Projektseminar KTS
Proseminar etit(Literaturseminar)
Ergänzung zum Projektseminar KTS

Fachgebiet Kommunikationstechnik, Prof. Dr.-Ing. Anja Klein
Summer Semester 2025

1 Übersicht

- Im 5. bzw. 6. oder höheren Semester des Bachelor Studiums etit oder WI-etit
- Die Themen werden idealerweise zusammen mit dem Thema für die Bachelorarbeit gewählt
- Ansprechpartner: alle Mitarbeitenden, die eine Bachelorarbeit anbieten
- Startzeitpunkt und Dauer der Projektarbeit (z.B. im Block oder vorlesungsbegleitend) können mit dem/der Projektbetreuer*in individuell vereinbart werden
- Je nach Thema kann Teamarbeit möglich sein
- Wird jedes Semester angeboten
- Ansprechpartner für das Fachgebiet Kommunikationstechnik bei allgemeinen Fragen:
  - Sumedh Dongare, s.dongare@nt.tu-darmstadt.de
  - Prof. Dr.-Ing Anja Klein, a.klein@nt.tu-darmstadt.de

2 Proseminar etit (Literaturseminar)

- Forschungsnahe Erarbeitung eines fachlichen Themas in Zusammenarbeit mit einem/einer wissenschaftlichen Mitarbeiter*in als Betreuer
- Detaillierte Beschäftigung mit technischen Artikeln
- Tiefes Verständnis des darin behandelten fachlichen Themas
- Praktische Erfahrung mit technischer Dokumentation
- Erlernen moderner Präsentationstechniken und deren Anwendung
- Präsentation und Diskussion des fachlichen Themas vor einer Gruppe

3 Projektseminar KTS

- Vorbereitung auf die Bachelorarbeit
- Idealerweise werden das Projektseminar und die Bachelorarbeit am selben Fachgebiet bei dem/derselben Betreuer*in absolviert und die Themen aufeinander abgestimmt
- Tiefes Verständnis eines speziellen, komplexen Forschungsthemas der KTS
- Praktische Erfahrung mit aktueller Literatur
- Praktische Erfahrung mit Algorithmen und/oder Simulation
- Strukturierung einer komplexen Aufgabe
- Präsentation eines komplexen Themas
- Dokumentation eines komplexen Themas

4 Ergänzung zum Projektseminar KTS

- Ergänzt das Modul Projektseminar
- Kann als Ersatz für das Einführungsprojekt belegt werden
- Kann nur zusammen mit dem Projektseminar belegt werden, dessen Aufwand sich dann von 8 CP auf 10 CP erhöht

5 Themen

Im Folgenden sind beispielhaft einige Themen des Fachgebiets Kommunikationstechnik dargestellt. Für weitere Informationen sowie zusätzliche, verwandte Themen kontaktieren Sie bitte den oder die jeweiligen Mitarbeitenden per e-mail. Natürlich können Sie auch, z.B. per Zoom, ein persönliches Gespräch führen.

5.1 Stackelberg Game Approach on Digital Twin Synchronization with Data Compression

Motivation:

The concept of Digital Twins (DTs) has emerged as a novel paradigm in future wireless systems, particularly in the context of the Internet of Everything (IoE) or the Internet of Things (IoT). A DT is a real-time, precise, digital replica of a physical system (PS) that enables virtual and extended reality services. To facilitate timely interactions between dynamic PSs and their virtual counterparts, DTs must be synchronized regularly under stringent requirements, including low latency, high data rates, and high reliability constraints. Achieving this necessitates efficient optimization and resource management.

Data compression (source coding) provides an effective measure to mitigate additional transmission overhead and accelerate data delivery. A key challenge lies in balancing data compression and transmission time. Increasing the time spent on compressing the data will reduce the time required for data transmission, creating a fundamental trade-off between compression and communication for DT synchronization. Finding an optimal compression-communication strategy is crucial for achieving precise, real-time DT updates.

A Stackelberg game defines a game-theoretic framework that models interactions between a leader and a follower in a hierarchical decision-making process. The leader first determines its own optimal strategy, while the follower has to react to the decision by the leader. Utilizing a Stackelberg game-theoretic framework, enables the modeling of dynamic interactions between different players. By leveraging this approach, one is able to effectively minimize the time required for DT synchronization.

Topic:

A Stackelberg game for DT synchronization with data compression was introduced in [1]. Here, a local base station (BS) acts as the leader, which allocates the communication resources and each sensor acts as a follower which chooses its own compression ratio for data compression. First, the best-response (BR) of the followers sub-game is derived which is utilized by the leader to predict the action of the sensors. Second, a gradient-ascent search is used in an iterative algorithm to derive the equilibrium strategy between the sensors and the BS.

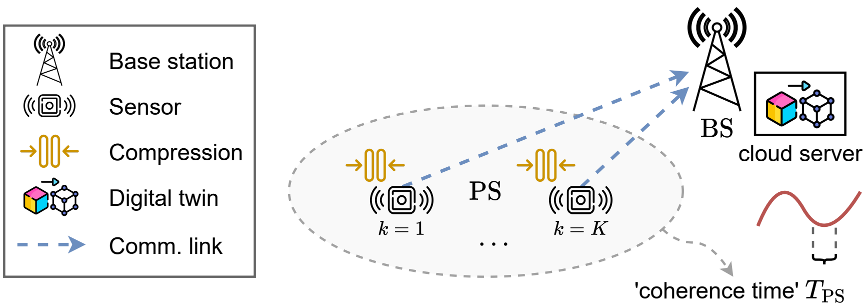


Figure 1: System model for DT synchronization with data compression [1]

The tasks of this project are:

1. Formulate a Stackelberg Game in the DT synchronization scenario that includes data compression
2. Implement an algorithm for finding the Stackelberg equilibrium strategy
3. Analyze the simulation results in different scenarios to evaluate the impact of data compression

Requirements: A fundamental knowledge of optimization, MATLAB, and game-theory will be helpful.

Introductory Literature:

[1] Markus Krantzik, Anja Klein, and Lin Xiang. *Optimizing Sensor Data Compression in Digital Twin Synchronization via a Stackelberg Game*. 2025

[2] Xiaoyang Li et al. "Wirelessly Powered Crowd Sensing: Joint Power Transfer, Sensing, Compression, and Transmission". In: *IEEE Journal on Selected Areas in Communications* 37.2 (2019), pp. 391–406

Contact:

Markus Krantzik, m.krantzik@nt.tu-darmstadt.de

5.2 Digital Twin Placement in Mobile Edge Computing

Motivation:

Digital twins (DTs) are regarded as one of the cornerstones of future sixth-generation (6G) wireless communication networks. A DT is a virtual software-based representation of a real physical system (PS), e.g., an autonomous vehicle or Internet of Things (IoT) device. By simulating the status of the PS in real-time, a DT replicates its PS's behavior in the virtual space. Since the real-time simulation of the PS requires large amounts of computation resources, DTs are usually hosted on computation servers.

DTs can provide additional functionalities like analysis of the PS's current state or prediction of future PS behavior, which can be used to gain insights into the PS's dynamics. Moreover, DTs can interact on behalf of the PSs with third parties, e.g., applications. In the context of 6G IoT networks, these functionalities can be used to optimize wireless communication systems to meet strict requirements regarding latency, data rate and reliability.

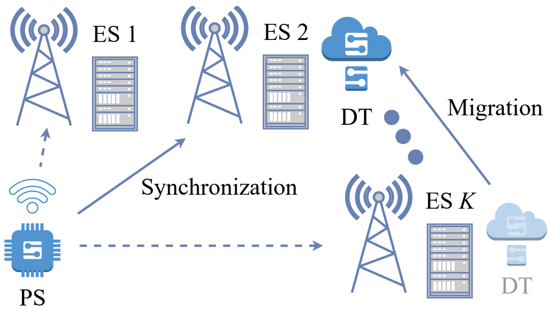
In order to accurately represent its PS, the DT needs to synchronize with its PS. This synchronization process entails two steps. Firstly, the PS transmits data regarding its current state to the host server of the DT. Secondly, the received data is being processed on the host server in order to update the DT model of the PS. For a seamless synchronization of PS and DT, the latency associated with the synchronization should be minimized.

Mobile Edge Computing (MEC) has shown to be a suitable technology for that purpose. By hosting the DTs on edge servers (ESs), which offer large computation resources at the network edge, the synchronization latency can be reduced compared to a deployment on remote cloud servers. However, the DT placement problem, i.e., the selection of a host ES for the DT, is challenging, as available communication and computation resources at the ESs are heterogeneous and shared with other users. Furthermore, real MEC systems evolve dynamically, which requires the DT placement to be adaptive.

Topic: DT Placement in Dynamic MEC Systems Using Reinforcement Learning

In [1], DT placement in an uncertain and dynamic environment, with the objective of jointly minimizing synchronization latency and energy consumption, is investigated. Specifically, a PS aims for selecting the optimal ESs without having any prior knowledge of the environment and MEC system characteristics, i.e., wireless channel qualities and the ESs' computation capabilities and loads. Furthermore, it is assumed that the environment changes dynamically in a statistically non-stationary manner. This requires a flexible and adaptive solution for the DT placement, which is able to identify the optimal ES in an unknown environment and migrate the DT between ESs to adjust to changes. Moreover, since the migration of the DT between ESs incurs an additional overhead, the DT placement strategy should also account for this.

To solve the aforementioned challenges, a reinforcement learning approach, based on Multi-Armed Bandits (MABs), is proposed as a DT placement approach.



The tasks of this project are:

- Familiarize yourself with the system model and DT placement problem formulation in [1].
- Understand the proposed DT placement algorithm based on a MAB reinforcement learning approach.
- Implement the proposed DT placement algorithm as well as the compared benchmark schemes in order to verify the results obtained in [1] with your own simulations.

Introductory Literature:

[1] Maximilian Wirth, Andrea Ortiz, and Anja Klein. "Risk-Aware Bandits for Digital Twin Placement in Non-Stationary Mobile Edge Computing". In: *2024 IEEE International Conference on Communications Workshops (ICC Workshops)*. IEEE. 2024, pp. 13–18

Contact:

Maximilian Wirth, m.wirth@nt.tu-darmstadt.de, S3|10 318

5.3 UAV-aided Integrated Sensing and Communication

Motivation:

Unmanned aerial vehicles (UAVs) are increasingly used in sensing and communication applications due to their agile mobility and flexible, low-cost deployment. Recently, UAV-aided integrated sensing and communication (ISAC) has been proposed as a promising approach to realize efficient simultaneous wireless sensing and communication onboard UAVs. ISAC enables a light-weight design ideal for UAVs constrained by size, weight, and power (SWAP), as it allows for onboard sensing and communication using shared spectrum, signal processing algorithms, and transmitter hardware. Moreover, by employing a common signal for sensing and communication, rather than separate, potentially interfering signals, ISAC enhances the utilization of limited radio resources. Further, mobile UAVs can also improve the ISAC performance by e.g. proactively seeking strong line-of-sight (LoS) channels and avoiding obstacles between the UAV and sensing targets or communication users, especially in emergency scenarios or complex environments.

Topic:

The goal of this project is to jointly consider the 3D radiation patterns of practical antennas, the orientation of the antenna array, and beamforming in UAV-aided ISAC systems. We focus on a UAV-aided ISAC system, as illustrated in Fig. 3, where a rotary-wing UAV serves as a dual-functional aerial access point (AP) to simultaneously perform downlink communication with multiple ground/aerial users and radar sensing towards multiple targets. The UAV is equipped with a novel, rotatable uniform linear array (ULA) comprising practical antenna elements, such as half-wavelength dipoles. Consequently, both beamforming and array steering can be optimized to enhance communication and sensing performance. References [1] and [2] have introduced a low-complexity iterative algorithm based on convex and manifold optimization to address this highly non-convex, multi-variate, joint optimization problem. However, this algorithm relies on several hyperparameters that significantly impact convergence and optimization outcomes. The aim is to refine the algorithm and determine the patterns of influence caused by different hyperparameters.

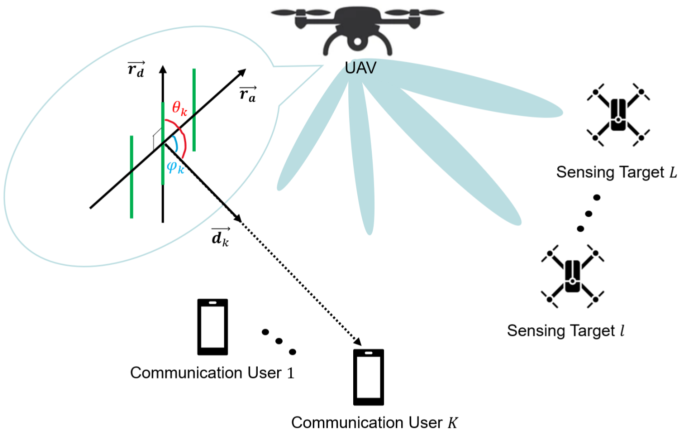


Figure 2: System model of UAV-aided ISAC using rotatable ULA

The tasks of this project are:

1. Learn convex optimization and manifold optimization.
2. Improve the algorithm in [1] and [2].
3. Apply the algorithm in other practical scenarios.

Introductory Literature:

[1] Fengcheng Pei Lin Xiang and Anja Klein. “Joint Optimization of Beamforming and 3D Array Steering for Multi-antenna UAV Communications”. In: ()

[2] Lin Xiang Fengcheng Pei and Anja Klein. “Joint Optimization of Beamforming and 3D Array-Steering for UAV-Aided ISAC”. in: ()

Contact:

Fengcheng Pei, f.pei@nt.tu-darmstadt.de

5.4 Fundamentals of Semantic Communications

Motivation:

With the development of deep learning (DL) and the increase in deployed devices, more intelligent services have been provided by the networks. These applications generate unprecedented amounts of data for serving different types of tasks, while the conventional communication system is facing the bottleneck to support such massive amount of data. To address this issue, semantic communication emerged as a key technology and have received great attention. Different from conventional communications, only essential semantic information relevant to the task is extracted from source message and transmitted to the receiver, which further compresses the data while reserving the task-related information.

Topic:

One goal of this project is to realize basic task-oriented communications using deep learning technologies. Initially, we need to build the semantic-channel encoder and decoder with a deep neural network for communications tailored to specific tasks, such as classification, recognition, and image transmission, as shown in 3. Then, we aim to develop semantic channel encoders and decoders that adapt to channel fluctuations, which involves creating algorithms to predict and adjust for environmental changes, ensuring stable and efficient communication. Furthermore, we will explore the mathematical principles of semantic communication, understand its theoretical limits, and enhance system performance.

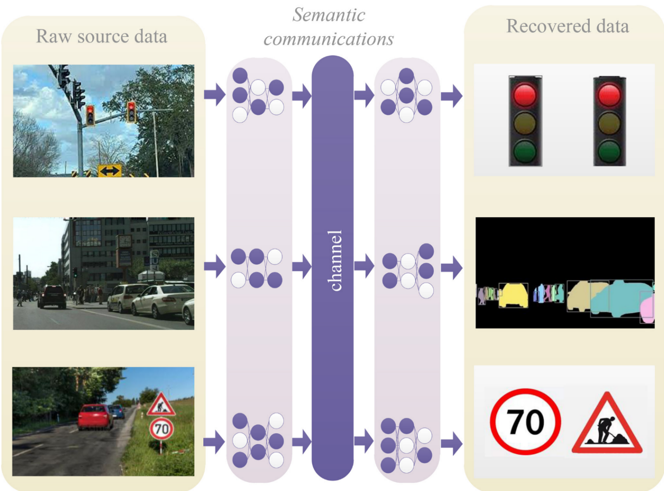


Figure 3: Task-oriented Semantic Communication

The tasks of this project are:

1. Learn the fundamental theory of semantic communication.
2. Realize some basic semantic communication cases
3. Investigate semantic information theory.

Introductory Literature:

[1] Wanting Yang et al. "Semantic Communications for Future Internet: Fundamentals, Applications, and Challenges". In: *IEEE Communications Surveys and Tutorials* 25.1 (2023), pp. 213–250

[2] Qiyu Hu et al. "Robust Semantic Communications Against Semantic Noise". In: *2022 IEEE 96th Vehicular Technology Conference (VTC2022-Fall)*. 2022, pp. 1–6

[3] Huiqiang Xie, Zhijin Qin, and Geoffrey Ye Li. "Task-Oriented Multi-User Semantic Communications for VQA". in: *IEEE Wireless Communications Letters* 11.3 (2022), pp. 553–557

Contact:

Fengcheng Pei, f.pei@nt.tu-darmstadt.de