Projektseminar KTS 8CP
Proseminar etit(Literaturseminar) 2 CP
Ergänzung zum Projektseminar KTS 2CP

TECHNISCHE UNIVERSITÄT DARMSTADT

Fachgebiet Kommunikationstechnik, Prof. Dr.-Ing. Anja Klein
Summer Semester 2024

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) 2 CP

- 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 8 CP

- 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 2 CP

- 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 Synchronization of Metaverse and Digital Twins

Motivation:

Metaverse is the one of the most anticipated technological breakthroughs of the coming decade. The metaverse is a massively scaled and iteroperable network of the digital world. The metaverse will enable physical-virtual-digital services, such as Augmented Reality (AR), Virtual Reality (VR), Industrial Internet of Things (IIoT) and etc., and revolutionize the interconnection between people, things, and places. End-to-end (E2E) synchronization of the real world with the metaverse and its components such as DTs is one of the key challenges. Achieving seamless replication imposes a set of stringent wireless network demands such as near-zero E2E latency, effective computing, and ultra-high data rates.

To fulfill the aformentioned demands, decentralized and Edge-enabled model should be adopted. However, (i) how to choose mobile edge computing (MEC) servers for hosting the metaverse, (ii) how to accommodate DTs in the metaverse accordingly define new research challenges.

Topics:

In [1], a novel decentralized metaverse framework that distributes DTs and sub-metaverses over the wireless edge network while preserving upmost synchronization requirements is proposed. A region equipped with massive sensing abilities is partitioned into separate regions and teleported as sub-metaverses at the MEC servers, and the residing physical systems (PSs) are accordingly associated with the corresponding MEC server. A joint synchronization problem is posed as an optimization problem whose goal is to minimize the average sub-synchronization time with the real world, while satisfying the DT synchronization intensity requirements.

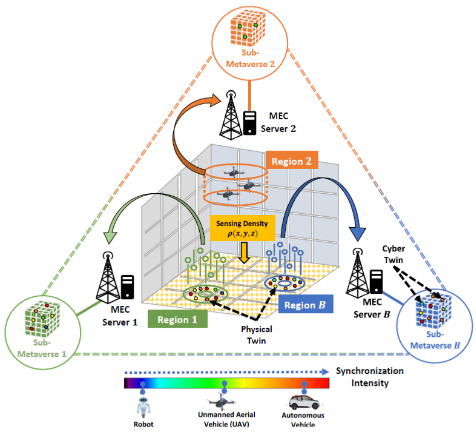

Figure 1: System model of the scenario as specified in [1]

The tasks of this project are:

- Understand the system model and constraints
- Formulate the joint optimization based on the given scenario
- Implement the iterative algorithm for region partition and DTs Association
- Evaluate the performance of the proposed iterative algorithm via simulations
- **BONUS** Improve the proposed algorithm in [1]

Introductory Literature:

[1] Omar Hashash et al. “Towards a Decentralized Metaverse: Synchronized Orchestration of Digital Twins and Sub-Metaverses”. In: *IEEE International Conference on Communications*. 2023, pp. 1905–1910

Contact:

Yi Wang, y.wang@nt.tu-darmstadt.de, S3|10 316

5.2 Improving Routing Algorithms in LEO Satellite Networks

Motivation:

In recent years, low-earth-orbit (LEO) satellite constellations such as Starlink and OneWeb became a more and more relevant part of research on global internet connectivity, particularly for remote areas where traditional broadband services are difficult or expensive to deploy. A central component of this research is to find suitable routing algorithms that allow the network to bring data from the internet to users and vice versa. During transmission, data is sent from user devices to satellites, from one satellite to the next via inter satellite links (ISLs), from satellites to ground stations via ground-satellite links (GSLs) and from ground stations to the internet via fiber links. Previously, only partial analyses of the global network were carried out. In this project, we will apply routing algorithms for uplink data to the complete global network and evaluate their performance in terms of latency, drop rate and throughput.

Topic:

The primary goal of this project is to improve the performance of reinforcement-learning based routing algorithms in LEO satellite networks. The given system model consists of a constellation of satellites, ground stations, an internet node and connections between them as indicated in Figure 2. In each time step, each satellite decides based on its position, the local time and its experiences, where to transmit received data. This can be either another satellite or a ground station, which then relays the data to the internet. The currently employed routing algorithm uses contextual multi-armed bandits and a tile-coding mechanism to improve generalization. Details about the model and the employed routing algorithm can be found in [1].
The described routing algorithm depends on several parameters that determine the satellites' precise behavior. The goal to improve the performance of the routing algorithm should be reached by analysing these parameters, discussing their respective influence and finding optimal choices.

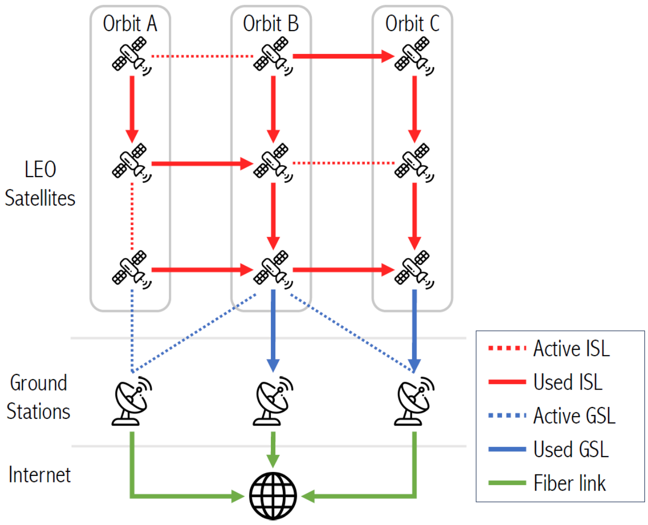

Figure 2: System model of the scenario as specified in [1]

The tasks of this project are:

1. Learn how to evaluate routing algorithms using an existing satellite simulator.
2. Optimize parameters for the reinforcement learning-based routing algorithm in various network scenarios.
3. **EXTRA:** Explore and develop more advanced routing algorithms or enhance the existing algorithm with additional features.

Introductory Literature:

[1] Wanja de Sombre et al. "SKYLINK: Dynamic Link Management in Space-Terrestrial Integrated Networks". In: (2024)

Contact:

Wanja de Sombre, w.sombre@nt.tu-darmstadt.de

5.3 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 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 and 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 consists of 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 at edge servers, which offer large computation resources and are deployed at the network edge, the synchronization latency can be reduced. However, the DT placement problem, i.e., the selection of a DT host edge server, is challenging, as available communication and computation resources at the edge servers are heterogeneous and shared. Furthermore, the MEC system can evolve dynamically.

Topics:

For enhancing the performance of an MEC system, [Wei+23] and [Zha+23] consider constructing DTs of edge servers. Specifically, the selection of a subset of edge servers for hosting the DTs of the remaining edge servers is investigated. The aim of the selection is to minimize the synchronization latency and DT modelling error. To solve this problem, [Wei+23] and [Zha+23] propose an approach based on cooperative game theory. Additionally, since the requirements of the MEC system can change dynamically, an adaptation scheme, that can migrate the DTs between edge servers according to the changing demands, is proposed in [Zha+23].

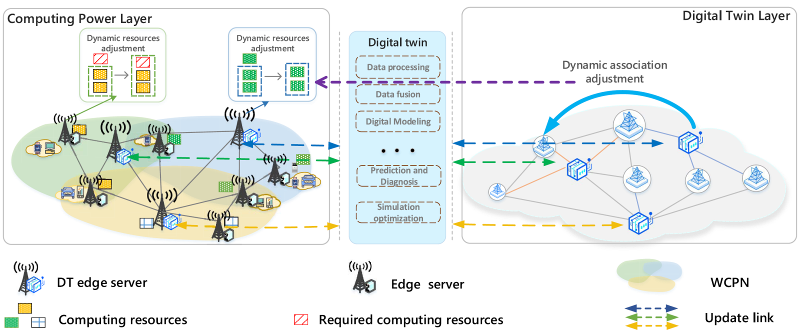

Figure 3: Scenario considered in [Zha+23].

The tasks of this project are:

- Familiarize yourself with the system model and DT placement problem formulation in [Wei+23], [Zha+23].
- Understand the proposed DT placement algorithm based on a game theoretic approach.
- Implement the DT placement algorithm and verify the results obtained in [Zha+23] with your simulations.
- **BONUS:** Additionally, implement the DT transfer algorithm from [Zha+23].

Introductory Literature:

- Lan Wei et al. "Energy-Efficient Digital Twin Placement in Mobile Edge Computing". In: (2023)
- Yadong Zhang et al. "Adaptive Digital Twin Placement and Transfer in Wireless Computing Power Network". In: (2023)

Contact:

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

5.4 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. 5, 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.

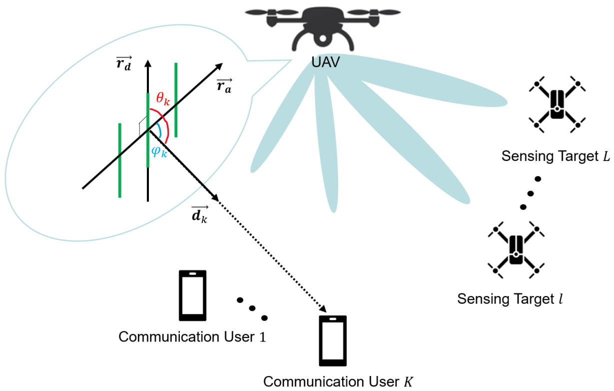

Figure 4: System model of UAV-aided ISAC using rotatable ULA

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] Lin Xiang, Fengcheng Pei, and Anja Klein. "Joint Optimization of Beamforming and 3D Array Steering for Multi-antenna UAV Communications". In: *IEEE WCNC*. 2024

[2] Fengcheng Pei, Lin Xiang, and Anja Klein. "Joint Optimization of Beamforming and 3D Array-Steering for UAV-Aided ISAC". in: *IEEE International Conference on Communications (ICC)*. 2024

Contact:

Fengcheng Pei, f.pei@nt.tu-darmstadt.de
Office: S310/318

5.5 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 5. 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.

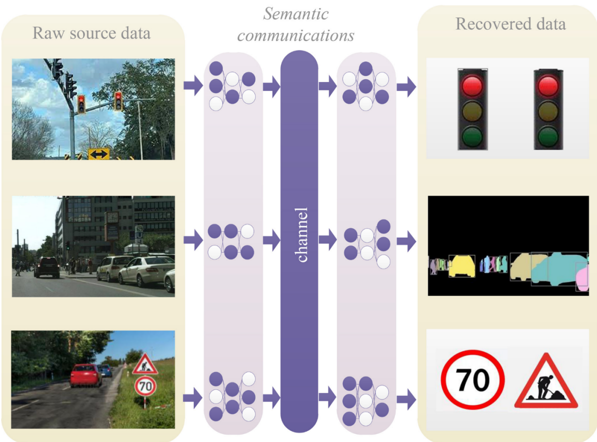

Figure 5: Task-oriented Semantic Communication

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
Office: S310/318

5.6 Learning-guided Matching in Mobile Crowd-sensing

Motivation:

In Mobile Crowdsensing (MCS) a mobile crowdsensing platform (MCSP) collects sensing data from mobile units (MUs) in exchange for payment. The MCSP broadcasts a list of available sensing tasks. Based on this list, each MU solves a task proposal problem to decide which task it is willing to perform and sends a proposal to the MCSP. Based on the MUs' proposals, the MCSP solves a task assignment problem.
There are two challenges when finding efficient task proposal strategies for the MUs and an efficient task assignment strategy for the MCSP (i) The techno-economic perspective of MCS: From the technical perspective, MCS should maximize the data quality while minimizing time and energy consumption. From the economic perspective, there are two sides, the MUs and the MCSP which act as selfish decision-makers, who aim at maximizing their own income. (ii) Incomplete information at two sides: Initially, the MCSP does not know the expected data quality and the MUs do not know the expected effort required for task completion.

Topic:

In the recent years, the reinforcement learning has become one of the central topics of research in the field of machine learning. Due to their generality, the RL approaches have proved to be useful in the wireless communications over unreliable channel. In this topic, the RL algorithms will be applied to the presented problem. The goal of the RL-approach will be to learn about the task assignment and task allocation considering battery and other constraints in order to make decisions that would maximize the average social welfare.

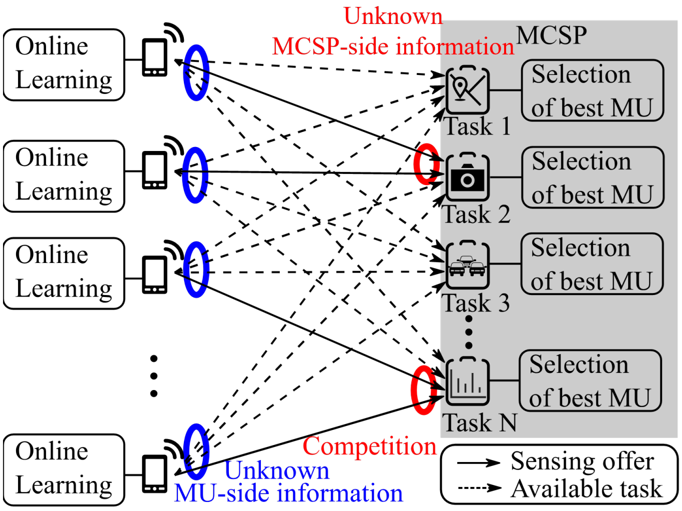

Figure 6: System model of the scenario as specified in [1]

The tasks of this project are:

1. To formulate a Markov Decision Process based on the given scenario and understand the system dynamics and constraints
2. To implement the reinforcement learning approaches to find the solutions to the given problem
3. To compare the results with reference algorithms for numerical evaluation

Introductory Literature:

[1] Bernd Simon et al. *Decentralized Online Learning in Task Assignment Games for Mobile Crowdsensing*. 2023. arXiv: 2309.10594

[2] Sumedh Dongare et al. "Two-Sided Learning: A Techno-Economic View of Mobile Crowdsensing under Incomplete Information". In: *IEEE International Conference on Communications (ICC)*. 2024

Contact:

Sumedh Dongare, s.dongare@nt.tu-darmstadt.de
Office: S310/319