EO 3330 – Network Calculus

Advanced PhD course, 10 credits
Oct 2021 – Mar 2022
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https://www.jamesgross.org/eo-3330-network-calculus/

1. Course Content

Motivated by novel applications, over the last several years there is a renewed interest in the analysis of networked systems through queuing-theoretic means. This renewed interest comes from the goal of building low-latency (wireless) communication systems with high reliability guarantees. The corresponding *delay analysis* is done on the one-hand using Markov-chain techniques, while on the other hand using effective capacity and stochastic network calculus. Furthermore, taking estimation and closed-loop control applications into account, significant work has been done with respect to *freshness analysis* for networked systems using a novel metric called Age of Information (AoI). The analysis and optimization of AoI is perhaps one of the hottest theoretical directions in networked systems research today.

This course intends to introduce PhD students to the foundations and some of the applications of both these directions: delay as well as freshness analysis. The course covers three blocks: We first review deterministic, worst-case analysis of delay in networked systems, i.e. the theory of deterministic network calculus. We next cover stochastic delay analysis in networked systems, where we consider effective bandwidth/capacity analysis as well as stochastic network calculus. Finally, we turn to freshness analysis and optimization of networked systems, i.e. age-of-information analysis. In each block the emphasis is put on the relation of theory to practical problems in communication systems and networks. Hence, after covering the theory we show the applicability of the theoretical framework in each block to real problems. The course furthermore consists of homework assignments and a final project in which students work on after the course lectures have been completed. The projects are intended to relate to the research area of each PhD student, connecting it with the tools discussed in the course. Thus, the course targets at enabling PhD students to apply the introduced tools to the analysis of delay and freshness of networked systems.

2. Intended Audience

The course is organized as an advanced PhD course and targets PhD students that are either working on networking-related problems or that are interested in extending their application- or system-oriented work to networks from a fundamental point of view.

3. Instructors

James Gross – jamesgr@kth.se
Jaya Champati - jaya.champati@imdea.org
Hussein al Zubaidy - hzubaidy@kth.se

4. Lectures

The course is composed of three units with the following content:

- **Worst-Case Delay Analysis (Lectures 2 & 3)**
  (Min,plus)- calculus
  Arrival- and service curves
  Delay & backlog bounds
  Leaky bucket
  Pay-burst-only-once
  Scheduling, GPS-PGPS equivalence

- **Stochastic Delay Analysis (Lectures 4 & 5)**
  Effective bandwidth and capacity theory
  Stochastic arrival and service curves
  Performance bounds
  Concatenation & scaling
  MGF-calculus & applications
  (Min,x)-calculus & applications

- **Freshness Analysis (Lectures 6, 7 & 8)**
  Analysis of Markov Chains
  Traditional analysis of M/M/1, M/M/1/N and M/G/1 Systems
  Average age-of-information analysis of queuing systems
  Tail AoI analysis
  Optimization of AoI

5. Schedule

NOTE: Students are supposed to read assignments before each lecture.

- Lecture 1: Initialization meeting
  Oct 12th 2021 10 am – 1 pm

- Lecture 2: Worst-case delay analysis I
  Oct 19th 2021 10 am – 1 pm
- Lecture 3: Worst-case delay analysis II
  Oct 26th 2021 10 am – 1 pm
  Exercise session: Nov 2nd 2021 10 – 11:30 am

- Lecture 4: Stochastic Delay Analysis I
  Nov 9th 2021 10 am – 1 pm
- Lecture 5: Stochastic Delay Analysis II
  Nov 16th 2021 10 am – 1 pm
  Exercise session: Nov 23rd 2021 10 – 11:30 am

- Lecture 6: Freshness Analysis I
  Nov 30th 2021 10 am – 1 pm
- Lecture 7: Freshness Analysis II
  Dec 7th 2021 10 am – 1 pm

- Lecture 8: Freshness Analysis III
  Dec 14th 2021 10 am – 1 pm
  Exercise session: Dec 21st 2021 10 – 11:30 am

- Project Meeting 1: Status
  Jan 11th 2022 10 am – 12 pm
- Project Meeting 1I: Status
  Feb 1st 2022 10 am – 12 pm
- Project Meeting III: Presentation of Project Results
  Mar 1st 2021 10 am – 12 pm

6. Grading

Three parts have to be fulfilled to pass the course:
- Attend all but two lectures (without valid excuse)
- Reach 75 % of points in each homework assignment (homeworks have to be solved individually)
- Pass the research project (turn in a written report, work out presentation and defend findings in a presentation to the group)

7. Course Goals

Students passing the course will have acquired the following skills:
- Model delay and freshness analysis problems with appropriate approaches
- Solve related problems with respect to the chosen framework
- Summarize the current state-of-the-art in delay and freshness analysis
- Summarize the strongest results from the delay and freshness literature regarding the design of networks

8. Work Load

Students are supposed to follow roughly the following work load
- 10 hours per lecture (3 hours presence, 7 hours of preparation and recap)
- 15 hours per homework
- 120 hours for the research project

9. Teaching and Learning Methodology

The material is presented (derived) during traditional lectures.
During the lectures, small problem sets are constantly assigned to students.
The lecture is offered as online course. The meeting link is provided with the registration.

10. Prerequisites

The course is self-contained. A solid background in analysis and in probability theory is beneficial.

11. Reading Material

Reading assignments will be handed out before the course. Three books exist on the material (all online available from within KTH):

- LeBoudec: Network Calculus – A Theory of Deterministic Queuing
- Yuming Jiang: Stochastic Network Calculus
- Kosta, Pappas et al.: Age of Information: A New Concept, Metric and Tool

However, the books above are not mandatory for the course, but serve for students as further reference material.

12. Registration

Short email to jamesgr@kth.se