Examination SS2016
Communication Systems and Protocols

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Communication Systems and Protocols

Date:	25.07.2016
Name:	Test Name
Matr. ID:	123456
ID:	1
Lecture Hall:	ITIV
Seat:	**1**

Prerequisites for the examination

Aids:

- writing utensils
- a non-programmable calculator
- a dictionary
- a single sheet of A4 paper with **self- and hand-written** notes. Writing may be on both sides
- Use only indelible ink - use of pencils and red ink is prohibited.
- Other material than that mentioned above, is strictly forbidden. This includes any type of communication to other people.

Duration of the examination:

The exam duration is 120 minutes.

Examination documents:

The examination comprises 31 pages (including title page, 8 blocks of tasks).

Answers may be given in English or German. A mix of language within a single (sub)-task is not allowed.

Please check your matriculation number and ID on every page before processing the tasks.

In your solution mark clearly which part of the task you are solving. Do not write on the backside of the solution sheets. If additional paper is needed ask the examination supervisor.

End of Exam:

You will not be allowed to hand in your examination and leave the lecture hall in the last 30 minutes of the examination. At the end of the examination: Stay at your seat and put all sheets (including this title page) into the envelope. Only sheets in the envelope will be corrected. We will collect the examination.

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Task 7:	Routing	26	11	**13**
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				$\sum$ **114**

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Task 1: Physical Basics

Task 1.1: Signal Transmission

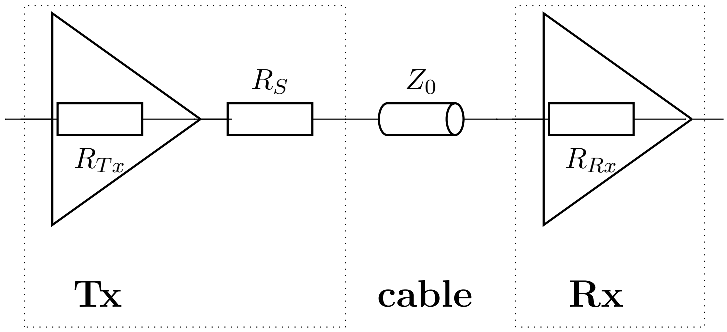


Figure 1.1: Test setup

In Figure 1.1, a transmission line is depicted. Here, a transmitter with the output impedance R_{Tx} is connected through a long cable to a receiver with input impedance R_{Rx}.
In order to minimize reflections, the transmitter is matched to the line with an impedance of Z_0 by adding a series termination resistor R_S.
The impedances are $Z_0 = 50\ \Omega$, $R_{Tx} = 7\ \Omega$ and $R_{Rx} > 1\ M\Omega$.

A) How should the value of R_S be chosen in order to minimize reflections? Give the equation which describes this relation. **2**

$R_s = Z_0 - R_{Tx} = 43\ \Omega$

1P for formula. 1P additionally if correct value.

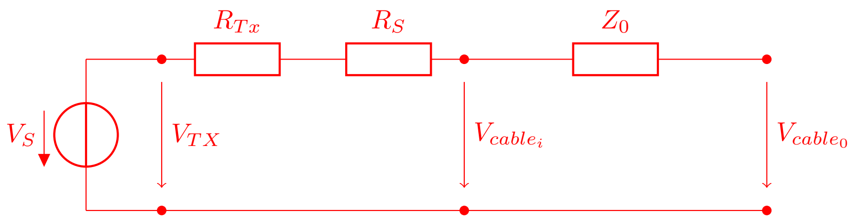
B) At which end of the line will be the least reflections for the case of the matched line in Figure 1.1?
Give the equation for the reflection factor in general. What does the equation look like at the selected end of the line where the least reflections are to be expected? **2**

At the source/transmitter.

$r = (R_T - Z_0)/(R_T + Z_0)$
$= ((R_{Tx} + R_S) - Z_0)/((R_{Tx} + R_S) + Z_0)$

1P for naming the correct terminal. 0.5P for abstract formula (from script), 0.5P for application to scenario.

C) What does the equivalent circuit diagram look like for the setup depicted in Figure 1.1? How can the receiver side of the diagram be abstracted for the transmission line described in this task? Draw the diagram. **2**



0.5 Point for resistors R_{Tx} and R_S in series, 0.5 Point for Z_0 in series, 1 Point for replacing R_{Rx} by an open end. Not wrong, but no additional points: If cable is replaced by Res+Coil in series, Res+Cap in parallel.

D) A step signal of $V_{Tx} = V_{step} = 2.5$V amplitude is now being sent by the transmitter. After the step has passed the transmitter circuit and the series termination resistor it reaches the beginning of the long cable.
Explain and give a reasoning: What will be the voltage $V_{cableIn}$ for the point in time when the transmitted step reaches the beginning of the cable for the first time? **1**

$V_{Tx}/2 = 1.25V$.

Since the wave sees Z_0 when looking into the cable, the circuit behaves like a symmetrical voltage divider.

$V_{cableIn} = V_{Step} * (Z_0/(R_T + Z_0)) = 1.25V$

1 Point for correct explanation OR giving the proper equation - no point without it / just 0.5P if value is missing .

E) What will the signal look like at half of the cable's length (the middle) for the properly terminated transmission line from Figure 1.1 for an ideal cable (no attenuation per unit length)? Here it takes the time **T** for the step with $V_{Tx} = +V_{step}$ at the transmitter to propagate from one end of the cable to the other. The propagation times of the signal at the transmitter and receiver side of the cable can be neglected.
If you didn't get a result in the previous task, use $V_{cableIn} = +1/4{*}V_{step}$.
Draw the signal curve into the diagram 1.2. **2**

0.5P for corr. value at t=0, 0.5P for corr. value at t=2T, 0.5P for correct value at t=T, 0.5P (together) for correctly changing the value at half and 3/2 T points in time.

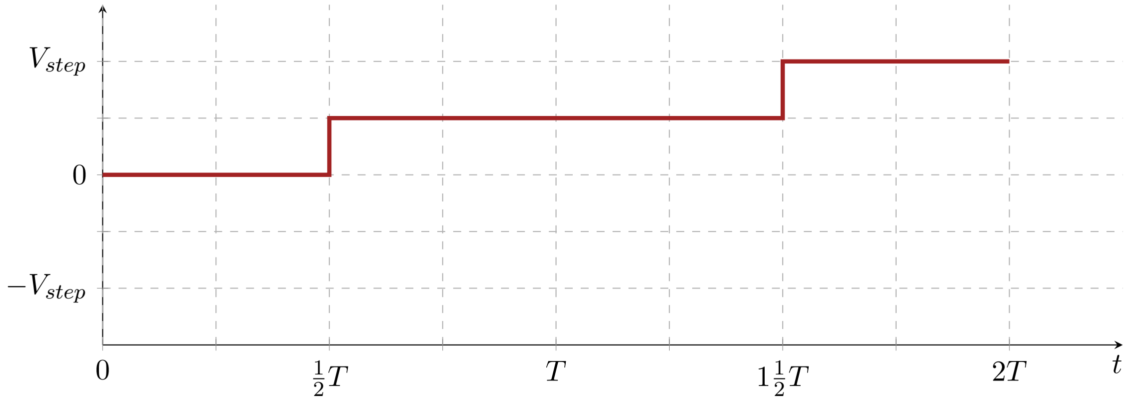


Figure 1.2: Diagram for drawing the voltage over time at half of the cable length

F) In this task, the voltages on the line have completely settled (steady state). **5**
For the transmission line, a coaxial cable of 100 meter length is used which has an attenuation of A = -3.5 dB. The transmitter and receiver are LVCMOS components, where the transmitter's output signal has an high-voltage of 2.5V (V_{Tx}) and the receiver requires a minimum signal of 2V (V_{minRx}) for interpreting it as an high level.
An amplifier with how much gain G_{min} (in dB) will be required in order to allow the receiver to properly receive the signal at the far end of the cable?

$A = 20^{*}log_{10}(V_{Rx}/V_{Tx})$, so $R_{Rx} = V_{Rx}/V_{Tx} = 10^{(A/20)} = 0.668$

1 Point Power/Voltage Ratio Rx/Tx.
1 Point actual receive Voltage.
1 Point Minimum Voltage Ratio 1 Point.
1 Point Gain in dB.

$\rightarrow V_{Rx} = R_{Rx} * V_{Tx} = 1.67\ V$

$R_{Rxmin} = V_{Rxmin}/V_{Rx} = 2V/1.67V = 1.197$

$G_{min} = 20^{*}log_{10}(R_{Rxmin}) = 1.566\ dB$

Alternative starting from Power Ratios:
$A = 10^{*}log_{10}(P_{Rx}/P_{Tx}) \rightarrow P_{Rx}/P_{Tx} = 10^{(A/10)} = 0.447$
$R_{Rx} = |V_{Rx}/V_{Tx}| = \sqrt{P_{Rx}/P_{Tx}} = 0.668 \rightarrow V_{Rx} = R_{Rx} * V_{Tx} = 1.67\ V$

Alternative Computing in the dB domain:
$R_{TxRxmin} = V_{Tx}/V_{Rxmin} = A_{max} = 20^{*}log_{10}(R_{TxRxmin}) = 1.9382\ dB$
$\rightarrow G_{min} = |A_{max} + A| = 1.9382\ dB - 3.5\ dB = 1.562\ dB$

Alternative Computing with absoulute numbers:
$V_{TxNeeded} * 10^{(A/20)} = V_{minRx} \rightarrow G_{min} = 20^{*}log_{10}(V_{TxNeeded}/V_{Tx}) = 1.562\ dB$

HINT: For equal impedances R it is true, that:
For Powers: $A = \mathbf{10}^{*}log_{10}(P_{Rx}/P_{Tx})$ AND $A = 10^{*}log_{10}((V_{Rx}^2/R)/(V_{Tx}^2/R))$
For Voltage: $A = \mathbf{20}^{*}log_{10}(V_{Rx}/V_{Tx})$
$|V_{Rx}/V_{Tx}| = \sqrt{P_{Rx}/P_{Tx}}$

Task 1.2: Sampling Theorem

A) What is the Nyquist theorem (explanation) and how is it defined in case of a non-baseband signal?

2

The Nyquist theorem is the lower bound for the sampling frequency which a (single-sideband) signal has to be sampled with in order to be able to fully reconstruct the signal after digitization.

1P explanation, 1P theorem using B instead of fmax, single-sideband doesn't have to be mentioned

$f_{S_min} = 2 * \text{B}$ or $f_S \geq 2 * \text{B}$

B) In the Figure 1.3 below you will find the bandwidth spectrum of an FM channel from a radio broadcast signal after downconversion.
If you were just interested in the **Audio Mono L+R** signal, how would you extract this signal's content from the spectrum (no FM demodulation in this step)?
Which are the components you will need in order to extract the signal?
What are the important properties of the required components and processing blocks regarding sampling rate and bandwidth?

2

Required component: **Low-pass or Bandpass** with cut-off frequency of 15...19 kHz as anti- aliasing filter

1P for sampling rate in SSB or CBB case, 1P for stating low-/bandpass filter with correct cut-off frequency

Sampling component (Possible solutions):

Single-sideband: Sampling with minimum 30 kHz

- IF explicitly stated - *Complex baseband signal*: Sampling with two converters (I/Q) at min. 15kHz

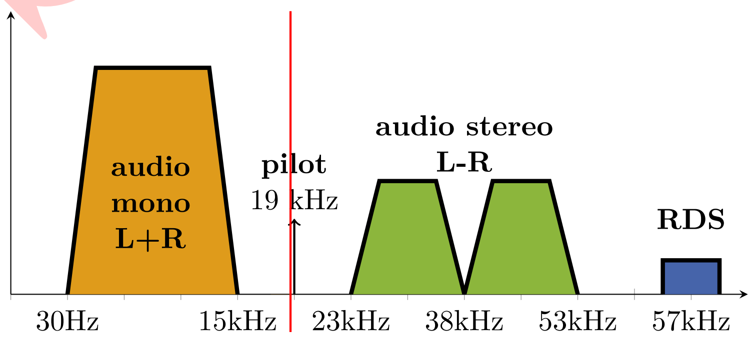


Figure 1.3: Base band spectrum of an radio broadcasting FM channel

Task 2: Media Access

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Task 2.1: Multiplexing

A) Name two different types of multiplexing and explain the underlying principle.

1

- *Space division*: Transmit each signal on individual lines
- *Time division*: Each signal is transmitted in a defined time slot using the same line
- *Frequency division*: Modulate each signal on a different carrier frequency
- *Wavelength division*: Special form of frequency division; Transmission of multiple wave lengths (colors) over a single optical waveguide

+0.5P per multiplexing method with correct explanation

B) Bus systems are often classified into serial and parallel buses. Please name one advantage and one disadvantage of parallel buses.

1

Advantages:

- Multiple bits can be transmitted at once
- Clock can be transmitted using a separate wire -> no clock reconstruction required

Disadvantages:

- More wires required
- Clock skew limits the transmission frequency
- Possible crosstalk between wires

+0.5P for advantage
+0.5P for disadvantage

Task 2.2: Multiple Access

Eight different devices communicate on a shared bus-system using TDMA with static time-slot assignment. It can be assumed, that the clocks of each node are perfectly synchronized using a separate clock wire (i.e. clock wire delays are completely compensated). On the data wire, only payload data needs to be transmitted without any additional synchronization overhead. The TDMA cycles (time frames) last for $t_f = 5ms$ and contain exactly one time-slot for each of the 8 participants. The physical signal propagation delay (one-way delay) between the two most distant nodes on the bus is $\Delta_{max} = 50\mu s$. All TDMA time-slots are of equal length and each symbol has a fixed duration of $t_{sym} = 2.5\mu s$.

A) To avoid symbol interference, a guard interval is inserted at the end of each time-slot. How long should this guard interval be at least in order to fully prevent symbol interference in the given system? Calculate the length of the time-slots t_{sl} as well as the time t_{send} which can be used for data transmission during a time-slot. **2**

The guard time must be at least Δ_{max} to avoid symbol interference.
Length of a time slot: $t_{sl} = t_f/8 = 625\mu s$
The maximum send time then is: $t_{send} = t_{sl} - \Delta_{max} = 575\mu s$

+1P for guard interval length
+0.5P for formula
+0.5 for correct solution

B) Some of the devices may need to transmit larger amounts of data which can take several seconds. Calculate the average baud-rate f_s that can be achieved for such transmissions. (If you did not solve the previous question, assume that in each time-slot $t_{send} = 605\mu s$ can be used for data transmission.) **2**

Number of symbols in each time slot: $n_{sym} = \frac{t_{send}}{t_{sym}} = \frac{575\mu s}{2.5\mu s} = 230$
Frequency of time frames: $f_f = \frac{1}{t_f} = 200Hz$
Baud rate for one sender: $f_s = n_{sym} \cdot f_f = 46000Hz = 46kHz$

+1P for correct approach / formula
+1P for correct solution

Alternative solution for $t_{send} = 605\mu s$:
Number of symbols in each time slot: $n_{sym} = \frac{t_{send}}{t_{sym}} = \frac{575\mu s}{2.5\mu s} = 242$
Frequency of time frames: $f_f = \frac{1}{t_f} = 200Hz$
Baud rate for one sender: $f_s = n_{sym} \cdot f_f = 48400Hz = 48.4kHz$

Task 2.3: Modulation

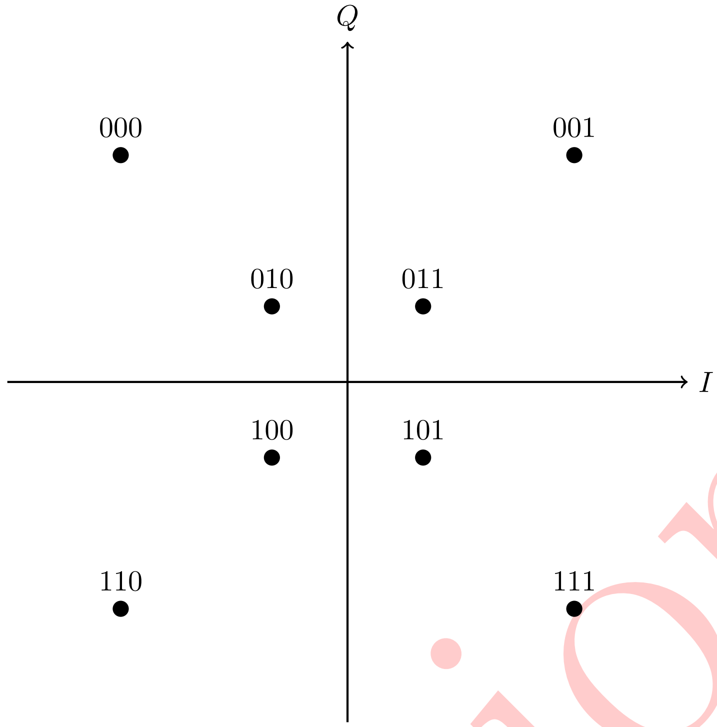

Figure 2.1: Constellation diagram

A) Figure 2.1 shows a constellation diagram for a digital modulation technique. Which type of modulation is used here? Which properties of the signal can be varied with this modulation type?

1

Modulation type: 8-QAM
Varied properties: Phase and Amplitude

+0.5P for 8-QAM
+0.5P for correct properties

B) The symbol constellation from Figure 2.1 is now used by a transmitter to modulate data bits on a carrier. The phase φ of the signal is defined relative to a sine reference signal as shown in Figure 2.2. A receiver device now picks up the modulated signal which is plotted in Figure 2.3. Which bits have been transmitted by the sender? Demodulate the signal and write down the resulting bit-stream. **3**

Transmitted bits:
111 100 101 001

+3P for correct solution
-1P per incorrect symbol

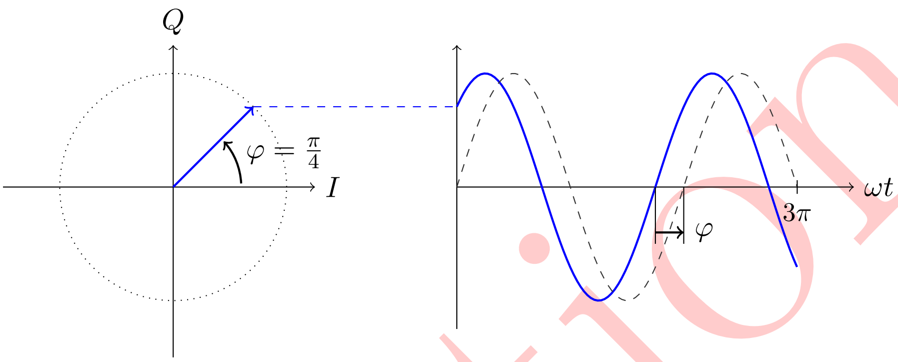

Figure 2.2: Phase difference of a sine signal compared to a reference signal (dashed line $\hat{=}$ reference signal).

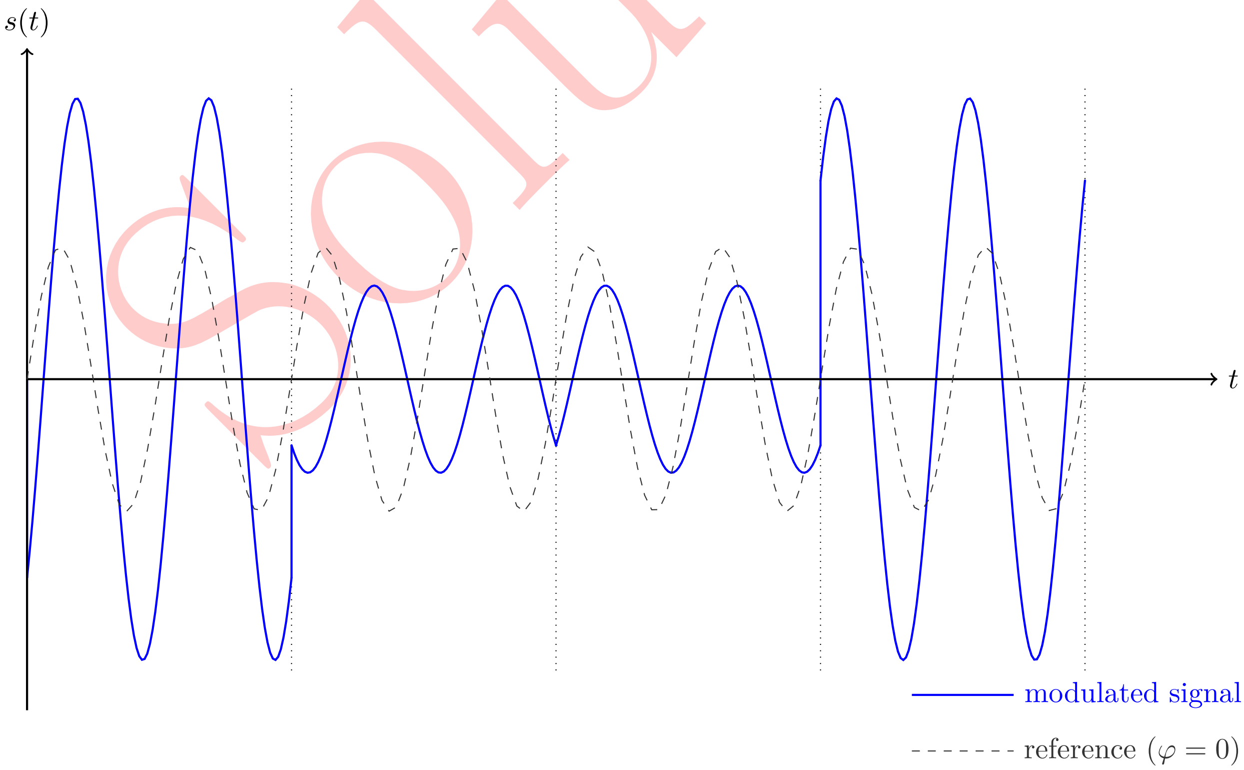

Figure 2.3: A modulated signal which uses the constellation from Figure 2.1 on the preceding page.

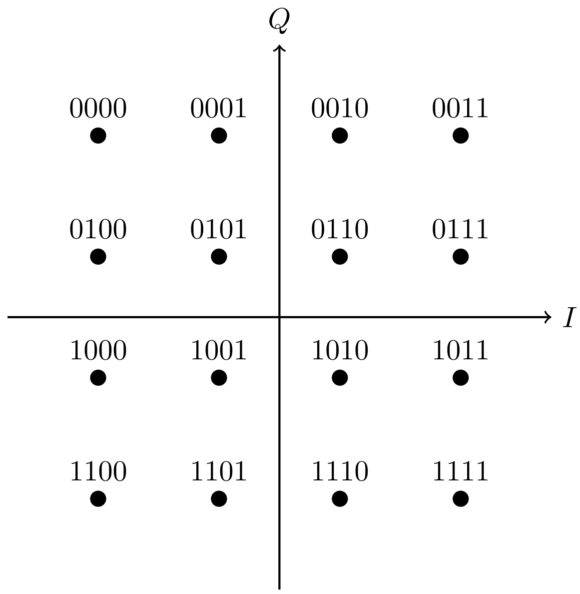

Figure 2.4: Constellation diagram

C) Now, a signal is modulated with the constellation diagram from Figure 2.4 and transmitted on a coaxial cable. The sender is able to generate a maximum voltage amplitude U_{max} of $\pm\sqrt{72}\,V$. Calculate the acceptance radius r_a for the symbols in the constellation diagram. **3**

From the constellation diagram geometry: $U_{max}^2 = (3\,r_a)^2 + (3\,r_a)^2$

$U_{max}^2 = 18\,r_a^2$

$r_a^2 = \frac{U_{max}^2}{18}$

$r_a = \sqrt{\frac{U_{max}^2}{18}}$

Insert numbers: $r_a = \sqrt{\frac{72}{18}}\,V = \sqrt{4}\,V = 2\,V$

+1P for correct approach
+1P for equation solving
+1P for calculating the solution

D) The symbol acceptance radius is a deciding factor for the symbol error probability. However the bit error probability also depends on the encoding of the symbols. The symbol-encoding in Figure 2.4 is not optimal because multiple bits can flip when neighboring symbols are mixed-up due to signal noise. Which kind of encoding could help to solve this problem? **1**

Gray-codes with a Hamming distance of 1 between neighboring symbols would solve this problem.

+1P for usage of gray-codes

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Task 3: Arbitration

Task 3.1: CSMA/CA

A bus system of four nodes are using CSMA/CA as arbitration scheme and are connected via open collector drivers (see figure 3.1). Each node has a five Bit identifier and the bus has to cover a maximum distance of 600m.

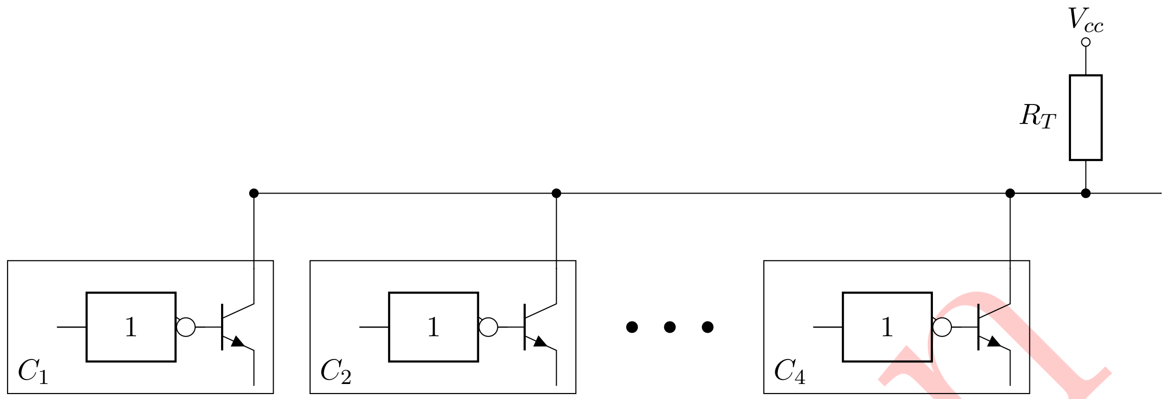

Figure 3.1: bus system

A) Which is the dominant bus level? Give a short explanation.

1

wired-AND: „0“ dominant, „1“ recessive

0.5p for zero as dominant bus level
0.5p for wired AND connection

B) What are the requirements of the arbitration process of CSMA/CA? Give at least two requirements.

1

- Unique ID per message/node
- All nodes start arbitration at the same time
- Bitwise arbitration
- Bit is long enough, so that all nodes can read it (Simultaneity)

0.5p for one correct requirement (max 1pt)

C) Which requirement has to be fulfilled in order to guaranty a faultless function of the bus system? Calculate the maximum bitrate that is achievable if the signal speed on the line equals to $0.66 \cdot c$. **2**

$\left[t_s = \frac{l}{v}\right] \ll \left[t_B = \frac{1}{TR}\right]$, with $l = 600m$, $v = 0.66 \cdot c = 0.66 \cdot 3 \cdot 10^8 \frac{m}{s}$
$\Rightarrow TR \ll \frac{v}{l} = \frac{0.66 \cdot 3 \cdot 10^8 \frac{m}{s}}{600m} = 330000 \frac{1}{s}$

1p for simultaneity and correct formula
1p for correct value

D) The data format uses a frame with a Start Of Frame bit (SOF) and an identifier with five bits. The identifiers can be taken from Table 3.1. Using Figure 3.2, draw the impulse diagram **3**

Node	Identifier
A	00101
B	01001
C	00100
D	00110

Table 3.1: Identifiers of the nodes

for the arbitration of the single nodes and the signal level of the shared bus line. Which node is granted exclusive access to the bus?

Node C is granted exclusive access to the bus.

0.5p for correct dominant SOF
0.5p for each consecutive correct time step (max 2)
0.5p for correct winning node

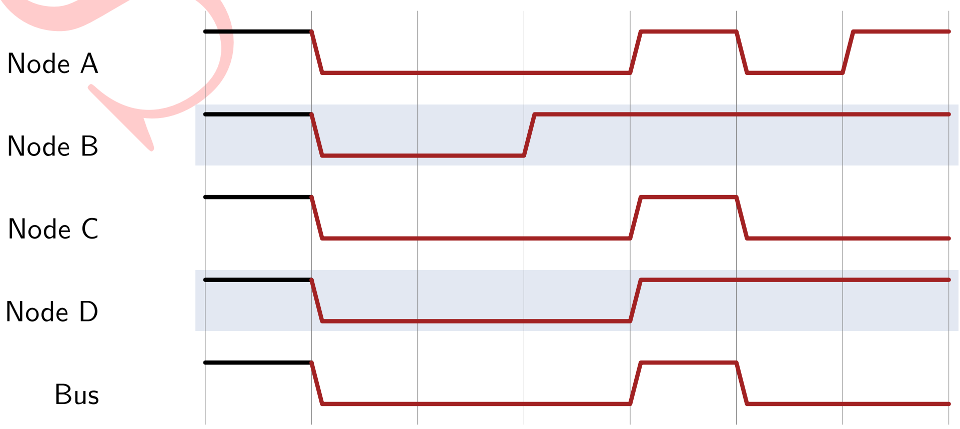

Figure 3.2: Bus Access

Task 3.2: Ethernet

Ethernet is a family of computer networking technologies commonly used in local area networks (LANs) and metropolitan area networks (MANs). Systems communicating over Ethernet divide a stream of data into shorter pieces called frames. Each frame contains source and destination addresses, and error-checking data so that damaged frames can be detected and discarded. The "Carrier Sense Multiple Access with Collision Detection" scheme is used to control access to the shared medium.

A bus system with several nodes is using the Ethernet standard with a transmission rate of $10Mbit/s$ and a signal speed of $2 \cdot 10^8 m/s$. A maximum distance of $2.5km$ for two nodes has to be considered.

A) Why is it necessary to establish minimal packet length? **1**

A minimal packet length is necessary to detect a collision.

1pt for collision detection

B) Calculate the resulting minimal package length in bits for the bus system. **2**

minimal time on the line for one package: $t = \frac{2 \cdot l}{v} = \frac{2 \cdot 2.5km}{2 \cdot 10^8 \frac{m}{s}} = 2.5 \cdot 10^{-5} s$

minimal package length: $PL \geq t \cdot TR = 2.5 \cdot 10^{-5} s \cdot 10Mbit/s = 250bit$

1pt for 2 times the length
1pt for correct amount of bits

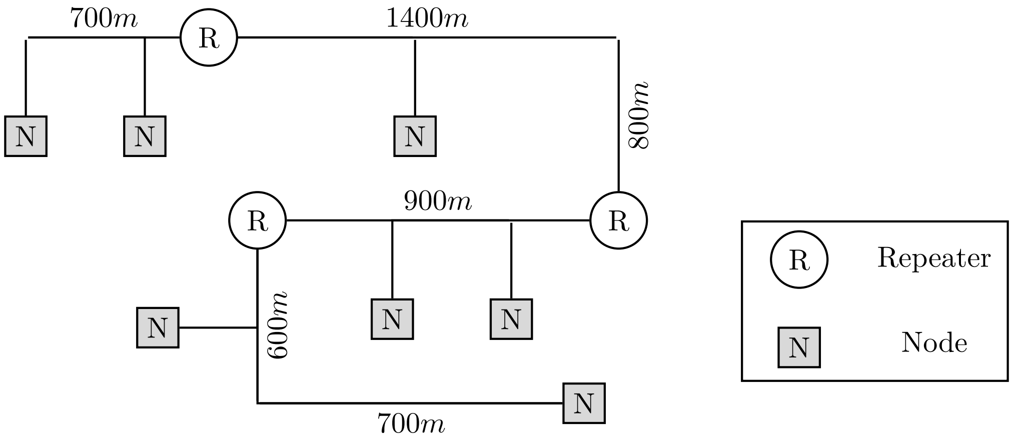

Figure 3.3: Ethernet topology

C) A minimal package length of 64 bytes for the bus system is determined. The bus system is illustrated in figure 3.3 and is used with a transmission rate of $10 Mbit/s$ and a signal speed of $2 \cdot 10^8 m/s$. Each repeater will add a delay of three bits. Is this bus system working with these constraints? Give an explanation!

3

$PL \geq t \cdot TR = \frac{2l}{v} \cdot TR \Leftrightarrow l \leq \frac{PL \cdot v}{2 \cdot TR}$

1pt for correct ansatz
1pt for correct delay
1pt for correct solution

$\Rightarrow l \leq \frac{PL \cdot 2 \cdot 10^8 m/s}{2 \cdot 10 Mbit/s} = 10 \frac{1}{bit} \cdot PL$

A delay of 3*3*2 bits has to be considered.

FIRST SOLUTION:
$\Rightarrow l + l_{delay} \leq 10 \frac{m}{bit} \cdot PL$
with $l_{delay} = \frac{18 bits \cdot v}{TR} = 360m$ and $l = 5100m$

$\Rightarrow 5100m + 360m \leq 10 \frac{m}{bit} \cdot PL$ with $PL = 512 bit$
$\Rightarrow 5460m \leq 5120m$
$\Rightarrow$ A secure detection of collisions is not possible

SECOND SOLUTION
$PL = 512 bits - (3 \cdot 3 \cdot 2 bits) = 494 bit$
$\Rightarrow 5100m \leq 4940m$
$\Rightarrow$ A secure detection of collisions is not possible

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Task 4: Error Protection

Task 4.1: General Questions

A) What is external redundancy? What is natural redundancy? Why does it make sense to replace natural redundancy with a constructed one?

2

External redundancy:
Adding additional redundancy by implementing multiple instances of the communication system as a whole or in parts.
Natural redundancy:
It is created randomly and often distributed uniformly with no dependable information.
It is important to replace the natural redundancy with aconstructed one (i) To reduce data
(ii) Add required information for error loading etc.,

0.5 pt.: External redundancy 0.5 pt.: Natural redundancy 1 pt.: reasoning of the second question

Task 4.2: Block Check

A) The following data was received. Check the even parity bits and mark the bits that can be possibly interpreted as erroneous bits.

2

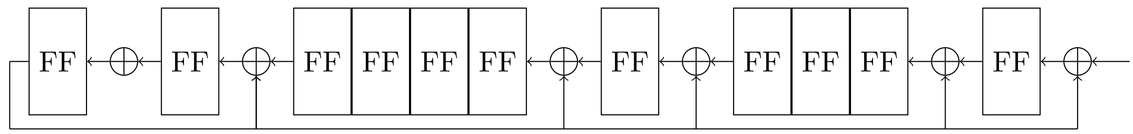
	Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	
Byte 0	0	1	1	0	1	1	0	0	
Byte 1	1	0	1	0	0	1	0	1	
Byte 2	1	1	0	0	0	1	0	1	
Byte 3	1	0	1	1	0	0	0	0	
Byte 4	0	1	0	1	1	1	0	0	
Byte 5	0	0	0	1	1	0	1	1	
Byte 6	0	1	1	0	1	0	1	1	
Byte 7	1	0	0	1	0	0	1	1	1
Parity	0	0	1	0	1	0	1	0	1

0.5 pt.: All vertical parity checks are done correctly
0.5 pt.: All horizontal parity checks are done correctly
1 pt.: all error bits are marked (1 pt. if atleast 6 error bits are identified) else 0 pt. Other possible solutions : only one bit for per row and per column either diagonally or randomly having three error bits in total.

Task 4.3: Cyclic Redundancy Check

A) To protect data transmission in a mobile device, the following CRC scheme is to be implemented using linear feedback registers with XOR operators. Give the generator polynomial for this simplified hardware layout.

1



$(x^{11} + x^{10} + x^9 + x^5 + x^4 + x + 1)$

1 pt.: for the correct polynomial
-0.5 pt.: without x^{11}

B) Calculate the data stream that will be transmitted if the following bit stream is to be protected, having a generator polynomial of $g(x) = x^3 + x + 1$:

3

1 1 0 1 0 0 1 1 1 0 1 1 0 0

```
1 1 0 1 0 0 1 1 1 0 1 1 0 0 0 0 0 : 1 0 1 1
1 0 1 1
-------
  1 1 0 0
  1 0 1 1
  -------
    1 1 1 0
    1 0 1 1
    -------
      1 0 1 1
      1 0 1 1
      -------
            1 1 0 1
            1 0 1 1
            -------
              1 1 0 1
              1 0 1 1
              -------
                1 1 0 0
                1 0 1 1
                -------
                  1 1 1 0
                  1 0 1 1
                  -------
                    1 0 1 0
                    1 0 1 1
                    -------
                          1 0 0   remainder
```

Bit string to be transmitted: 1101 0011 1011 00 100

0.5 pt.: if three zeroes are appended to the bit stream
1.5 pt.: All calculations are correct
-0.5 pt.: for each calculation error
0.5 pt.: for the correct remainder
0.5 pt.: the correct data stream with the appended remainder

C) The data string that has been calculated in Task 4.3 B) has been received with the 4th, 5th and 6th bits from the LSB being flipped due to channel errors. Assume that the generator polynomial of CRC-4 ($x^3 + x + 1$) has been used by the receiver for error detection. What is the received bit string and what does the receiver conclude from the result?

3

Received bit string: 1101 0011 1010 11 100

0.5 pt.: for the correct received bit string 1.5 pt.: All calculations are correct -0.5 pt.: for each calculation error 1 pt.: receiver assumes an error free transmission

```
1 1 0 1 0 0 1 1 1 0 1 0 1 1 1 0 0   :   1 0 1 1
1 0 1 1
----------------------------------
  1 1 0 0
  1 0 1 1
----------------------------------
    1 1 1 0
    1 0 1 1
----------------------------------
      1 0 1 1
      1 0 1 1
----------------------------------
              1 1 0 1
              1 0 1 1
----------------------------------
                1 1 0 0
                1 0 1 1
----------------------------------
                  1 1 1 1
                  1 0 1 1
----------------------------------
                    1 0 0 1
                    1 0 1 1
----------------------------------
                        1 0 1 0
                        1 0 1 1
----------------------------------
                              1 0   remainder
```

Since the remainder is not zero, the receiver will assume that an error has occured during the transmission.

Task 4.4: CAN Bus Error Detection

A) Consider the following data frames at Node A (sender) and Node B (receiver).
Name the three errors that can be detected from the given information and also justify your answer.

3

Node A (Sender)

SOF	Arbitration Field												CTRL Field						Data Field								CRC Field								ACK Field		EOF			
1	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	1	2	3	4	5	6	7	8	1	2	3	..	..	..	14	15	1	2	1	..	..	7
	ID10										ID0	RTR																		..	..	..		DEL	ACK	DEL		..	..	
0	1	1	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	..	..	..	1	1	1	1	1	..	..	0

Node B (Receiver)

ACK Field		EOF			
1	2	1	..	..	7
ACK	DEL		..	..	
1	1	1	..	..	0

(i) Acknowledge error as the ACK slot in Node B is recessive, which means the message has not been received correctly.
(ii) Form error as a dominant has been found in the EOF
(iii) Stuff error as there are 6 consecutive '1' bits between SOF and CRC field.

1 pt.: for each correct error identification and justification (total 3 pts.)
0.5 pt.: for each correct error identification

B) For the given CAN bus protocal in Task 4.4 A), the following error frame in Fig. 4.1 gets generated in order to cancel a faulty transmission.
Assume that there is a sender (Node 1) and two receivers (Node 2 and Node 3). Node 3 receives the data correctly, whereas Node 2 encounters a CRC error due to some data error. Complete the signal sequence in Fig. 4.2 with respect to the error frame generation of Node 2 and the consequence effect on Node 1, Node 3 and bus level.

3

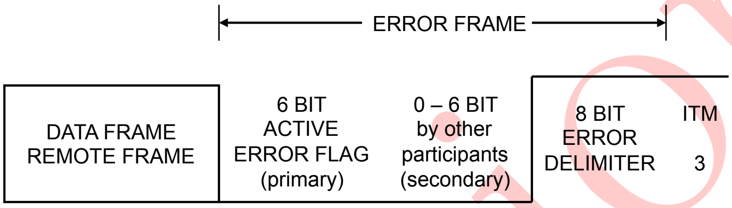
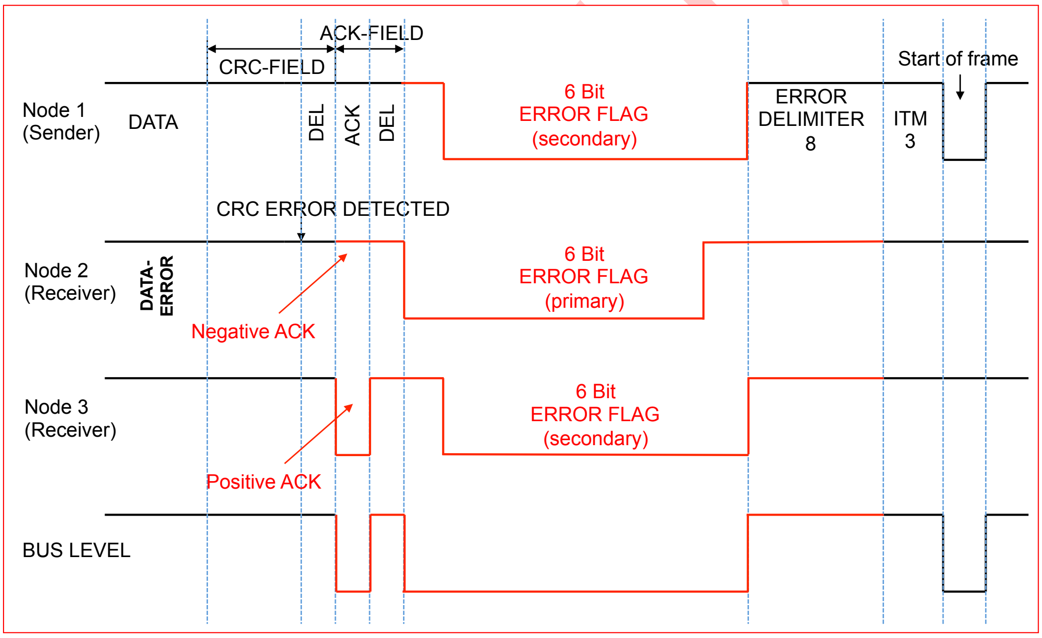


Figure 4.1: Error Frame



1 pt.: for positive and negative ACK in node 2 and node 3
1 pt.: for the correct bus level
1 pt: for primary error flags in receivers and secondary error flag in sender
-0.5 pt: for wrong marking

Figure 4.2: Signal sequence diagram of CAN bus

Task 5: Bus Systems

19

Task 5.1: I^2C: General Questions

A) Which arbitration scheme are used in I2C bus systems, when multiple senders wants to access the bus? 1

CSMA/CA

B) Which mechanism is used to synchronize a master communicating with a slower slave node? Which signal of the I2C bus is involved in this mechanism? 2

The I2C-Bus allows slave nodes to insert so called wait states if the master provides new data too fast. The wait state insertion is controlled by the SCL signal. In general, the SCL signal is generated by a wired- AND connection with dominant “0” of the participants CLK signals. A wait state is inserted if the SCL signal remains “LOW” and is initiated by a slave.

+1P insertion of wait states by the slave with SCL signal;
+1P generating wait state by the slave by pulling down SCL signal to LOW

Task 5.2: I^2C Arbitration

In this task we want to investigate the data transmission on the I^2C-Bus. The simplified packet format is given in Figure 5.1. Three master nodes are simultaneously trying to transmit or read one byte of data to or from different slaves over the I^2C-Bus.

S	slave address	$R/\bar{W}$	A	DATA	A	DATA	$A/\bar{A}$	P

data transfered (n bytes + acknowledge)

term	description
S	start condition
slave address	7-bit slave address
$R/\bar{W}$	read/write: read 1, write 0
A	acknowledge from slave ('0')
$\bar{A}$	not acknowledge ('1')
DATA	8-bit data
P	stop Condition

Figure 5.1: I^2C-Bus frame format

A) The addresses of the slaves, communication mode (R/$\overline{W}$) and the data to be send or read to or from them is shown in the Table 5.1. Complete the signal diagram in the Figure 5.2.

4

1 Point for correct SDA, 0.5 Point for other correct lines; -0.5 Point per error

node	slave address	R/$\overline{W}$	data
Master 1	1001001	0	$0x15$
Master 2	0101101	0	$0x81$
Master 3	0101100	1	$0x45$

Table 5.1: I2C Communication Parameters

B) Which Master is winning the arbitration? Justify your answer!

1

Master 3 is winning arbitration, because its slave has the lowest address (Wired-AND).

+1P only with justification!

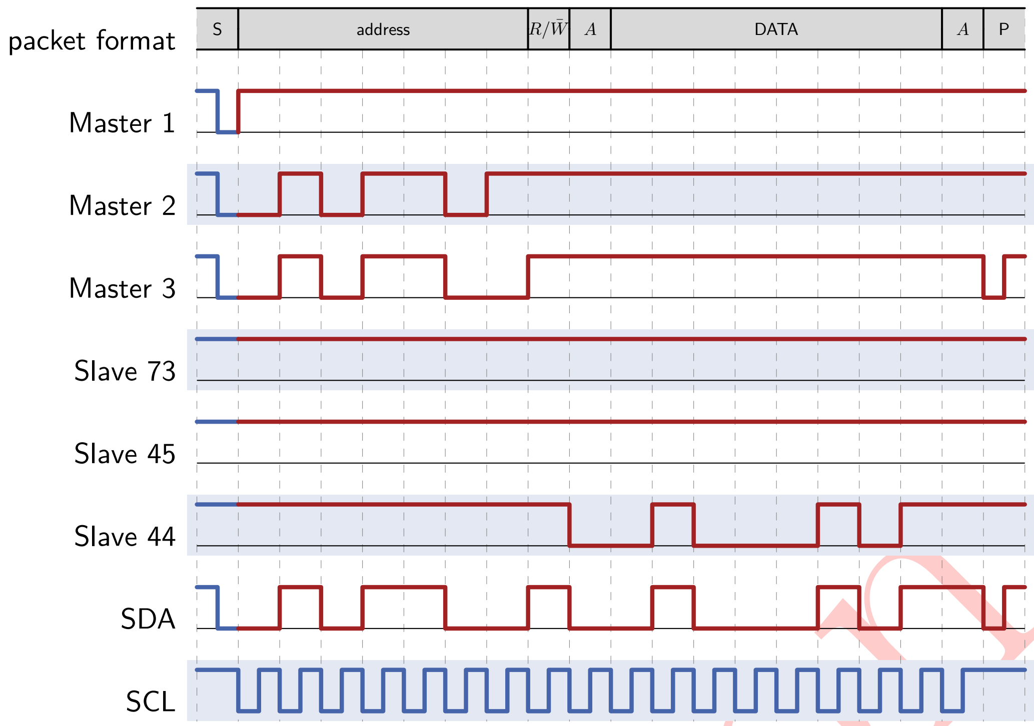


Figure 5.2: Signal sequence

Task 5.3: Flexray: General Questions

A) What is the main goal of Flexray in automotive network topologies compared to conventional bus systems? Name at least two features to fulfill this goal. **2**

Development of deterministic, fault tolerant communication system with high-bandwidth (10 MBit/s) as a backbone connecting several bus gateways.

+1P for communication backbone connecting several bus gateways. +0,5P for each named feature of: deterministic, fault-tolerant or redundancy, high-bandwith.

B) With Flexray it's possible to run the system in dual-channel mode. Explain the advantage and disadvantage of the dual-channel mode over single channel mode. **1**

Advantage: double the bandwidth (20MBit/s) compared to single channel mode. Disadvantage: Less reliability, because it's not possible to transmit redundant frames.

+0,5P per adv./disadv.

C) Which arbitration schemes is used in the different segments in order to cope with multiple senders? **2**

Static Segment	Dynamic Segment
TDMA	FTDMA

Task 5.4: Flexray: Bus Access

+1pt. per correct arbitration scheme and correct assignment; TDMA or Timeslots, FTDMA or Mini-Slotting

In this task we want to investigate the data transmission and scheduling with Flexray. The used topology is shown in Figure 5.3. Additionally, the slot durations for the scheduling are given in Table 5.2.

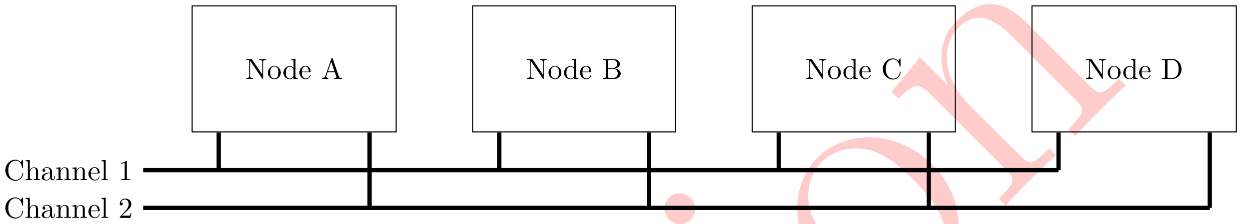


Figure 5.3: Flexray Topology

Static slots	Dynamic slots
$10\mu s$	$1\mu s$

Table 5.2: Slot durations

A) In Table 5.3 the nodes shown in Figure 5.3 and the assignment of their available frames to the static slots are given. Complete the signal diagram in the Figure 5.4 and perform the static scheduling of the frames according to the Table 5.3.

2

0.5 Point for A, B, C, D

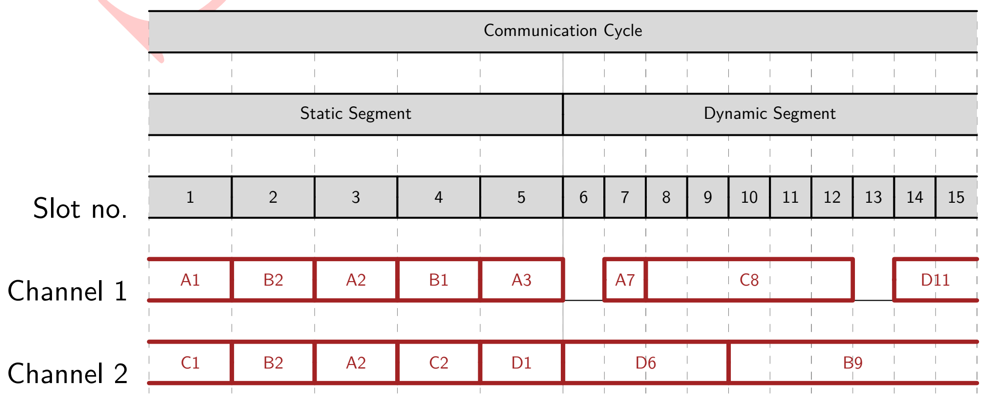


Figure 5.4: Signal sequence

Node	Static Slots	Frames	Redundant Frames
A	1, 3, 5	A1, A2, A3	A2
B	2, 4	B1, B2	B2
C	1, 4	C1, C2	—
D	5	D1	—

Table 5.3: Static Node Assignments

B) Calculate the duration of a complete communication cycle! **1**

$5 * t_{static} + 10 * t_{dynamic} = 5 * 10\mu s + 10 * 1\mu s = 60\mu s$

C) In Table 5.4 the parameters for the dynamic segment are given. Complete the signal diagram in the Figure 5.4 and perform the dynamic scheduling of the frames according to the Table 5.4 **2**

0.5 Point per correct node

Node	Frames	Slot-ID	Frame Duration
A	A7	7	$1\mu s$
B	B9	9	$6\mu s$
C	C8	8	$5\mu s$
D	D6 D11	6 11	$4\mu s$ $2\mu s$

Table 5.4: Dynamic Segment Parameters

D) Is the dynamic scheduling feasible in the sense that all dynamic frames could be served in one communication cycle? Justify your answer! **1**

Yes, because all frames fit into the communication cycle

Task 6: FireWire

6

Task 6.1: FireWire Structures

3

A) Different FireWire structures were built during a student laboratory. During test phase you notice that not all FireWire systems are working correctly. Please state if the FireWire systems given below are working correct. Mark the roots, if the systems are correct. Give a reason, if the FireWire system is not working correctly.

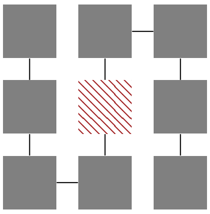
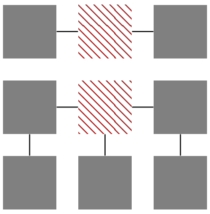
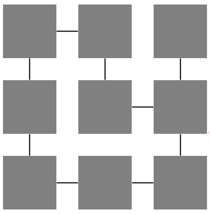
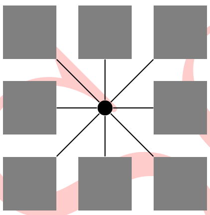
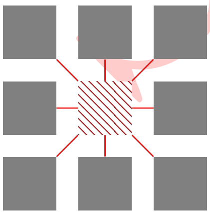
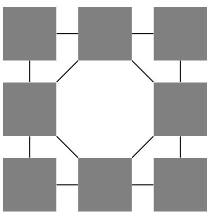
	Correct	Wrong	Reason
	x		
	x		
		x	Rings are not allowed in FireWire
		x	One output cannot have multiple connections
	x		
		x	Rings are note allowed in FireWire

Table 6.1: FireWire structures

Task 6.2: FireWire Arbitration

The FireWire network shown below is given. The complete self-configuration of the network is already done including initialization, tree identification and self identification.

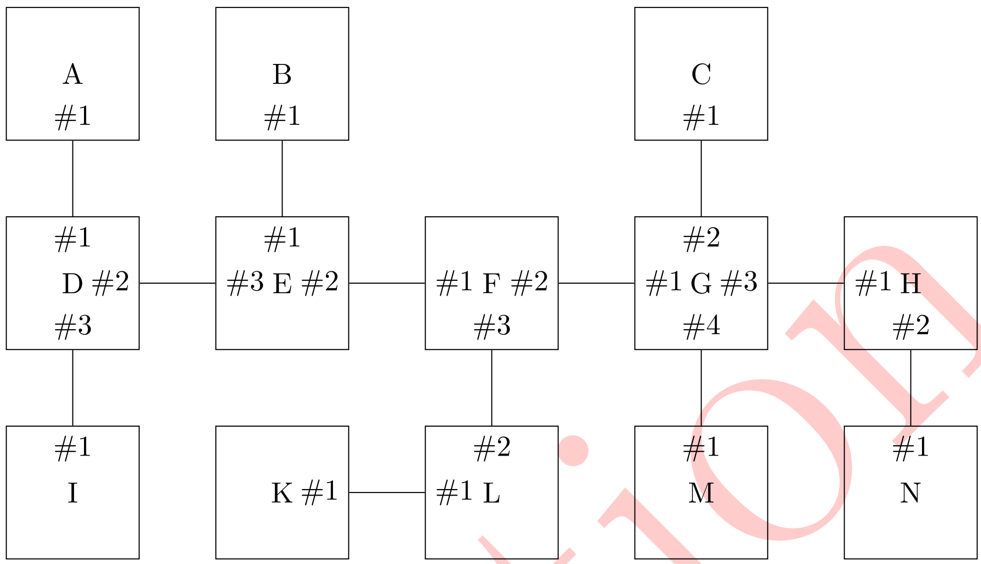


Figure 6.1: FireWire network

Now a normal FireWire bus cycle should be considered. For simplification, several assumptions should be taken into account:

- A list of nodes wanting to send is given.
- All nodes start requesting the bus at the same time.
- Processing of arbitration request is done in zero time. There are no delays for propagation of the arbitration decision.
- If a node receives multiple bus request, it will always forward the request that it receives from the port with the lowest number.

A) Mark the root of the FireWire Network!
The following nodes request access to the bus: **A, E, F, I, M**. Determine the order in which the nodes will be granted access to the bus.

3

F, E, A, I, M

1pt for root
2pt for correct order

Task 7: Routing

13

Task 7.1: General Questions

A) Comparing online or predetermined routing, which one is more suitable when low latency is required ? Justify you answer !

1

Predetermined routing since online routing might need additional calculation

all or nothing

B) Comparing wormhole routing and traditional routing, which one is more suitable when low memory consumption in each node is desired? Justify your answer !

2

Wormhole Routing less because only (lead) flit to be stored

all or nothing

C) Describe the difference between adaptive and deterministic routing. Additionally describe an application in which deterministic routing is more suitable than adaptive. Justify your answers !

2

Adaptive routing change the route during runtime Deterministic always same route is taken Realtime Application since latency deterministic.

Difference 1Pt and Application 1 Pt

Task 7.2: Dijkstra's Algorithm

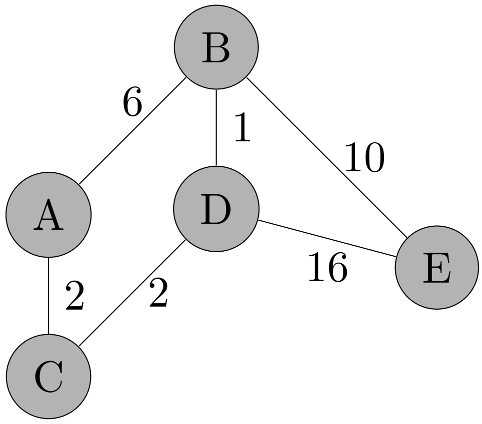


Figure 7.1: Given network topology

A) With node A as the starting point, calculate the shortest paths in the network shown in 7.1, by using Dijkstra's algorithm. For that write down the order in which nodes are visited in each bracket under the current step and fill out the given tables that encompass the shortest paths after each visitation of a node. 4

node	step 1 **A**		step 2 A		step 3 C		step 4 D		step 5 B	
vertex	dist.	pred.	dist.	pred.	dist.	pred.	dist.	pred.	dist.	pred.
A			0	A	0	A	0	A	0	A
B	∞	-	6	A	6	A	5	D	5	D
C			2	A	2	A	2	A	2	A
D	∞	-	∞	-	4	C	4	C	4	C
E			∞	-	∞	-	20	D	15	B

Table 7.1: Dijkstra algorithm

Correct Table and correct order of execution 1 Pt -> 4 Tables 4 Points ; if second step is wrong because B no following points

B) Describe a network in which Dijkstra's algorithm is more suitable than XY-Routing and justify your answer.

1

Non mesh based networks. For example Trees or abstract topologies

all or nothing

C) Write down at least 2 reasonable examples for the meaning of the weights in a topology commonly routed with Dijkstra's algorithm

1

traffic loads, bandwidth, latency

all or nothing, only 1 example -> nothing

D) Suppose a failure occurs in a network in which a communication path between 2 nodes is not available anymore. Under the assumption that routing was created using Dijkstra's algorithm, is communication between these nodes still possible even after the failure? Justify your answer !

2

If the edge is not on the shortest path between nodes, communication is still possible. If edge is on the shortest path, than communication is lost

one of those answers, only with justification (well otherwise the question is stupid)

Task 8: Network Topologies

14

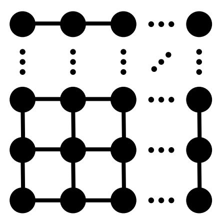
Task 8.1: General Questions

A) Which network topology is more suitable in a safety critical system, star or ring topology? Justify your decision!

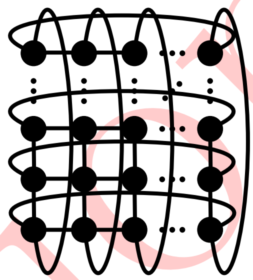
1

Ring is more suitable than star because a star network dies if the central node fails, whereas the ring topology has a higher routing flexibility and thus a higher fault tolerance.
ALTERNATIVE: Star: if one component of the ring fails, the communication between all other parts is affected.

Alternative solutions are possible. The reasoning needs to be sound. No points without reasoning!



(a) Mesh



(b) 2D torus

Figure 8.1: General structure of a) mesh and b) 2D torus network topologies

B) The flexibility F describes the number of possible directions in which a network node can transmit. What is the average flexibility F_avg in a 10x10 mesh topology? *Hint: the general structure of a mesh network topology is depicted in Fig. 8.1a.*

1

F_avg=((64*4) + (4*2) + (32*3))/100=360/100=3.6

C) The flexibility F describes the number of possible directions a network node can transmit to. What is the average flexibility F_avg in a 10x10 2D torus topology? *Hint: the general structure of a 2D torus network topology is depicted in Fig. 8.1b.*

1

F_avg=4

D) Explain one possible case or system where a bus is preferable over a network. **1**

A system that requires minimum latency and has a comparably low number of nodes. Since a bus doesn't require routing it has the lowest latency.

Alternative solutions are possible.

E) Explain one possible case or system where a network is preferable over a bus. **1**

In systems with a large number of nodes a network is preferable over a bus as it comes with a lower wiring and control overhead.
Alternative: In systems where multiple nodes should be able to transmit simultaneously a network is preferable as it allows the simultaneous transmission.

Further alternative solutions are possible.

Task 8.2: 3D Mesh Topology

A) Comparing a 6x3 2D-mesh topology with a 3x3x2 3D-mesh topology, which has the lower maximum latency when using a shortest path routing strategy and how much is the relative improvement when replacing one topology with the other? Assume that there is no heavy traffic or congestions and that all routing segments have the same delay! **3**

The diameter of the 2D mesh is D_2=(nX-1)+(nY-1)=(6-1)+(3-1)=7.
The diameter of the 3D mesh is D_3=(nX-1)+(nY-1)+(nZ-1)=(3-1)+(3-1)+(2-1)=5. Thus it has the lower maximum latency.
The 3D mesh has a (7-5)/7=2/7 relative latency improvement compared to the 3D mesh.

+1pt. for the correct topology with the lowest latency
+2pts. for the relative improvement

B) In Fig. 8.2 a 4x4x3 mesh topology is given. Find the shortest path from the source point (0,2,0) to the destination point (3,3,2). Thereby, the routing policy that each node has to obey is described as follows: **3**

1. Try first to route in the direction of the largest vector component (Δx, Δy or Δz) from the local position towards the destination.
2. In case a segment is congested, disregard the respective direction and choose among the remaining directions the one of the next largest vector component from the local position towards the destination.
3. In case there are multiple directions with the same largest value for the respective vector components possible, choose the direction of the previous step.
4. In case none of the above rules is possible, prioritize first x then y then z.

In your answer please name all traversed nodes (i.e. their coordinates) in the correct sequence.

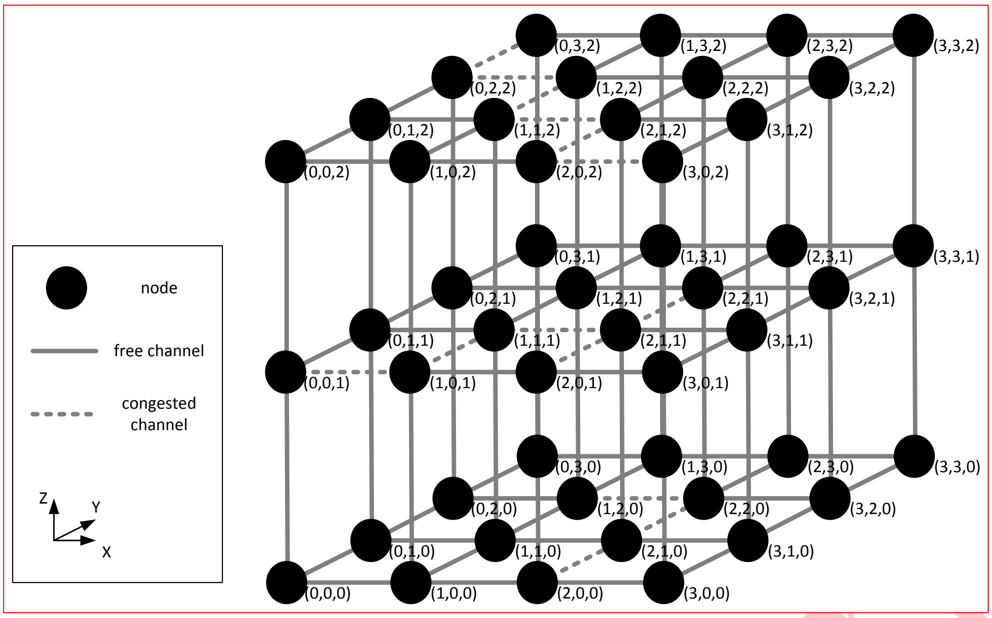


Figure 8.2: Structure of a 3D mesh network topology

(0,2,0) -> (1,2,0) -> (1,2,1) -> (2,2,1) -> (3,2,1) -> (3,3,1) -> (3,3,2)

-0.5 pts per wrong step

C) The network nodes in Fig. 8.2 support simultaneous multipath communication, while each channel has a bandwidth of 1Gbit/s. What is the maximum communication throughput between the nodes (1,1,1) and (3,2,2)? Assume that there are no congestions. Justify your answer.

2

(1,1,1) has 6 channels, while (3,2,2) has 4 channels. Thus the communication between the 2 nodes can be established with up to 4 simultaneous channels, yielding a maximum throughput of 4Gbit/s.

+1pt for the correct throughput
+1pt for a reasonable explanation

D) Explain one possible extension of the topology in Fig. 8.2 to further reduce the maximum latency.

1

Extending the topology towards a 3D torus can reduce the maximum latency by up to 50% as the opposite borders are seperated by only 1 segment.

Alternative solutions possible, e.g. long lines, etc.