|--|--|
| <input type="checkbox"/> Repeater | <input checked="" type="checkbox"/> Bridge         | <input checked="" type="checkbox"/> Router         |
| <input type="checkbox"/> Hub      | <input checked="" type="checkbox"/> Layer-2-Switch | <input checked="" type="checkbox"/> Layer-3-Switch |

2. Which devices **divide the broadcast domain**?

|                                   |   |  |
|-----------------------------------|---|--|
| <input type="checkbox"/> Repeater | <input type="checkbox"/> Bridge         | <input checked="" type="checkbox"/> Router         |
| <input type="checkbox"/> Hub      | <input type="checkbox"/> Layer-2-Switch | <input checked="" type="checkbox"/> Layer-3-Switch |

3. Sketch in the diagram of the network topology all **collision domains** and all **broadcast domains**.



### Exercise 3 (Addressing in the Network Layer)

1. What is the meaning of **Unicast** in the network layer of computer networks?  
*An IP address is assigned to a single receiver.*
2. What is the meaning of **Broadcast** in the network layer of computer networks?  
*An IP address is assigned to all receivers in the subnet.*
3. What is the meaning of **Anycast** in the network layer of computer networks?  
*An IP address is used to reach a single device of a group of devices.*
4. What is the meaning of **Multicast** in the network layer of computer networks?  
*An IP address is assigned to a group of receivers.*
5. Why contains the IPv4 **address space** only 4,294,967,296 addresses?  
*IPv4 addresses have a length of 32 bits (4 bytes). Thus, the address space contains  $2^{32} = 4,294,967,296$  possible addresses.*
6. Why was **Classless Interdomain Routing (CIDR)** introduced?

*Because with address classes, many addresses are wasted and it is impossible to dynamically adjust address classes.*

7. Describe in simple words the **functioning of CIDR**.

*Focus on the way, IP addresses are treated and subnets are created.*

*Since the introduction of CIDR, the address class of an IPv4 address is no longer important. All hosts in a network have a subnet mask assigned, which has a length of 32 bits (4 bytes) and is used to specify the number of subnets and hosts. The network mask splits the host ID of an IP address into subnet ID and host ID. 1-bits in the subnet mask indicate, which part of the address space is used for subnet IDs and 0-bits indicate, which part of the address space is used for host IDs.*

## Exercise 4 (Addressing in the Network Layer)

Calculate for each subtask of this exercise the **first and last host addresses**, the **network address** and the **broadcast address** of the subnet.

|                     |                |                                     |
|---------------------|----------------|-------------------------------------|
| IP Address:         | 151.175.31.100 | 10010111.10101111.00011111.01100100 |
| Subnet mask:        | 255.255.254.0  | 11111111.11111111.11111110.00000000 |
| Part for host IDs:  |                | x xxxxxxxx                          |
| Network address?    | 151.175.30.0   | 10010111.10101111.00011110.00000000 |
| First host address? | 151.175.30.1   | 10010111.10101111.00011110.00000001 |
| Last host address?  | 151.175.31.254 | 10010111.10101111.00011111.11111110 |
| Broadcast address?  | 151.175.31.255 | 10010111.10101111.00011111.11111111 |

|                     |                 |                                     |
|---------------------|-----------------|-------------------------------------|
| IP Address:         | 151.175.31.100  | 10010111.10101111.00011111.01100100 |
| Subnet mask:        | 255.255.255.240 | 11111111.11111111.11111111.11110000 |
| Part for host IDs:  |                 | xxxx                                |
| Network address?    | 151.175.31.96   | 10010111.10101111.00011111.01100000 |
| First host address? | 151.175.31.97   | 10010111.10101111.00011111.01100001 |
| Last host address?  | 151.175.31.110  | 10010111.10101111.00011111.01101110 |
| Broadcast address?  | 151.175.31.111  | 10010111.10101111.00011111.01101111 |

|                     |                 |                                     |
|---------------------|-----------------|-------------------------------------|
| IP Address:         | 151.175.31.100  | 10010111.10101111.00011111.01100100 |
| Subnet mask:        | 255.255.255.128 | 11111111.11111111.11111111.10000000 |
| Part for host IDs:  |                 | xxxxxxxx                            |
| Network address?    | 151.175.31.0    | 10010111.10101111.00011111.00000000 |
| First host address? | 151.175.31.1    | 10010111.10101111.00011111.00000001 |
| Last host address?  | 151.175.31.126  | 10010111.10101111.00011111.01111110 |
| Broadcast address?  | 151.175.31.127  | 10010111.10101111.00011111.01111111 |

| binary representation | decimal representation | binary representation | decimal representation |
|-----------------------|------------------------|-----------------------|------------------------|
| 10000000              | 128                    | 11111000              | 248                    |
| 11000000              | 192                    | 11111100              | 252                    |
| 11100000              | 224                    | 11111110              | 254                    |
| 11110000              | 240                    | 11111111              | 255                    |

## Exercise 5 (Addressing in the Network Layer)

In each subtask of this exercise, a sender transmits an IP packet to a receiver. Calculate for each subtask the **subnet ID of sender and receiver** and specify whether the IP packet **leaves the subnet during transmission** or not.

```

Sender:      11001001.00010100.11011110.00001101    201.20.222.13
Subnet mask: 11111111.11111111.11111111.11110000    255.255.255.240
      AND -----
            11001001.00010100.11011110.00000000    => Subnet ID = 0

```

```

Receiver:    11001001.00010100.11011110.00010001    201.20.222.17
Subnet mask: 11111111.11111111.11111111.11110000    255.255.255.240
      AND -----
            11001001.00010100.11011110.00010000    => Subnet ID = 1

```

Subnet ID of sender? 0

Subnet ID of receiver? 1

Does the IP packet leave the subnet [yes/no]? yes

```

Sender:      00001111.11001000.01100011.00010111    15.200.99.23
Subnet mask: 11111111.11000000.00000000.00000000    255.192.0.0
      AND -----
            00001111.11000000.00000000.00000000    => Subnet ID = 3

```

```

Receiver:    00001111.11101111.00000001.00000001    15.239.1.1
Subnet mask: 11111111.11000000.00000000.00000000    255.192.0.0
      AND -----
            00001111.11000000.00000000.00000000    => Subnet ID = 3

```

Subnet ID of sender? 3

Subnet ID of receiver? 3

Does the IP packet leave the subnet [yes/no]? no

## Exercise 6 (Addressing in the Network Layer)

Calculate for each subtask of this exercise the **subnet masks** and answer the **questions**.

1. Split the class C network 195.1.31.0 for implementing 30 subnets.

Network ID: 11000011.00000001.00011111.00000000 195.1.31.0  
Number of bits for subnet IDs? 30 => 32 ( $= 2^5$ ) => 5 bits  
Subnet mask: 11111111.11111111.11111111.11111000 255.255.255.248  
Number of bits for host IDs? 3  
Number of host IDs per subnet?  $2^3 - 2 = 6$

2. Split the class A network 15.0.0.0 for implementing 333 subnets.

Network ID: 00001111.00000000.00000000.00000000 15.0.0.0  
Number of bits for subnet IDs? 333 => 512 ( $= 2^9$ ) => 9 bits  
Subnet mask: 11111111.11111111.10000000.00000000 255.255.128.0  
Number of bits for host IDs? 15  
Number of host IDs per subnet?  $2^{15} - 2 = 32766$

3. Split the class B network 189.23.0.0 for implementing 20 subnets.

Network ID: 10111101.00010111.00000000.00000000 189.23.0.0  
Number of bits for subnet IDs? 20 => 32 ( $= 2^5$ ) => 5 bits  
Subnet mask: 11111111.11111111.11111000.00000000 255.255.248.0  
Number of bits for host IDs? 11  
Number of host IDs per subnet?  $2^{11} - 2 = 2046$

4. Split the class C network 195.3.128.0 into subnets, which contain 17 hosts each.

Network ID: 11000011.00000011.10000000.00000000 195.3.128.0  
Number of bits for host IDs? 17 => 32 ( $= 2^5$ ) => 5 bits  
Number of bits for subnet IDs?  $8 - 5 = 3$  bit  
Number of possible subnets?  $2^3 = 8$   
Subnet mask: 11111111.11111111.11111111.11100000 255.255.255.224

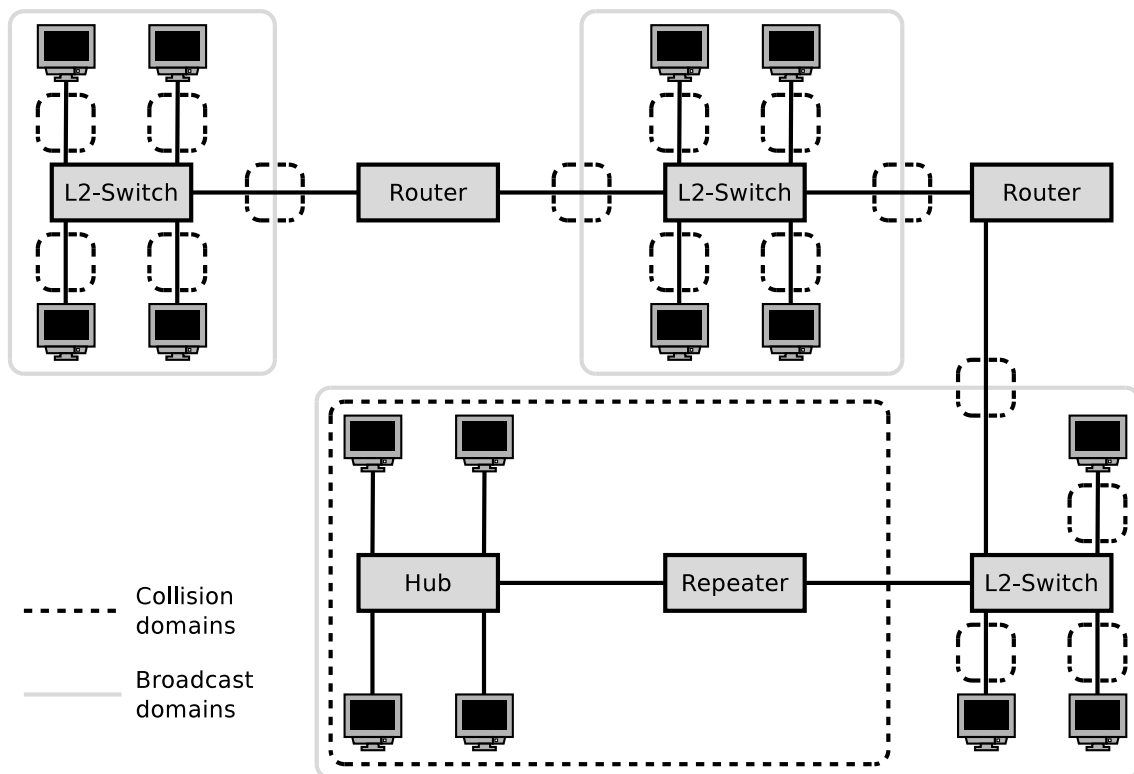
5. Split the class B network 129.15.0.0 into subnets, which contain 10 hosts each.

Network ID: 10000001.00001111.00000000.00000000 129.15.0.0  
 Number of bits for host IDs? 10  $\Rightarrow$  16 ( $= 2^4$ )  $\Rightarrow$  4 bits  
 Number of bits for subnet IDs? 16  $-$  4 = 12 bit  
 Number of possible subnets?  $2^{12} = 4096$   
 Subnet mask: 11111111.11111111.11111111.11110000 255.255.255.240

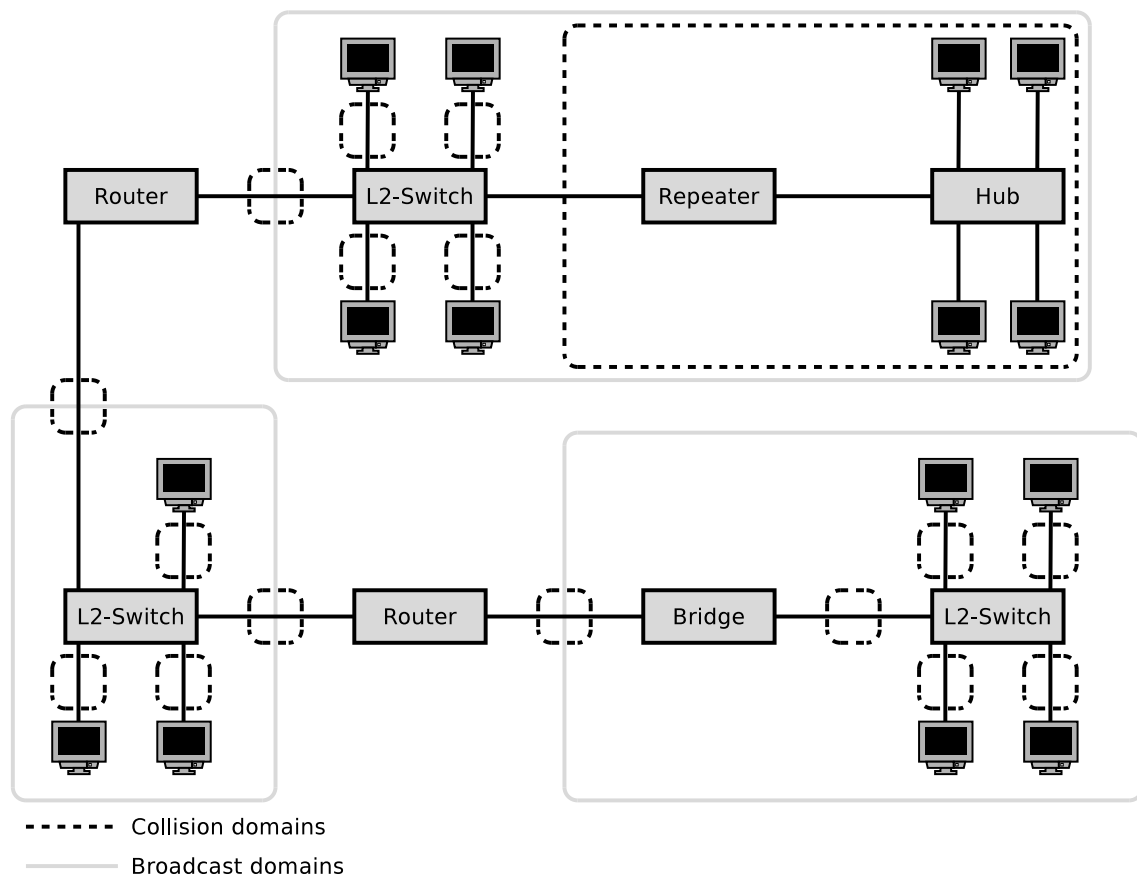
| binary representation | decimal representation | binary representation | decimal representation |
|-----------------------|------------------------|-----------------------|------------------------|
| 10000000              | 128                    | 11111000              | 248                    |
| 11000000              | 192                    | 11111100              | 252                    |
| 11100000              | 224                    | 11111110              | 254                    |
| 11110000              | 240                    | 11111111              | 255                    |

## Exercise 7 (Collision Domain, Broadcast Domain)

1. Sketch in the diagram of the network topology all **collision domains** and all **broadcast domains**.

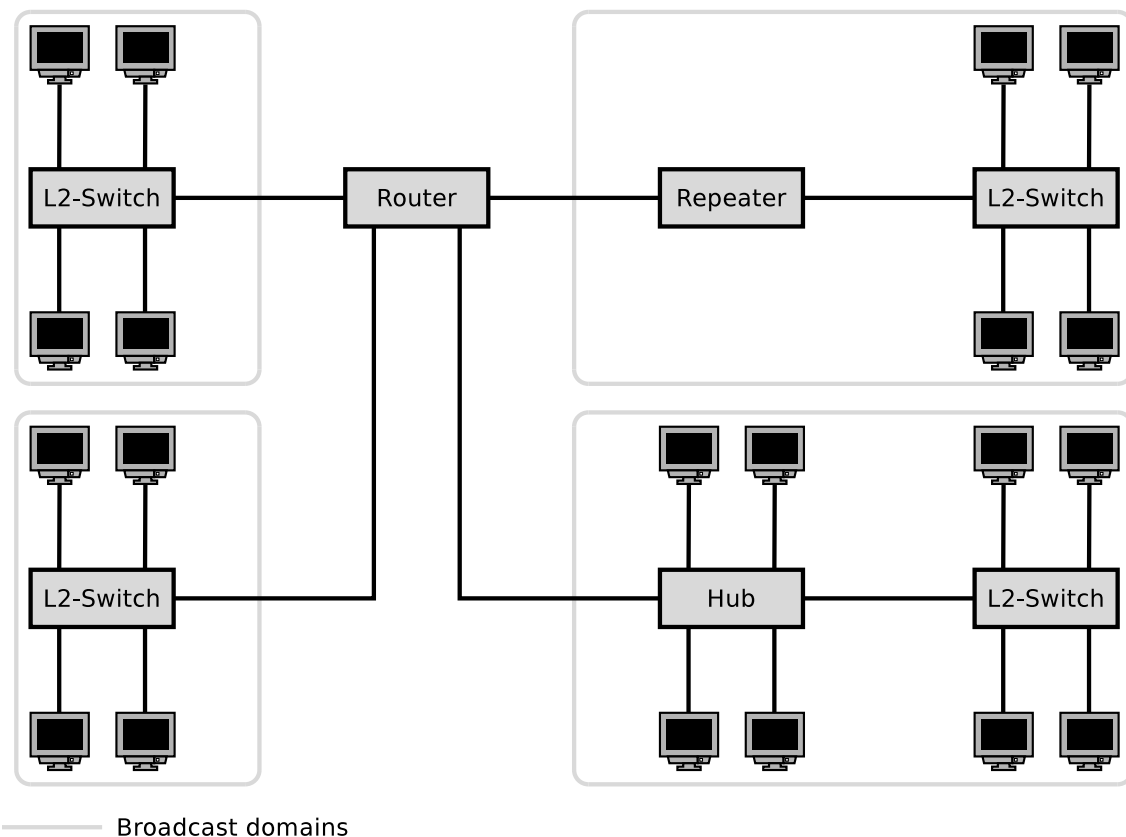


2. Sketch in the diagram of the network topology all **collision domains** and all **broadcast domains**.



## Exercise 8 (Broadcast Domain)

1. Sketch in the diagram of the network topology all **broadcast domains**.
2. What is the **required number of subnets** for this network topology?



*4 subnets are required because each port of a Router is connected to a different IP network. It is impossible to operate an IP subnet on multiple ports of a Router.*

## Exercise 9 (Private IP Address Spaces)

Name the three private IPv4 address spaces.

- 10.0.0.0/8
- 172.16.0.0/12
- 192.168.0.0/16

## Exercise 10 (Addressing in the Network Layer)

Calculate for each network configuration in the table whether an IP packet, which is sent from the given IP address to the destination address, **leaves the subnet during transmission** or not.



| IP address    | Subnet mask     | Destination address | Leaves the subnet [yes/no] |
|---------------|-----------------|---------------------|----------------------------|
| 201.20.222.13 | 255.255.255.240 | 201.20.222.17       | yes                        |
| 15.200.99.23  | 255.192.0.0     | 15.239.1.1          | no                         |
| 172.21.23.14  | 255.255.255.0   | 172.21.24.14        | Private IPs are not routed |
| 210.5.16.198  | 255.255.255.252 | 210.5.16.197        | no                         |
| 210.5.16.198  | 255.255.255.252 | 210.5.16.201        | yes                        |
| 5.5.5.5       | 255.254.0.0     | 5.6.6.6             | yes                        |

(A part of the solution is the calculations performed. Where no calculation is required, you need to give a reason for your answer. Answering the question with just „yes“ or „no“ is not sufficient!)

Source: Jörg Roth. Prüfungstrainer Rechnernetze. Vieweg (2010)

```

      11001001.00010100.11011110.00001101      201.20.222.13
AND  11111111.11111111.11111111.11110000      255.255.255.240
-----
      11001001.00010100.11011110.00000000
                        ~~~~
                        => 0 = subnet ID sender

      11001001.00010100.11011110.00010001      201.20.222.17
AND  11111111.11111111.11111111.11110000      255.255.255.240
-----
      11001001.00010100.11011110.00010000
                        ~~~~
                        => 1 = subnet ID sender

```

Sender and receiver have different subnet IDs  $\implies$  the subnet is left.

```

      00001111.11001000.01100011.00010111      15.200.99.23
AND  11111111.11000000.00000000.00000000      255.192.0.0
-----
      00001111.11000000.00000000.00000000
                ^^
                => 3 = subnet ID sender

      00001111.11101111.00000001.00000001      15.239.1.1
AND  11111111.11000000.00000000.00000000      255.192.0.0
-----
      00001111.11000000.00000000.00000000
                ^^
                => 3 = subnet ID sender

```

Sender and receiver have equal subnet IDs  $\implies$  the subnet is not left.

172.21.23.14 and 172.21.24.14 are private IP addresses  $\implies$  they are not forwarded by Routers.

```
11010010.00000101.00010000.11000110    210.5.16.198
AND 11111111.11111111.11111111.11111100    255.255.255.252
-----
11010010.00000101.00010000.11000100
                        ~~~~~~
=> 49 = subnet ID sender
```

```
11010010.00000101.00010000.11000101    210.5.16.197
AND 11111111.11111111.11111111.11111100    255.255.255.252
-----
11010010.00000101.00010000.11000101
                        ~~~~~~
=> 49 = subnet ID sender
```

*Sender and receiver have equal subnet IDs  $\implies$  the subnet is not left.*

```
11010010.00000101.00010000.11000110    210.5.16.198
AND 11111111.11111111.11111111.11111100    255.255.255.252
-----
11010010.00000101.00010000.11000100
                        ~~~~~~
=> 49 = subnet ID sender

11010010.00000101.00010000.11001001    210.5.16.201
AND 11111111.11111111.11111111.11111100    255.255.255.252
-----
11010010.00000101.00010000.11001000
                        ~~~~~~
=> 50 = subnet ID receiver
```

*Sender and receiver have different subnet IDs  $\implies$  the subnet is left.*

```
00000101.00000101.00000101.00000101    5.5.5.5
AND 11111111.11111110.00000000.00000000    255.254.0.0
-----
00000101.00000100.00000000.00000000
        ~~~~~~
=> 2 = subnet ID sender

00000101.00000110.00000110.00000110    5.6.6.6
AND 11111111.11111110.00000000.00000000    255.254.0.0
-----
00000101.00000110.00000000.00000000
        ~~~~~~
=> 3 = subnet ID sender
```

*Sender and receiver have different subnet IDs  $\implies$  the subnet is left.*

## Exercise 11 (Addressing in the Network Layer)

Specify for each subtask of this exercise the correct **subnet mask**.

1. A maximum number of subnets with 5 hosts each in a class B network.

*5 hosts  $\Rightarrow$  3 bit are required.*

11111111 11111111 11111111 11111000                      255.255.255.248

2. 50 subnets with 999 hosts each in a class B network.

*999 hosts  $\Rightarrow$  10 bit are required.*

11111111 11111111 11111100 00000000                      255.255.252.0

3. 12 subnets with 12 hosts each in a class C network.

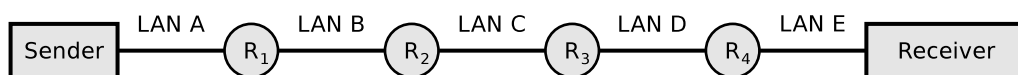
*12 hosts  $\Rightarrow$  4 bit are required.*

11111111 11111111 11111111 11110000                      255.255.255.240

Source: Jörg Roth. *Prüfungstrainer Rechnernetze*. Vieweg (2010)

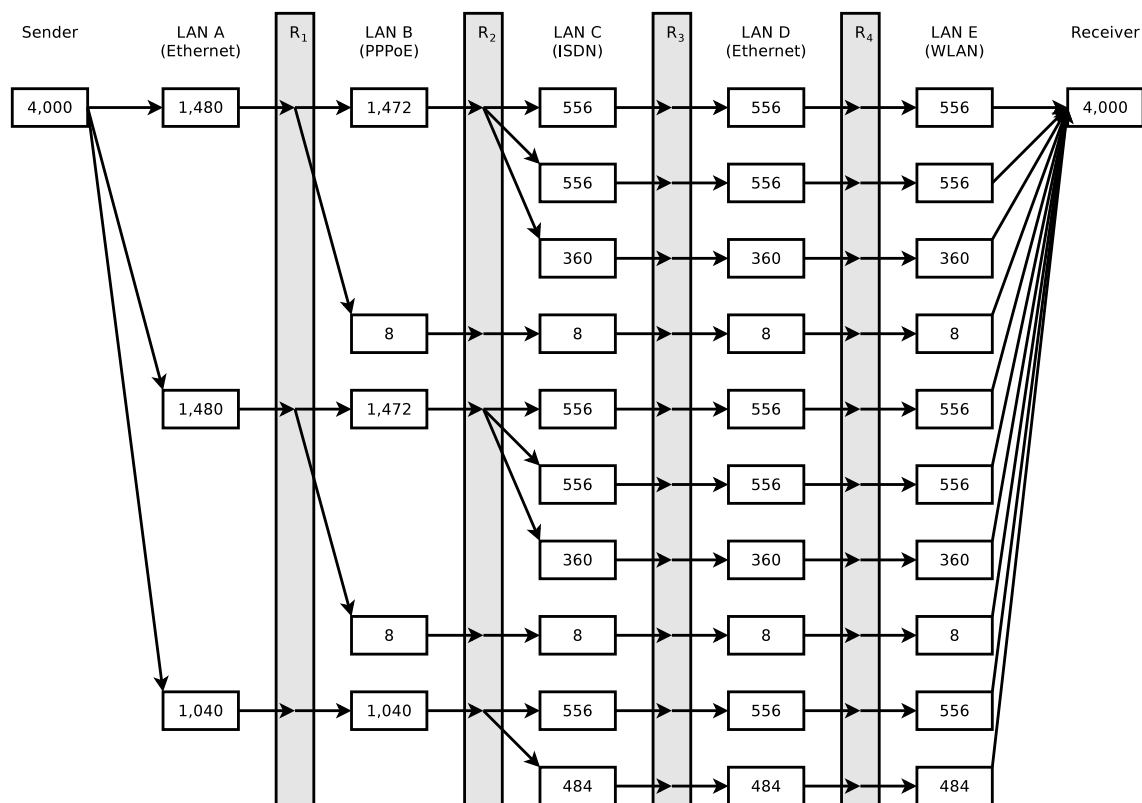
## Exercise 12 (Fragmenting IP Packets)

4,000 bytes payload need to be transmitted via the IP protocol. The payload must be fragmented, because it is transmitted over multiple physical networks, whose MTU is  $< 4,000$  bytes.



|                         | LAN A    | LAN B | LAN C | LAN D    | LAN E |
|-------------------------|----------|-------|-------|----------|-------|
| Network technology      | Ethernet | PPPoE | ISDN  | Ethernet | WLAN  |
| MTU [bytes]             | 1,500    | 1,492 | 576   | 1,400    | 2,312 |
| IP-Header [bytes]       | 20       | 20    | 20    | 20       | 20    |
| maximum payload [bytes] | 1,480    | 1,472 | 556   | 1,380    | 2,292 |

Display graphically the way, the payload is fragmented, and how many bytes of payload each fragment contains.



## Exercise 13 (Forwarding and Path Calculation)

1. Which two major classes of **routing protocols** exist?

*Distance Vector Routing Protocols and Link State Routing Protocols.*

2. Which **algorithms for best path calculation** implement the routing protocol classes from subtask 1?

*Distance Vector Routing Protocols implement the Bellman-Ford algorithm.*

*Link State Routing Protocols implement the Dijkstra algorithm.*

3. What is an **autonomous system**?

*Each AS consists of a group of logical networks, which use the Internet Protocol, are operated and managed by the same organization (e.g. an Internet Service Provider, a corporation or university) and use the same routing protocol.*

4. The **Border Gateway Protocol** (BGP) is a protocol for...

☐ Intra-AS routing      ☒ Inter-AS routing

5. Which **routing protocol class** from subtask 1 implements the BGP?

*Link state routing.*

6. **Open Shortest Path First** (OSPF) is a protocol for...

☒ Intra-AS routing      ☐ Inter-AS routing

7. Which **routing protocol class** from subtask 1 implements OSPF?

*Link state routing.*

8. The **Routing Information Protocol** (RIP) is a protocol for...

☒ Intra-AS routing      ☐ Inter-AS routing

9. Which **routing protocol class** from subtask 1 implements the RIP?

*Distance vector routing.*

10. When RIP is used, each Router communicates only with its **direct neighbors**. What are the **advantages** and **drawbacks** of method?

*Advantage: The network is not flooded  $\implies$  protocol causes little overhead.*

*Drawback: Long convergence time because updates propagate slowly.*

11. When RIP is used, the path cost (metric) depend only on the number of Routers (**hops**), which need to be passed on the way to the destination network. What is the **drawback** of this method?

The metric hop count often results in routes, which are not optimal, because all network segments have an equal weight.

12. When OSPF is used, **all Routers** communicate with each other. What are the **advantages** and **drawbacks** of method?

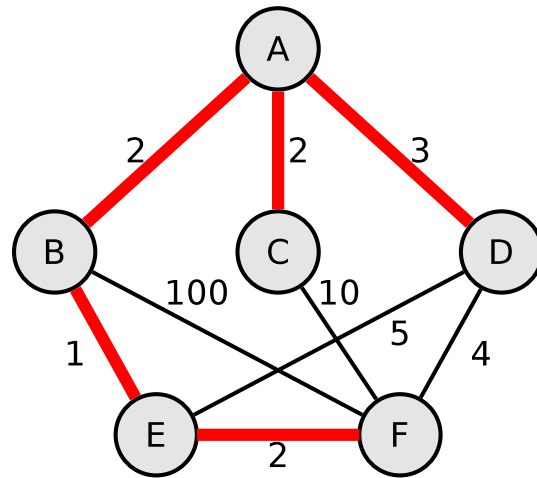
*Advantage: Short convergence time.*

*Drawback: The network is flooded  $\implies$  protocol causes strong overhead.*

## Exercise 14 (Dijkstra's Algorithm)

1. Calculate the shortest path from node A to all other nodes using Dijkstra's algorithm.

Source: Jörg Roth. Prüfungstrainer Rechnernetze. Vieweg (2010)



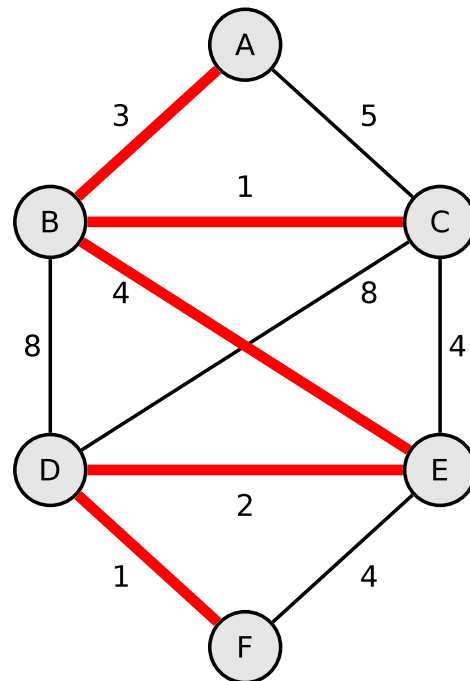
|       | Distance values           |                           |                           |                           |                           |                           |
|-------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
|       | Initial                   | Step 1                    | Step 2                    | Step 3                    | Step 4                    | Step 5                    |
| $d_A$ | <b>0</b> $\leftarrow$ min | <u>0</u> ✓                | 0 ✓                       | 0 ✓                       | 0 ✓                       | 0 ✓                       |
| $d_B$ | $\infty$                  | <b>2</b> $\leftarrow$ min | <u>2</u> ✓                | 2 ✓                       | 2 ✓                       | 2 ✓                       |
| $d_C$ | $\infty$                  | 2                         | <b>2</b> $\leftarrow$ min | <u>2</u> ✓                | <u>2</u> ✓                | <u>2</u> ✓                |
| $d_D$ | $\infty$                  | 3                         | 3                         | <b>3</b> $\leftarrow$ min | <u>3</u> ✓                | <u>3</u> ✓                |
| $d_E$ | $\infty$                  | $\infty$                  | 3                         | 3                         | <b>3</b> $\leftarrow$ min | <u>3</u> ✓                |
| $d_F$ | $\infty$                  | $\infty$                  | 102                       | 12                        | 7                         | <b>5</b> $\leftarrow$ min |

The active node is underlined.

Nodes visited = {A, B, C, D, E, F}

Shortest paths = {A, A  $\rightarrow$  B, A  $\rightarrow$  C, A  $\rightarrow$  D, B  $\rightarrow$  E, E  $\rightarrow$  F}

2. Calculate the shortest path from node A to all other nodes using Dijkstra's algorithm.



|       | Distance values           |                           |                           |                           |                           |                            |
|-------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|----------------------------|
|       | Initial                   | Step 1                    | Step 2                    | Step 3                    | Step 4                    | Step 5                     |
| $d_A$ | <b>0</b> $\leftarrow$ min | <u>0</u> ✓                | 0 ✓                       | 0 ✓                       | 0 ✓                       | 0 ✓                        |
| $d_B$ | $\infty$                  | <b>3</b> $\leftarrow$ min | <u>3</u> ✓                | 3 ✓                       | 3 ✓                       | 3 ✓                        |
| $d_C$ | $\infty$                  | 5                         | <b>4</b> $\leftarrow$ min | <u>4</u> ✓                | 4 ✓                       | 4 ✓                        |
| $d_D$ | $\infty$                  | $\infty$                  | 11                        | 11                        | <b>9</b> $\leftarrow$ min | <u>9</u> ✓                 |
| $d_E$ | $\infty$                  | $\infty$                  | 7                         | <b>7</b> $\leftarrow$ min | <u>7</u> ✓                | 7 ✓                        |
| $d_F$ | $\infty$                  | $\infty$                  | $\infty$                  | $\infty$                  | 11                        | <b>10</b> $\leftarrow$ min |

The active node is underlined.

Nodes visited = {A, B, C, E, D, F}

Shortest paths = {A, A  $\rightarrow$  B, B  $\rightarrow$  C, B  $\rightarrow$  E, E  $\rightarrow$  D, D  $\rightarrow$  F}

## Exercise 15 (Internet Control Message Protocol)

1. What is the **function** of the Internet Control Message Protocol (ICMP)?

*It is used for the exchange of diagnostic and control messages, as well as error messages.*

2. Give two examples for **command line tools**, which use ICMP.

*ping, traceroute*

## Exercise 16 (IPv6)

1. Simplify these IPv6 addresses:

- 1080:0000:0000:0000:0007:0700:0003:316b

*Solution:* 1080::7:700:3:316b

- 2001:0db8:0000:0000:f065:00ff:0000:03ec

*Solution:* 2001:db8::f065:ff:0:3ec

- 2001:0db8:3c4d:0016:0000:0000:2a3f:2a4d

*Solution:* 2001:db8:3c4d:16::2a3f:2a4d

- 2001:0c60:f0a1:0000:0000:0000:0000:0001

*Solution:* 2001:c60:f0a1::1

- 2111:00ab:0000:0004:0000:0000:0000:1234

*Solution:* 2111:ab:0:4::1234

2. Provide all positions of these simplified IPv6 addresses:

- 2001::2:0:0:1

*Solution:* 2001:0000:0000:0000:0002:0000:0000:0001

- 2001:db8:0:c::1c

*Solution:* 2001:0db8:0000:000c:0000:0000:0000:001c

- 1080::9956:0:0:234

*Solution:* 1080:0000:0000:0000:9956:0000:0000:0234

- 2001:638:208:ef34::91ff:0:5424

*Solution:* 2001:0638:0208:ef34:0000:91ff:0000:5424

- 2001:0:85a4::4a1e:370:7112

*Solution:* 2001:0000:85a4:0000:0000:4a1e:0370:7112