Proposal for INTERACT Training Day on September 16, 2024 in Linz, Austria:
Wired and Wireless Time-Sensitive Networking for Deterministic Real-Time Systems: Concepts, Technologies, and Simulation Tools

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DETERMINISTIC6G Project (https://deterministic6g.eu/)

The goals of this training day are:

- An introduction to the concepts and technologies for the implementation of deterministic real-time systems based on Time-Sensitive Networking (TSN) and 5G/6G networks (lectures/presentations).
- Practical tutorials and hands-on experience with tools to simulate and emulate wired and wireless TSN networks, Linux system mechanisms for real-time scheduling and communication, and tools to calculate time-driven schedules for TSN (interactive tutorials/exercises)

The following tentative[1] schedule gives a more detailed overview of the topics to be covered. Lectures (presentations from experts) are alternating with interactive tutorials guided by tutors where the participants can immediately apply the presented concepts (virtual machine images will be provided and participants bring their own devices (laptops)).

Schedule (tentative)

Lecture 1a: Introduction to TSN (60 min) – Frank Dürr (University of Stuttgart)

- Architecture (centralized vs. distributed configuration)
- Traffic shapers for real-time packet scheduling: time-aware shaper, credit-based shaper, asynchronous traffic shaper
- Frame replication and elimination
- Per stream filtering and policing

Tutorial 1b: Simulating TSN in OMNeT++/INET (60 min) – Lucas Haug, Simon Egger (University of Stuttgart)

- Simulation of the TSN mechanisms from Lecture 1 in OMNeT++/INET

Lecture 2a: From Wired to Wireless TSN (60 min) – Joachim Sachs (Ericsson), Gourav Prateek Sharma (KTH Royal Institute of Technology)

- Integration of 5G and TSN
- Characteristics packet delay, latency monitoring and prediction
- Packet Delay Correction

Tutorial 2b: Simulating and Emulating Wireless TSN Bridges (60 min) – Lucas Haug, Simon Egger (University of Stuttgart)

[1] Currently planned as full day event. Could be scaled down to a half-day event if required.

- Simulating characteristic packet delay in OMNeT++/INET using the DETERMINISTIC6G extensions
- Emulating characteristic packet delay with Linux (DETERMINSTIC6G Network Delay Emulator/QDisc)

Lecture 3a: Time-synchronization (30 min) – Mahin Ahmed (Silicon Austria Labs)

- Importance of time synchronization
- Time synchronization for TSN - Generalized Precision time protocol
- 5G/6G-TSN time synchronization mechanisms

Tutorial 3b: Simulating PTP in OMNeT++/INET (30 min) – Lucas Haug, Simon Egger (University of Stuttgart)

- Simulation of PTP with OMNeT++/INET and the DETERMINSTIC6G extensions

Lecture 4a: On the Edge: Real-Time Task Scheduling and Packet Scheduling with Linux (60 min) – Frank Dürr (University of Stuttgart)

- Real-Time task scheduling: Rate Monotonic and Earliest Deadline First Scheduling
- Queuing Disciplines (QDiscs):
    - TAPRIO (Time Aware Priority Shaper)
    - ETF (Earliest TxTime First)

Tutorial 4b: Implementing a virtual TSN bridge with Linux (30 min) – Frank Dürr (University of Stuttgart)

- Linux virtual bridge + TAPRIO + virtual Ethernet devices + Talkers/Listeners

Lecture & Tutorial 5 (interactive demo): Calculating Time-Driven Schedules at the centralized Network Controller (90 min) – Frank Dürr, Simon Egger, Lucas Haug (University of Stuttgart)

- Methods: Integer Linear Programming, Constrained Programming, ...
- Example scheduling problems for Time-Aware Shaper: interactive demo with Gurobi/Cplex/...

Short Biographies of Speakers

Frank Dürr is a senior researcher and lecturer at the University of Stuttgart (Germany), Institute of Parallel and Distributed Systems (IPVS). He received his doctoral degree and diploma in computer science from University of Stuttgart, and currently works in the areas of distributed systems, computer networks (software-defined and time-sensitive networking), and mobile computing. He is author/co-author of more than 85 conference papers and journal articles. His teaching activities include lectures on real-time concepts for embedded systems, system concepts and programming, and lab-courses on software-defined and time-sensitive networking. He has been co-organizer of several tutorials on SDN (NetSys 2015, Informatik 2014, ACM/IFIP/USENIX Middleware 2013, DEBS 2013) and served in the organizing committee of different conferences (e.g., Workshops Chair IEEE PerCom 2022).

Simon Egger is a PhD student at the Institute of Parallel and Distributed Systems (IPVS) at University of Stuttgart, Germany. His current research interest covers adaptive and robust scheduling with formal reliability guarantees in wireless Time-Sensitive Networks.

Lucas Haug is a PhD student at the Institute of Parallel and Distributed Systems (IPVS) at University of Stuttgart, Germany. His research is focused on robust "wireless-friendly" scheduling for wireless Time-Sensitive Networks.

Joachim Sachs has more than 25 years of experience in mobile telecommunication from 2G to 6G. He is a senior expert at Ericsson Research and coordinates research on 5G and 6G mobile networks for Industrial IoT and vertical use cases, including cross-industry research collaborations. Joachim studied electrical and electronics engineering at RWTH Aachen University, ENSEEIHT Toulouse, NTNU Trondheim and University of Strathclyde Glasgow. He received Ph.D. and diploma degrees from Technical University Berlin and RWTH Aachen University, respectively. In 2009 he was a visiting scholar at Stanford University. Joachim was awarded as Ericsson Inventor of the Year and received the Research Award of the Vodafone Foundation for Scientific Research. He is co-chair of the Technical Committee on Communication Networks and Systems of the German VDE Information Technology Society and a VDE ITG Fellow. Joachim holds numerous patents and has published 3 books, 2 book chapters and around 90 papers in international journals and conferences. He is a regular invited speaker and co-organizer of workshops, panels, sessions and journal special issues.

Mahin Ahmed is a wireless communications scientist at Silicon Austria Labs GmbH. Her current research focus is on the development of 5G/6G communication for the industrial Internet of Things, wireless time-sensitive networking, and industrial wireless communications. Previously she has worked as a research and teaching staff member at the University of Klagenfurt, Austria, where she focused on interference dynamics and stochastic modeling. She received my doctoral degree in interference dynamics in wireless networks from the University of Klagenfurt, Austria. Her master's was in information and communication engineering from Sejong University in Seoul (South Korea).

Gourav Prateek Sharma received the Ph.D. degree from the IDLab, Ghent University, in June 2022. His Ph.D. dissertation work involved developing and analyzing optimization algorithms for efficient resource allocation in telecom and media broadcast networks. He has been a Postdoctoral Researcher with the ISE Division (School of EECS), KTH Royal Institute of Technology, Sweden, since October 2022. His current research interests include time-sensitive networking (TSN), deterministic networking (DetNet), and their integration with wireless technologies (e.g., WiFi and 5G URLLC).