ELEX 3525 : Data Communications
2020 Fall Term

Solutions to Final Exam

Question 1 (3 marks)

A guidance system transmits three different commands to a remote-controlled vehicle with the following probabilities:

- continue straight: 75%
- turn left: 12.5%
- turn right: 12.5%

1. What is the entropy of the source?
2. If one message is transmitted every 100ms, what is the information rate of the commands being transmitted?

Answer

As defined in Lecture 1, the entropy is:

$$H = \sum_i (-\log_2(P_i) \times P_i) \quad \text{bits/message}$$

$$= -0.75 \times \log_2(0.75) - 2 \times 0.125 \times \log_2(0.125)$$

$$= 1.06 \text{ bits/message}$$

If one message is transmitted every 100 ms the message rate is 10 messages/second and the information rate is $1.06/0.1 = 10.6$ bps.

Question 2 (3 marks)

The Korean character for Kim (김) has a Unicode code point of U+AE40. What are the values of the x, y and z bits as defined in Table 3-6 of the Unicode standard?

Answer

The code point in binary is **`1010 1110 0100 0000`**. The z, y and x bits are defined by the four, six and six bits starting at the most-significant bit:

```
z = 1010
y = 1110 01
x = 00 0000
```

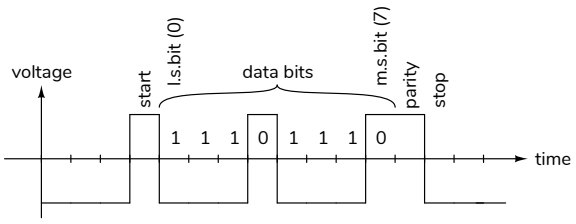
Question 3 (2 marks)

You measure an RS-232 signal with an oscilloscope and find that the voltages are +7 V and −2.5 V. Is this signal guaranteed to be properly decoded by an RS-232 receiver? Why or why not?

Answer

At the receiver the voltage must be greater (more positive) than +3 V or less (more negative) than −3 V. −2.5 V is not more negative than −3 V so it is an invalid level and the receiver may not properly decode it as a low level.

Question 4 (4 marks)



You observe the waveform shown above and are told it's an asynchronous serial transmission with 8 bits per character.

1. Was parity used?
2. If so, was it even or odd parity?
3. What value, in hexadecimal, was transmitted?

Answer

As shown above, there is an additional bit after the eight data bits following the start (high) bit. This must be a parity bit. So **yes**, parity was used.

The parity bit is high (0) and the sum of the data bits is 6 so the sum of all the bits is 6, an even number and so **even** parity was used.

The bits in order from most- to least-significant are **`0111 0111`** which is **0x77** in hexadecimal.

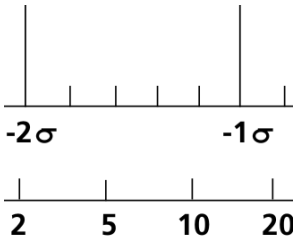
Question 5 (3 marks)

A noise signal appears to have a Gaussian probability distribution and zero mean. About 10% of the time the voltage is less than −3 V. What is the RMS voltage of the signal?

Hint: Use the graph in the Lecture 3 notes to obtain the *normalized* threshold from the probability given in the question.

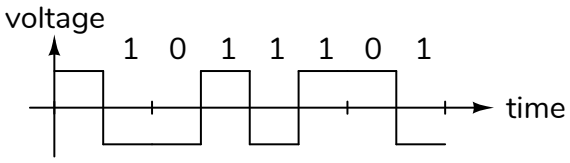
Answer

From the graph in Lecture 3:



the normalized threshold, t, for a cumulative probability of 10% is approximately −1.2. Solving the equation $t = {}^{(x-\mu)}/_{\sigma}$ for the RMS voltage of the signal, σ: $\sigma = {}^{(x-\mu)}/_{t}$. Substituting $x = -3$, $\mu = 0$, and $t \approx -1.2$, the RMS voltage is $\sigma \approx {}^{-3}/_{-1.2} = 2.5\ V_{\text{rms}}$.

Question 6 (4 marks)



The diagram above shows a data signal encoded using differential NRZ (NRZI). Assuming a '1' is encoded as a change, what bit sequence was transmitted? Ignore the value of the first bit.

Answer

The diagram has been marked with a '1' where the level changed and a '0' where the level did not change from bit to bit, ignoring the first bit. The bit sequences is thus: `1011101`.

Question 7 (2 marks)

You measure the following voltages for a communication system using differential signalling:

- on TD+: 5 V
- on TD−: 3 V

What are the common-mode and differential voltages?

Answer

The common-mode voltage is the average of the two voltages: ${}^{(5+3)}/_{2} = 4$ V. The differential voltage is the difference: $5 - 3 = 2$ V. (The opposite polarity for the differential voltage was also marked correct.)

Question 8 (1 marks)

A modem has an output impedance of 75 ohms. What type of transmission line is it probably designed to work with?

- 50 ohm coaxial cable
- 75 ohm coaxial cable
- 100 ohm twisted pair cable

Answer

The characteristic impedance of the transmission line should match the output impedance of the transmitter (and input impedance of a receiver) for the highest power transfer and lowest reflections. Thus the answer is 75 Ω cable.

Question 9 (1 marks)

An optoisolator requires the same ground connection for the input and output.

- True
- False

Answer

The advantage of an optoisolator is that data is transferred using light and no electrical connection, not even a ground return, is needed. Thus the answer is False.

Question 10 (3 marks)

Use PPP framing to convert the following sequence of bytes into a PPP frame (do not add a header; only add the bytes and other changes required for framing and escaping).

```
0x20  0x73 0x7d 0x00
```

For PPP framing we add a flag byte (`0x7e`) before and after the frame, insert an escape character (`0x7d`) before each flag or escape character and invert bit 5 of each escaped character (xor with `0x20`). This results in:

```
0x7e 0x20  0x73 0x7d 0x5d 0x00 0x7e
```

Answer

Question 11 (3 marks)

The message consisting of the sequence of the nine bits 1001 1101 0 includes a CRC computed using the basic CRC algorithm described in the lecture notes. The generator polynomial for computing the CRC was $x^3 + 1$ (1001).

- What is the remainder after dividing by the generator polynomial?
- Does the message contain errors?

Answer

The long division of the message and CRC by the generator polynomial is:

```
100111010
1001
----
 0001
 ----
  0011
  ----
   0110
   ----
    1101
    1001
    ----
     1000
     1001
     ----
      001
```

Since the remainder, 001, is not zero then an error must have been introduced by the channel.

Question 12 (4 marks)

A code includes the four four-bit codewords: 1001, 0110, 1010, and 0101.

1. What is the minimum distance of this code?
2. What is the maximum number of errors that this code is guaranteed to detect?
3. What is the maximum number of errors that this code is guaranteed to correct?

Answer

1. The Hamming distances between the codewords are either 4 bits or 2 bits. The minimum distance is thus $d_{min} = 2$ bits.
2. This code is guaranteed to detect $d_{min} - 1 = 1$ errors.
3. This code is guaranteed to correct $\lfloor (d_{min}-1)/2 \rfloor = 0$ errors.

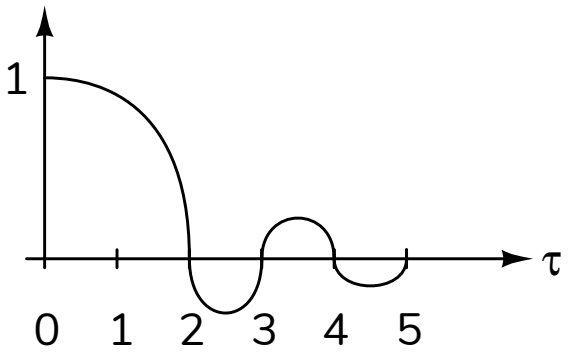
Question 13 (2 marks)

You analyze a maximal-length pseudo-random bit sequence and find that the longest run of zeros is 12 continuous zero bits. What is the period of this PRBS?

Answer

The longest run of zeros for a ML PRBS is $n - 1$ for a generator with n-bits of state. In this case $n - 1 = 12$ so $n = 13$ and the period of the generator is $2^n - 1 = 8191$.

Question 14 (2 marks)



A channel has the impulse response shown above. The time axis units are microseconds. What is the maximum symbol rate that can be transmitted over this channel without ISI?

Hint: For what value of T does the impulse response pass through zero every T microseconds?

Answer

By inspection, a symbol rate of 500 kHz (2 μs period) would have no ISI because the impulse response is zero at multiples of 2 μs (2, 4, ...).

Question 15 (2 marks)

An OFDM system uses a sample rate of 64 kHz and operates over a channel with an impulse response that extends for 200 microseconds. What would be an appropriate guard time duration? Give your answer as the number of samples.

Answer

The duration of the guard time should be longer than the duration of the impulse response of the channel (200 μs) to allow the ISI to die down between frames. This corresponds to at least $64 \times 10^3 \times 200 \times 10^{-6} = 12.8$ samples (i.e. 13). Although longer guard times would also work, they could needlessly reduce the throughput.

Question 16 (2 marks)

The first 16 bytes of an Ethernet frame following the preamble are shown below in hexadecimal:

```
12 34 56 78 9A BC DE 11 22 33 44 55 66 77 88 99
```

What is the source MAC address?

Answer

The first six bytes is the destination MAC address and the next six are the source MAC address. Thus the source MAC address is: **`DE 11 22 33 44 55`**.

Question 17 (3 marks)

Select the protocol layer that would specify each of the following protocol characteristics. *(This was matching question.)*

Answer

- MAC address: data link layer
- IP address: network layer
- Manchester line code: physical layer

Question 18 ((1 point) marks)

Which of the following would be used to implement a full-duplex system?

- TDMA
- TDD

Answer

TDD (time division duplexing) would be used to implement duplexing. A duplex system *could* also use TDMA but the purpose of TDMA would be to share a channel between multiple users.

Question 19 (1 marks)

Which of the follow ARQ protocols would provide the highest throughput over a channel with high latency and a high error rate?

- go-back-N
- stop-and-wait
- selective-repeat

Answer

Stop-and-wait ARQ would have a lower throughput on a channel with high latency due to the shorter delay between transmissions.

Go-back-N ARQ would have a lower throughput on a channel with high error rate due to fewer retransmissions compared to selective-repeat.

The ARQ protocol with the highest throughput over this channel would be selective-repeat ARQ.