UNIVERSITY OF PATRAS
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

Computer Engineering and Informatics

Distributed approaches for signal processing and machine learning tasks in 5G/6G wireless communications

Research group of the
Signal Processing and Communications Laboratory (SPCLab)

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Outline

- Introduction of SPCLab
- Activities at the PHY/Access of wireless systems
- Activities for SP&ML learning tasks
- Concluding remarks

Introduction of SPCLab (1/3)

- The Signal Processing and Communications Lab
  - Established in 1998 at CEID of UPatras
  - Research and education activities covering the general areas of Signal Processing, Wireless Communications and Machine Learning
- The team of SPCLab consists of
  - 4 Faculty members
  - 4 Collaborating faculty members
  - 4 Research fellows
  - 12 PhD candidates
  - About 15 post-graduate students per year
  - About 30 under-graduate students per year

Introduction of SPCLab (2/3)

- SPCLab has been involved in numerous national, European and bilateral R&D projects
  - In recent years, SPCLab handled over 10MEuro via multiple roles (including coordination and WP/Task leading)
- Research areas
  - *Signal processing and learning in Communications* (e.g., interference management, MIMO, channel estimation and equalization, multicarrier systems –OFDM, FBMC–, adaptive beamforming, cooperative comm, cognitive radio networks)
  - *Signal processing and learning over WSNs* (e.g., localization, distributed source coding, prediction mechanisms, node placement, distributed (adaptive) detection, estimation and statistical learning)

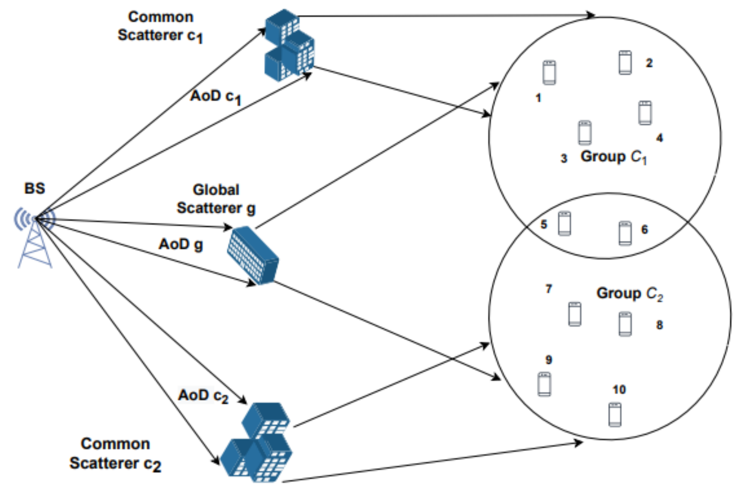
Introduction of SPCLab (2/3)

- Research areas (continued)
  - *Signal Processing & Learning: Algorithms &Theoretical Studies* (e.g., Array signal processing / DOA / BSS, Compressed sensing techniques, Distributed (adaptive) detection and estimation, dictionary learning)
  - Machine Learning / Computer Vision / Image Analysis (e.g., registration, super-resolution, motion estimation, object reconstruction and detection, hyperspectral imaging)
  - *Biomedical Signal Processing* (e.g., EEG-based biometrics, EEG-based emotion recognition, automated diagnosis)
- Application areas
  - PHY / Access COM layers, smart-grid, forestry safety, autonomous vehicles, robotics, non-distractive health monitoring, sign language translation, et al

Current activities concerning the PHY/Access layers of modern wireless communications

Fully distributed channel estimation

- In machine-type communications, channel estimation raises training overheads (due to massive MIMO in mmWaves) and scalability issues (high device density per area)
- An efficient, fully distributed approach has been devised when many devices and multiple antennas are involved



- An adaptive voting mechanism allows the devices to collaborate and estimate their channels by exploiting underlying (even partially) overlapping sparsity patterns manifesting in mmWaves

[1]M. Trigka, C. Mavrokefalidis, K. Berberidids, "Efficient Distributed Multi-task Schemes for mmWave MIMO Channel Estimation", submitted to IEEE Access

[2]-----,"A Distributed Sparse Channel Estimation Technique for mm Wave Massive MIMO Systems", in proc. of EUSIPCO'21

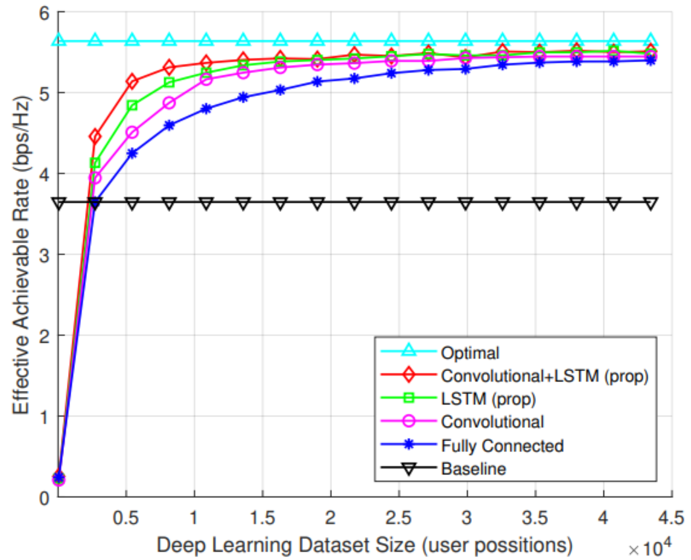
UAVs comm: Channel estimation in view of the Beam Squint effect

- Using large bandwidths in mmWave/THz bands and massive MIMO lead to the so-called beam squint effect
  - There are measurable propagation delays manifesting along the large antenna arrays
  - The steering vectors become frequency dependent, thus, current channel estimation algorithms are not applicable
- We have considered the problem of channel estimation for UAV-based mmWave massive MIMO communications with beam squint
- An efficient (computationally- and performance-wise) algorithm has been devised by employing the alternating method of multipliers
  - The algorithm estimates not only the channel gains and AoA but also the doppler shifts due to the UAV mobility

[1]E. Vlachos, C. Mavrokefalidis, K. Berberidids, "Channel Estimation for UAV-based mmWave Massive MIMO Communications with Beam Squint", to be presented in EUSIPCO'22

Deep-learning-aided coordinated beamforming

- The multi-cell, coordinated beamforming problem towards a user has been simplified recently via deep learning
- Once a model has been trained, beamforming vectors can be selected very fast, but training requires many training data

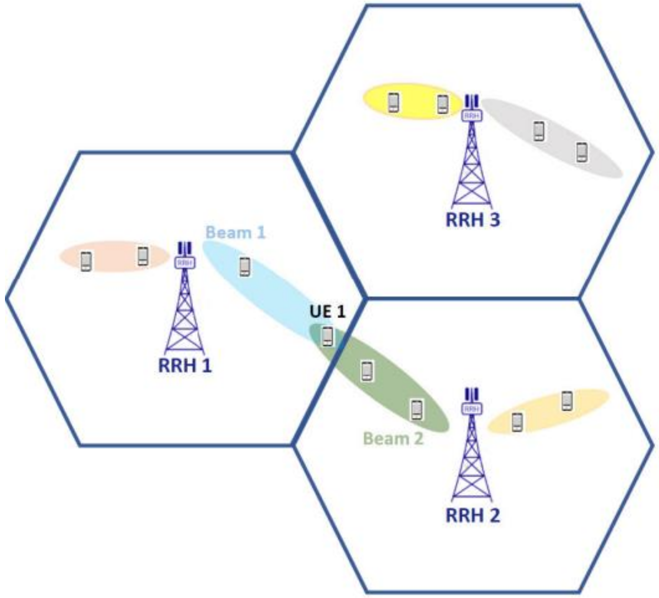


- Aiming for fast training phases (with less required training data), novel CNN and LSTM-based models have been designed that exploit inherent time and frequency correlations of the transmitted OFDM signals (96% of peak performance achieved with only 18% of training data for the best model – red line)

[1]I. Nikas, C. Mavrokefalidis, K. Berberidids, "Efficient Deep Model Training for Coordinated Beam-Forming in mmWave Communications", to be presented in IWSSIP'22

Cell-edge throughput improvement via JT-CoMP in small cells

- To support many users in modern wireless systems, existing and new technologies need to coexist and share limited resources
- Assuming a C-RAN with small cells, clustering of BSs in JT-COMP employing NOMA and beamforming is considered



- A coalition formation game is formulated for clustering the BSs and the solution, having linear complexity, aims at improving cell-edge user throughput without negatively impacting the remaining users

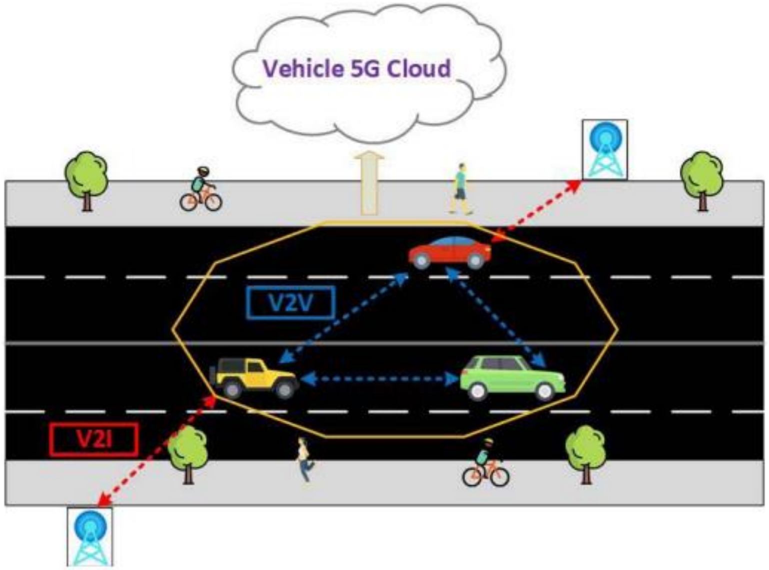
[1]P Georgakopoulos et al., "Coalition Formation Games for Improved Cell-Edge User Service in Downlink NOMA and MU-MIMO Small Cell Systems", IEEE Access, 2021

[2]T Akhtar et al.,"Efficient radio resource management with coalition games using NOMA in small cell networks", in proc. of IEEE Globecom'20

Current activities concerning SP&ML learning tasks

Distributed Localization in CAVs

- Localization in CAVs, i.e., accurate knowledge of self and other's road users/vehicles locations, is a vital task
- The accuracy of GPS sensors is highly degraded in dense urban canyons or tunnels
- Cooperative localization has received extensive interest for coping with GPS limitations

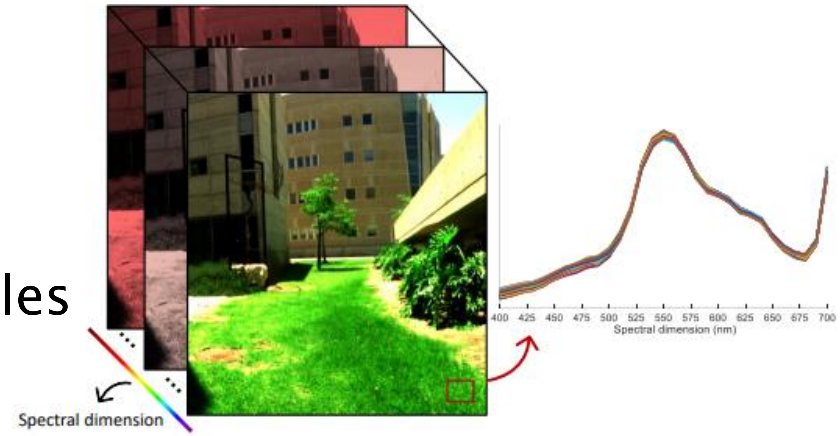


- Novel distributed multi-modal localization approaches for CAVs employing diffusion approaches have been devised
- Each agent estimates accurately its position and the position of the neighboring vehicles enabling more accurate 4D situational awareness

[1]N. Piperigkos, A. S. Lalos, K. Berberidis, "Graph Laplacian Diffusion Localization of Connected and Automated Vehicles", IEEE Transactions on Intelligent Transportation Systems, 2021

Multi-dimensional data modeling and processing

- Effective modeling of multi-dimensional visual data (e.g., hyper-spectral, SAR imaging, FMRI, geophysical signals) enables denoising, super-resolution, unmixing, deconvolution



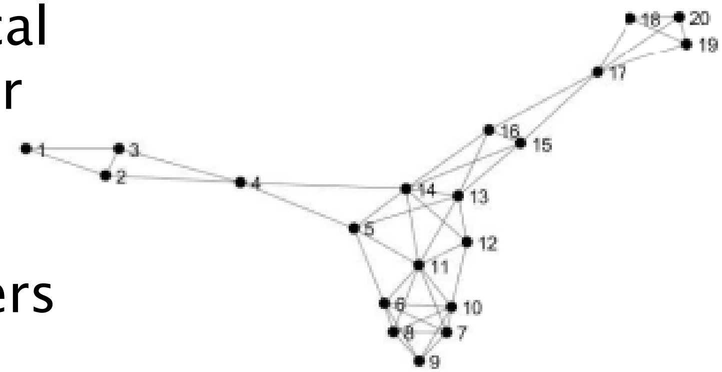
- Novel sparse coding schemes have been proposed that utilize the idea of CNN-based regularizers for imposing learnable structure priors with an application to hyper-spectral denoising
- An efficient distributed unmixing scheme has been devised by employing a sparse and low rank non-negative factorization

[1]A. Gkillas, D. Ampeliotis, K. Berberidis, "Connections between Deep Equilibrium and Sparse Representation models with Application to Hyperspectral Imaging", submitted to IEEE Transactions on Image Processing

[2]C.G. Tsinos, A.A. Rontogiannis and Kostas Berberidis, "Distributed Blind Hyperspectral Unmixing via Joint Sparsity and Low-Rank Constrained Non-Negative Matrix Factorization", IEEE Transactions on Computational Imaging, 2017.

Federated learning over non-iid datasets

- In FL, collaborating agents employ local datasets and exchange only parameter information for training purposes



- Practically, the local datasets are statistically different, a fact that hinders the convergence of the training procedure
- A fully distributed (server-less) FL scheme of low communication overhead has been devised with adaptive combination gradient-based weights for training acceleration
- FL dictionary learning has been considered by introducing the concept of “atom probabilities” for appropriate parameter aggregation

[1]A. Gkillas, D. Ampeliotis, K. Berberidis, “Federated Dictionary Learning from Non-IID Data”, to be presented in IVMSP’22

[2]E. Georgatos, C. Mavrokefalidis, K. Berberidis, “Efficient Fully Distributed Federated Learning with Adaptive Local Links”, arXiv:2203.12281, 2022

Concluding remarks

- Modern wireless communication systems will support (massive) machine-type transmissions with a large number of participating devices
- This scenario raises several challenges like communication overheads, scalability and latency issues as well as privacy considerations
- Signal processing and machine learning (SPML) is “moving” towards the edge of the network (EdgeSPML) in distributed architectures to address these challenges
- Two main directions can be identified
  - SPML for communications and communications for SPML
- In HE, several related topics (e.g., in SNS-JU, CL4&5)
- A combined expertise at the intersection of signal processing, machine learning and wireless communications, enables to effectively address many of the challenges in EdgeSPML

Thank you for your attention!

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