Chair of Network Architectures and Services
Department of Informatics
Technical University of Munich

Eexam
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Network Coding

Exam:	IN2315 / Endterm	**Date:**	Tuesday 18th February, 2020
Examiner:	Prof. Dr.-Ing. Georg Carle	**Time:**	13:30 – 15:00

Working instructions

- This exam consists of **12 pages** with a total of **5 problems**.
  Please make sure now that you received a complete copy of the exam.
- The total amount of achievable credits in this exam is 60 credits.
- Detaching pages from the exam is prohibited.
- Allowed resources:
  - one **cheatsheet (A4)**
  - one **non-programmable pocket calculator**
  - one **analog dictionary** English ↔ native language
- Subproblems marked by * can be solved without results of previous subproblems.
- **Answers are only accepted if the solution approach is documented.** Give a reason for each answer unless explicitly stated otherwise in the respective subproblem.
- Do not write with red or green colors nor use pencils.
- Physically turn off all electronic devices, put them into your bag and close the bag.

Left room from ____________ to ____________ / Early submission at ____________

Problem 1 **Network flow problem (22 credits)**

We consider the four-node wireless network $G = (N, A)$, where all possible induces arcs are depicted in Figure 1.1.

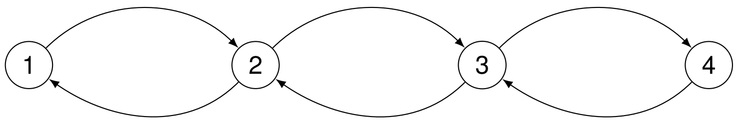

Figure 1.1: four-node network

We assume that packet losses, i. e., erasure events, are indepedently and identically distributed with expectation ϵ_k for all $k \in A$. Assume that all arcs $k \in A$ have unit capacity. Resource shares are denoted by $0 \leq \tau_i \leq 1$ for all $i \in N$. We further assume orthogonal medium access, i. e., nodes do not transmit concurrently. All nodes are in range of each other, i. e., only one node can transmit at a time.

a)* Enumerate the arcs in Figure 1.1 in lexicographic order as known from the lecture.

b)* Determine the incidence matrix.

c)* List all hyperarcs $(a, B) \in \mathcal{H}$ in lexicographic ascending order and assign numbers $j \equiv (a, B)$ in Table 1.1.

d)* List the set of induced arcs A_j for all $j \in H$ in Table 1.1.

e)* Determine the network's hyperarc capacity region (Table 1.1).

f) Determine the network's broadcast capacity region (Table 1.1).
We now consider a unicast session between nodes $s = 1$ and $t = 4$.

g)* Enumerate all $s - t$ cuts S and their respective capacities $v(S_a)$.

cut	capacity

$(a, B) \in \mathcal{H}$	$j \equiv (a, B)$	A_j	z_j	y_j

Table 1.1: Fill in values from different subproblems. (An additional pre-print can be found on Page 12)

0
1

h)* Write the link quality condition(s) for the communication from s to t.

0
1

i)* Express the minimum number of packets to be transmitted by each node on average to transmit N packets.

0
1
2
3

j) Express the resource shares considering all nodes in range.

0
1
2
3

k) Express the resource shares considering nodes 1 and 3 are not in range of each other.

Problem 2 Finite fields and finite extension fields (12 credits)

Given a finite field (Galois field) $\mathbb{F}_p \subset \mathbb{N}_0$ as introduced in the lecture, we seek to define a set of polynomials $F_q[x]$ such that $F_q[x]$ becomes a finite extension field over $\mathbb{F}_p$.

a)* State the condition on $p \in \mathbb{N}$ as well as the finite operators $< +, \cdot >$ such that $\mathbb{F}_p$ is a finite field.

0
1

b)* For which q is an extension field guaranteed to exist?

0
1

c) State the set of elements $F_q[x]$ of an extension field over $\mathbb{F}_p$.

0
1
2

d) Define the binary operators $< +, \cdot >$ such that $F_q[x]$ becomes an extension field.
Note: Take care to fully define all variables you use in your definition!

0
1
2
3

For any $a, b \in F_q[x]$ must hold ...

$$a + b :== \sum_{i=0}^{n-1} (a_i + b_i \mod p)\, x^i$$

$a \cdot b :=$

There are various different implementations for multiplication over binary extension fields. Common approaches are *full table lookups* and *log tables*.

0 1

e) Briefly explain how *full table lookups* work.

0 1 2

f) Briefly explain how *log table lookups* work.

0 1 2

g) For each of those algorithms, give an example of a binary extension field for which you would use the respective algorithm and explain, why you think this algorithm is appropriate for that field.

Problem 3 Link quality estimations (12 credits)

A receiver receives eight packets with the following sequence numbers:

$s_1 = 0$	$s_2 = 22$	$s_3 = 68$	$s_4 = 98$
$s_5 = 102$	$s_6 = 126$	$s_7 = 152$	$s_8 = 201$.

a)* Calculate the number of accumulated received (p_k), accumulated lost (q_k), and lost-since-the-last-reception packets (z_k). 0 1 2 3

$p_1 =$	$p_2 =$	$p_3 =$	$p_4 =$
$p_5 =$	$p_6 =$	$p_7 =$	$p_8 =$
$q_1 =$	$q_2 =$	$q_3 =$	$q_4 =$
$q_5 =$	$q_6 =$	$q_7 =$	$q_8 =$
$z_1 =$	$z_2 =$	$z_3 =$	$z_4 =$
$z_5 =$	$z_6 =$	$z_7 =$	$z_8 =$

b) Calculate and update *EWMA* link quality estimation after every reception for given $\alpha = 0.97$ and initial estimation $EWMA[0] = 1.0$. 0 1 2 3 4

c)* Determine Δt to be able to estimate 1% of link quality, in packet rate of one packet per second. 0 1

0
1
2
3
4

d) Calculate and update *WM-EWMA* link quality estimation after every reception for given α = 0.97, initial estimation *WM-EWMA*[0] = 1.0, and for the previosly calculated Δt.

Problem 4 ETX and EOTX metric (9 credits)

We consider the network depicted in Figure 4.1 that consists of four nodes $N = \{1, 2, 3, 4\}$ ordered according to their EOTX distance $d_{ij}\ \forall i, j \in N$ from left to right in ascending order. The erasure probabilities between nodes are considered independentely and identically desitrbuted with expectation $0 < \epsilon_{ij} < 1\ \forall i, j \in N$.

Figure 4.1: Four-node network. We consider all possible hyperarcs being present.

The EOTX distance d_{ij} between nodes $i, j \in N$ is known from the lecture to be

$$d_{ij} = \underbrace{\frac{1}{1 - \prod_{k<i} \epsilon_{ik}}}_{a)} + \underbrace{\sum_{k<i} d_{kj}(1 - \epsilon_{ik}) \prod_{l<k} \epsilon_{il}}_{b)} . \tag{1}$$

a)* Explain in your own words the meaning the of the first summand in (1).

b)* Explain in your own words the meaning the of the second summand in (1).

c)* Derive d_{12}.

0
1

d) Derive d_{13}.

0
1
2

e) Derive d_{14}.

Problem 5 Quiz (5 credits)

Each of the following subproblems can be solved independently of each other.

a)* Explain the difference between network coding and forward error correction.

0
1

b)* Give an example of bidirectional network coding.

0
1

c)* In multicast networks, state the reasons for maximum flow increase through store-forward, tree-based forwarding and network coding approaches both formally (in terms of constraints) and practically (in terms of actions in the nodes).

0
1
2

store-forward vs tree-based forwarding

formal:

practical:

tree-based forwarding vs network coding

formal:

practical:

d)* How are control frames prioritized over data frames when using the distributed coordination function (DCF) in IEEE 802.11?

0
1

$(a, B) \in \mathcal{H}$	$j \equiv (a, B)$	A_j	z_j	y_j

Table 5.1: Additional pre-print for Problem 1