Chair of Distributed Systems and Security
School of Computation, Information and Technology
Technical University of Munich

Registration number

Signature

Note:

- Cross your immatriculation number in the crossboxes. It will be evaluated automatically.
- Sign in the signature field.
- Allowed tools are only a pocket calculator and an analog dictionary English ↔ native language without notes.
- Potentially helpful formulas from the cheat sheet are printed at the backside.
- Do not write with red or green colors nor use pencils.

This quiz contains multiple choice/multiple answer sub-tasks, i.e. at least one answer option is correct in each case. These sub-tasks are scored with 1 point per correct answer and -1 point per incorrect answer. Missing answers have no effect. The minimum score per sub-task is 0 points.

a)* Which steps in the message transmission add redundancy to the message?

- [ ] Souce coding
- [ ] Channel decoding
- [x] Source decoding
- [x] Channel coding
- [ ] Demodulation
- [ ] Modulation
- [ ] Detection
- [ ] Line coding

b)* What are equivalent values for the size of a 420 000 B large file?

- [ ] 3360 Mbit
- [x] ∼410.16 KiB
- [ ] 420 kbit
- [x] 0.42 MB
- [ ] ∼430.33 KiB
- [ ] 3360 kB

c)* What is the approximate SNR when sending a signal with a power of 17 mW and a noise power of 260 µW is measured?

- [ ] ∼16.85 dB
- [x] ∼18.15 dB
- [ ] ∼46.45 dB
- [ ] ∼2.82 dB
- [x] ∼65.38
- [ ] ∼0.15

d)* What is the smallest achievable step size when quantizing the interval $I_Q = [45; 160]$ with 6 bit codewords?

- [ ] ∼0.70
- [ ] 64
- [ ] ∼0.18
- [ ] ∼0.90
- [x] ∼1.80
- [ ] ∼109.86

e)* What is the quantization error for the read value 9 when the quantization levels are $Q = \{0.5, 1.5, 2.5, 3.5\}$?

- [ ] 6.5
- [x] 5.5
- [ ] 4.5
- [ ] 9
- [ ] 0.5
- [ ] 7.5

f)* A message source Q, emits characters independently and uniformly from the alphabet $\mathcal{A} = \{\pi, \epsilon\}$. What is the information content of the character π, rounded to two decimals?

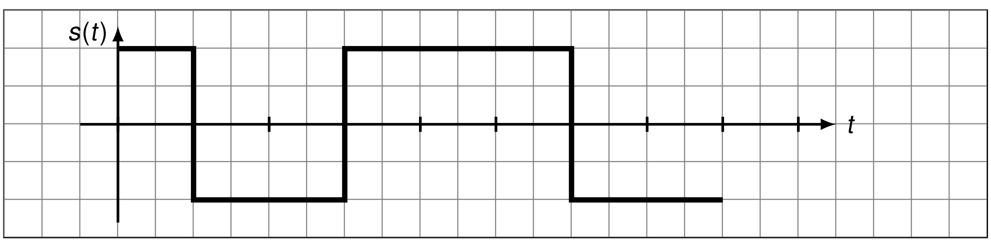
- [ ] 2.71
- [ ] 0.50
- [ ] 0.00
- [ ] 5.75
- [x] 1.00
- [ ] 3.14

g)* What factor **does not** affect the theoretical capacity of a channel?

- [x] Propagation delay
- [ ] Channel bandwidth
- [ ] Number of symbols
- [ ] Signal-to-noise ratio

h)* Given is the baseband signal shown below, which encodes the bit sequence `1001 1100`. Which line code was used to encode the signal?

- [ ] MLT-3
- [ ] Manchester
- [ ] RZ
- [x] NRZ
- [ ] PAM-4



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i)* Argue with an example why clock recovery cannot be done reliably on a signal encoded with the MLT-3 line code.

MLT-3 only changes the signal level on the bit value 1 (depending on the definition also on bit value 0 possible). If the bit sequence to encode is a long sequence of 1 bits, there are no level changes in the signal and the receiver cannot recover the clock in each period but instead has to rely on its internal clock.

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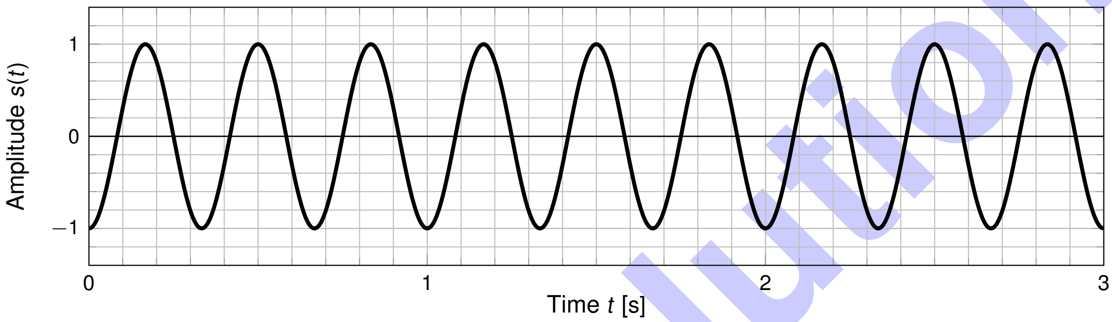
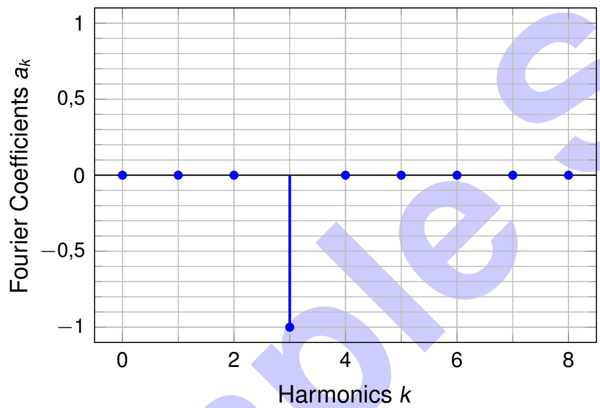
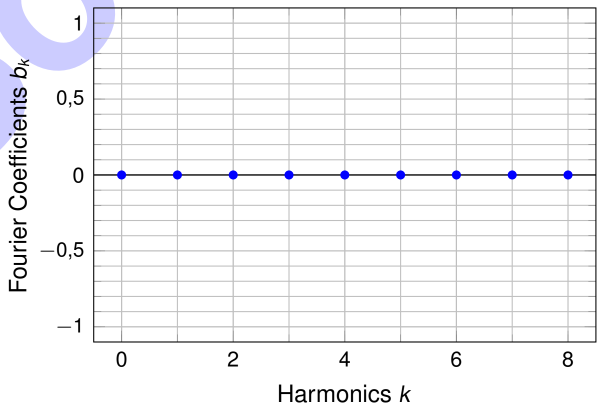
j)* Given is the periodic time signal $s(t)$ shown below. The period of the signal is $T = 1$ s and the angular frequency the standard $\omega = \frac{2\pi}{T}$. Draw the spectrum of the time signal $s(t)$ in the solution box and **include zero values**.







Information content and entropy: Memoryless source emits characters $x \in \mathcal{X}$, expressed by random variable X:

Information content of $x \in \mathcal{X}$: $I(x) = -\log_2(\Pr[X = x])$

Entropy of the source: $H(X) = -\sum_{x \in \mathcal{X}} \Pr[X = x] \log_2(\Pr[X = x])$

Fourier series: angular frequency $\omega = 2\pi/T$

$$s(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos(k\omega t) + b_k \sin(k\omega t) \quad \text{where}$$

$$a_k = \frac{2}{T}\int_{-T/2}^{T/2} s(t)\cos(k\omega t)\,\mathrm{d}t, \quad b_k = \frac{2}{T}\int_{-T/2}^{T/2} s(t)\sin(k\omega t)\,\mathrm{d}t\,.$$

Sampling, Quantization and Reconstruction:

Sampling theorem (Nyquist): $f_N = 2B$ (B is single-sided cutoff frequency in baseband)

Step width: $\Delta = \frac{b-a}{M}$, with $M = 2^N$ steps at N bit accuracy

Quantization levels: $Q = \{a + \Delta/2, a + \Delta(1 + 1/2), \dots, a + \Delta(M - 1 + 1/2)\}$

$\mathbb{R} \to Q$, $\hat{s}[n] \mapsto \bar{s}[n]$ (rounded)

Quantization error: $q_e(t) = s(t) - \bar{s}(t) \leq \Delta/2$, if $a \leq s(t) \leq b$

Channel bandwidth: $C_{\max}$ is an upper bound for the achievable net data rate in bit/s, i.e. transmission of redundancy-free data. For this purpose it may be necessary to add redundancy (channel coding), but this does not change the information content of the message.

Hartley: $C_H = 2B\log_2(M)$ bit

Shannon/Hartley: $C_S = B\log_2(1 + \mathrm{SNR})$ bit

Signal-to-noise ratio: $\mathrm{SNR} = \frac{P_S}{P_N} = \frac{\text{signal power}}{\text{noise power}} = 10^{\frac{\mathrm{SNR}}{10\,\mathrm{dB}}} = 10\log_{10}(\mathrm{SNR})\,\mathrm{dB}$

Upper bound: $C_{\max} \leq \min\{C_H, C_S\}$

Channel coding: Example - Block codes: Blocks with length k bit are mapped to channel words with length n bit where $n > k$. Depending on the code, it is possible to correct $m < n - k$ bit bit errors per channel word.

$x \xrightarrow{k} \boxed{C} \xrightarrow{n} x'$ Code rate: $R = k/n$

Serialization time, Propagation delay, Transmission time, Bandwidth delay product:

Serialization time: $t_s = L/r$

Propagation delay: $t_p = d/(\nu c_0)$

Transmission time: $t_d = t_s + t_p$

Bandwidth delay product: $C = t_p r$