Examination (WS 2019/2020)
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 13, 2020

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 **38 sheets** and a two-page formulary.

		Page	≈ Pts. in %	Points
Task 1:	Physical Basics	2	14	
Task 2:	Transmission Principles	9	12	
Task 3:	Modulation and Spread Spectrum	13	12	
Task 4:	Media Access	19	12	
Task 5:	Error Protection	23	12	
Task 6:	Protocols	27	12	
Task 7:	Routing	32	11	
Task 8:	Network Topologies	35	11	
				$\sum$

Task 1: Physical Basics

Task 1.1: Differential Signaling

A) What are the advantages of differential signal transmission over single-ended signaling?

Task 1.2: Drivers

A) Insert the logic level (HIGH/1, LOW/0) of the output and the state of the transistors (conducts, blocks) into the table according to the input configuration x_1 and x_2 at the standard TTL output driver.

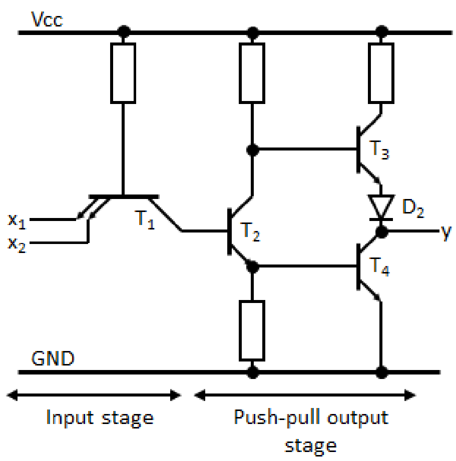


Figure 1.1:

x_1	x_2	T_1	T_2	T_3	T_4	y
0	0					
0	1					
1	0					
1	1					

B) List two advantages of using TTL drivers over open-collector drivers.

C) When using TTL drivers on a communication bus, which problems can occur? In which situation(s) may these problems occcur?

D) Considering the problem in question C: What could be added to the TTL driver to avoid this problem? The answer should include a brief explanation how the suggested solution solves the problem.

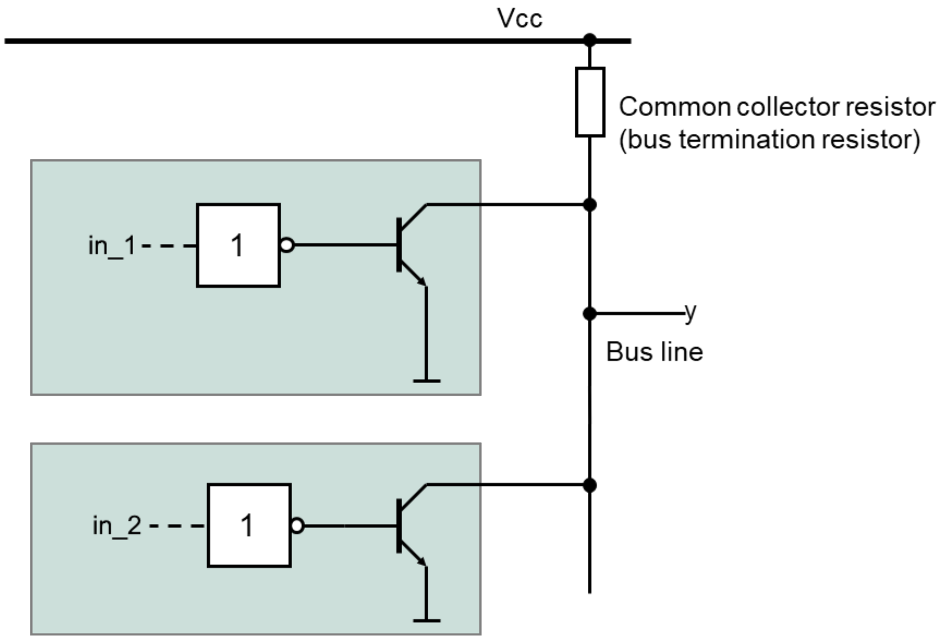


Figure 1.2: Communication bus implementing a wired AND function

E) One way to avoid the problem stated in the previous question is to use the WIRED AND concept. This is shown in Figure 1.2. Draw the corresponding WIRED OR function. The drawing should make clear how the nodes pull the line to VCC and/or GND level. Indicate the node input lines by in_1 and in_2 and the bus line by y. The bus voltage level shall be equal to the node's input voltage level (when sending the dominant level).

Task 1.3: Channel Capacity

A digital transmission system has a bandwidth of $B = 10^7$ Hz. It shall be used to transmit data at a rate of 25 MBit/s.

A) Give the general formula describing the relation between channel capacity C, bandwith B and signal-to-noise ratio (SNR). What is the minimum SNR in dB at which this transmission is possible (according to Shannon)?

Task 1.4: Reflections on wires

In Figure 1.3 a transmission system is given. It consists of a voltage source of unknown voltage U_q (including an internal resistance R_i), a signal line of length L and a resistor R_L as receiver. The signal propagates with speed v. The propagation time of the signal from one end of the line to the other is t_d.

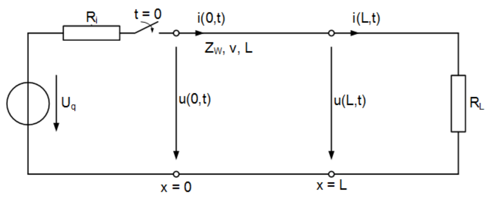


Figure 1.3: Transmission system

For varying R_i and R_L the following signal diagrams (figure 1.4) can be drawn. They are showing the voltage $u(0,t)$ at the beginning of the signal line and the voltage $u(L,t)$ that can be measured at the end of the line.

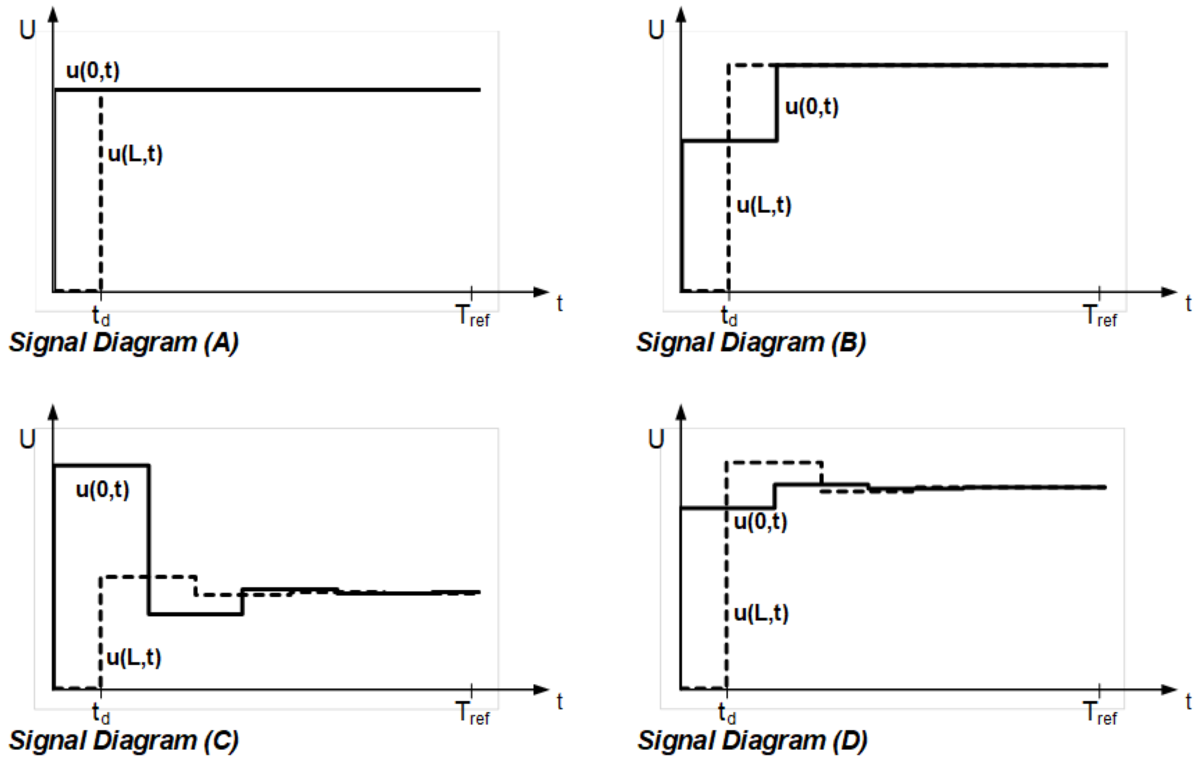


Figure 1.4: Voltages on signal line

A) In which of the examples given in Figure 1.4, if any, is the line terminated correctly with a suitable value of R_L? Justify your answer.

B) For each of the signal diagrams denote in the following table:

- Is the reflection factor r_i at the beginning of the signal line negative, positive, or zero?
- Is the reflection factor r_L at the end of the signal line negative, positive, or zero?

If the reflection factor cannot be determined from the signal diagram, indicate this with a dash (−).

	r_i **[neg, pos, 0, −]**	r_L **[neg, pos, 0, −]**
Signal diagram (A)		
Signal diagram (B)		
Signal diagram (C)		
Signal diagram (D)		

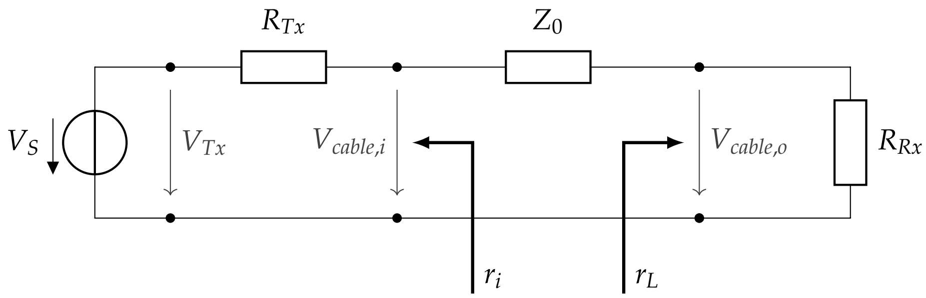


Figure 1.5: Test setup

Figure 1.5 shows the equivalent circuit diagram of an ideal (lossless) transmission line in a general case: A transmitter having output impedance R_{Tx} is connected to a receiver with the input impedance R_{Rx} using a long cable.
In this case, there is a short circuit at the end of the cable. Therefore $R_{Rx} = 0\,\Omega$. The signal line is characterized by $Z_0 = 40\,\Omega$. $R_{Tx} = 60\,\Omega$.

C) Calculate the value of the reflection factors r_i and r_L as well as the formula how to calculate them.

At the time $t = 0$ the voltage V_S of the sender changes from 0 V to 5 V and is constant afterwards.

D) Calculate the value of the voltage $V_{cable,i}$ at the time $t = 0$.

Task 2: Transmission Principles

Task 2.1: Line Codes

A) We want to transmit the value 1100 1010 0010 through a serial wire communication channel. Complete Figure 2.1 with the digital signals transmitted using each given encoding scheme. All codes start from their lower state (-Level 1 or Level 2).

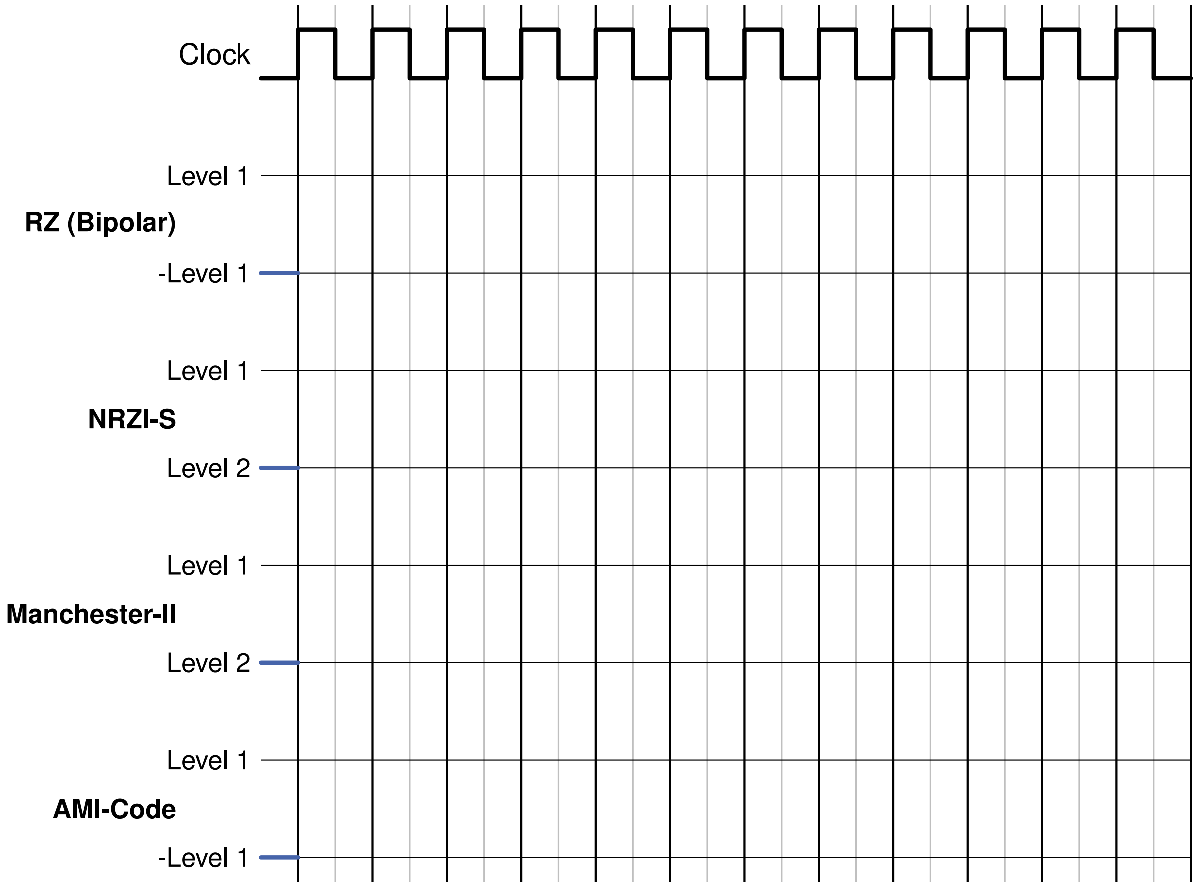


Figure 2.1: Line codes

B) Classify the following line codes according to their clock recovery properties for three possible different inputs: a long sequence of '1's, a long sequence of '0's, and a random signal. Mark in the table with a 'yes' or 'no' if the code enables the recovery of the clock for the specific input.

Input / Code	**Sequence of '1's**	**Sequence of '0's**	**Unknown**
RZ (Bipolar)			
NRZI-S			
Manchester-II			
AMI-Code			

C) An approach used to synchronize communication processes is the use of Flow Control. Complete the signals in Figure 2.2 to perform two new transmissions with DATA values 0xA and 0xB using *Level-Triggered Closed-Loop Flow Control*. Ignore delays and consider that:

- the Sender and Receiver reads signals at the falling edge of its clock.
- the Sender and Receiver writes signals at the rising edge of its clock.
- the Sender and Receiver will set or unset their signals as soon as possible.
- the Sender must free the bus for at least one cycle before new data can be sent.
- the Receiver receives the DATA values at the instant it is read.

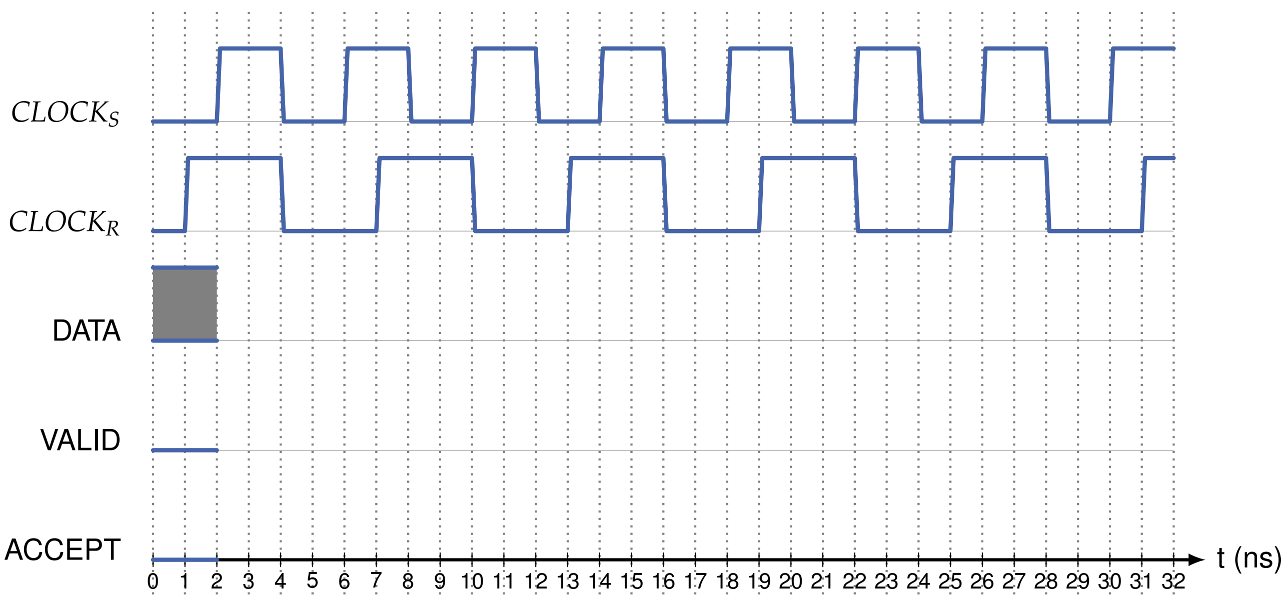


Figure 2.2: Signal sequence

Task 2.2: I^2C Communication

In this task we want to investigate the data transmission on the I^2C-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 I^2C-Bus.

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

data transfered (n bytes + acknowledge)

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: I^2C-Bus frame format

A) Is I^2C a synchronous or asynchronous protocol? Justify your answer.

B) Consider an I^2C Multimaster configuration with two masters M1 and M2, and one slave S. For each of the following cases, is a collision detected and what operation is done on the slave? Justify your answer for each case.

Case1 M1 tries to write **'1'** to S and M2 tries to write **'0'** to S at the same time.
Case2 M1 tries to read from S and M2 tries to write **'1'** to S at the same time.
Case3 M1 tries to write **'1'** and M2 tries to write **'1'** to S at the same time.

C) The diagram in Figure 2.4 corresponds to a connected I^{2}C Multimaster configuration. The system is composed of three Slave and three 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	1	0x5A
Master 3	1011101	1	0xAA

Table 2.1: I^{2}C Communication Parameters

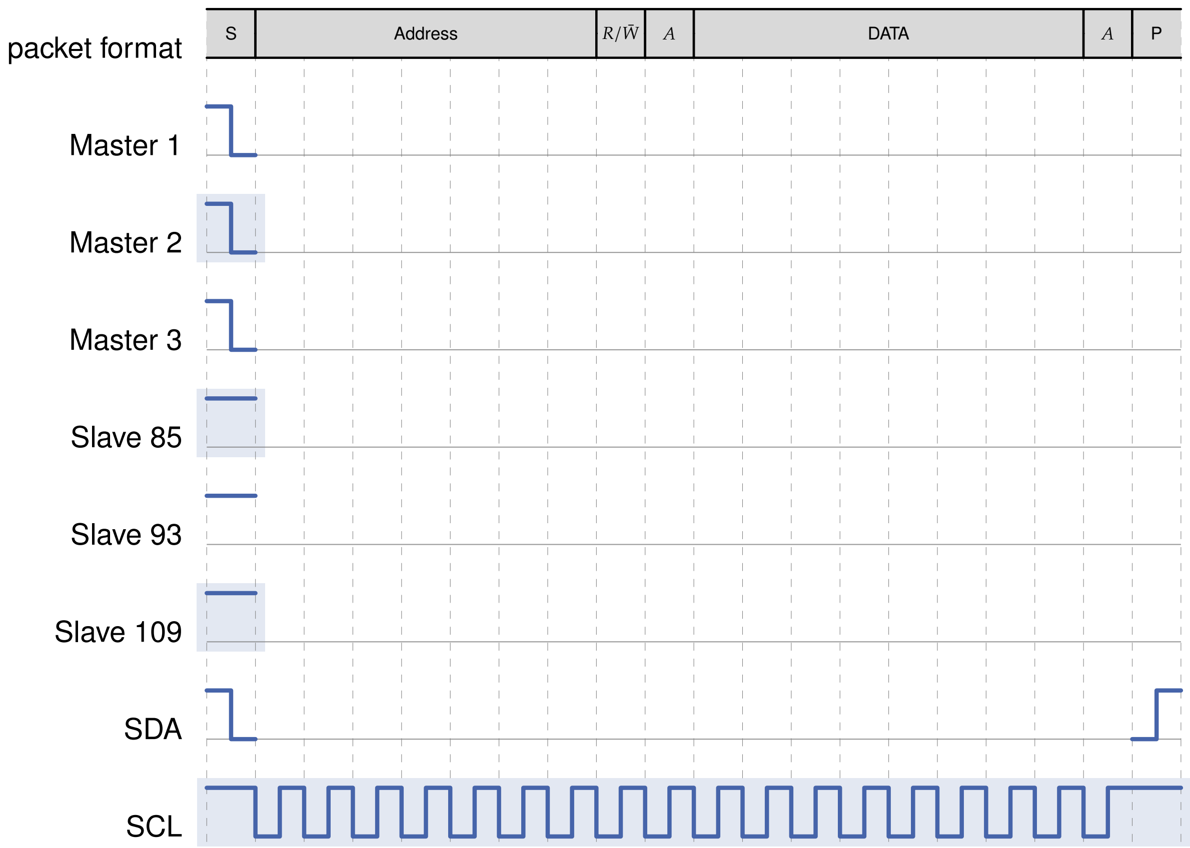


Figure 2.4: I^{2}C Signal sequence

Task 3: Modulation and Spread Spectrum

Task 3.1: Modulation

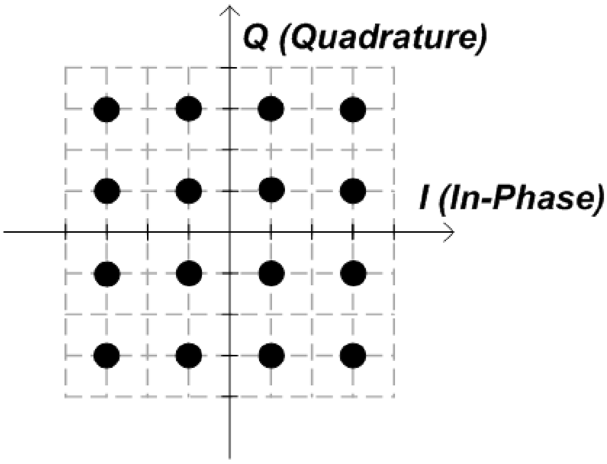


Figure 3.1: Constellation Diagram

A) Figure 3.1 shows the constellation diagram of a certain modulation scheme. How many different amplitude values can be used in this modulation scheme?

B) How many bits can be represented per symbol in N-QAM? (Assume that N is a power of 2).

C) How many bits does a symbol for the modulation scheme in Figure 3.1 represent at least?

D) How many carrier frequencies are used in the PSK modulation scheme?

E) Draw a block diagram for the QAM demodulator. Use $I(t)$ and $Q(t)$ as names for the outputs and $r(t)$ as name for the input.

A constellation diagram of an 8-QAM scheme is shown in Figure 3.2. The bits **100110001111** shall be transmitted and will be encoded from the left to right.

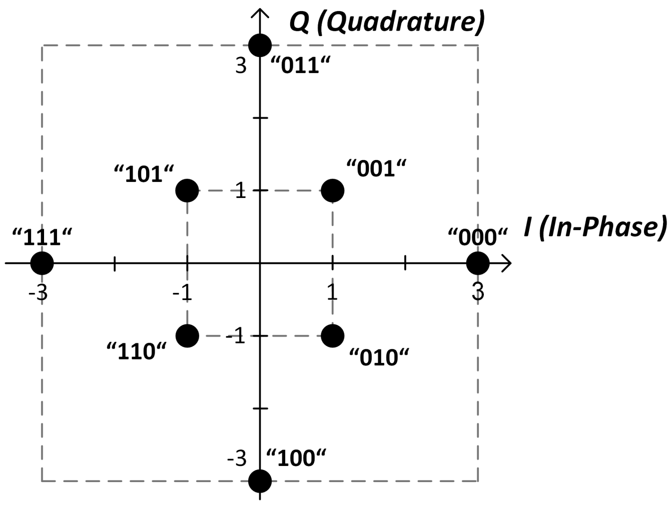


Figure 3.2: Constellation Diagram of an 8-QAM scheme

F) Figure 3.3 shows the in-phase symbol (A), in-phase carrier signal (B) and in-phase modulated signal (C). Use this figure to sketch the waveforms of symbol representations (A) and modulated information signals (C) for the in-phase axis. In (A), also label the symbols using their bit representation. The symbol period is twice as long as the period of the carrier signal.

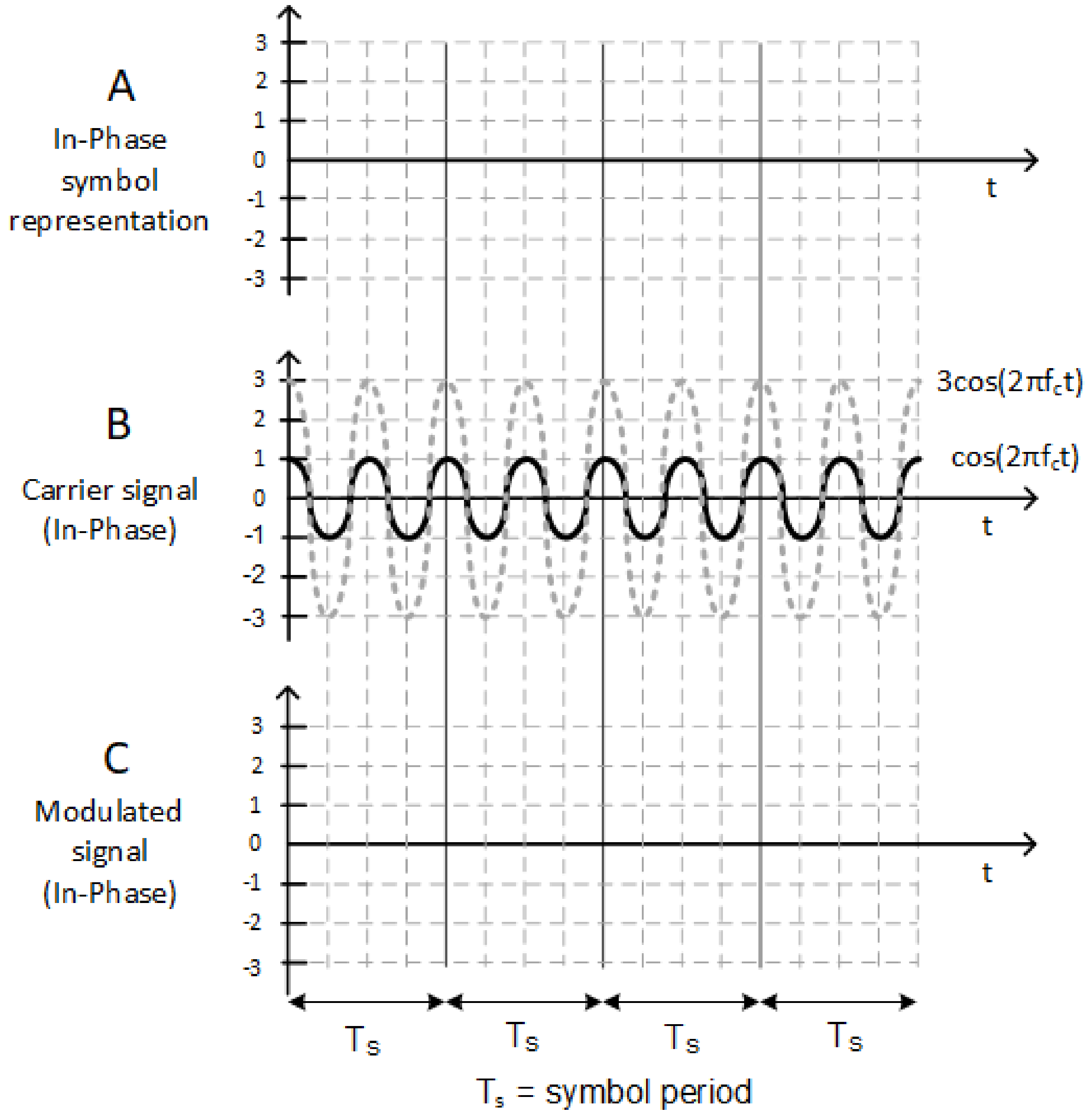


Figure 3.3: In-Phase Symbol Representation, Carrier Signal (In-Phase), and Modulated Signal (In-Phase)

G) Figure 3.4 shows the quadrature symbol (D), quadrature carrier signal (E) and quadrature modulated signal (F). Use this figure to sketch the waveforms of symbol representations (D) and modulated information signals (F) for the quadrature axis. In (D), also label the symbols using their bit representation. The symbol period is twice as long as the period of the carrier signal.

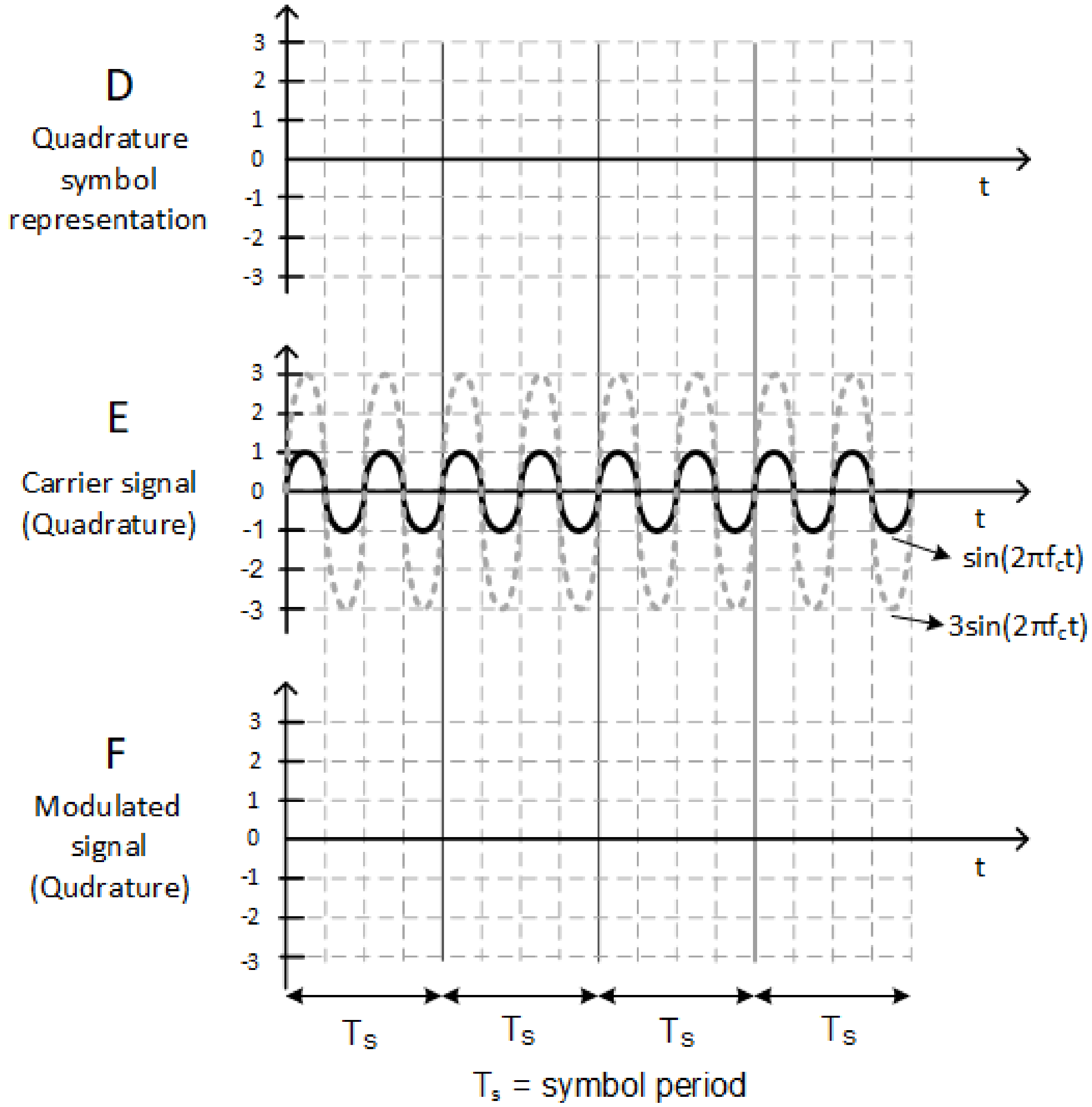


Figure 3.4: Quadrature Symbol Representation, Carrier Signal (Quadrature), and Modulated Signal (Quadrature)

Task 3.2: Spread Spectrum

A) The Walsh functions in Table 3.1 shall be used for the simultaneous data transmission of eight nodes. Complete the blank cells in Table 3.2 with the sending signal for each node.

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: Walsh Functions for Nodes

Node	Data	Signal to be Sent							
1	"0"								
2	"1"								
3	"0"								
others	"silent"								
Signal on Media									

Table 3.2: Transmission with CDMA

B) Assume the signal on media is **(-1, 1, 3, 1, -3, -1, 1, -1)**. A node connected to the bus wants to receive data from nodes 1 and 4. Give a generic formula to calculate the received value d_n for node n (use s for the signal on media vector, w_n for node n's Walsh function vector). Then give the calculated values (d_1, d_4) and the bit values (b_1, b_4, if there's no data from a node, use x) received from nodes 1 and 4.

C) Which property of Walsh functions enables them to be used in CDMA systems?

D) Using the Walsh function construction scheme explained in the lecture, how many Walsh functions will be constructed for N nodes, where $N \in \mathbb{N} \setminus \{0\}$?

Task 4: Media Access

Task 4.1: CSMA/CD

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 10 Mbit/s and a signal speed of $2 \cdot 10^8$ m/s. A maximum distance of 2 km for two nodes has to be considered.

A) Two nodes n_1 and n_2 want to send data at the same time and the shared media is not occupied at this moment. Describe the sending procedure and necessary actions of node n_1 until the transmission is fully completed.

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

C) What might happen if a package consisting of 120 bit is sent over the bus? Give a short explanation.

D) A minimal package length of 64 bytes for the bus system is determined. The bus system is illustrated in Figure 4.1 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!

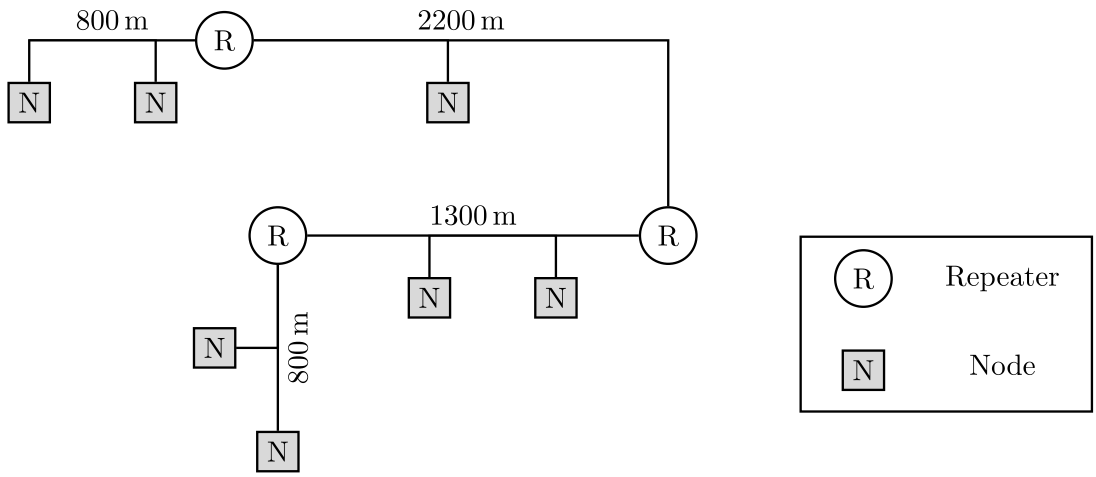


Figure 4.1: Ethernet topology

Task 4.2: CSMA/CR

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

A) Which requirements have to be fulfilled in order to guarantee a faultless function of the system? What are the implications for the transmission rate?

B) Name two disadvantages of CSMA/CR, explain your answers briefly.

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
A	00101
B	01001
C	00100
D	00110

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?

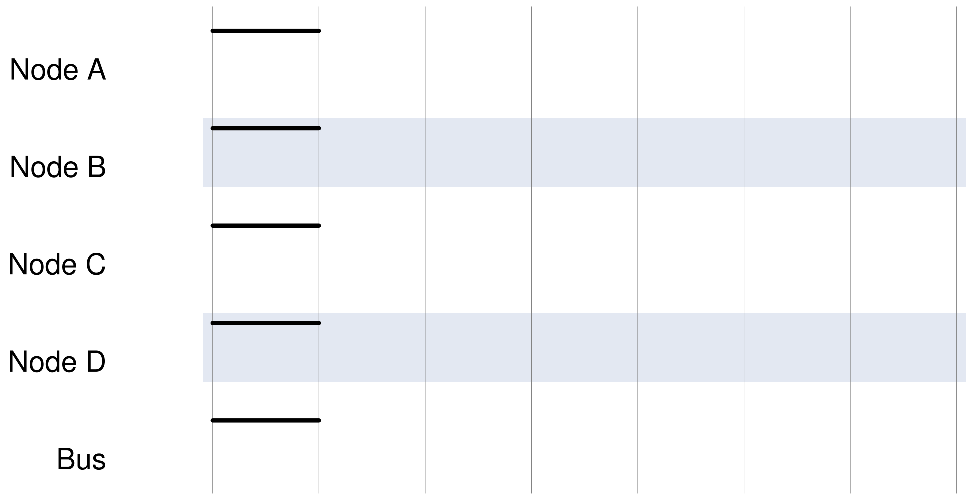


Figure 4.2: Bus Access

Task 5: Error Protection

Task 5.1: Cyclic Redundancy Check (CRC)

A) Given is a CRC generator polynomial of $G(x) = x^9 + x^5 + x + 1$. Does the CRC scheme based on $G(x)$ allow a receiver to detect burst errors of length 9? Justify your answer.

B) A sender and a receiver have agreed to exchange CRC-protected messages based on the generator polynomial $G(x) = x^4 + 1$. Perform the CRC error detection scheme that the receiver carries out for the received bit string "0010 1000 0001 0010". Which guarantee does the receiver obtain with respect to the occurrence of transmission errors?

C) Draw the simplified from of the linear feedback shift register with XOR operations implementing the CRC generator polynomial $G(x) = x^{11} + x^{10} + x^9 + x^5 + x^2 + 1$.

D) In order to transmit it over a channel, the message "1110 1101 11" shall be protected by a CRC checksum. Using the generator polynomial $G(x) = x^4 + x^3 + 1$, calculate this checksum and give the bit string that is sent to the receiver.

Task 5.2: Redundancy

A) A transmission system makes use of a parity-based block check for error detection. The communicating nodes have agreed to make use of even parity. Assume that one of the nodes receives the message shown in Figure 5.1, where the parity bits are shown in the rightmost column and the bottom row, respectively. What can the node deduce with respect to the correctness of the message and from which property can it conclude this?

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

Figure 5.1: Received block check message

Task 5.3: Controller Area Network (CAN)

A) Consider a CAN network that consists of three individual CAN nodes. Suppose that one of these nodes, in the following referred to as the sender, transmits a data frame that is received by the remaining two nodes (see Figure 5.3). During the transmission of the data field, the bus level is distorted for the duration of exactly one bit (visualized by the "↯" symbol). The sender registers this disturbance as a bit monitoring error. Complete the empty columns in Figure 5.3 with the signal values that the three CAN nodes transmit in response to this event and determine the resulting bus level for all columns.

Hints: *The general form of a CAN error frame is visualized in Figure 5.2. One column in Figure 5.3 corresponds to one bit duration. Assume that immediately after the distortion, the bus recovers and exhibits fault-free behavior for all following bits.*

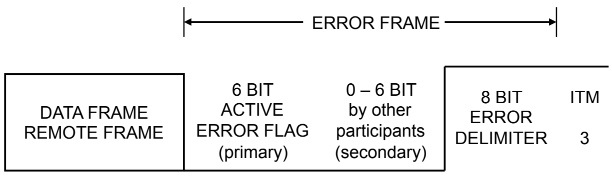


Figure 5.2: Error frame of the CAN protocol

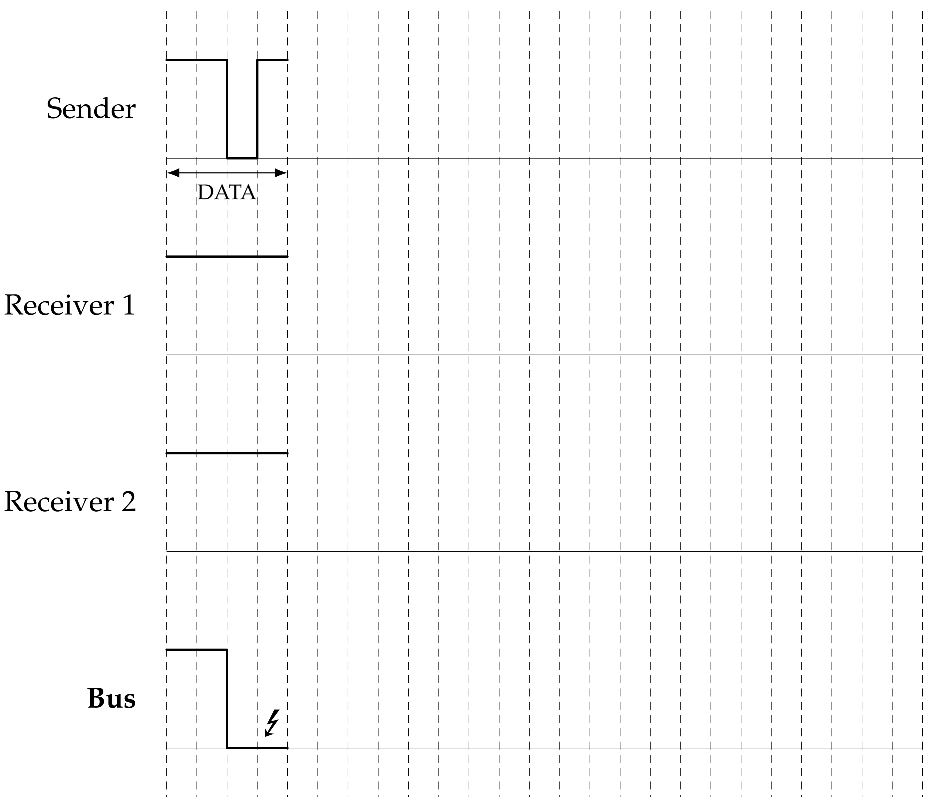


Figure 5.3: Signal sequence diagram of the CAN bus

B) How does the general concept of "error states" contribute to the robustness of a CAN network? Describe the goal shortly and name the error states that the protocol defines.

C) Consider a CAN node with a receive error count of `RX_CNT` = 0 and a transmit error count of `TX_CNT` = 167. It is connected to a network with another, fully functional CAN node that does not transmit any messages. Assume that the considered node begins to transmit an infinite stream of CAN messages and that no further errors occur. How does the `TX_CNT` value change with each such transmission quantitatively? Which error state will the CAN node eventually enter and retain?

Task 6: Protocols

Task 6.1: FireWire Arbitration

The FireWire network shown in Figure 6.1 is given.

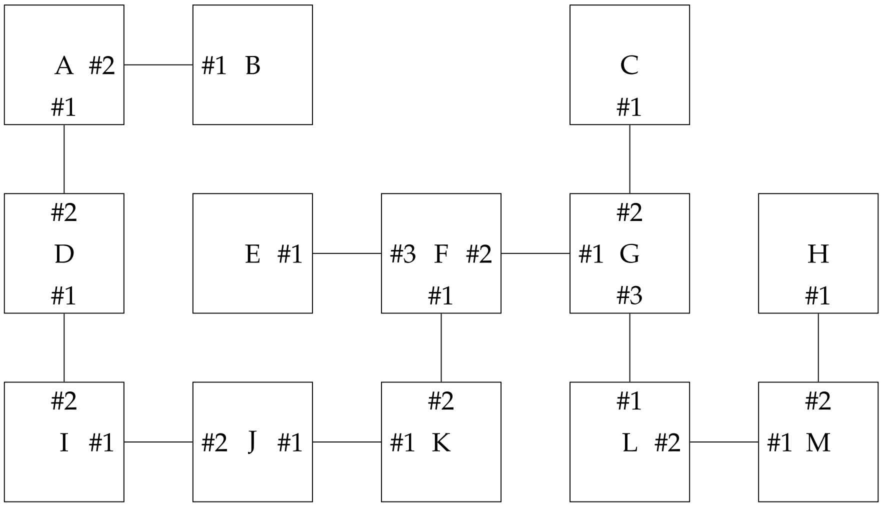


Figure 6.1: FireWire network

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) The nodes in Figure 6.1 are named using letters from A to M. What is the root of the FireWire network?

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

C) What happens if two nodes send parent requests to the same node and at the same time during the tree identification process? Does this influence which node becomes the root node? Justify your answer.

D) FireWire uses a special coding scheme with an additional STROBE signal. Explain the purpose of the this signal and a possible implementation.

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 correctly. Modify the erroneous FireWire systems given below by adding or removing as few connections as possible to get one correct FireWire system each. Draw the corrected system in column 2 (*Corrected System*) and give a reason why the system has to be modified in column 3 (*Reason*) or note that the given system is already correct.

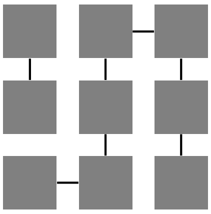
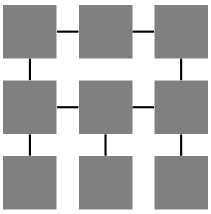
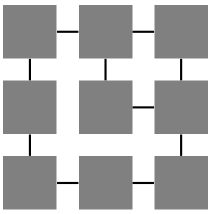
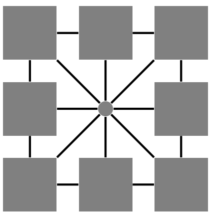
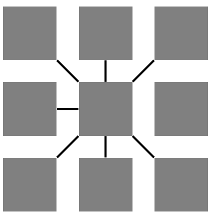
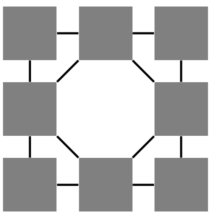
	Corrected System	Reason
		
		
		
		
		
		

Table 6.1: FireWire structures

Task 6.3: Protocol Design

A customized protocol with serial bus and multiple bus masters should be built for transmission of information with id and data.

A) The transmitted data-field can have any length between 2 and 17 byte, but only full bytes are allowed. To determine the length of the data either an additional length-field or a delimiter can be used. What is the overhead when using an additional length-field?

B) As an alternative to the above task, a delimiter could be used. To ensure, that the delimiter does not appear within the data stream, bitstuffing should be implemented. With respect to bitstuffing, would you prefer a length of 6 bit or 16 bit for the delimiter? Justify your answer.

C) In order to protect messages from transmission errors, a suitable mechanism to guarantee data integrity shall be used. Name two such aproaches and describe them shortly.

D) This network protocol shall be extended to support real time capability for all participants. Name a suitable media access scheme that can be used to ensure this.

E) Why can CSMA/CD not be used to transmit frames of 64 byte data from campus north to campus south (10 km) on a copper 10 Megabit line? What is the maximum allowed transmission bitrate to use this arbitration?
Assume a speed of propagation of $v = 2.5 \cdot 10^8 \frac{m}{s}$.

Task 7: Routing

Task 7.1: General Questions

A) Name and explain two categories of routing strategies, which are addressing different optimization goals.

B) Name an example for a non-minimal routing strategy. Additionally provide one advantage and one disadvantage of non-minimal routing.

C) Describe and explain the two switching schemes circuit and packet switching.

Task 7.2: Routing

A) Describe the routing strategy used for hot potato routing. Describe one advantage and one disadvantage.

B) Name and describe three evaluation criteria for routing algorithms.

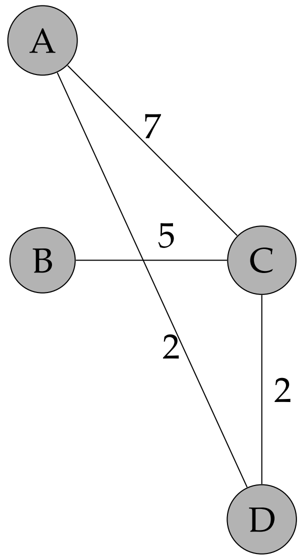


Figure 7.1: Given network topology

C) Figure 7.1 represents a network for which an optimal routing has to be found. The weights represent an abstract metric for traffic present at each connection. With node **B** as the starting point, calculate the paths with the lowest total traffic in the network 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.

node	step 1 **B**		step 2		step 3		step 4		step 5	
vertex	trf.	pred.	trf.	pred.	trf.	pred.	trf.	pred.	err.	pred.
A	∞	-								
B	0	B								
C	∞	-								
D	∞	-								

Table 7.1: Dijkstra's algorithm

Task 8: Network Topologies

Task 8.1: General Questions

A) Explain diameter of a network. What is the diameter of a 5x5 Torus network?

B) Compute the Edge Connectivity and Diameter for 1x4 Torus, 8 node Star, 8 node Ring and 2x2x2 Torus topologies. All links here are bidirectional. Use the table below.

Topology	Edge Connectivity	Diameter
1x4 Torus		
8 Node Star		
8 Node Ring		
2x2x2 Torus		

Table 8.1: Topologies and Metrics

Task 8.2: 3D Topology

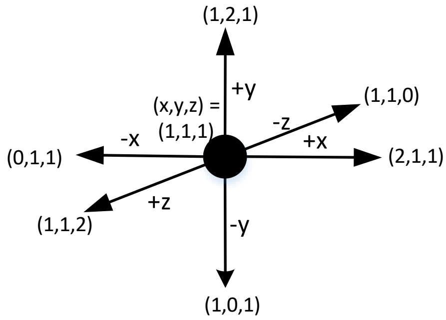


Figure 8.1: Node at (x,y,z) = (1,1,1)

A) Consider a 7x6x3 3D mesh topology for this task. There is a congestion present in the link from node (5,3,2) to node (5,2,2). Find the path from the source point (x,y,z) = (6,4,2) to the destination point (x,y,z) = (5,1,1) using the 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 the link chosen is congested, disregard it and choose among the remaining directions from the local position towards the destination, prioritising first X, then Y, then Z.

Rule3 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.

Rule4 If the direction chosen using Rules 1 or 2 or 3 leads you to the most recently visited node, delete the packet.

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

B) There is another congestion present in the link from node (2,1,2) to node (2,2,2). Find the path from the source point (x,y,z) = (4,1,2) to the destination point (x,y,z) = (2,2,2) using the routing algorithm described above. Does the packet reach the destination? In your answer please name all traversed nodes (i.e. their coordinates) in the correct sequence. Mention which of the above mentioned rules you used at each step to go to the next node.

C) Explain deadlock and livelock in a network.

Additional sheet for task $\boxed{}$: