Examination (SS 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: September 20, 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.
- 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 **35 sheets**.

		Page	≈ Pts. in %	Points
Task 1:	Physical Basics	2	13	
Task 2:	Transmission Principles	7	12	
Task 3:	Modulation and Spread Spectrum	12	12	
Task 4:	Media Access	18	11	
Task 5:	Error Protection	21	11	
Task 6:	Protocols	25	12	
Task 7:	Routing	29	13	
Task 8:	Network Topologies	32	11	
				Σ

Task 1: Physical Basics

Task 1.1: Differential Signaling

A) Name two advantages of differential signal transmission over single-ended signaling.

B) For the following schematic of an Emitter Coupled Logic (ECL) sender compare the case when Input is HIGH ($Input_H$) and when Input is LOW ($Input_L$). Consider the currents I_{T_1} ... I_{T_4} flowing through the transistors T_1 ... T_4 and the output voltages V_{Out_1} and V_{Out_2}. In the boxes indicate if these currents and voltages, respectively, are higher (>), lower (<) or equal (=) for $Input_H$ in comparison to $Input_L$.

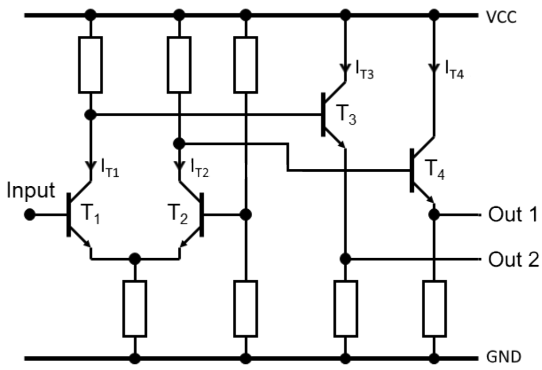


Figure 1.1: Diffential output driver

$I_{T_1}(Input_H)$	☐	$I_{T_1}(Input_L)$
$I_{T_2}(Input_H)$	☐	$I_{T_2}(Input_L)$
$I_{T_3}(Input_H)$	☐	$I_{T_3}(Input_L)$
$I_{T_4}(Input_H)$	☐	$I_{T_4}(Input_L)$
$V_{Out1}(Input_H)$	☐	$V_{Out1}(Input_L)$
$V_{Out2}(Input_H)$	☐	$V_{Out2}(Input_L)$

Task 1.2: Communication Buses

A) Name two ways to avoid short circuits when connecting multiple senders to a bus line.

B) Draw a bus line with two open-collector drivers. 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).

C) Explain the concept of "Wired AND" in bus communications.

Task 1.3: Reflection on wires

A) A long signal line can be modelled as a sequence of quadripoles each representing an infinitesimally short segment of the line. Explain the four components R', L', C', and G' and what they represent in this model.

B) Which components of the quadripole model are known in the lossless case? Give the values for these components.

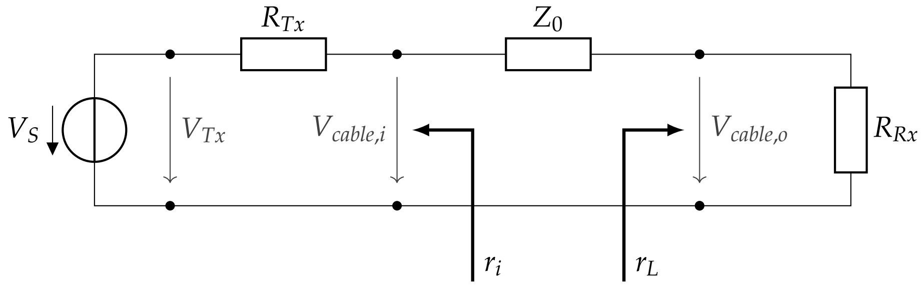


Figure 1.2: Test setup

In Figure 1.2, the equivalent circuit diagram of an ideal (lossless) 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 signal line is characterized by $Z_0 = 30\,\Omega$. $R_{Tx} = 50\,\Omega$, $R_{Rx} = 90\,\Omega$.

C) Give the formula for calculating the reflection factors in general. Give the value of the reflection factors r_i and r_L.

At the time $t = 0$ the voltage V_S of the sender changes from 0 V to 16 V and is constant afterwards. The run time of a wave on the cable is t_d.

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

E) Calculate the voltage $V_{cable,m}$ in the middle of the line at the times $t \in \{0, t_d, 2t_d, 3t_d\}$. Neglect all transient events, use ideal rectangular impulses for calculation.

F) What needs to be fulfilled to avoid reflection at the end of the line? Give the general requirement. What can be done to achieve this for the receiving side of the setup shown in Figure 1.2 (no calculation required)?

Task 2: Transmission Principles

Task 2.1: Line Codes

A) We want to transmit the value "1001 0110 0111" through a serial wire communication channel. Complete Figure 2.1 with the digital signals transmitted using each given encoding scheme.

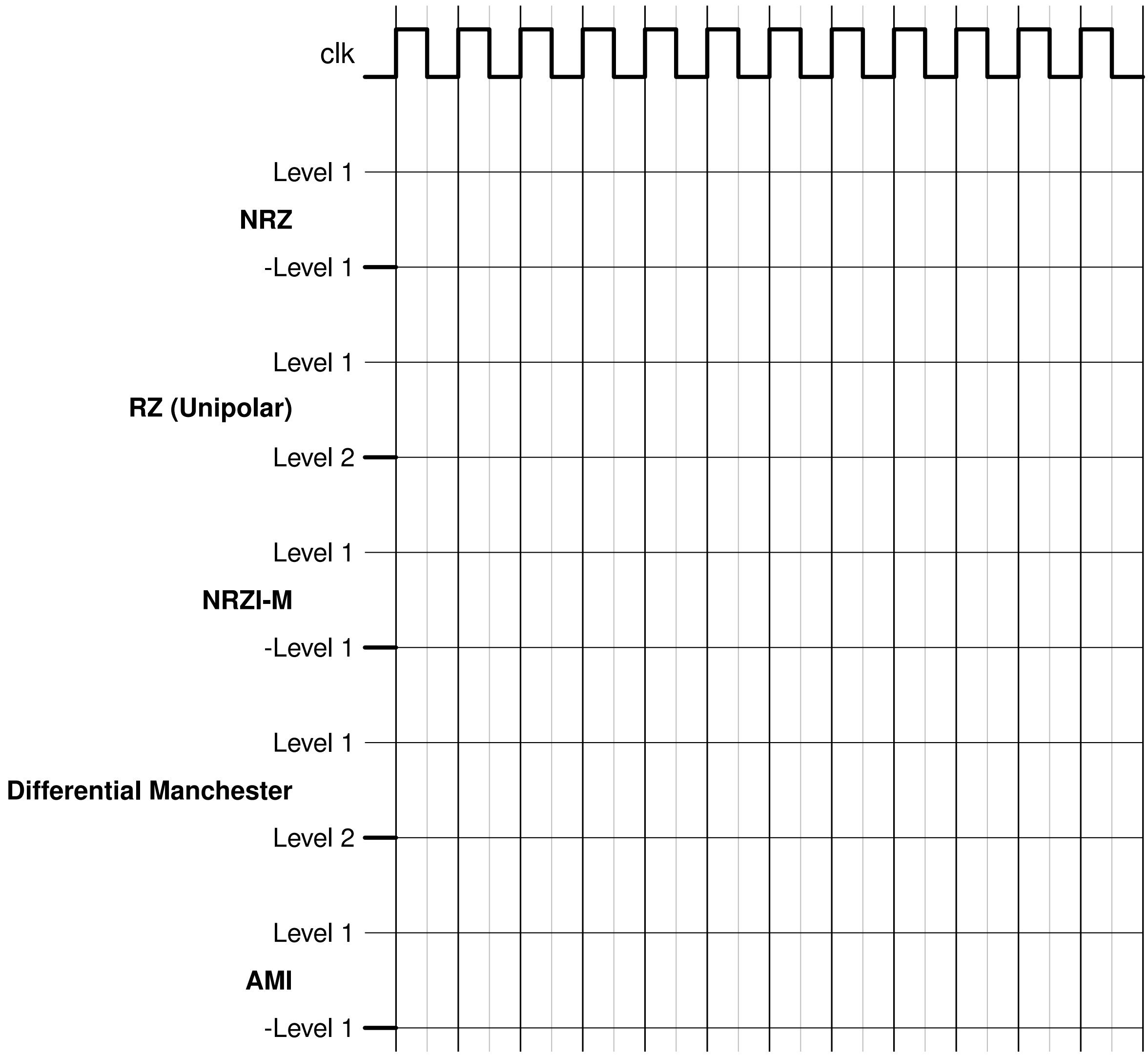


Figure 2.1: Line codes

B) Classify the line codes given in Question A according to their clock recovery properties. Do the codes always have this property? Justify your answer for each of the codes.

NRZ:

Unipolar RZ:

NRZI-M:

Differential Manchester:

AMI:

C) An approach used to synchronize communication processes is the use of Flow-Control. Complete the signals in figure 2.2 to perform two transmissions of DATA values 0xA and 0x5 using Level-Triggered Closed-Loop Flow Control II. This approach uses Valid and Busy signals. 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 at falling edge of the clock, and that the receiver required 1 cycle to read the value.

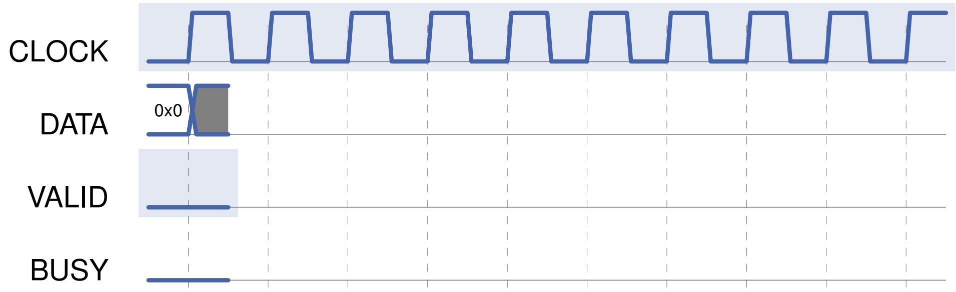


Figure 2.2: signal sequence

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.

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

data transfered (n bytes + acknowledge)

term	description
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) Consider the following cases where two masters try to access the same slave.
Case 1: Two masters try to perform a read operation at the exact same time.
Case 2: Two masters try to perform a write operation at the exact same time.
Case 3: One master tries to read and the other master tries to write at the exact same time.
What happens in each case ? Is the write or read operation successful in each case? Explain if any collisions could be detected and how they are detected. Justify your answer for each of the cases.

C) The diagram in Figure 2.4 corresponds to a I^2C 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	0	01111001
Master 2	1010101	1	01011010
Master 3	1010111	0	01000011

Table 2.1: I^2C Communication Parameters

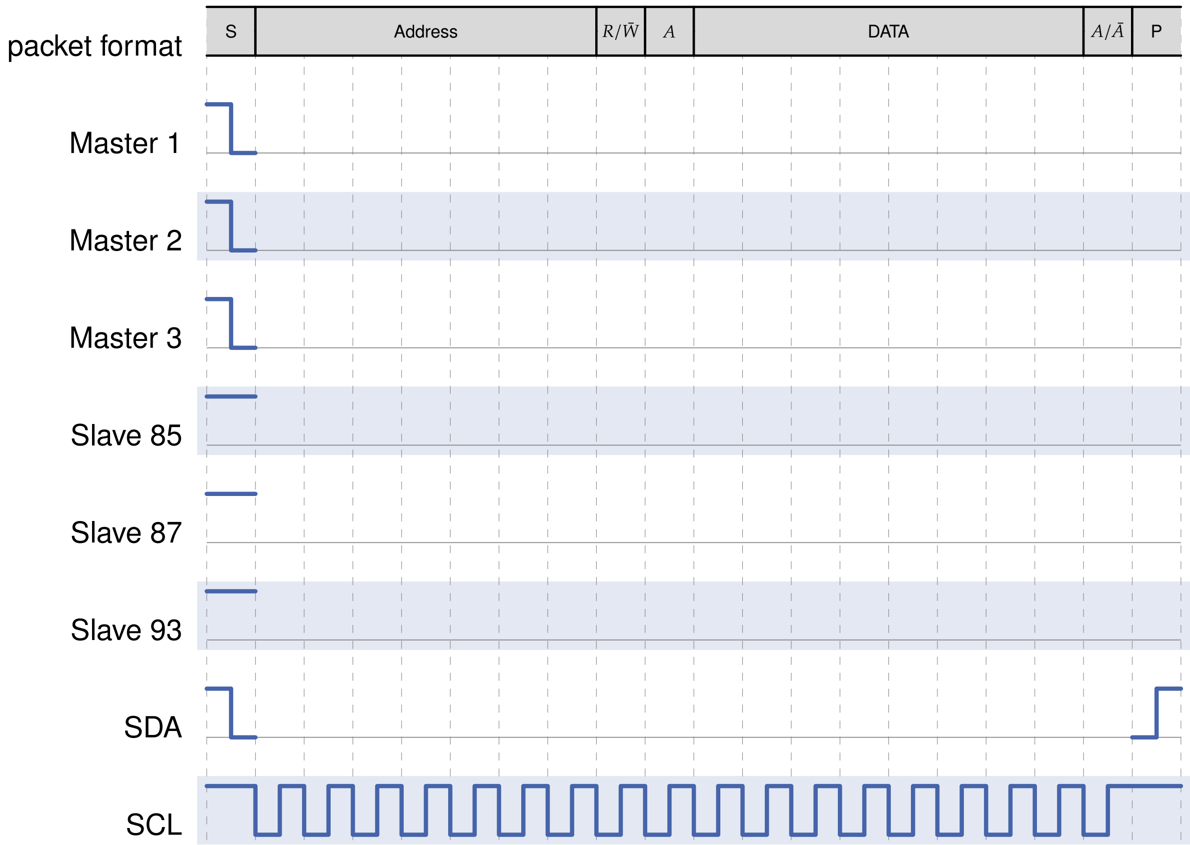


Figure 2.4: I^2C Signal sequence

Task 3: Modulation and Spread Spectrum

Task 3.1: Modulation

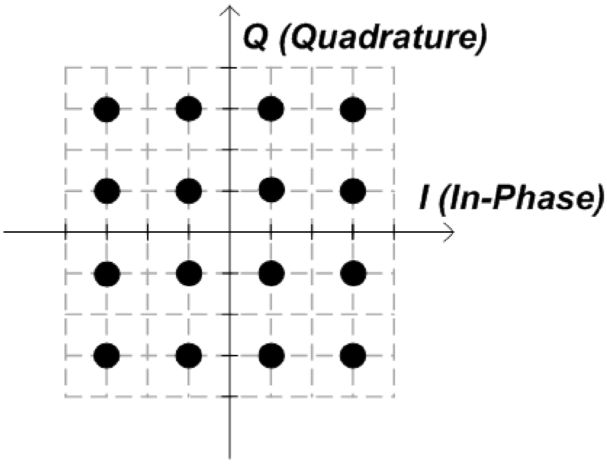


Figure 3.1: Constellation Diagram

A) The constellation diagram of a certain modulation scheme is shown in Figure 3.1. How many possible phase values can be used in this modulation scheme? Indicate the values in the Figure 3.1.

B) How many carrier frequencies are used in the QAM modulation scheme?

C) Draw a block diagram (using adders and multipliers) for the QAM modulator. Use $I(t)$ and $Q(t)$ as names for the inputs and $s(t)$ as name for the output.

D) A constellation diagram of an 8-QAM scheme is shown in Figure 3.2. The bits **111001110100** shall be transmitted and will be encoded from the left to the right. The Figure 3.3 shows the in-phase carrier signal (B), in-phase symbol (A), and in-phase modulated signal (C). Figure 3.4 shows the quadrature carrier signal (E), quadrature symbol (D), quadrature modulated signal (F). Use Figure 3.3 (A and C) and Figure 3.4 (D and F) to sketch the waveforms of symbol representations and modulated information signals seen from in-phase and quadrature axes. The symbol period is twice as long as the period of carrier signal.

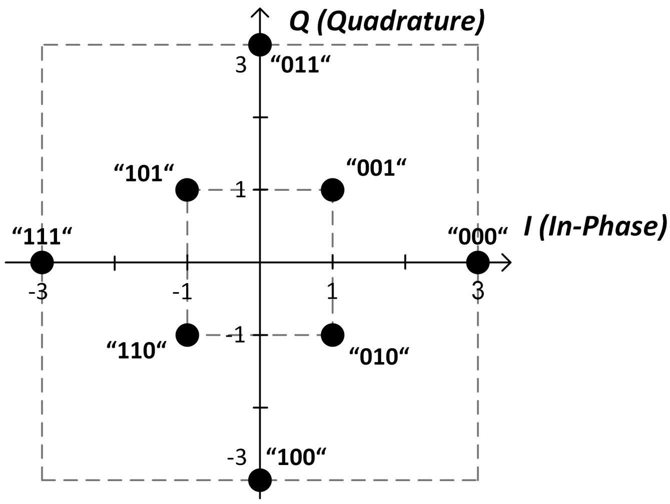


Figure 3.2: Constellation Diagram of an 8-QAM scheme

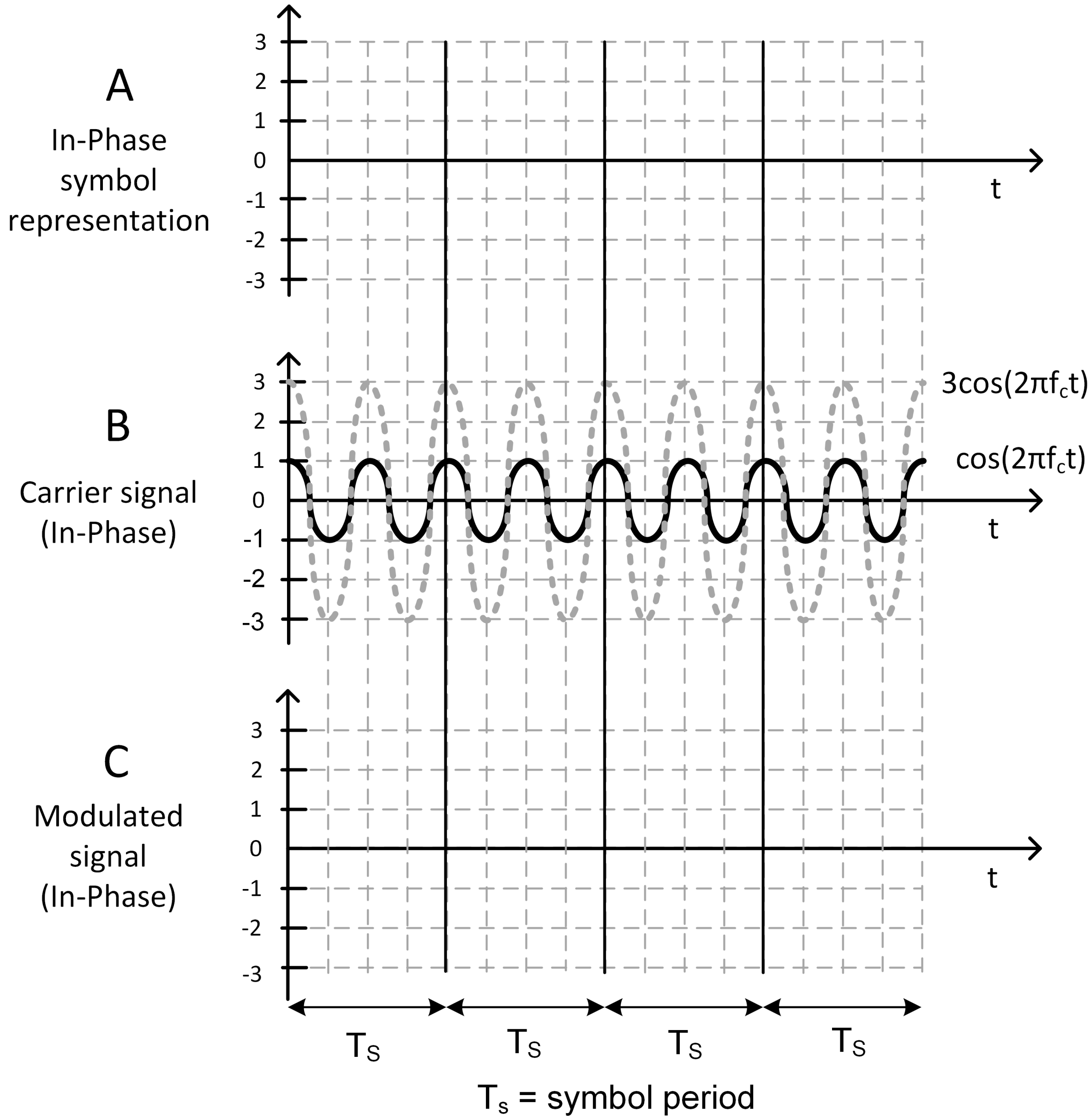


Figure 3.3: In-Phase Symbol Representation, Carrier Signal (In-Phase), and Modulated Signal (In-Phase)

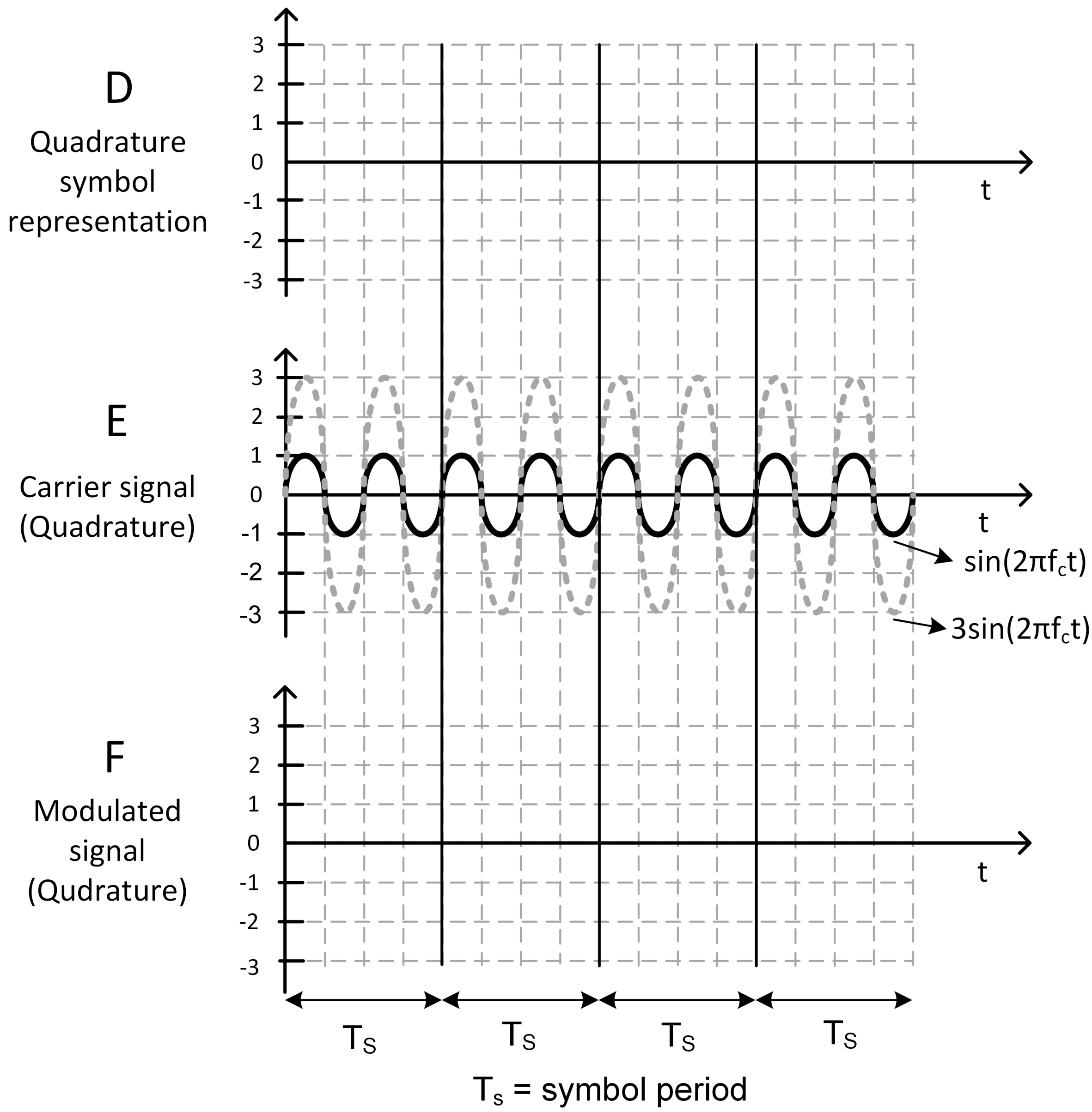


Figure 3.4: Quadrature Symbol Representation, Carrier Signal (Quadrature), and Modulated Signal (Quadrature)

Task 3.2: Spread Spectrum

A) The Walsh functions in Table 3.1 shall be used for the simultaneous transmission of eight nodes. To determine which signal is sent, complete the blank cells in the *Signal to be Sent* column of Table 3.2 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							
0	"0"								
4	"0"								
5	"0"								
6	"1"								
others	"silent"								
Signal on Media									

Table 3.2: Transmission with CDMA

B) In the *Signal on Media* row of Table 3.2, write down the summation value when nodes 0,4,5,6 are sending data as shown and other nodes are silent. Now consider a case where one node connected to the bus wants to receive the data encoded by node 4. Write down the summation value which would be calculated by the receiver node. Explain how you calculate the received value and write down the calculation steps.

C) Consider a case where one node connected to the bus wants to receive data sent by node 1. Use the *Signal on Media* values computed in the previous task and write down the summation value which would be calculated by the receiver node. Write down the calculation steps. Consider that there is no disturbance in the bus.

D) Show that Walsh function 0 is orthogonal to function 1. Also give the result of the inner product of Walsh function 0 with itself.

E) Explain why the orthogonality is required for this CDMA scheme.

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 an 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 1.5 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) Why is it necessary to establish minimal packet length when using CSMA/CD as arbitration scheme?

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

D) A minimal package length of 64 bytes for the bus system is chosen. 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 four bits. Is this bus system working with these constraints? Give an explanation!

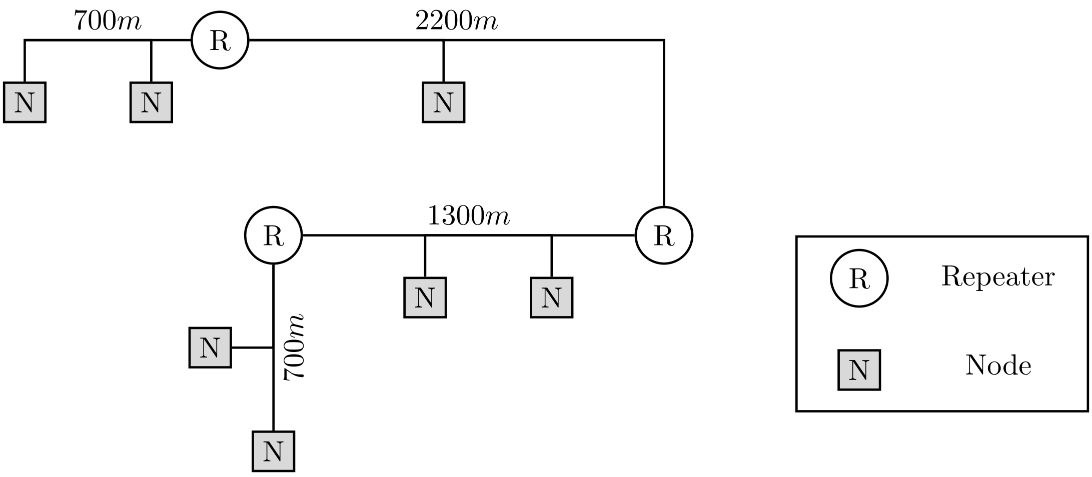


Figure 4.1: Ethernet topology

Task 4.2: CSMA/CR

A bus system of four nodes is using CSMA/CR as arbitration scheme and is 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) Name two advantages of CSMA/CR in contrast to CSMA/CD, explain your answers briefly.

B) The data format includes 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

Node	Identifier
A	10101
B	10011
C	10010
D	10100

Table 4.1: Identifiers of the nodes

diagram 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?

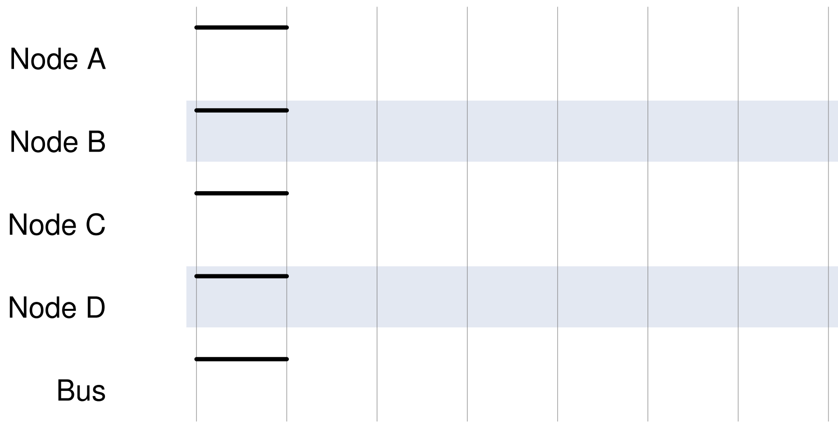


Figure 4.2: Bus Access

Task 5: Error Protection

Task 5.1: Cyclic Redundancy Check (CRC)

A) Given a CRC generator polynomial of $G(x) = x^5 + x^4 + 1$, what is the maximum burst error length that is guaranteed to be detectable in a CRC-protected frame? Justify your answer.

B) Assume that a specific CRC scheme employs $G(x) = x^4 + x^3 + x^2 + 1$ as its generator polynomial. Does this guarantee the detection of all error patterns with an odd number of erroneous bits in a protected frame? Justify your answer.

C) Draw the simplified form of the linear feedback shift register with XOR operations implementing the CRC generator polynomial $G(x) = x^{12} + x^8 + x^7 + x^6 + x^2 + 1$.

D) Assume that the message "1101 0100 1110" is to be transmitted over a channel. In order to enable the receiver to detect transmission errors, a CRC checksum based on the generator polynomial $G(x) = x^6+x^3+x^2+x+1$ shall be added. Calculate the corresponding checksum and give the bit string that is sent to the receiver.

E) Suppose that for CRC protection, a sender and a receiver have agreed upon the generator polynomial $G(x) = x^5+x^2+x+1$. Perform the CRC error detection scheme that the receiver carries out for the received bit string "0110 1000 0011 1". Which guarantee can the receiver deduce from the result with respect to single-bit errors?

Task 5.2: 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 5.1). During the transmission of the data field, just after a bit has successfully been transmitted, the sender is affected by a permanent supply voltage failure (visualized by the "↯" symbol). From this point on, the sender transmits recessive bits only. Complete the empty columns in Figure 5.2 with the signal values that the three CAN nodes transmit in response to this event.

Hint: *The general form of a CAN error frame is visualized in Figure 5.1. Assume that throughout the considered time interval, none of the receivers has any data to transmit. Assume further that since the last hardware reset of the three nodes, no other errors have occurred.*

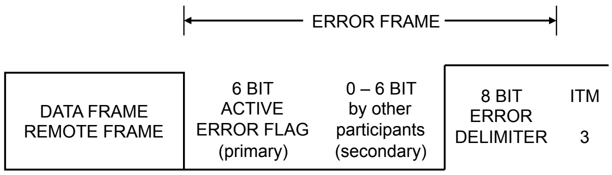


Figure 5.1: Error frame of the CAN protocol

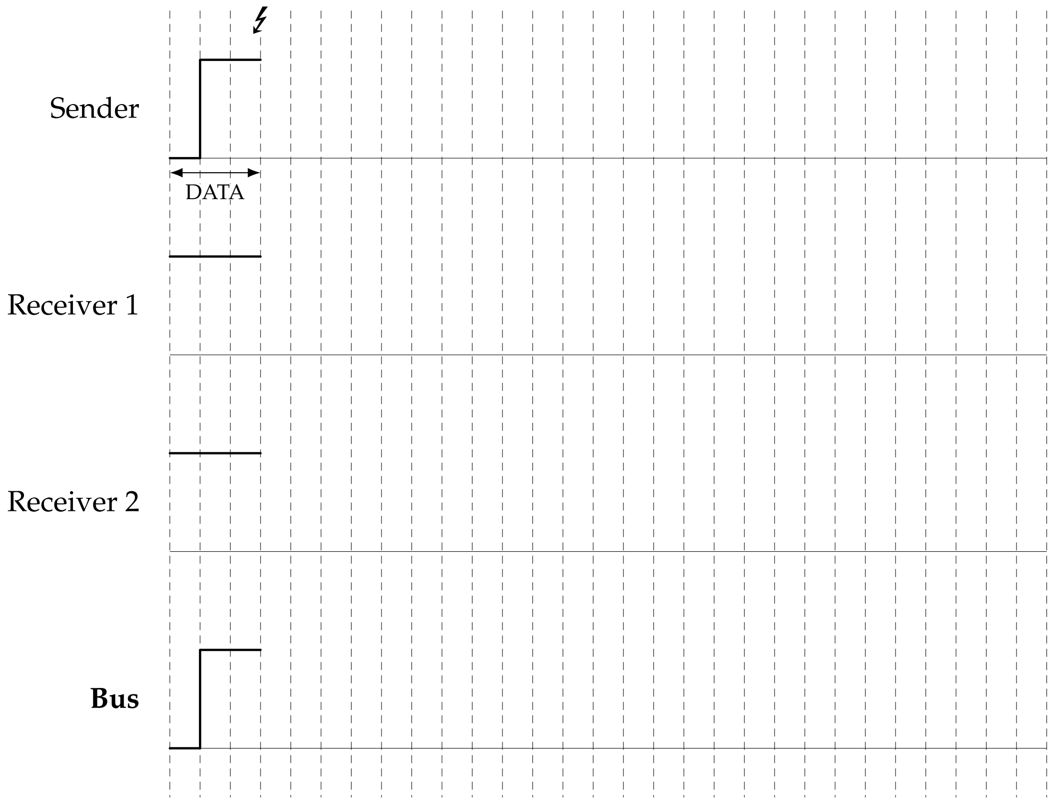


Figure 5.2: Signal sequence diagram of the CAN bus

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

C) Consider a CAN node that is connected to a CAN network with no further activated nodes. Initially, both its receive and its transmit error counter is zero. Suppose that this node begins to transmit an infinite stream of CAN messages, remains free from physical faults, and does not encounter any bit monitoring errors. Which error state will it eventually enter and retain? Justify your answer.

Task 6: Protocols

Task 6.1: FireWire Arbitration

The FireWire network shown below is given.

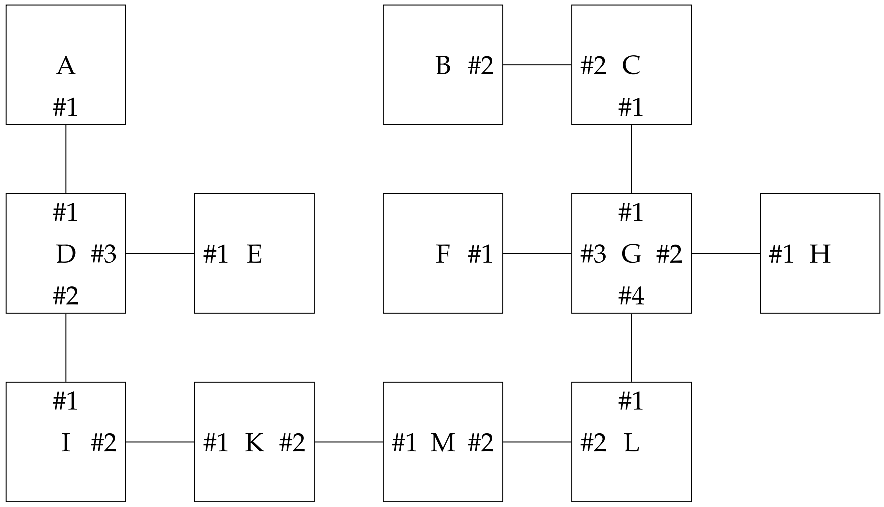


Figure 6.1: FireWire network

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

B) Which connection needs to be changed in Figure 6.1 in order to get node E as root. Hint: Only one connection needs to be removed and one connection needs to be inserted. You may mark the conecction in Fig. 6.1

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.

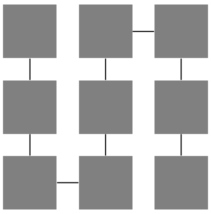
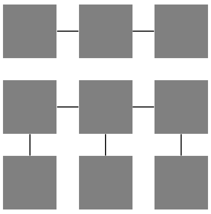
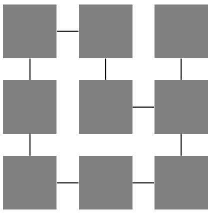
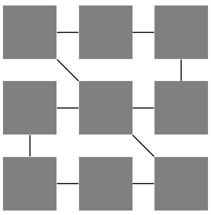
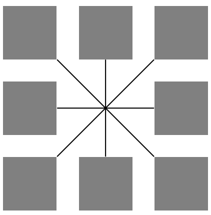
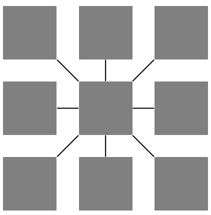
	Correct	Wrong	Reason
			
			
			
			
			
			

Table 6.1: FireWire structures

Task 6.3: ITIV-Protocol

A customized protocol with multiple clients should be build for transmission of information with id and data.

A) The transmitted data-field can have any length between 2 and 64 bits. To determine the length of the data either an additional length-field or a delimiter can be used. What is the minimum additional worst case overhead when using an additional length-field?

B) In the above task, consider when a delimiter is used. Consider a case where a delimiter of size 6 bits is used and another case where a delimiter of size 16 bits is used. Explain advantage and disadvantage of the different sized delimiters with respect to bitstuffing.

C) The custom protocol should ensure data integrity. How can data integrity be checked on physical layer without adding additional bits or sending the data frame redundantly.

D) Besides of data integrity an error correction is necessary. Name a possible mechanism to correct faulty data without sending the data-field twice.

E) To read the data from the bus a clock recovery is neccessary. How can clock recovery be done without changing line code?

F) In order to isolate the network and the components, the components should be capacitively coupled. Therefore a DC free conecction is necessary. Name two line codes to get an DC free transmission.

G) Why can CSMA/CD not be used to transmit frames of 64 bit data from campus north to campus south (10 km) on a copper Gigabit line? What's the maximum allowed transmission bitrate to use this arbitration?

H) How can a network made real time capable for all participants?

Task 7: Routing

Task 7.1: NoCs

A) Name the three building blocks of a NoC and explain their basic function.

B) Both NoCs and bus systems have their advantages and disadvantages. Compare both systems in terms of their scalability with increasing demand for bandwidth due to additional participants.

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

D) Which switching approach is preferable in networks, where messages are sent rarely and with small payloads ? Explain the reasons for your choice.

Task 7.2: Routing

A) Routing approaches are tightly coupled to a network's topology. Name and describe one algorithm that can be efficiently used for mesh topologies and one that is efficient for irregular topologies. Compare these algorithms in terms of their complexity.

B) Explain both static and dynamic routing algorithms. For each routing scheme describe a network in which the respective scheme is preferable.

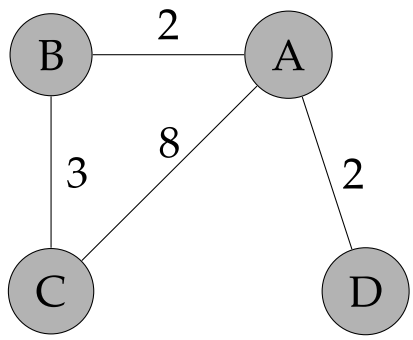


Figure 7.1: Given network topology

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 C 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.

	step 1		step 2		step 3		step 4		step 5	
node	**C**									
vertex	trf.	pred.	trf.	pred.	trf.	pred.	trf.	pred.	trf.	pred.
A	∞	-								
B	∞	-								
C	∞	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 12x5 mesh network?

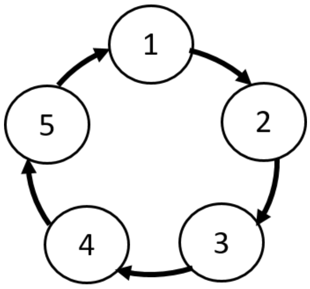


Figure 8.1: A five node unidirectional ring network

B) What is the diameter of a N node unidirectional Ring network? A 5 node unidirectional ring network is shown in Figure 8.1 as an example. Is such a topology suitable for safety critical applications? Explain your answer.

C) Compute the Edge Connectivity and Diameter for 5x3 Torus, 15 node Star and 15 node Ring topologies. All links here are bidirectional. Use the table below.

Topology	**Edge Connectivity**	**Diameter**
5x3 Torus		
Star		
Ring		

Table 8.1: Topologies and Metrics

Task 8.2: 3D Topology

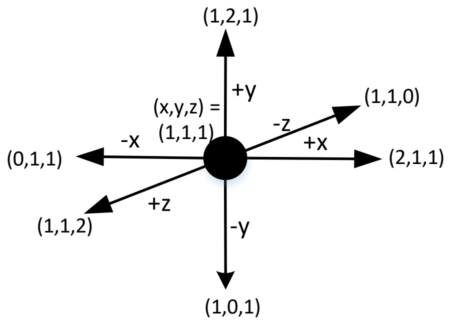


Figure 8.2: Node at (x,y,z) = (1,1,1)

A) Consider a 4x8x6 3D mesh topology for this task. There is a congestion present in the link from node (1,3,1) to node (1,2,1). Find the path from the source point (x,y,z) = (2,4,1) to the destination point (x,y,z) = (1,2,2) 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 8.2 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 mentioned rules you used at each step to go to the next node.

B) Another congestion has occured in the network along with the previous one. The new congestion is present in the link from (2,5,4) to (2,6,4). Find the path from the source point (2,3,4) to the destination point (2,7,4). 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. What do you notice ? Explain your answer.

C) Is the result of the above routing algorithm minimal? Explain your answer.

D) What is the diameter and edge connectivity of a 4x8x6 3D Mesh topology.

E) Explain deadlock and livelock in a network.

F) Name one motivation for using virtual channels in a NoC router.

Additional sheet for task $\boxed{}$: