Curriculum for the
Master’s Programme in
Networks and Distributed Systems

Aalborg University
September 2017
Preface:
Pursuant to Act 261 of March 18, 2015 on Universities (the University Act) with subsequent changes, the following curriculum for the Master's programme in Networks and Distributed Systems is stipulated. The programme also follows the Joint Programme Regulations and the Examination Policies and Procedures for The Technical Faculty of IT and Design.
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Chapter 1: Legal Basis of the Curriculum, etc.

1.1 Basis in ministerial orders
The Master's programme in Networks and Distributed Systems is organised in accordance with the Ministry of Higher Education and Science’s Order no. 1061 of June 30, 2016 on Bachelor’s and Master’s Programmes at Universities (the Ministerial Order of the Study Programmes) and Ministerial Order no. 1062 of June 30, 2016 on University Examinations (the Examination Order). Further reference is made to Ministerial Order no. 258 of March 18, 2015 (the Admission Order) and Ministerial Order no. 114 of February 3, 2015 (the Grading Scale Order) with subsequent changes.

1.2 Faculty affiliation
The Master's programme falls under The Technical Faculty of IT and Design, Aalborg University.

1.3 Board of Studies affiliation
The Master's programme falls under the Board of Studies for Electronics and IT.

1.4 External Examiners Corps
The Master's programme is associated with the external examiners for engineering educations: electro (In Danish: censorkorps for Ingeniøruddannelsernes landssækkende censorkorps; elektro).

Chapter 2: Admission, Degree Designation, Programme Duration and Competence Profile

2.1 Admission
Applicants with a legal claim to admission (retnskrav):
Applicants with one of the following degrees are entitled to admission:
- Bachelor of Science in Electronics and IT, Aalborg University
- Bachelor of Science in Computer Engineering, Aalborg University

Applicants without legal claim to admission:
Students with another Bachelor's degree, upon application to the Board of Studies, will be admitted after a specific academic assessment if the applicant is deemed to have comparable educational prerequisites. The University can stipulate requirements concerning conducting additional exams prior to the start of study.

2.2 Degree designation in Danish and English
The Master’s programme entitles the graduate to the designation civilingeniør, cand.polyt. (candidatus/candidata polytechnices) i netværk og distribuerede systemer. The English designation is: Master of Science (MSc) in Engineering (Networks and Distributed Systems).

2.3 The programme’s specification in ECTS credits
The Master’s programme is a 2-year, research-based, full-time study programme. The programme is set to 120 ECTS credits.

2.4 Competence profile on the diploma
The following competence profile will appear on the diploma:

A graduate of the Master’s programme has competencies acquired through an educational programme that has taken place in a research environment.

The graduate of the Master’s programme can perform highly qualified functions on the labour market on the basis of the educational programme. Moreover, the
graduate has prerequisites for research (a Ph.D. programme). Compared to the Bachelor’s degree, the graduate of the Master’s programme has developed her/his academic knowledge and independence, so that the graduate can independently apply scientific theory and method in both an academic and occupational/professional context.

2.5 Competence profile of the programme:

The graduate of the Master’s programme:

Knowledge
- Has an understanding of the concept of complex distributed systems
- Has an understanding of methods within network planning.
- Has an understanding of network design of both general purpose, multipurpose and dedicated networks.
- Has knowledge in one or more subject areas that is based on the highest international research within the fields of networks and distributed systems

Skills
- Can analyze and apply methods, including analytical, numerical and experimental methods, for analysis, design and test of networks and distributed systems, including systems with reliability and/or timing requirements.
- Demonstrate insight in relevant theories, methods and techniques used for distribution, storage and processing of data in a distributed system
- Demonstrate insight in real-time, performance, safety and robustness aspects
- Can apply modeling methods for the behavior of a network, including traffic and queuing.
- Can select and apply advanced methods within analysis and simulation of networks.
- Can apply appropriate methods for performance analysis within networks and distributed systems.
- Can communicate research-based knowledge and discuss professional and scientific problems with peers as well as non-specialists, using the correct terminology.

Competencies
- Have a deep understanding of analysis and design of networks, distributed systems and applications within this domain.
- Can select and apply appropriate methods for solving a given problem within networks and distributed systems and evaluate the results regarding their accuracy and validity
- Can identify scientific problems within networks and distributed systems and select and apply proper scientific theories, methods and tools for their solution
- Can develop and advance new analyses and solutions within networks and distributed systems
- Can manage work-related situations that are complex and unpredictable, and which require new solutions
- Can initiate and implement discipline-specific as well as interdisciplinary cooperation and assume professional
• Can take responsibility for own professional development and specialization.
• Work according to a scientific method and present results in the form of a scientific article and at a seminar/scientific conference.
• Formulate and explain scientific hypotheses and results achieved through scientific work.
• Analyze results and draw conclusions on a scientific basis.

Chapter 3: Content and Organization of the Programme

The programme is structured in modules and organised as a problem-based study. A module is a programme element or a group of programme elements, which aims to give students a set of professional skills within a fixed time frame specified in ECTS credits, and concluding with one or more examinations within specific exam periods. Examinations are defined in the curriculum.

The programme is based on a combination of academic, problem-oriented and interdisciplinary approaches and organised based on the following work and evaluation methods that combine skills and reflection:

• lectures
• classroom instruction
• project work
• workshops
• exercises (individually and in groups)
• teacher feedback
• reflection
• portfolio work
3.1 Overview of the programme:

All modules are assessed through individual grading according to the 7-point scale or Pass/Fail. All modules are assessed by external examination (external grading) or internal examination (internal grading or by assessment by the supervisor only).

<table>
<thead>
<tr>
<th>Semester</th>
<th>Module</th>
<th>ECTS</th>
<th>Assessment</th>
<th>Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>Networks and distributed systems *)</td>
<td>15</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Stochastic Processes</td>
<td>5</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Distributed Real Time Systems</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Wireless PHY/MAC Fundamentals (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Communication Networks and Ambient Intelligence (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>Distributed Systems Design</td>
<td>15</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td>Wireless Systems Performance</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Fault Detection, Isolation and Modelling (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Network Performance and Applications</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>Performance Analysis and Network Planning</td>
<td>20</td>
<td>7-point scale</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Systems of Systems/Complex Systems (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Machine Learning (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td></td>
<td>Non-linear Control (Elective)</td>
<td>5</td>
<td>Pass/Fail</td>
<td>Internal</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Master’s Thesis</td>
<td>30, possibly 60</td>
<td>7-point scale</td>
<td>External</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*) A compulsory course in Problem Based Learning (PBL) is offered as an integrated part of the project module to non-AAU bachelors. If non-AAU students get credit transfer for the 1<sup>st</sup> Semester project module, then it has to be ensured that they get the PBL competences in other ways.

On 3<sup>rd</sup> Semester the student must choose two of the three elective courses
3.2 Descriptions of modules
3.2.1 - 1st Semester

Networks and Distributed Systems (Focus on Scientific Communication) (15 ECTS)
Netværk og distribueret processering (Fokus på videnskabelig kommunikation)

Prerequisites:
BSc. in Electronics & IT or BSc. in Computer Science

Objective:
Students who complete the module:

Knowledge
Must have knowledge about:

- distribution, storage and processing of data in a distributed system
- at least one of the following aspects: real-time, performance, safety, robustness, mobility and positioning aspects

Skills
Must be able to:

- conduct synthesis of theories, methods and techniques used for distribution, storage and processing of data in a distributed system
- apply relevant theories, methods and techniques to the chosen system to ensure that at least one of the following requirements are satisfied:
  - timing requirements in connection with distribution, storage and processing of data are satisfied
  - performance, safety and robustness requirements are satisfied
  - mobility and positioning requirements are satisfied
- can explain the process of and criteria for peer reviewed and scientific communications
- can write a paper for a scientific conference/journal
- can prepare and give an oral and poster presentation for a scientific conference

Competencies
Must have the ability to:

- read and understand selected scientific literature and next apply the theories, methods, and/or tools in order to solve a problem which requires distribution of networking or processing functionalities.
- present the problem, the suggested solution(s), experiments and simulation results, as well as the overall conclusion in terms of a scientific paper and a poster
- present orally the main contribution and conclusion from the work in terms of a 15 minutes conference presentation
- Work according to a scientific method and present results in the form of a scientific article and at a seminar/scientific conference
- Formulate and explain scientific hypotheses and results achieved through scientific work
- Analyze results and draw conclusions on a scientific basis

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral examination. The examination is based on questions that take their starting points in the written documentation for the project module. For further information concerning the
examination procedure, refer to the Framework Provisions.

**Evaluation criteria:**
As stated in the Joint Programme Regulations, it is a precondition for students, with a non-AAU bachelor’s degree that they have passed the course in Problem Based Learning (PBL) at Aalborg University prior to the project examination.
Problem Based Learning (PBL) at Aalborg University

Problembaseret læring på Aalborg Universitet

Prerequisites:
None, but the course is compulsory for non-AAU bachelors.

Learning outcomes:
After completion of the course the student should

Knowledge
- know how to describe in own words some of the fundamental principles of Problem Based Learning (PBL) as implemented in the Aalborg PBL model at the Faculty of Engineering and Science.
- Know how to identify similarities and differences between the Aalborg PBL study environment and previous study environments, incl. strengths and weakness in both environments.

Skills
- be able to structure project management activities based on a well-formulated problem statement
- be able to assess project documentation based on scientific codes of conduct

Competences
- be able to plan for effective collaborative learning in an intercultural environment and manage group conflicts
- be able to reflect on, plan and manage a study project in a PBL learning environment

Content:
Lectures, discussions and group work.

Assessment:
Internal assessment during the course/class participation according to the rules in the Examination Policies and Procedures, Addendum to the Joint Programme Regulations of the Technical Faculty of IT and Design, Aalborg University. In this case the assessment is primarily based on the oral performance during the course. This means that the student has to be active during the course time and participate in discussions. The course is an integrated part of the project and a precondition for participation in the project examination for non-AAU bachelors. Consequently, no diploma will be issued for the course nor will it appear on the academic transcripts.

Grading:
Passed/Failed

Assessment criteria:
As stated in the Joint Programme Regulations
Stochastic Processes (5 ECTS)

Prerequisites:
Solid knowledge in Probability, Statistics, Linear Algebra, Fourier Theory, and Programming

Objective:
Students who complete the module must:

Knowledge
- Have knowledge about the theoretical framework in which stochastic processes are defined.
- Be able to understand the properties of the stochastic processes introduced in the course, such as wide-sense stationary (WSS) processes, Auto Regressive Moving Average (ARMA) processes, Markov models, and Poisson point processes.
- Be able to understand how WSS processes are transformed by linear time-invariant systems.
- Be able to understand the theoretical context around the introduced estimation and detection methods ((non-parametric and parametric) spectral estimation, Linear Minimum Mean Square Error (LMMSE) estimation, Wiener filter, Kalman filter, detection of signals, ARMA estimation, etc.)

Skills
- Be able to apply the stochastic processes taught in the course to model real random mechanisms occurring in engineering problems.
- Be able to simulate stochastic processes using a standard programming language.
- Be able to apply the taught estimation and detection methods to solve engineering problems dealing with random mechanisms.
- Be able to evaluate the performances of the introduced estimation and detection methods.

Competencies
- Have the appropriate “engineering” intuition of the basic concepts and results related to stochastic processes that allow – for a particular engineering problem involving randomness – to design an appropriate model, derive solutions, assess the performance of these solutions, and possibly modify the model, and all subsequent analysis steps, if necessary.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Distributed Real Time Systems (5 ECTS)

Prerequisites:
Knowledge, skills and competences sufficient to pass BSc in Electronic Engineering. Basics in basic Network communication and protocols as e.g. obtained in courses Communication in Electronic Systems (EIT 5th Semester) or Network technologies and distributed systems (ITC 5th Semester).

Objective:
Students who complete the module:
Knowledge
The students must have insight in:
- fieldbus technologies and concepts of communication
- global state protocols
- replication of systems for redundancy concerns
- application domains and their requirements, relevant Quality of Service parameters
- queuing theory, basic models
- synchronization issues
- reliability modeling, including safety, scalability, maintainability issues
- modeling tools, such as Deterministic Network Calculus
- network simulation tools (examples include ns-2/ns-3, OMNET)

Skills
The students must have understanding of …
- Service models for field bus and their limitation
- utilizing consistency between automates in a distributed system
- describing a loose coupled system with basic traffic pattern modeling
- home automation and similar domain areas in perspective of communication and safety
- quality of service
- protocol design

Competencies
The students must be able to
- identify requirements and select an appropriate communication architecture
- analyze and design complex networked systems with hard requirements such as providing real time guarantees
- model system behavior using analytical or simulation tools

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.
For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
Wireless PHY and MAC Fundamentals (5 ECTS)
Trådløse PHY og MAC grundbegreber

Prerequisites:
A basic understanding of Wireless Communications Fundamentals, Mathematics and Statistics corresponding to a BSc in Electrical Engineering

Objective:
Students who complete the module:

Knowledge
Must have knowledge about the following:

- Fundamental communication theory for wireless transmission
  - Classical communication theory
  - Noise handling in wireless communications
    - Loss and channel models (Friis transmission formula)
    - Analog chains, noise factor
    - Digital chains, coding
  - Detection and demodulation theory (coherent vs non-coherent)
- Transceiver architectures, blocks and components
  - Transceiver structures and synchronization (incl. duplexing and access aspects)
  - Non-ideal components (non-linearities, compression and intercept)
  - Dynamic range and link budget
  - S-parameter description of components
  - RF/u-wave measurements of wireless communication blocks and chains
- Modeling and simulation of transceiver systems
  - Complex baseband representation of pass-band communication
  - Signal distortion due to block imperfections

Skills
Must be able to:

- Establish a link budget
- Synthesize a transceiver system on a block diagram level
- Describe the modifications that a signal undergoes through a transceiver chain
- Calculate key performance characteristics for a full transceiver chain based on specifications for the individual blocks
- Simulate the transmission of digital data through a full transceiver chain – including transmitter, lossy and noisy wireless channel, and receiver

Competencies
- Must be able to:
  - Discuss and evaluate the impact of different transceiver blocks in a communication link
  - Set up a simulation model to access and evaluate the performance of (digital data) transmission over a wireless communication link

Type of instruction:
As described in the introduction to Chapter 3.

**Exam format:**
Individual oral or written examination.

**Evaluation criteria:**
As stated in the Joint Programme Regulations
Communication Networks and Ambient Intelligence (5 ECTS)
Kommunikationsnetværk og omgivende intelligens

Objective:
Students who complete the module:

Knowledge

Knowledge
- Must have knowledge about general network models and architectures including the OSI model (MAC, transport, network and application layers) as well as the TCP/IP protocol stack (IP, TCP and UDP protocols).
- Must have knowledge about selected technologies within Internet of Things (IoT), including wireless sensors, wireless sensor networks and RFID, and their application within IoT.
- Must have knowledge of simulation tools.
- Must have knowledge of protocols for unicast, multicast and broadcast.

Skills

- Must be able to understand the OSI model and the TCP/IP protocol stack at such a level that they are able to model selected data link, network, transport, and application layer protocols.
- Must be able to monitor and observe traffic from different networks, and to use the observations for creating simple traffic models that can be used for simulations.
- Must be able to describe and evaluate basic security mechanisms.
- Must be able to select and compare methods for traffic engineering at data link, network and transport layers: in particular the students must be able to understand how Quality of Service mechanisms are actually implemented through e.g. marking and queuing policies.
- Must be able to understand the RFID and Sensor networking and protocols at such a level that they are able to model selected parts of such protocols.
- Must be able to apply relevant methods for designing services and applications based on RFID and wireless sensor networks.

Competencies

- Must be able to compare different network technologies and configurations by selecting and using appropriate methods, including analysis, simulation and experiments.
- Must have understanding of the scenarios where IoT can be applied, both from technical and business viewpoints, identifying possible new services and applications.
- Must have understanding of a network’s topology and its topological properties and qualities.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination. For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations
3.2.2 - 2nd Semester

Distributed Systems Design (15 ECTS)

*Design af distribuerede systemer*

**Prerequisites:**
1st NDS MSc Semester

**Objective:**
Students who complete the module:

**Knowledge**
Must have knowledge about:

- system design methodologies within distributed systems in general
- major performance measures in distributed systems
- design choices w.r.t. how architecture, topology and technology influence various performance measures, including among others location-based services

**Skills**
Must be able to:

- demonstrate understanding at analysis level of system design methodologies within distributed systems in general, and understanding at synthesis level of selected design methodologies.
- demonstrate understanding at analysis level of major performance measures in distributed systems of various scales.
- explain design choices wrt architecture, topology and technology, and be able to analyze how this influence various performance measures.

**Competencies**
Must have the ability to:

- undertake the construction of well-functioning distributed systems and associated communication facilities

**Type of instruction:**
As described in the introduction to Chapter 3.

**Exam format:**
Individual oral examination. The examination is based on questions that take their starting points in the written documentation for the project module. For further information concerning the examination procedure, refer to the Joint Programme Regulations

**Evaluation criteria:**
As stated in the Joint Programme Regulations
Wireless Systems Performance (5 ECTS)
Trådløs system performance

Prerequisites:
Skills and competences sufficient to pass BSc in electronics engineering or Telecommunications Engineering

Objective:
Students who complete the module:

Knowledge
Must have knowledge about the following:

- Link budget analysis
- Wave types
- Power vs protection margins
- Dynamic radio channel characterization
- Short terms descriptions
- Channel hardening/Diversity
- Radio Resource allocation
- Methods for fixed and dynamic channel allocation
- Cellular concept and hand-over
- Link and MAC control, Power control, AMC
- Wireless network performance and traffic analysis
- Dynamic routing
- Transport – congestion control – performance impact
- Wireless network architectures
- Short range infra-structures
- Cellular infra-structure

Skills
The students must be able to

- Establish a link budget with account for dynamic protection margins for a given wireless communication system
- Select the relevant metrics to establish and estimate Quality of Service (QoS) performance
- Establish radio resource requirements based on traffic load
- Evaluate feasibility of routing strategies based on system properties and requirements
- Evaluate and select different wireless networking architectures based on system requirements
- Evaluate properties of dynamic channels and apply stabilization techniques

Competencies
The students must be able to

- Analyze, evaluate and model the chain from PHY to Transport layer and how it combines towards the total performance and QoS of a wireless communication system

Type of instruction:
As described in the introduction to Chapter 3.
Exam format:
Individual oral or written examination. For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Fault detection, Isolation and Modeling (5 ECTS)
Fejldetektion, -isolation og -modellering

Prerequisites:
Basic Probability Theory, Dynamical Systems Formulated in State Space and Frequency, Stochastic Processes

Objective:
Every real life system will at some point or another experience faults. Students who complete this course will be able to, in a systematic manner, to analyze dynamic systems as well as distributed, network coupled systems. For each of the two system types the student will be able to:

- List the different considered faults, how they propagate through the system and assess their severity and occurrence likelihood.
- Develop methods for estimating if a given fault is present or not.
- Develop fault tolerant strategies for ensuring the continuation of the system in the presence of faults.

Students who complete the module:

Knowledge
- The taxonomy of fault tolerant systems
- Simulation tools for testing and verification

Skills
- In analyzing a system for possible faults and modeling these
  - Failure Mode and Effect Analysis
  - Structural analysis
  - Faults in TCP/IP based Networks
- In evaluating the severity of different faults and prioritizing
  - By means of simulations
  - Stochastic models for components and their availability
- In designing detectors for selected faults
  - Structural analysis
    - Analytical Redundancy Relations
  - Passive fault detection
    - Unknown input observers
    - Parameter estimators
    - Parity space filters
  - Active fault detection
    - Design of perturbation signals
    - Neighbor discovery
    - Round-trip time
    - Heartbeats
    - Acknowledged transmissions
  - Decision ruling
    - Threshold based
• Stochastic based

- In designing strategies for handling faults
  - Passive fault tolerance
    - Robust controllers
    - Reliable message broadcasting
    - Multipath routing
  - Active fault tolerance
    - Control strategy change
    - Redundant systems with backup components

**Competencies**
- In designing fault tolerance strategies for a given system

**Type of instruction:**
As described in the introduction to Chapter 3.

**Exam format:**
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations.
Network Performance and Applications (5 ECTS)
Netværksperformance og applikationer

Prerequisites:
Stochastic Processes and Estimation and Distributed Real Time Systems

Objective:
Students who complete the module:

Knowledge
- Must have knowledge about the network planning process, including the planning of backbone, distribution and access networks, and of the tools involved in this process.
- Must have knowledge of network topologies and structural quality of service.
- Must have knowledge of GIS data and handling of these.
- Must have knowledge about localization techniques.
- Must have knowledge about advanced queuing models, including matrix analytical and matrix exponential models

Skills
- Must be able to understand simple and advanced traffic and queuing models, and apply these in analysis of real-life traffic systems.
- Must be able to apply the knowledge of advanced traffic and queuing models in performance analysis based on simulation as well as analysis.
- Must be able to create realistic traffic models, based on knowledge on the behavior of relevant components including users and applications and/or on knowledge of existing traffic.
- Must be able to apply knowledge of network planning tools and methods in a concrete project of limited scale.

Competencies
- Must be able to select the appropriate queuing and traffic models to be used in the modeling of a specific system.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination. For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
3.2.3 – 3rd Semester

Performance Analysis and Network Planning (20 ECTS)
Performanceanalyse og netværksplanlægning

Prerequisites:
1st and 2nd NDS MSc Semester

Objective:
Students who complete the module:

Knowledge
Must have knowledge about at least one of the following:

• tools and methods for planning large scale communication systems.
• tools and methods for distributed systems management and security.
• tools and methods for positioning in distributed systems

Skills
Must be able to:

• apply basic as well as advanced methods for performance analysis in distributed systems
  and/or communication networks.
• apply tools for performance analysis and simulation of distributed systems and/or
  communication networks.

Competencies
Must have the ability to:

• make a choice of parameters, methods and tools for the analysis of a problem where a
  distributed system and/or communication system comprises a part of the solution.
  Emphasis is on the communication facility and the associated network planning.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral examination. The examination is based on questions that take their starting points in
the written documentation for the project module. For further information concerning the
examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Systems of Systems/Complex Systems (elective) (5 ECTS)
Komplekse systemer

Prerequisites:
Knowledge from the Areas of Systems and Control Theory, Network Theory, Distributed Systems and Embedded Systems

Objective:
The students will be introduced to methodologies for design of a system of systems in terms of designing the properties of the individual systems as well as their interconnecting behavior, establishing the system of systems. A systematic approach to the design of network architectures and local behavior rules, which together constitute systems of systems that are optimal with respect to objectives formulated at a macroscopic level, will be presented.

Students who complete the module:

Knowledge
- The formalized concept of systems of systems
- A systematic approach to the design of network architectures and local behavior rules, which together constitute systems of systems that are optimal with respect to objectives formulated at a macroscopic level.

Skills
- To combine the areas of systems and control theory, network theory, distributed systems and embedded systems into design principles for systems of systems
- Design of the properties of the individual systems, as well as their interconnecting behavior, establishing the system of systems

Competencies

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Machine Learning (elective) (5 ECTS)

Prerequisites:
Basic knowledge in Probability Theory, Statistics, and Linear Algebra

Objective:
The course gives a comprehensive introduction to machine learning, which is a field concerned with learning from examples and has roots in computer science, statistics and pattern recognition. The objective is realized by presenting methods and tools proven valuable and by addressing specific application problems.

Students who complete the module:

Knowledge
- Must have knowledge about supervised learning methods including K-nearest neighbors, decision trees, linear discriminant analysis, support vector machines, and neural networks.
- Must have knowledge about unsupervised learning methods including K-means, Gaussian mixture model, hidden Markov model, EM algorithm, and principal component analysis.
- Must have knowledge about probabilistic graphical models, variational Bayesian methods, belief propagation, and mean-field approximation.
- Must have knowledge about Bayesian decision theory, bias and variance trade-off, and cross-validation.
- Must be able to understand reinforcement learning.

Skills
- Must be able to apply the taught methods to solve concrete engineering problems.
- Must be able to evaluate and compare the methods within a specific application problem.

Competencies
- Must have competencies in analyzing a given problem and identifying appropriate machine learning methods to the problem.
- Must have competencies in understanding the strengths and weaknesses of the methods.

Type of instruction:
As described in the introduction to Chapter 3.

Exam format:
Individual oral or written examination.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

Evaluation criteria:
As stated in the Joint Programme Regulations.
Non-linear Control (elective) (5 ECTS)
*Ikke-lineære kontrolsystemer*

**Objective:**
Students who complete the module will obtain skills within Nonlinear Control including analysis of controllability, observability, and stabilizability and stability, along with control synthesis for non-linear systems, hybrid systems covering dynamical system with both discrete and continuous components, the optimal linear estimator - the Kalman filter - as well as non-linear estimation and sensor fusion.

Students who complete the module:

**Knowledge**
- Lyapunov stability
- Backstepping
- Linear Kalman Filters and their limitations
- The extended Kalman filter
- The unscented Kalman filter
- Particle filtering
- Kalman filters as parameter estimators
- The influence of (coloured) sensor and model noise on the filter estimate.
- Must be able to understand…
- The invariance principle
- Feedback linearization

**Skills**
- Controllability
- Observability
- Online estimation techniques to a given system
- Understand and analyze systems with multiple sensors for the purpose of fusing sensor information to control-relevant information
- Stabilizability

**Competencies**

**Type of instruction:**
As described in the introduction to Chapter 3.

**Exam format:**
Individual oral or written examination. For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations.
3.2.4 – 4th Semester

Master's Thesis (30, possibly 60 ECTS)  
*Kandidatspeciale*

The master thesis can be conducted as a long master thesis. If choosing to do a long master thesis, it has to include experimental work and has to be approved by the study board. The amount of experimental work must reflect the allotted ECTS.

**Prerequisites:**  
1st – 4th Semester

**Objective:**  
Students who complete the module:

**Knowledge**
- have knowledge, at the highest international level of research, of at least one of the core fields of the education
- have comprehension of implications of research (research ethics)

**Skills**
- are able to reflect on a scientific basis on their knowledge,
- can argue for the relevance of the chosen problem to the education including specifically account for the core of the problem and the technical connections in which it appears
- can account for possible methods to solve the problem statements of the project, describe and assess the applicability of the chosen method including account for the chosen delimitation and the way these will influence on the results of the product
- can analyze and describe the chosen problem applying relevant theories, methods and experimental data
- are able to describe the relevant theories and methods in a way that highlights the characteristics and hereby document knowledge of the applied theories, methods, possibilities and delimitations within the relevant problem area
- have the ability to analyze and assess experimental data, including the effect the assessment method has on the validity of the results.

**Competencies**
- are able to communicate scientific problems in writing and orally to specialist and non-specialist.
- are able to control situations that are complex, unpredictable and which require new solutions,
- are able to independently initiate and to perform collaboration within the discipline and interdisciplinary as well, and to take professional responsibility,
- are able to independently take responsibility for his or her own professional development and specialization.

If the project is carried out as a long master's thesis the learning objectives include those defined for the 3rd Semester of the education.

**Type of instruction:**  
As described in the introduction to Chapter 3.

- Problem based project oriented project work individual or in groups of 2-3 persons

**Exam format:**  
Individual oral examination. An external censor is appointed.

The examination is based on questions that take their starting points in the written documentation.
for the project module.

For further information concerning the examination procedure, refer to the Joint Programme Regulations.

**Evaluation criteria:**
As stated in the Joint Programme Regulations.
Chapter 4: Entry into Force, Interim Provisions and Revision

The curriculum is approved by the Dean of The Technical Faculty of IT and Design and enters into force as of September 2017.

Students who wish to complete their studies under the previous curriculum from 2011 must conclude their education by the summer examination period 2018 at the latest, since examinations under the previous curriculum are not offered after this time.

Chapter 5: Other Provisions

5.1 Rules concerning written work, including the Master's thesis
In the assessment of all written work, regardless of the language it is written in, weight is also given to the student's spelling and formulation ability, in addition to the academic content. Orthographic and grammatical correctness as well as stylistic proficiency are taken as a basis for the evaluation of language performance. Language performance must always be included as an independent dimension of the total evaluation. However, no examination can be assessed as ‘Pass’ on the basis of good language performance alone; similarly, an examination normally cannot be assessed as ‘Fail’ on the basis of poor language performance alone.
The Board of Studies can grant exemption from this in special cases (e.g., dyslexia or a native language other than Danish).

The Master’s thesis must include an English summary.\footnote{Or another foreign language (upon approval from the Board of Studies)} If the project is written in English, the summary must be in Danish.\footnote{The Board of Studies can grant exemption from this.} The summary must be at least 1 page and not more than 2 pages. The summary is included in the evaluation of the project as a whole.

5.2 Rules concerning credit transfer (merit), including the possibility for choice of modules that are part of another programme at a university in Denmark or abroad
In the individual case, the Board of Studies can approve successfully completed (passed) programme elements from other Master’s programmes in lieu of programme elements in this programme (credit transfer). The Board of Studies can also approve successfully completed (passed) programme elements from another Danish programme or a programme outside of Denmark at the same level in lieu of programme elements within this curriculum. Decisions on credit transfer are made by the Board of Studies based on an academic assessment. See the Joint Programme Regulations for the rules on credit transfer.

5.3 Rules for examinations
The rules for examinations are stated in the Examination Policies and Procedures published by the Technical Faculty of IT and Design on their website.

5.4 Exemption
In exceptional circumstances, the Board of Studies study can grant exemption from those parts of the curriculum that are not stipulated by law or ministerial order. Exemption regarding an examination applies to the immediate examination.

5.5 Rules and requirements for the reading of texts
It is assumed that the student can read academic texts in his or her native language as well as in English and use reference works etc. in other European languages.
5.6 Additional information
The current version of the curriculum is published on the Board of Studies’ website, including more detailed information about the programme, including exams.