

ETSN11, Final Exam 2025-10-30, 08:00-13:00

Note: The exam is performed via the Inspira platform, using Inspira Safe Exam Browser. You are welcome to use a calculator, and the formula sheet.

If there are typos in this document, it is the exam in Inspira that is correct.

The exam includes 90 points. Grade 3: You need in total 45 points to pass the exam. **Grade 4:** At least 60 points. **Grade 5:** At least 75 points (the limits for Grade 4 and 5 may be adjusted downwards depending on the results).

Part A: Technologies and architectures (30 points)

In the **multiple-choice questions**, you get points for each correct answer, but **minus 2 points** for each incorrect answer. You cannot get a lower score than 0 in the multiple-choice questions. In the **text questions**, you need to correctly describe the specific terms and concepts to get full points.

1. Which of the following technologies and concepts are suitable for **resource-constrained networking**? (5p)
 - a. BLE Mesh
 - b. ZigBee
 - c. WiFi 6 Mesh
 - d. NB-IoT
 - e. Starlink
 - f. 5G URLLC
 - g. LTE-M
 - h. Argos
 - i. IEEE 802.11
 - j. LoRa
 - k. AODV
 - l. DTN
 - m. DTN
 - n. 5G eMBB
 - o. 5G mMTC
 - p. OFDMA
2. Which of the following statements are true for **ad-hoc networks**? (5p)
 - a. They require contention-free MAC protocols.
 - b. They require contention-based MAC protocols.
 - c. They can use centralized network architectures.
 - d. They can use decentralized network architecture.
 - e. They can be used for time-critical applications.
 - f. They can be used for non-critical applications.
 - g. They can have a DTN architecture.
 - h. They require low communication error rates.
 - i. The nodes in an ad-hoc network always require low energy consumption.

- j. There is always only one gateway in the network.
- k. There can be multiple gateways in the network.
- l. They always use radio-based communication links.
- m. LoRa is an ad-hoc network.
- n. ZigBee is an ad-hoc network.

3. Which of the following statements are true? (5p)
- a. Communication links in outer space can use acoustic communication.
 - b. Communication links in outer space can use optical communication.
 - c. Underwater communication links can use radio communication.
 - d. Space relays are used as base stations on planets.
 - e. Outer space networks often have solar-powered systems.
 - f. Underwater networks often have solar-powered systems.
 - g. Space relays are used to re-direct communication links.
 - h. Space relays are used as base stations on planets.
 - i. A DTN node in space is always placed on a planet.
 - j. DTNs in outer space always use scheduled routing.
 - k. The Bundle protocol is a DTN protocol.
 - l. JANUS is a DTN protocol.
 - m. A space link provides one-way communication between two nodes.
 - n. A space link provides two-way communication between two nodes.
4. Describe the purpose, architecture and main functions of **Bluetooth**. (5p)
5. Describe the main functions for **DTNs** and describe an example of a network system based on a DTN architecture. (5p)
6. Describe the main purpose and functions of **Backhaul links** and give at least three examples of such links. (5p)

Part B: Performance analysis problems (30 points)

Your solutions must be clear and well explained, and please note that there is a math editor. You need to motivate your chosen formulas and calculations to get full points.

7. You design a wireless access network including a base station and several user devices, see the illustration below. You decide to use a MAC protocol based on **slotted ALOHA**. In slotted ALOHA, user devices share a common radio channel, but a user device can only send data frames at specific time instants, called slots. If more than one user device sends a data frame in the same slot, the data is corrupted and lost. When the base station correctly receives a data frame, it sends an ACK to the sender on another radio channel.

There are 4 user devices, A-D.

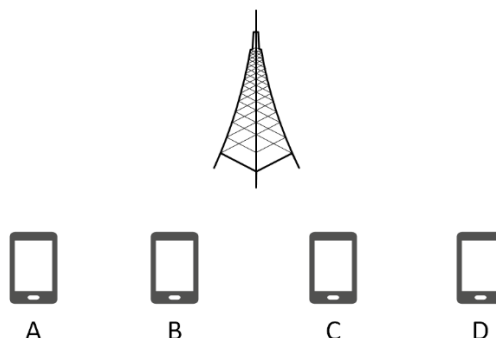
- For each slot, user devices A and B send data frames with probability 0.2, and user devices C and D send data frames with probability 0.3.
- Assume that ACKs always are received before the next time slot has started. The probability that an ACK from the base station is received correctly by the user device is 0.8.
- All user devices and data transmissions are independent of each other.

(15p)

- a. What is the probability that a slot is empty, i.e. none of the user devices send a data frame in this slot? (2p)
- b. What is the probability that there is a data collision in a slot? (2p)
- c. Assume that user device B sends a data frame in a slot. What is the probability that this data frame will be received correctly by the base station? (3p)
- d. What is the efficiency of the MAC protocol, including the ACKs? (4p)

Assume that the application on user device B includes a **Stop-and-Wait ARQ protocol**. If the user device does not receive an ACK when it has sent a data frame, the user device retransmits the data frame in the next slots until it receives an ACK. We can assume that the other user devices send data frames with the same probabilities as above.

- e. Assume that user device B wants to send a data frame. What is the average number of required slots for a successful transmission of this data frame? (4p)



8. You are designing a new **application protocol**. The application protocol receives data packets with information from the transport protocol. The information should be processed by the application and then shown in the graphical user interface (which means that the data packet leaves the application protocol).

The arrivals of data packets can be modelled as a Poisson process with mean 2 packets per second. The average processing time for one data packet is 0.25 seconds. All packets and processing times are independent of each other. (15p)

- a. What is the probability that exactly 2 new data packets will arrive at the application protocol during an interval of one second? (2p)

Assume that you first model the application protocol process as one worker thread with an unlimited job queue. If the worker thread is busy when a data packet arrives, the data packet is placed in the queue. The data packets in the queue are processed first-come-first-served by the worker thread.

- b. Assume that the processing times are modelled with an exponential distribution. What is the average response time for a data packet? (3p)
- c. Assume that the processing times are modelled with a deterministic distribution. What is the average response time for a data packet? (3p)

Assume instead that you model the application protocol as 4 parallel worker threads that independently can process data packets. If there is an idle worker thread when a data packet arrives then the packet is processed (the work is randomly shared between worker threads). If all worker threads are busy when a data packet arrives, the data packet is blocked and leaves the system. The processing time for a data packet that enters a worker thread can be modelled as an exponential distribution with mean 0.25 seconds.

- d. What is the probability that a data packet is blocked? (3p)
- e. What is the average throughput of processed data packets? (4p)

Part C: System design scenarios (30 points)

For each of the scenarios (15p each), describe how you would design the network system. You need to give a suitable solution to the specific scenario. This solution must address the requirements and challenges in the specific scenario and include specific protocols and technologies to get full points.

- Foodora has started a trial with food-delivery robots together with Stockholm municipality, see figure below. About 15 Foodora robots are driving around the area of Södermalm, see map below, delivering food to customers. Currently, the robots are autonomous, using sensors and cameras to avoid crashing into people and other things in their way. The robots have a range of about 3 kilometers. When they have delivered food, they go back to the main central placed in the middle of Södermalm for re-charging and receiving instructions for new deliveries.

Currently, robots are fully autonomous and self-driving, meaning that robot AI is computed in the robot itself. However, Foodora would like to develop a solution for cloud robotics, meaning that the robots should be connected to a network and that robot AI computing is performed in the cloud instead of in the robot itself.

Your task is to help Foodora with this cloud robotics solution. The robots have sensors and cameras, but all computing should be placed in a cloud-based back end. You must suggest a complete network design solution that is suitable for the Foodora food-delivery robots. The robots will continue to operate in Södermalm. You have a decent budget for your solution and all available required technologies.



10. Måkläppen is a nature reserve that protrudes from the Falsterbo peninsula south of Malmö (see figures below). It was created by sandbanks built on top of a moraine core. The total size of Måkläppen (land + water) is about 8 km², where 0.3 km² is based on land and the rest is water.

Måkläppen is mainly famous for the seals that live and breed there. Therefore, Måkläppen is only open for visitors during Nov 1 - Jan 31 to protect the seals. Unfortunately, lots of people do not respect these rules, and they try to visit the nature reserve at other times of the year as well, thereby disturbing the seals and their pups.

Måkläppen Foundation, based in Falsterbo, manages the nature reserve. Your task is to help Måkläppen Foundation with a complete end-to-end network system that has two main objectives:

1. Monitor the seal colony and learn more about the lives of the seals. For example, Måkläppen Foundation wants to learn more on how deep the seals dive when they are looking for food and the seals' average swimming distance per day. You can assume that the seals stay within the Måkläppen reserve.
2. Act as an alarm system to detect when people visit the reserve when it is closed for visitors. You can assume that people come on foot from Falsterbo or by boat.

You have a relatively limited budget, since Måkläppen Foundation is a non-profit organization. You have access to different types of sensors that are animal friendly and that can measure depth and other relevant metrics. Also, the sensors include functions that can detect if they are above or underwater, and they can use GPS. Further, you have access to web cameras and other standard monitoring equipment. Finally, all sensors and equipment can use various wireless network technologies.

