Project Seminar Wireless Communications

TECHNISCHE UNIVERSITÄT DARMSTADT

Fachgebiet Kommunikationstechnik, Prof. Dr.-Ing. Anja Klein
April 13, 2022

1 General Information

This project seminar gives you the opportunity to work on up-to-date research projects related to wireless communication networks, machine learning in communications, and optimization techniques for communication problems. It is intended for master students of the German and International master programmes like etit, iCE, WI-etit, iST.
Depending on your preference, you can work on your own or in a team of two students. The projects are related to the work of the research assistants' current research. You will be given literature for an introduction to the specific topic.
In a first step, the results from the given literature should be reproduced. In the second phase, you can extend the existing work by your own ideas. Depending on the topic, the implementation can be done in MATLAB or in Python. In the end, you will write a short report and present your findings in a talk.

An information session will be held on April 13, 2022, at 5:10 PM in a hybrid format (i.e. in presence in Room S306/53 and simultaneously online via Zoom). The formal issues and the offered topics will be briefly explained in the information session. The Zoom-link is as follows:
https://tu-darmstadt.zoom.us/j/89120418649?pwd=aCtKa2xGRVUzelBzVjJwN2MxQi9EUT09
Meeting-ID: 891 2041 8649
Kenncode: 017520

2 What will you learn

- A deep understanding of your particular up-to-date research topic
- Practical experience with journal/conference papers
- Practical experience with MATLAB or Python
- Structuring of complex tasks to finish the work on time
- Writing a report about a complex topic
- The presentation of your topic in a research talk
- Writing and presenting in English as "the" language in telecommunications

3 Project Selection and Registration

The offered topics are introduced in the following in this document. To get further information about the offered topics, please attend the information session and get in contact with the respective tutors by eMail. You can then arrange an individual Zoom-Meeting and discuss further details. If multiple topics sound interesting, you can always contact multiple tutors to decide what topic is most interesting for you. The project can be started at any time. If you have made a decision, tell the tutor you want to work on this topic. Without having talked to the tutor, it will not be possible to participate in the project seminar. After your participation is confirmed by the tutor, please make sure you are registered in TUCaN for the Project Seminar.

4 Deliverables

By the end of the project seminar you should give:

- a written documentation of less than 10 pages describing your model, problem and solution,
- a presentation of your topic in about 15-20 min.,
- the program code you wrote during the implementation.

5 General Literature

- K. D. Kammeyer, V. Kühn, Matlab in der Nachrichtentechnik; Schlembach Verlag, 2001 J. G. Proakis, M. Salehi, and G. Bauch, Contemporary communication systems using MATLAB and Simulink, Brooks and Cole, 2000
- V. O. K. Li, “Hints on writing technical papers and making presentations,” IEEE Transactions on Education, vol. 42, no. 2, May 1999, pp. 134 – 137
- G. M. Blair, “Planning a project,” Engineering Management Journal, vol. 3, no. 1, Feb. 1993, pp. 15 – 21

Additional literature, which is specific for the individual topics, is mentioned in the project descriptions below.

6 Projects

6.1 Resource Allocation for millimeter wave and THz Communications

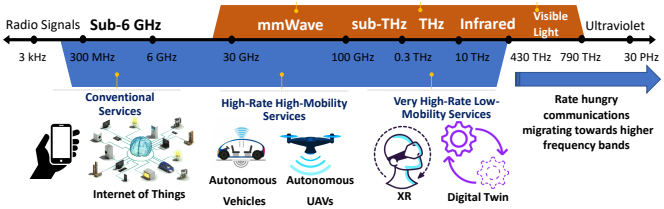
Motivation:

Emerging wireless applications such as eXtended reality (xR), digital twins, and immersive telepresence require not only extremely high data rates, but also ultra-reliability and low-latency for communication. To satisfy these demands in the future sixth-generation (6G) cellular networks, both industry and academia have extended their focus on wireless communications in the sub-6 GHz frequency band to exploring the new frontiers of wireless communications in the millimeter wave (30–300 GHz) and the terahertz (THz) frequency bands (0.3–10 THz). The main advantage for communications in the millimeter wave and the THz bands lies in that large spectrum bandwidths can be released to resolve the radio resource scarcity of wireless communication systems. However, they also bring brand new challenges in system design and resource allocation optimization.

Tasks:

This project aims to understand the new paradigm shift towards mmWave and THz communications by looking into the following research questions:

- What are the new channel characteristics for wireless communications at mmWave and THz bands, compared with sub-6 GHz band? How to capture them via mathematical modeling?
- What are the key (channel access, transmit, receive etc.) technologies to enhance reliability of mmWave and THz wireless communications?
- How to optimize resource allocation in mmWave and THz wireless communication networks for given technology (e.g. hybrid beamforming) up to your selection?



Introductory literature

- Anthony Ngozichukwuka Uwaechia and Nor Muzlifah Mahyuddin. “A comprehensive survey on millimeter wave communications for fifth-generation wireless networks: Feasibility and challenges”. In: *IEEE Access* 8 (2020), pp. 62367–62414
- Qingjiang Shi and Mingyi Hong. “Spectral efficiency optimization for millimeter wave multiuser MIMO systems”. In: *IEEE Journal of Selected Topics in Signal Processing* 12.3 (2018), pp. 455–468
- Mehdi Naderi Soorki, Walid Saad, and Mehdi Bennis. “Ultra-Reliable Millimeter-Wave Communications Using an Artificial Intelligence-Powered Reflector”. In: *2019 IEEE Global Communications Conference (GLOBECOM)*. 2019, pp. 1–6
- Ian F Akyildiz, Josep Miquel Jornet, and Chong Han. “Terahertz band: Next frontier for wireless communications”. In: *Physical Communication* 12 (2014), pp. 16–32
- Christina Chaccour et al. “Seven Defining Features of Terahertz (THz) Wireless Systems: A Fellowship of Communication and Sensing”. In: *arXiv preprint arXiv:2102.07668* (2021)
- Christina Chaccour et al. “Risk-based optimization of virtual reality over terahertz reconfigurable intelligent surfaces”. In: *IEEE International Conference on Communications (ICC)*. 2020, pp. 1–6

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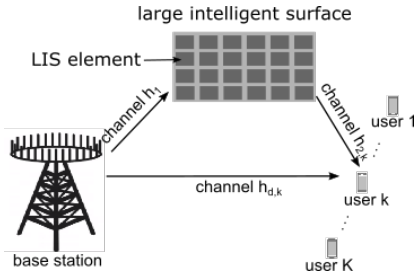
6.2 Reconfigurable intelligent surfaces for wireless communications

Motivation: The 5G mobile communication standard aims to provide broadband, massive and ultra-reliable low-latency connectivity relying on different technologies for system performance including millimeter wave, massive MIMO (mMIMO) and cell densification. However, its practical realization comes with the price of high power consumption, hardware cost and processing complexity that compromise scalable deployments in future networks. Therefore new communication techniques for system efficiency and ubiquitous connectivity is of relevant importance.

Large intelligent surface (LIS) is an emerging technology that has been recently proposed to contribute to the above goals. It enables the reconfiguration of the radio propagation environment for favorable transmission as well as the design of low-complex mMIMO radios. The LIS operates by changing the electromagnetic characteristics of its elements in a way the incoming waves are reflected towards desired destinations (e.g. base stations and mobile users) to increase the network coverage and reliability and provide signal-to-interference-plus-noise ratio gains. This concept can be realized by arrays of low cost antennas, smart reflect arrays or reconfigurable meta-surfaces. To provide increased communication performance, the design of the antenna beamforming should be jointly coordinated between the transmitter and the LIS as the radio propagation conditions changes.



Topic: Design of beamforming algorithms This example scenario consists of a multiple-user MISO system assisted by a LIS where h_1, $h_{2,k}$ and $h_{d,k}$ are the BS-LIS, LIS-user$_k$ and BS-user$_k$ channels respectively. This project aims to study state-of-the-art antenna beamforming methods that exploits the knowledge of the channels in a coordinated manner and develop new transmit beamforming algorithms using optimization tools.

References:

Introduction:

- Marco Di Renzo et al. *Smart Radio Environments Empowered by AI Reconfigurable Meta-Surfaces: An Idea Whose Time Has Come*. URL: `https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/s13638-019-1438-9`
- Emil Björnson. *Fundamentals of Intelligent Reflecting Surfaces (video)*. URL: `https://youtu.be/CDt0JNrOKxk`

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6.3 Optimal UAV deployment as base station

Motivation

In case of an extreme event, such as natural disasters, congestions within the cell, or malfunctions of the infrastructure, the ground base stations may become unable to serve all users within their area. However, these situations are either unexpected, or temporary. As a result, it is not feasible to invest in an infrastructure that will operate for a relatively short amount of time. Unmanned aerial vehicles (UAV) that can serve as aerial base stations are proposed to assist cellular networks with their quick deployment opportunity and low cost. However, one of the biggest challenges is to determine the optimal placement of the UAV so that the network can benefit the most.
Placement of a UAV base station (UAV-BS) poses a different challenge than terrestrial cell placement due to multiple reasons. Firstly, in addition to choosing the UAV's location in the horizontal space, we need to determine its altitude as well. Secondly, the coverage area of a terrestrial cell is known a priori. However, the coverage area of a UAV-BS depends on its altitude and is unknown before solving the placement problem. Lastly, the mobility of the UAV-BS allows it to move wherever the demand is, in contrast to terrestrial cells waiting for the demand to come towards them. As a result, the coverage region providing the maximum revenue to the network should be found.

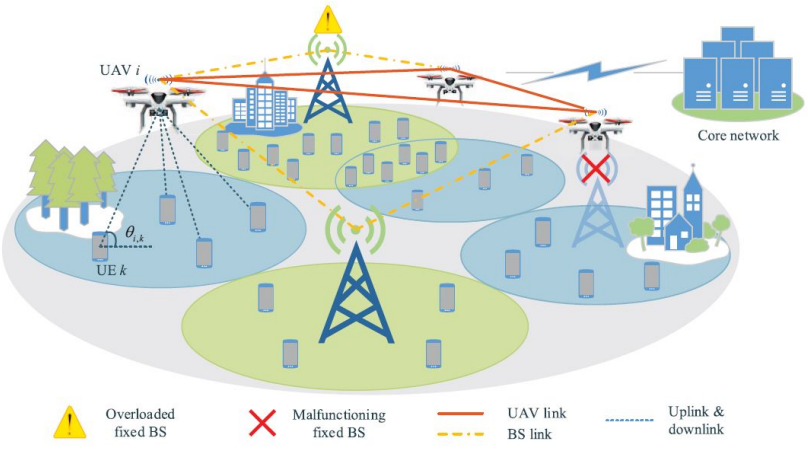

Illustration of the UAV-assisted cellular network.

Tasks

This scenario depicts several users in the cell that cannot be served due to infrastructure failure, which will be served with help of the deployed UAV base stations. Task in this project is to implement a simulation environment for the depicted scenario and the solution provided by literature. It could be also further extended to a more complex model with more constraints.

Introductory Literature

- M. Mozaffari et al. "A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems". In: *IEEE Communications Surveys Tutorials* 21.3 (2019), pp. 2334–2360. DOI: 10.1109/COMST.2019.2902862. URL: https://ieeexplore.ieee.org/document/8660516
- E. Kalantari, H. Yanikomeroglu, and A. Yongacoglu. "On the Number and 3D Placement of Drone Base Stations in Wireless Cellular Networks". In: *2016 IEEE 84th Vehicular Technology Conference (VTC-Fall)*. 2016, pp. 1–6. DOI: 10.1109/VTCFall.2016.7881122. URL: https://ieeexplore.ieee.org/document/7881122
- H. Wang et al. "Deployment Algorithms of Flying Base Stations: 5G and Beyond With UAVs". In: *IEEE Internet of Things Journal* 6.6 (2019), pp. 10009–10027. DOI: 10.1109/JIOT.2019.2935105. URL: https://ieeexplore.ieee.org/document/8796414

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6.4 Matching-Based Resource Allocation for Reliable Communication

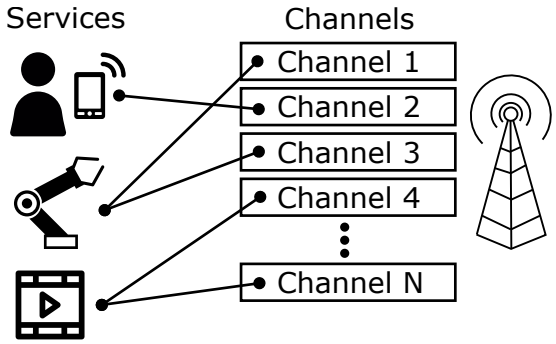
Motivation:

A broad range of applications depending on reliable and fast transfer of information will play an important role in future wireless networks. These delay-sensitive services include control tasks like factory automation or real-time human and machine interaction like augmented reality. To enable the use of these applications in edge networks, the upcoming standard for cellular networks (5G) will provide a new communication paradigm: Ultra Reliable Low Latency Communications (URLLC).

To measure the performance of the wireless network the quality-of-service (QoS) metric is used. The QoS models the relevant performance metric for an application considering latency, throughput or packet error rate. In URLLC each application has strict minimum requirements on the QoS. These strict requirements concern e.g. the maximum latency, the minimum throughput or the maximum packet loss of the transmission. Because of the time-varying channel conditions the correct transmission of a packet in a wireless channel cannot be guaranteed. The more resource blocks are assigned to a user the higher is the probability of correct decoding the transmitted message. To provide stochastic guarantees sufficient communication resources are required for every user depending on its application type.

Topic:

Instead of solving the problem from a centralized perspective, we model the problem as a strategic game with interaction of individual rational users and the available communication channels provided by the network operator. The game is called a one-to-many-matching, meaning that one user is matched to multiple communication channels. The goal is the design of a game-theoretic mechanism that provides a decentralized solution for resource allocation.



The research questions of this project are:

1. How to model the reliability requirements and available communication resources?
2. How to achieve a stable matching between users and and channels concerning their preferences?
3. How is the performance of the solution compared to state-of-the-art methods?

Introductory Literature:

[1] T. Hößler, M. Simsek, and G. P. Fettweis. “Matching-Based Resource Allocation for Multi-User URLLC in Unlicensed Frequency Bands”. In: *2019 16th International Symposium on Wireless Communication Systems (ISWCS)*. 2019, pp. 102–106. URL: https://ieeexplore.ieee.org/abstract/document/8877361

[2] Zhu Han et al. *Game Theory for Next Generation Wireless and Communication Networks: Modeling, Analysis, and Design*. Cambridge University Press, 2019. DOI: 10.1017/9781108277402. URL: http://dx.doi.org/10.1017/9781108277402

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6.5 Reinforcement learning solutions for age of information minimization in IoT applications

Motivation:

Age of Information (AoI) is a metric which evaluates the relevance of the sensed information in Internet of Things (IoT) applications. Consider an example of a traffic monitoring system in which traffic information is being sensed in a decentralized fashion with the help of sensing infrastructures such as wireless sensor networks (WSNs) and mobile crowdsensing (MCS). This information will rapidly loose its relevance if not used in timely manner due continuously changing traffic. In order to ensure the relevance, timely status updates (i.e. sensed information) are sent over the wireless channel to a central entity. The task becomes increasingly complex in the practical scenarios in which the channel is noisy and varies over time. The challenges here is to minimize the long-term average age of information, i.e. to utilize the sensed information while it is valuable in the presence of unreliable channel.

This problem is formulated as a model-free Markov Decision Process (MDP) in which the scenario is represented in the the form of states, actions and cost functions for a single sensor device. In addition to this, hybrid automatic repeat request (HARQ) protocol is used. HARQ utilizes the channel information from previously failed transmission in order to improve the probability of success for the same data. However, this would increase the age of the information by one time step. Due to this, there is a trade-off between lower probability of error with old sensing data and lower age of information with a new sensing data. Since the channel fluctuations are a random process, it becomes increasingly hard to choose which action to choose after a failed transmission such that the age of information is minimized. Another challenge is to analyze the implications of the decisions which are made on the battery of the sensor device.

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 channel fluctuations and the battery constraints in order to make decisions that would minimize the age of information.

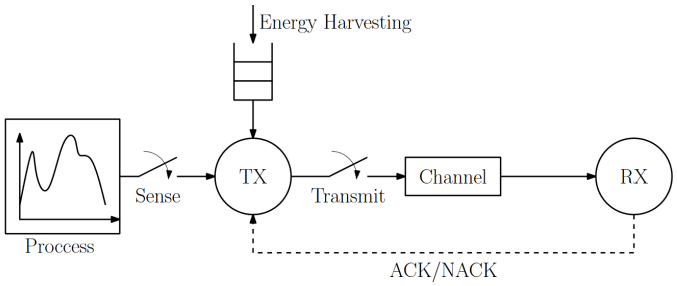

Figure 1: System model of the scenario as specified in [1]

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] Elif Tugce Ceran, Deniz Gunduz, and Andras Gyorgy. *Learning to Minimize Age of Information over an Unreliable Channel with Energy Harvesting*. 2021. arXiv: `2106.16037 [cs.IT]`

[2] Elif Tuğçe Ceran, Deniz Gündüz, and András György. "A Reinforcement Learning Approach to Age of Information in Multi-User Networks With HARQ". in: *IEEE Journal on Selected Areas in Communications* 39.5 (2021), pp. 1412–1426

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