Examination (WS 2018/2019)
Communication Systems and Protocols

Institut für Technik der Informationsverarbeitung
Prof. Dr.-Ing. Dr. h. c. Jürgen Becker
Dr.-Ing. Jens Becker

Exam: Communication Systems and Protocols
Date: February 14, 2019

Participant:
Matr. №:
ID:

Lecure hall:
Seat №:

The following rules apply:

- The writing time of the examination is 120 minutes.
- No examination aids are permitted, except for
  - one double-sided DIN-A4 sheet of hand-written notes,
  - a non-programmable calculator and
  - a dictionary.
- Answers can be given in English or in German.
- Use **permanent ink** only. The usage of pencils or red color is prohibited.
- You are not permitted to use your own writing paper.
- Please do not write on the back sides of the sheets.
- Additional solution sheets are available from the examination supervisors.
  - Make sure that you label all such sheets with your matriculation number.
  - Each additional solution sheet needs to be assigned to exactly one task.

The examination comprises **39 sheets** and a two-page formulary.

Task 1: Physical Basics

Task 1.1: Sampling and A/D conversion

A) Name the four classes of signals which exist in communication channels.

An exemplary signal is shown below.

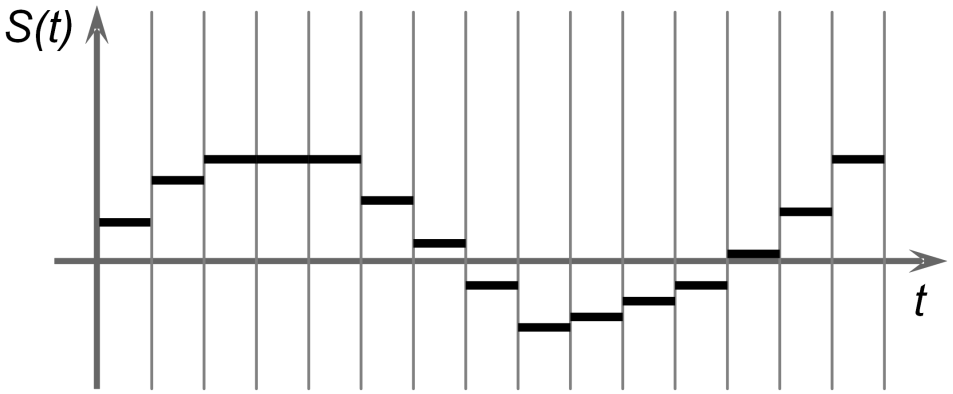


Figure 1.1: Exemplary signal

B) Which class does the signal shown in Figure 1.1 belong to?

C) An analog signal shall be converted into a digital signal. The maximum frequency occuring in the analog signal is $f_{max} = 40\,\text{kHz}$. What needs to be considered concerning sampling to be able to unambiguously reconstruct the signal? Give the name (of the rule) and calculate the resulting requirement concerning the sampling frequency.

D) What is oversampling of digital signals? Give a definition and explain how the bit value is determined after sampling. What is the advantage of increasing the oversampling frequency?

E) Consider a transmission system for digital signals. Explain the concept of acceptance bands for digital signals. Why are acceptance bands needed? Which digital value is assumed if the signal is in the 'undefined' band?

Task 1.2: Channel Capacity

A digital transmission system has a bandwidth of $B = 20\,\text{kHz}$.

A) Assuming an ideal channel, calculate the maximum data rate achievable on this channel using quaternary signals?

B) Why can we not keep increasing the number of signal steps in a real channel to achieve a higher bit rate?

Task 1.3: Signal Transmission

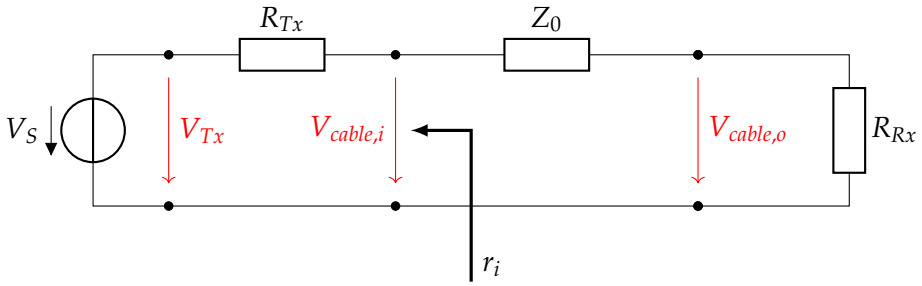


Figure 1.2: Test setup

In Figure 1.2, the equivalent circuit diagram of a transmission line is depicted. A transmitter having output impedance R_{Tx} is connected to a receiver with the input impedance R_{Rx} using a long cable.
The impedances are $Z_0 = 50\,\Omega$, $R_{Tx} = 10\,\Omega$. R_{Rx} is unknown.

A) Give the formula for calculating the reflection factors in general. Give the value of the reflection factor r_i at the beginning of the line.

At $t = 0$, the voltage V_S switches from 0 V to 6 V and is constant afterwards.

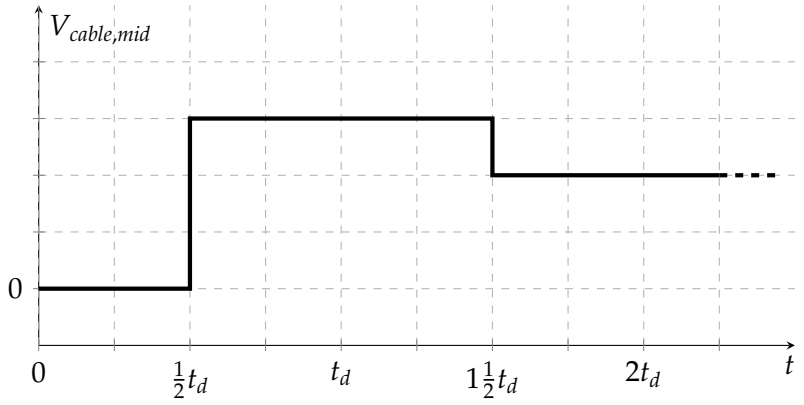


Figure 1.3: Voltage level in the middle of the line

B) An ideal cable (no attenuation per unit length) is assumed. The propagation times of the signal at the transmitter and receiver side of the cable are neglected. The propagation time of the signal from one end of the line to the other end is t_d.
Figure 1.3 shows the voltage signal at half of the cable's length (the middle). What is the reflection factor at the end of the line? Give a reasoning for your answer.
Determine the receiver's impedance R_{Rx}.

C) What needs to be fulfilled to avoid reflection at the end of the line? Give the general formula and give a solution for proper termination, assuming that $R_{Rx} = 20\,\Omega$.

Task 2: Transmission Principles

Task 2.1: Line Codes

A) We want to transmit the value 0110 0011 1001 through a serial wire communication channel. Complete Figure 2.1 with the digital signals transmitted using each given encoding scheme.

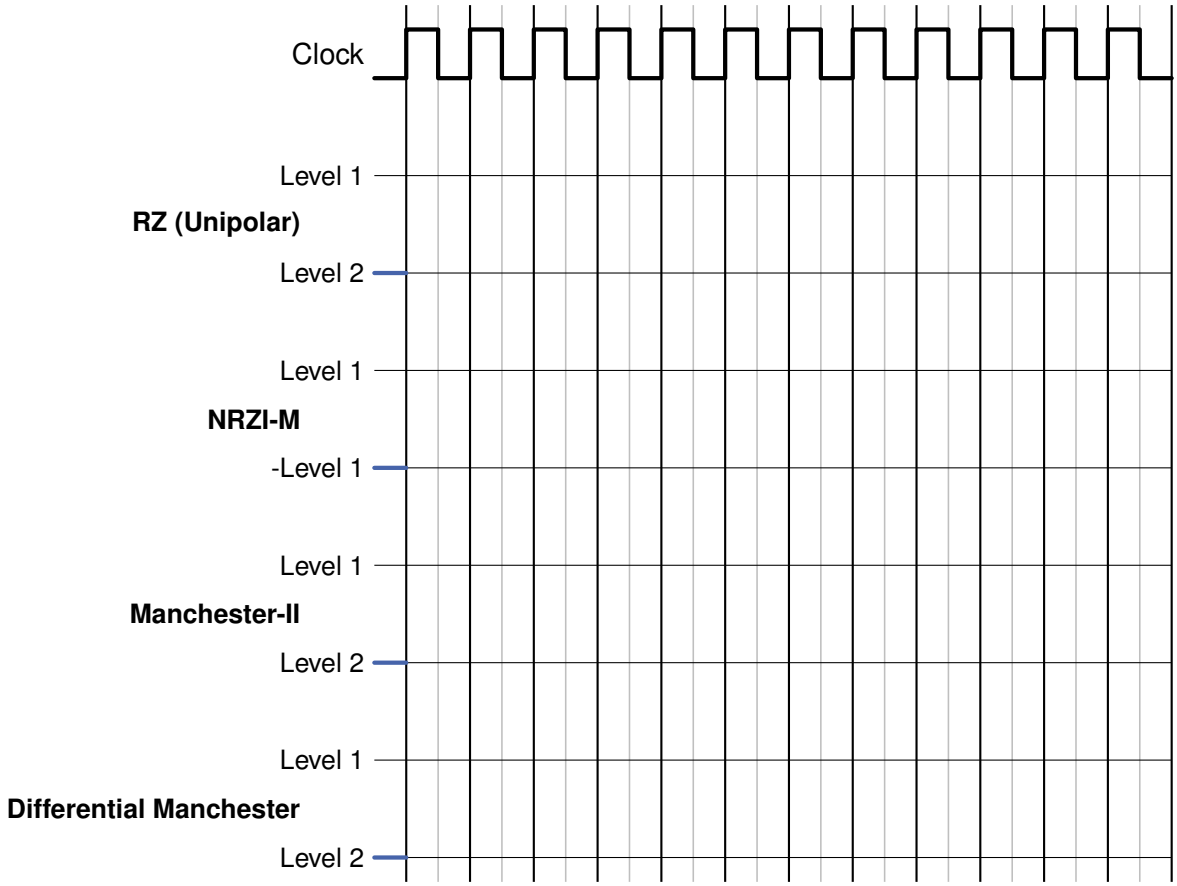


Figure 2.1: Line codes

B) Given the transmission of a random sample signal, which code(s) in Question A do NOT enable clock recovery of the transmitter's frequency? Justify your answer.

C) For the codes in Question A that enable clock recovery, what is a disadvantage that they share? Justify your answer.

D) An approach used to synchronize communication processes is the use of Handshakes. Complete the signals in figure 2.2 to perform two transmissions of DATA values 0x1 and 0x2 using a Full Duplex Handshake. A grey color symbolises that the DATA line is idle and that no value is being driven on the bus. Ignore delays and consider that a read occurs at the rising edge and signal change occurs at falling edge of the clock.

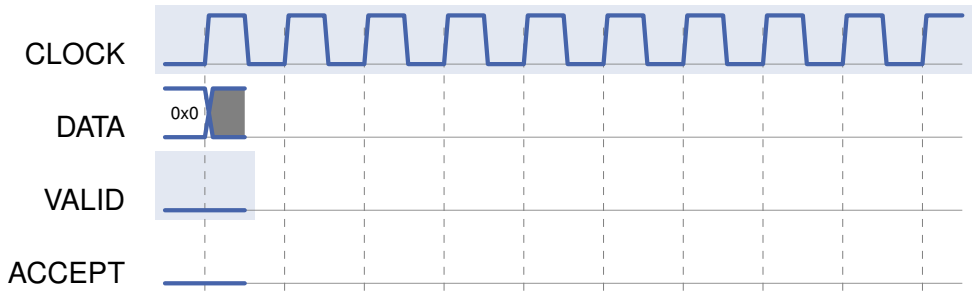
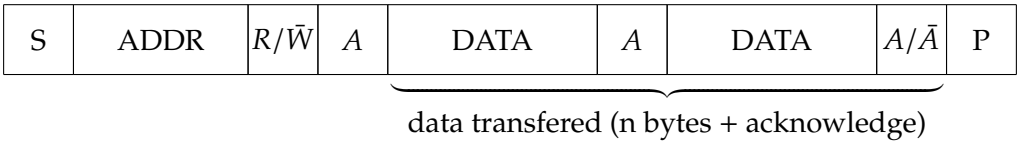


Figure 2.2: signal sequence

Task 2.2: I²C Communication

In this task we want to investigate the data transmission on the I²C-Bus. The simplified frame format is given in Figure 2.3. Three master nodes are simultaneously trying to transmit or read one byte of data to or from different slaves over the I²C-Bus.



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

Figure 2.3: I²C-Bus frame format

A) Is I²C a synchronous or asynchronous protocol? Justify your answer.

B) Among the 3 transmission types presented in the lectures (Simplex, Half-Duplex, Full Duplex), what type does I²C belong to? Justify your answer.

C) In an I^{2}C Multimaster configuration, how are bus access collisions among Masters resolved? Describe how a collision is detected by a Master.

D) What happens to the arbitration if 2 Masters try to access the same Slave? What happens if they try to perform the same or different operations (Read/Write)? Justify your answer for each of the three possible cases.

E) The diagram in Figure 2.4 corresponds to a connected I^{2}C Multimaster configuration. The system is composed of 3 Slave and 3 Master nodes. Complete the diagram with the signals generated by each node for the simultaneous transactions presented in Table 2.1 and for the resulting SDA line of this bus. The table shows for each master, the address of the slave it is accessing, the communication mode (R/W) and the data to be sent or read.

node	slave address	R/$\overline{W}$	data
Master 1	1011101	1	$0x55$
Master 2	1010101	0	$0x5A$
Master 3	1011101	1	$0xAA$

Table 2.1: I^{2}C Communication Parameters

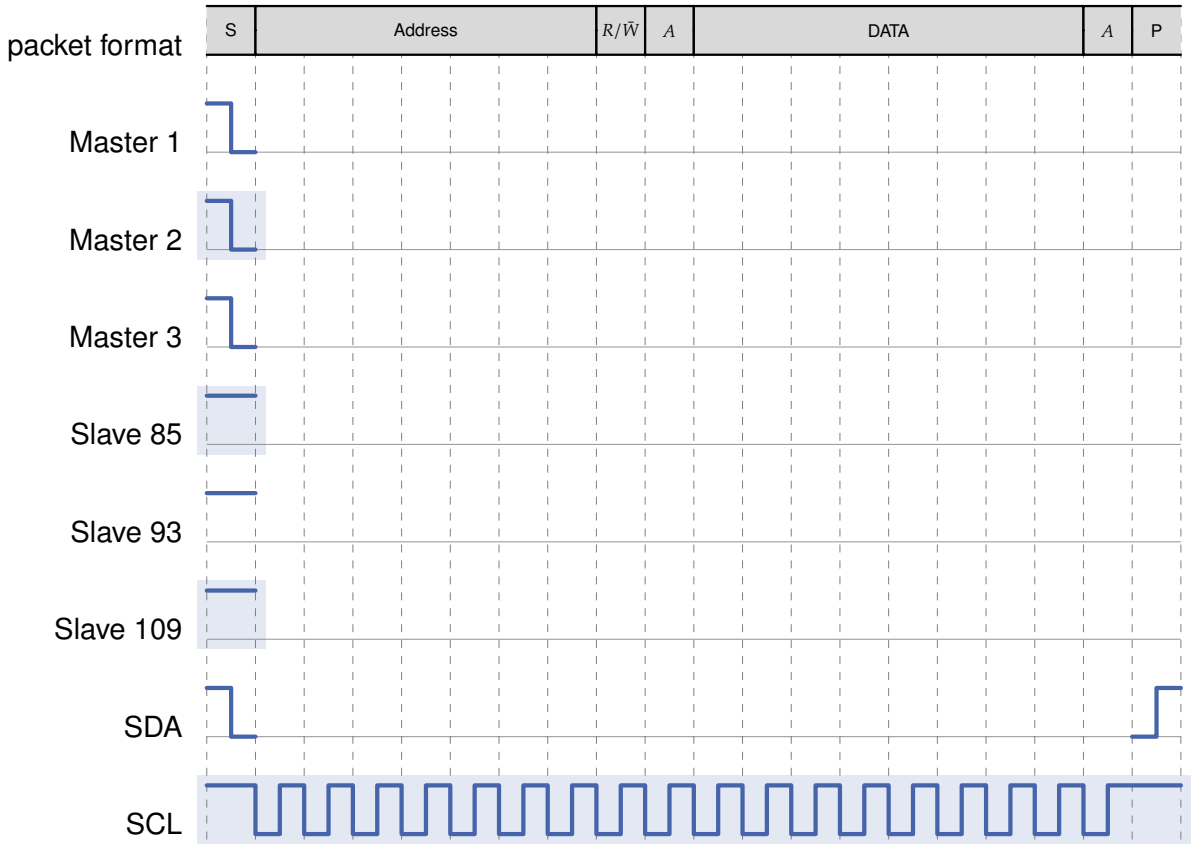


Figure 2.4: I^2C Signal sequence

Task 3: Modulation and Spread Spectrum

Task 3.1: Modulation

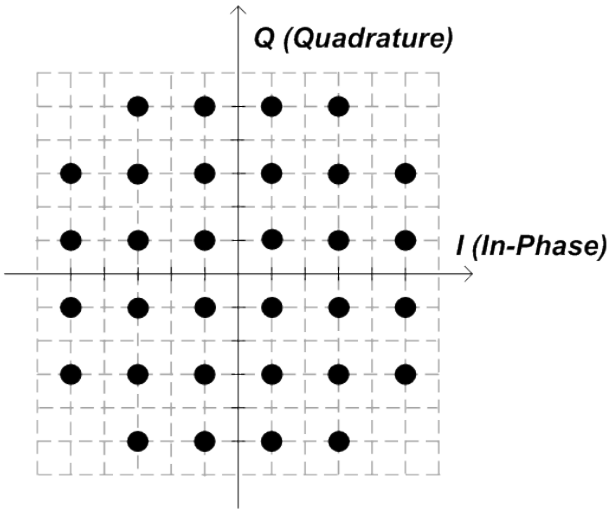


Figure 3.1: The constellation diagram of a certain modulation

A) The constellation diagram of a certain modulation is shown in Figure 3.1. How many possible absolute amplitude values can be used in that modulation? Sketch the amplitude values in the Figure 3.1!

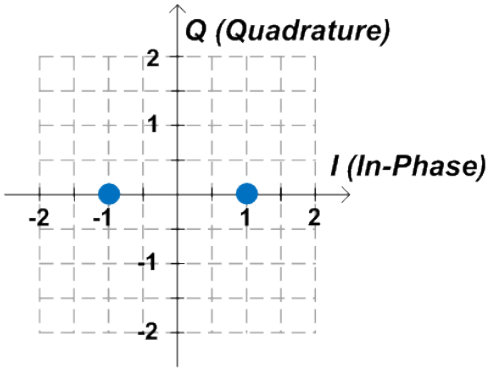


Figure 3.2: The constellation diagram of a digital modulation

B) What type of digital modulation scheme is shown in the Figure 3.2? Explain your answer based on the constellation diagram! Hint: the modulator does not have the quadrature component.

C) What is the main difference between an absolute PSK and relative PSK?

D) A constellation diagram of 8-QAM is shown in Figure 3.3. The following bits are transmitted: **001000010100** which will be encoded from the left to the right. The Figure 3.4 (B) shows the in-phase carrier signal. Moreover, the Figure 3.5 (E) shows the quadrature carrier signal. Use the Figure 3.4 (A and C) and Figure 3.5 (D and F) to sketch the waveforms of symbol representations and modulated information signals based on in-phase and quadrature axes of the constellation diagram. The symbol period is twice as long as the period of carrier signal.

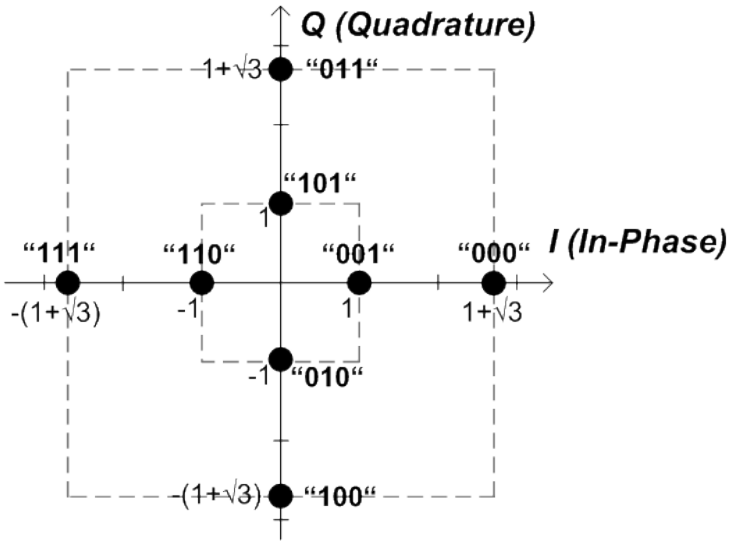


Figure 3.3: A constellation diagram of 8-QAM

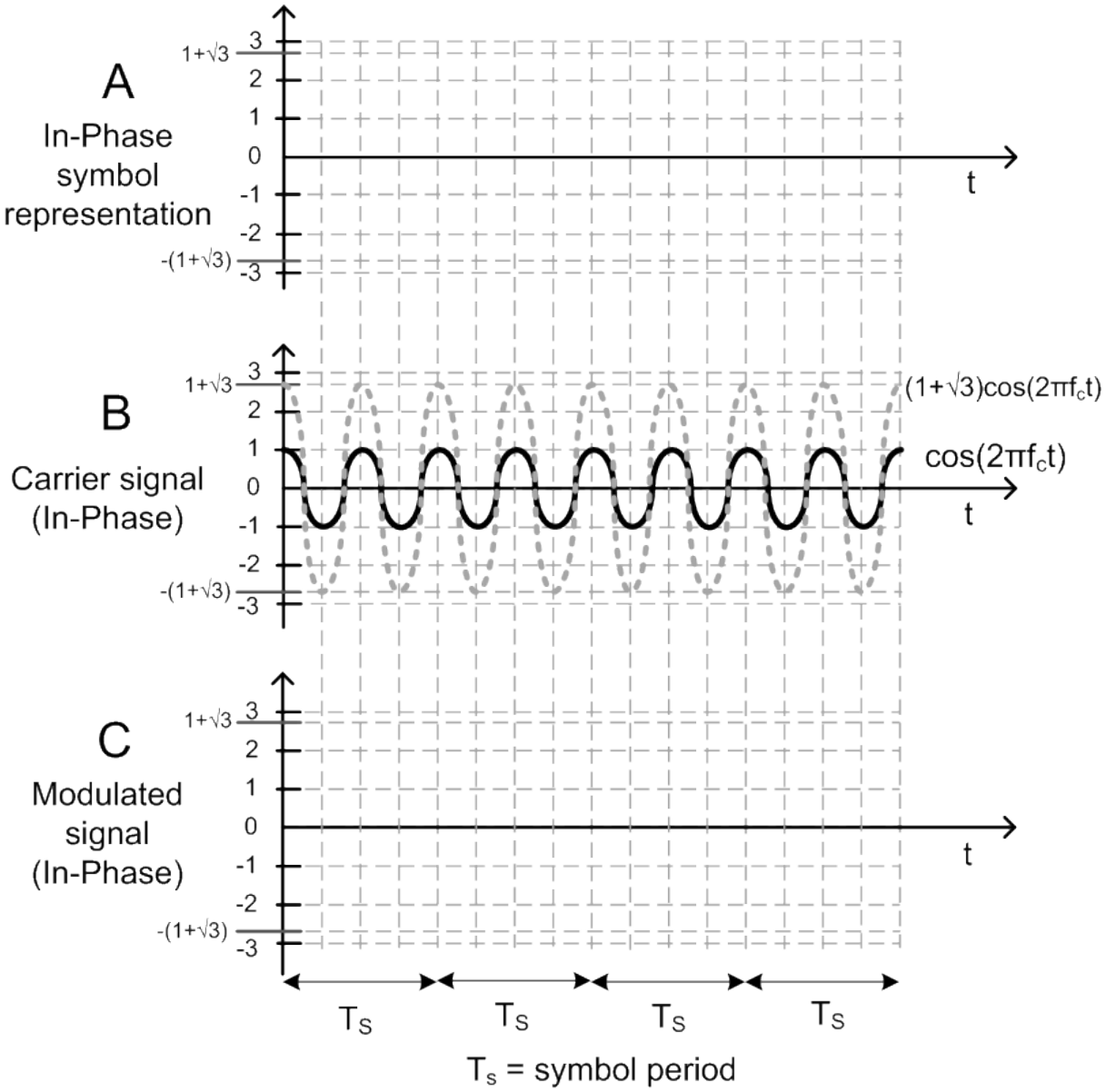


Figure 3.4: In-Phase symbol representation, carrier signal (in-phase), and modulated signal (in-phase)

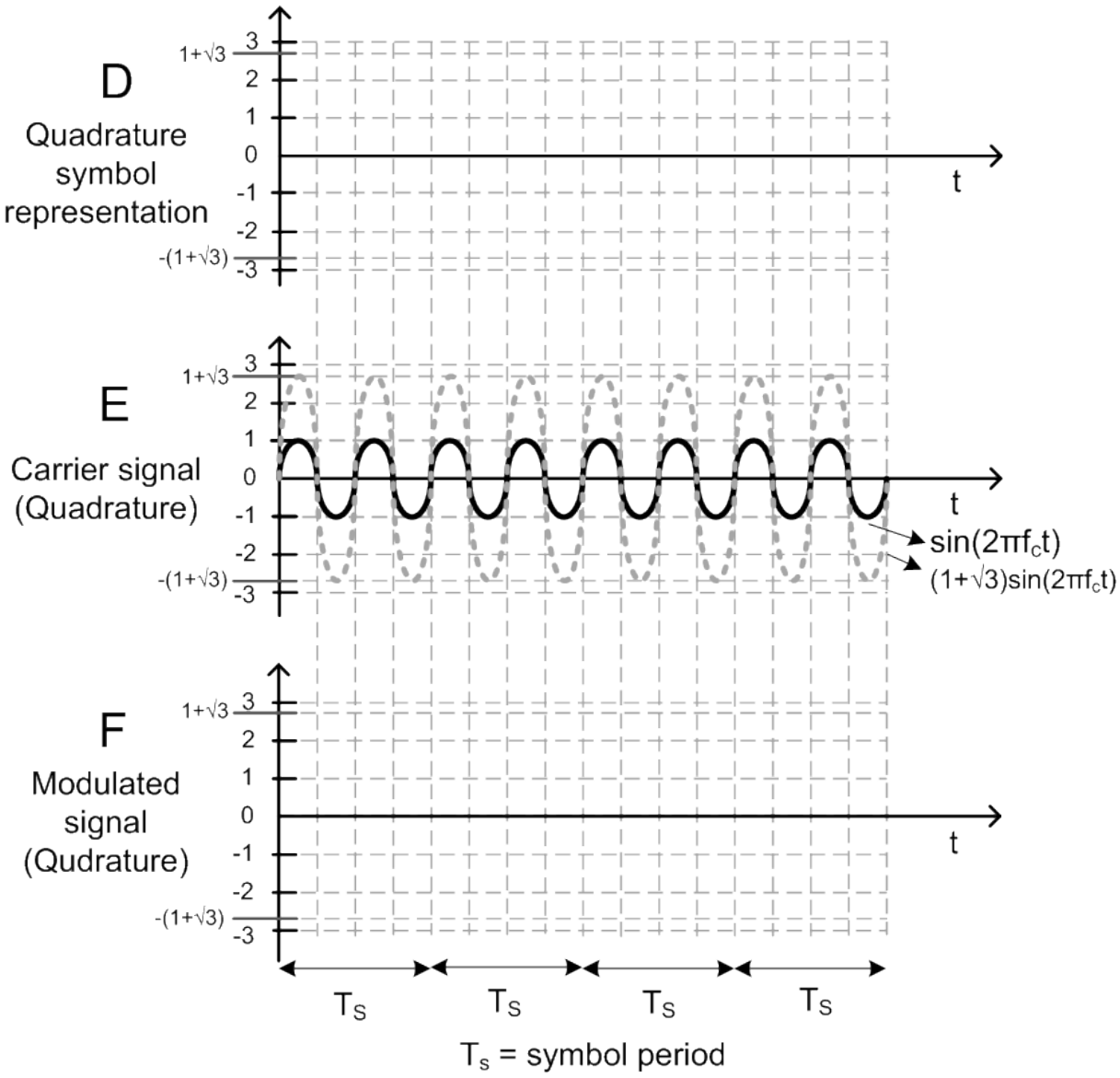


Figure 3.5: Quadrature symbol representation, carrier signal (quadrature), and modulated signal (quadrature)

Task 3.2: Spread Spectrum

A) For the simultaneous transmission of eight messages by eight nodes, the Walsh functions shown in Table 3.1 can be used. Complete the blank cells of Node 1, 2, 4, 7 and other nodes in Table 3.2 by using the Walsh functions.

Sender Node	Function							
0	+1	+1	+1	+1	+1	+1	+1	+1
1	+1	-1	+1	-1	+1	-1	+1	-1
2	+1	+1	-1	-1	+1	+1	-1	-1
3	+1	-1	-1	+1	+1	-1	-1	+1
4	+1	+1	+1	+1	-1	-1	-1	-1
5	+1	-1	+1	-1	-1	+1	-1	+1
6	+1	+1	-1	-1	-1	-1	+1	+1
7	+1	-1	-1	+1	-1	+1	+1	-1

Table 3.1: Functions for sender nodes

Node	Data	Signal							
1	"0"								
2	"1"								
4	"1"								
7	"0"								
other nodes	"silent"								
Signal on media									

Table 3.2: Transmission with CDMA

B) The following Signal has been received from a transmission using all the eight Walsh functions from this task.

-2.9 +0.7 +4.5 -0.2 +1.6 +3.3 -0.8 +1.0

As corruptions might happen during transmission, the receiver has a tolerance band for the detection. Indeed, all calculated values differing up to ±0.5 from the ideal values, i.e. -8 or +8, will still be accepted. Calculate the bit value that the receiver will detect for node 0 and node 7.

Task 4: Media Access

Task 4.1: General questions

A) Name two advantages of CSMA/CD in contrast to Aloha. Explain your answers briefly.

B) CSMA/CD ist used as transmission scheme. Is the length of the media related to the duration of sending? Give a short explanation.

C) Arrange the media access schemes CSMA/CR, CSMA/CD and Aloha according to their average channel utilization, start with the lowest channel utilization.

Task 4.2: Carrier Sense Multiple Access/Collision Resolution

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

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

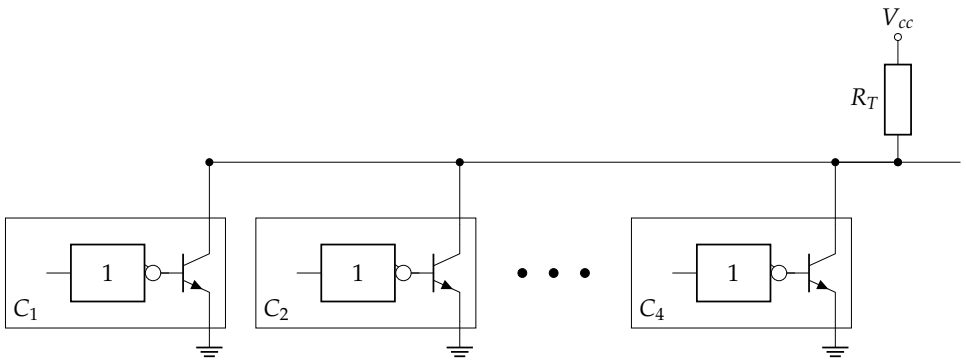


Figure 4.1: bus system

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

C) 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 4.1. Using Figure 4.2, draw the impulse diagram

Node	Identifier
C_1	10010
C_2	10000
C_3	10001
C_4	11101

Table 4.1: 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?

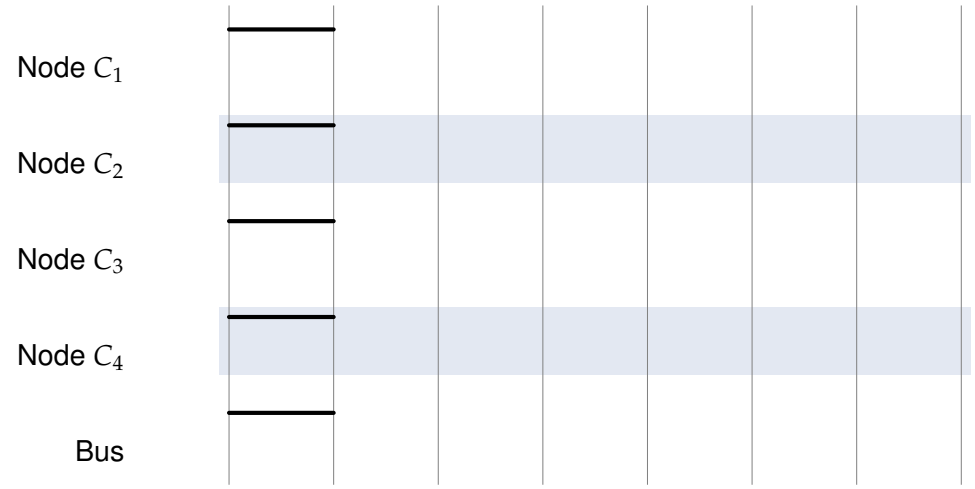


Figure 4.2: Bus Access

Task 4.3: Arbitration

A) Name one advantage of arbitration compared to static multiplexing schemes like CDMA. Justify your answer briefly.

B) Explain the differences between centralized and decentralized arbitration schemes briefly.

C) Name two arbitration schemes mentioned in the lecture that use the decentralized approach.

A decentralized Daisy-Chain is shown in Figure 4.3.

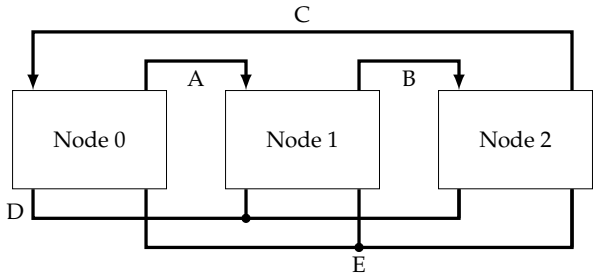


Figure 4.3: Decentralized Daisy-Chain

D) Explain the purpose of the five signal lines A-E of the decentralized Daisy-Chain with a few sentences.

E) An exemplary arbitration cycle of the system is shown in Figure 4.4. The transmission is ongoing and at the time t_0 node 0 and node 2 want to send further data. At time t_1 node 1 wants to send data again. The sending time for all data packages of all senders are equal. The time steps are shown at the top of the Figure 4.4, complete this diagram accordingly. Mark down the sending nodes and the signal curves of each signal line.

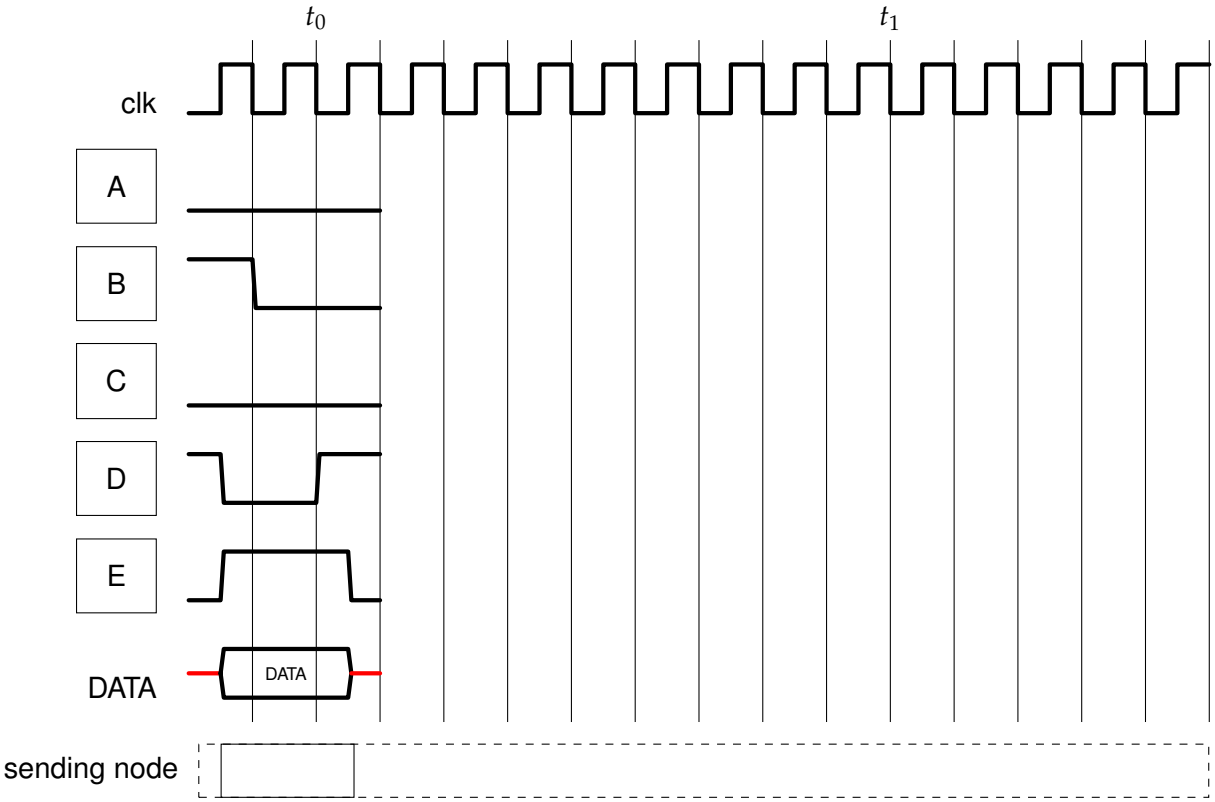


Figure 4.4: Signal flow for Daisy-chain

Task 5: Error Protection

Task 5.1: General Questions

A) How many data bytes can a normal CAN data transmission transfer at most? In addition, explicitly specify the four bit DLC field that must be selected for this purpose.

B) How many different priorities can be realized on the CAN bus? (Indicate calculations)

C) Name two errors that can be detected with the CRC and describe additionally which conditions the generator polynomial must have.

Task 5.2: CRC-Calculation

A) To protect data transmission in a mobile device, the given CRC generator polynomial should be implemented. Draw the short form of the linear feedback registers with XOR operators for the given generator polynomial.
Given CRC generator polynomial: $x^7 + x^6 + x^4 + x^3 + 1$

B) Calculate the data stream that will be transmitted if the following bit stream is to be protected using the CRC generator polynomial given in task 5.2 A): $x^7 + x^6 + x^4 + x^3 + 1$.
Data stream for transmission: **1011 1000 0000**

C) In a transmission system that uses CRC for error detection, a receiver receives the following bitstream: **1011 1010 0011**
Carry out the CRC error detection scheme of the receiver, assuming that the generator polynomial $x^5 + x^3 + x + 1$ has been used to generate the checksum at the sender. What does the receiver conclude from the result?

D) Specify the correct bit stream, assuming that only one bit error has occurred in the transmitted bitstream of the task 5.2 C).

Task 5.3: CAN Bus

A) For a given CAN bus protocol, the following error frame in Fig. 5.1 gets generated in order to cancel a faulty transmission. Assume that there is a sender (Node1) and two receivers (Node 2 and Node 3). Node 2 receives the data corretly, whereas Node 3 encounters a CRC error due to some data error. Complete the signal sequence in Fig. 5.2 with respect to the error frame generation of Node 3 and the consequence effect on Node 1, Node 2 an bus level. In addition, clearly mark where Node 2, Node 3 and Node 1 detects the error.

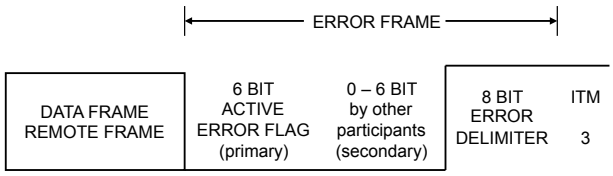


Figure 5.1: Error Frame

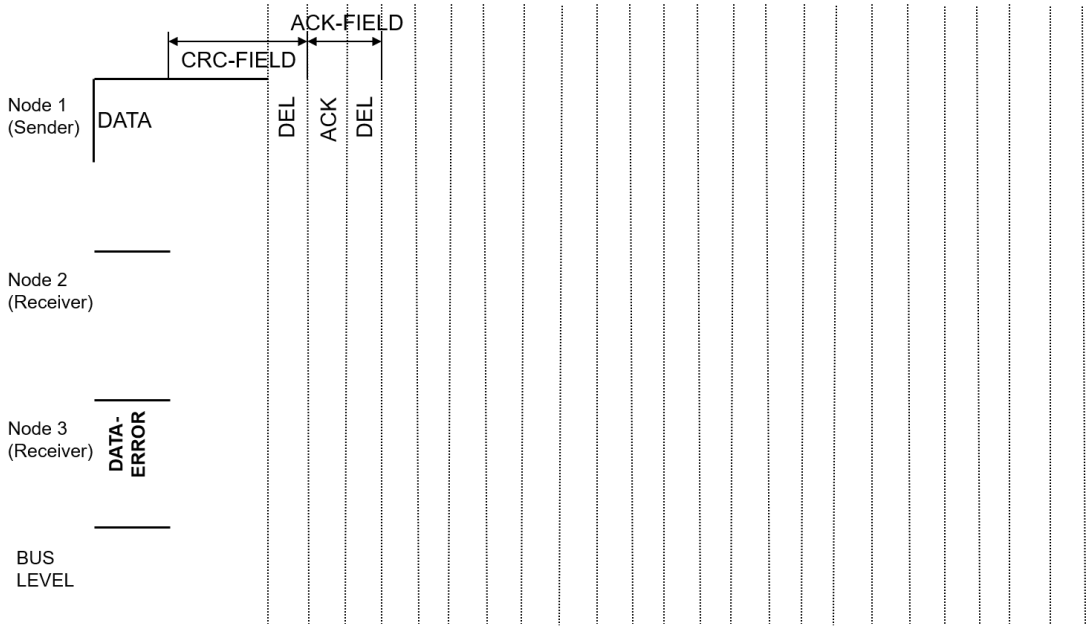


Figure 5.2: Signal sequence diagram of CAN bus

B) Consider the following CAN data stream at Node A (sender). Name four errors that can be detected from the given data stream and justify your answer.

Node A (sender)

SOF	Arbitration Field				CTRL Field						Data Field								CRC Field				ACK Field		EOF			
1	1	..	11	12	1	2	3	4	5	6	1	2	3	4	5	6	7	8	1	..	15	16	1	2	1	2	..	7
	ID10	..	ID0	RTR	Ext.	Res.	DL3	...		DL0	DB7	...						DB0	CRC14	..	CRC0	DEL	ACK	DEL	EOF6	EOF5	..	EOF0
1	1	..	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	1	1	..	1	0	0	0	0	1	..	1

Task 6: Protocols

Task 6.1: 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.

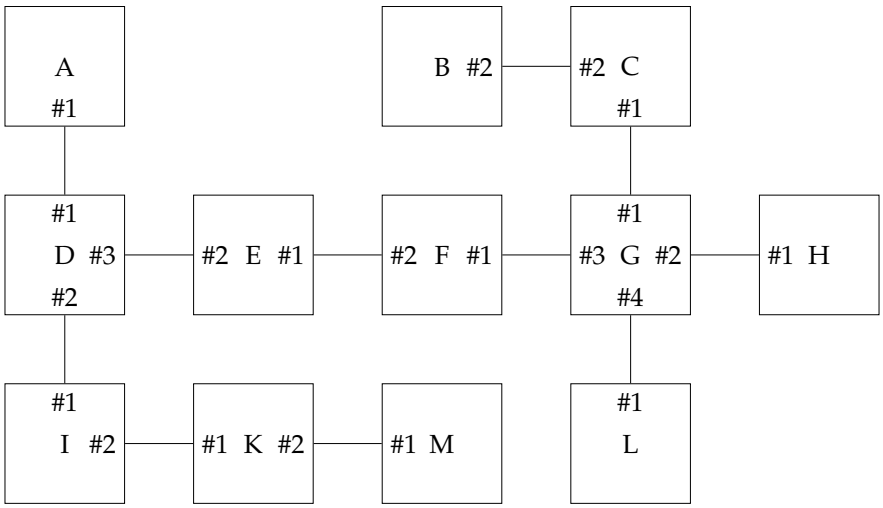


Figure 6.1: FireWire network

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 requests are done in zero time. There are no delays for propagation of the arbitration decision.
- If a node receives multiple bus requests, it will always forward the request that it receives from the port with the lowest number.

A) Mark the root of the FireWire network in Figure 6.1!
The following nodes request access to the bus: **A, B, G, F, K, L**. Determine the order in which the nodes will be granted access to the bus.

B) If the root sends continuously, it would always grant access to the bus. How does FireWire preserve fairness?

Task 6.2: FireWire Structures

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

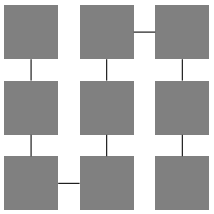
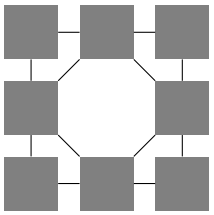
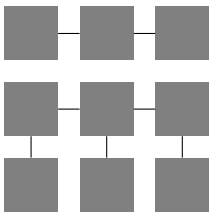
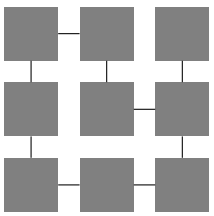
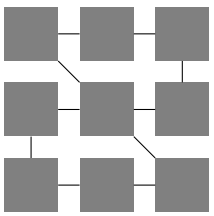
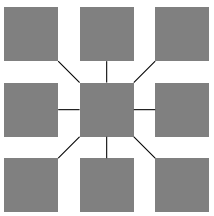
	Correct	Wrong	Reason
			
			
			
			
			
			

Table 6.1: FireWire structures

Task 6.3: ITIV-Protocol

The ITIV want to transmit data bidirectional from campus south to campus north with multiple clients. Therefore a customized protocol is build by the ITIV for transmission of information with id, data and a check sum. The bus should use Manchester coding to transmit the raw data. Use the Manchester code where data bit '1' is represented by signal transition from low level to high level. The voltage level on the bus is induced by an open-collector that is connected to the output stage of the microcontroller (see Figure 6.2). The transmission is initialized by a start-bit (low) and finished with a stop-bit (high).

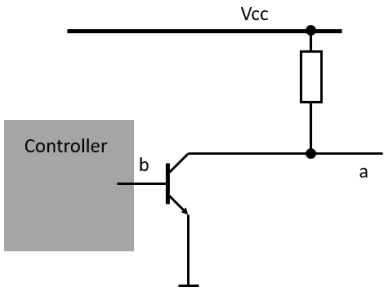


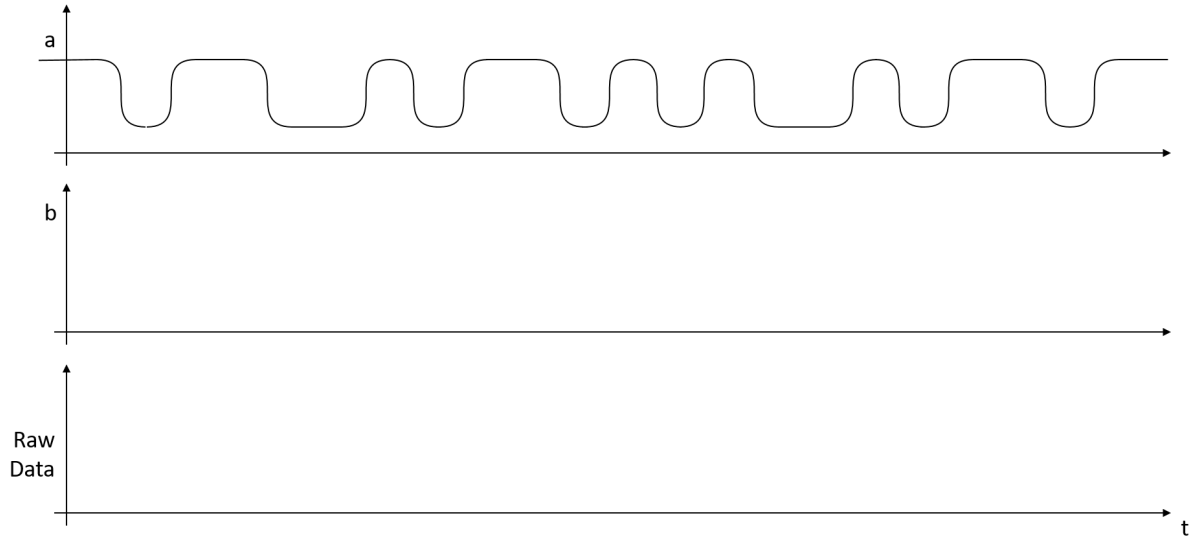
Figure 6.2: Open collector schematics

A) How can data integrity be checked on physical layer without changing the protocol?

B) The transmitted data-field will have variable length. Name two ways of determining the data-field length within a transmission.

C) Can the clock be recovered within this system? Justify your answer. If clock recovery is not working give a possible solution.

D) Draw the Manchester coded and raw data (8-bit of information) transmitted over the channel in the following graphic. The signal names correspont to the names from Figure 6.2. Please write down the transmitted data.



E) Because of license reasons the Manchester coding cannot be used. Why can't differential Manchester be used for the system? Please name the Problem and a possible solution. Hint: What happens to the bus line after transmission.

Task 7: Routing

Task 7.1: Router and Switching

A) Which approach, Network-on-Chip or a Bus system, is better suited for a large number of nodes that can act as a master, with regards to scalability? Justify your answer.

B) Describe the main and at least one reasonable additional function that is provided by routers in networks.

C) One of the major components of a router is the switch matrix. Describe its purpose and name the unit inside the router that is configuring the matrix. Additionally describe how that unit can be implemented when using static routing algorithms.

D) Are all flits of a message routed through the same path in a network when using circuit switching? Additionally describe the situation when using packet switching. Justify your answer relative to the characteristics of the switching scheme.

E) Describe the two routing algorithms Hot Potato and XY Routing. Additionally provide an advantage and disadvantage for each algorithm.

Task 7.2: Routing

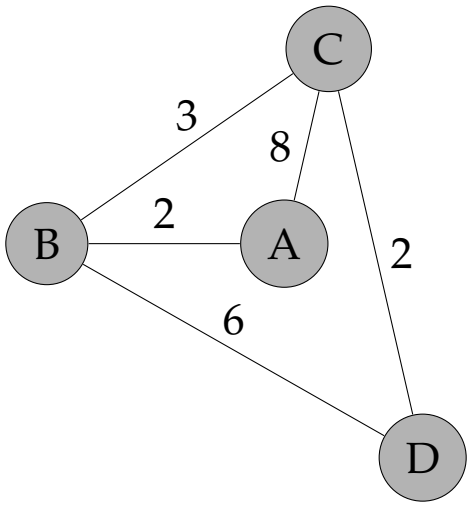


Figure 7.1: Given network topology

A) Figure 7.1 represents a network for which an optimal routing has to be found. The weights of each connection represent an abstract metric that is to be minimized through routing. Combining the weights across connections, is done by addition. Node A represents the starting point from which optimal routes are to be determined. Calculate the paths with the smallest accumulated weights in the given network by using Dijkstra's algorithm. For that write down which node is visited in each step. Fill out the given table that contains the optimal paths after each step.

	step 1		step 2		step 3		step 4		step 5	
node	**A**									
vertex	dist.	pred.	dist.	pred.	dist.	pred.	dist.	pred.	dist.	pred.
A	∞	A								
B	∞	-								
C	∞	-								
D	∞	-								

Table 7.1: Dijkstra's algorithm

B) Name and describe at least 3 optimization goals of routing algorithms! Provide and explain a suitable metric for each goal!

Task 8: Network Topologies

Task 8.1: General Questions

A) Which network topology is more suitable when there is a high possibility of link failure, ring, mesh or torus? Justify your decision.

B) What is the edge connectivity and diameter of a 16 node network which uses 4x4 2-D Torus topology

C) There are four topologies given: Mesh, Star, Ring. Assume for each topology a network with 16 nodes. Order the topologies in the given table from best (top) to worst (bottom) regarding the given metric. Metrics: edge connectivity, diameter, resource cost(i.e. in this case the total amount of links in the network). Hint: Think about what is desirable for each metric in a network when deciding the order.

Edge Connectivity	Diameter	Resource Cost

Table 8.1: Metrics and topologies

Task 8.2: 3D Topology

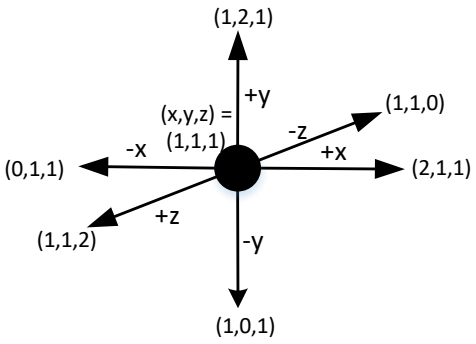


Figure 8.1: Node at (x,y,z) = (1,1,1)

A) Consider a 5x4x7 mesh topology for this task. In the network, a fault occurs in router at node (x,y,z) = (4,2,5) and at (x,y,z) = (4,3,4) and these two routers stop working. Due to this, a packet needs to avoid both these routers to reach its destination. Find a path from the source point (x,y,z) = (1,2,5) to the destination point (x,y,z) = (4,3,5) using the adaptive XYZ routing algorithm described below:

Rule1 Try to first route in the X direction towards the destination. Then the Y direction, and then the Z direction.

Rule2 If a link chosen leads you to a faulty router, disregard it and choose among the remaining directions from the local position towards the destination, prioritising first X, then Y, then Z.

Rule3 If the direction chosen leads you to an already visited node, disregard it and choose among the remaining directions from the local position towards the destination, prioritising first X, then Y, then Z.

Rule4 In case none of the above rules is possible, choose among the remaining directions in the decreasing order of priority -x,-y,-z,+x,+y,+z. Use Figure 8.1 as a guide .Here it is possible for the packet to go away from the destination.

In your answer please name all traversed nodes (i.e. their coordinates) in the correct sequence. Mention which of the above rules you used at each step to go to the next node.

B) Now find the path from the source point (4,3,5) to the destination point (4,3,3). The two faulty routers still exist at nodes (x,y,z) = (4,2,5) and at (x,y,z) = (4,3,4). In your answer please name all traversed nodes (i.e. their coordinates) in the correct sequence. Mention which rule you used at each step to go to the next node..

C) If Rule 3 in the above algorithm was not present and a packet travels from the source point (4,3,5) to the destination point (4,3,3), does it reach the destination ? Explain your answer.

D) What is the diameter and edge connectivity in a 5x4x7 3D Mesh topology?

E) Explain livelock and deadlock in a network.

Additional sheet for task [ ]: