Tutorial Proposal for ICCC 2021

Title: Deep Learning Empowered Large-Scale Antenna Systems

Abstract:

With the depletion of spectrum, wireless communication systems turn to exploit large antenna arrays to achieve the degree of freedom in space domain, such as millimeter wave massive multi-input multi-output (MIMO), and reconfigurable intelligent surface (RIS) assisted communications. Meanwhile, it has been recently admitted that implementing deep learning (DL) into large-scale antenna communications will extensively benefit the system capacity and enhance the robustness to complicated transmission environments. Different from traditional model-driven approaches, DL can help deal with the existing communications and signal processing problems in a data driven perspective by digging the inherent characteristic from the real data. Thus, DL is particularly suitable for large-scale antenna systems under unideal scenarios like modeling mismatching, insufficient resource, hardware impairment, as well as dynamical transmissions. Motivated by this, this tutorial aims to provide the audience a general picture of the recent developments in this exciting area. Specifically, in this interactive presentation we will introduce the merging of DL and large-scale antenna systems, over various topics, including channel acquisition, signal detection, and beamforming design, etc. We will also discuss the challenges of DL empowered large-scale antenna systems and present some interesting future directions.

Length of the tutorial: Half-day

Objective and motivation:

With the rapid development of wireless technologies, we are entering the era of the fifth generation (5G) wireless communications and are heading towards the sixth generation (6G). Massive MIMO will continue to serve as one of the key technologies for 6G, as it can provide much more degrees of freedom than the conventional MIMO. In particular, massive MIMO combined with millimeter wave (mmWave) communications can achieve orders of magnitude enhancement in system throughput. Besides, RIS with massive number of passive antennas can effectively perform the desired beamforming and reconstruct the radio scattering environment into an intelligent environment.

Enormous signal processing techniques were utilized to deals with the communications issues in RIS, such as the sparse Bayesian learning, the iterative optimization, and the orthogonal matching pursuit algorithms. However, conventional signal processing approaches exhibit certain drawbacks. The conventional signal processing techniques are closely dependent on hypothetical mathematical models. In practical scenarios, the rapid changing of the radio scattering and the hardware impairments will cause serious mismatch and nonlinear characteristics to the assumed mathematical models, which will deteriorate the performance of conventional signal processing techniques.

DL is well known for its capability to map nonlinear models caused by any complicated scenario, and has been widely applied in the areas of image recognition, speech recognition, text recognition, and computer vision, etc. For a non-model situation, DL could approximate unknown relations from sufficient real data. Naturally, re-investigation of the signal processing problems of the large-scale antenna systems, e.g., the channel acquisition, the signal detection, and the beamforming design, via DL techniques has become a major research topic. Motivated by this, this tutorial aims to provide a comprehensive introduction about the basic concepts of DL empowered large-scale antenna systems and disclose the start-of-the-art exposition of the recent advancements on the application of artificial intelligence in wireless communications.

Indented audience:

The content of this tutorial will be intended for diverse audience, including researchers working on RIS assisted communications, massive MIMO, and mmWave communications, industry peers interested in B5G techniques, and graduate students working in the area of wireless communications.

Name, affiliation, and a short biography of each tutorial speaker

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Feifei Gao (F’20) received the B.Eng. degree from Xi’an Jiaotong University, Xi’an, China, in 2002, the M.Sc. degree from McMaster University, Hamilton, ON, Canada, in 2004, and the Ph.D. degree from the National University of Singapore, Singapore, in 2007. Since 2011, he has been with the Department of Automation, Tsinghua University, Beijing, China, where he is currently an Associate Professor. His research interests include signal processing for communications, array signal processing, convex optimizations, and artificial intelligence assisted communications. He has authored/coauthored more than 150 refereed IEEE journal articles and more than 150 IEEE conference proceeding papers that are cited more than 8800 times in Google Scholar. He has served as a technical committee member for more than 50 IEEE conferences. He has also served as the Symposium Co-Chair of the 2019 IEEE International Conference on Communications (ICC), the 2018 IEEE Vehicular Technology Conference (VTC) Spring, the 2015 IEEE International Conference on Communications (ICC), the 2014 IEEE Global Communications Conference (GLOBECOM), and the 2014 IEEE Vehicular Technology Conference (VTC) Fall. He has served as an Editor for IEEE Transactions on Wireless Communications, IEEE Transactions on Cognitive Communications and Networking, IEEE Wireless Communications Letters, and China Communications, a Lead Guest Editor for IEEE Journal of Selected Topics in Signal Processing, and a Senior Editor for IEEE Signal Processing Letters and IEEE Communications Letters.

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Shun Zhang (Senior Member, IEEE) received the B.S. degree in communication engineering from Shandong University, Jinan, China, in 2007, and the Ph.D. degree in communications and signal processing from Xidian University, Xi'an, China, in 2013. He is currently with the State Key Laboratory of Integrated Services Networks, Xidian University, where he is currently an Associate Professor. His research interests include massive MIMO, millimeter wave systems, RIS assisted communications, deep learning for communication systems, orthogonal time frequency space (OTFS) systems, and multiple access techiques. He is an Editor for Physical Communication. He has authored or coauthored more than 80 journal and conference papers, and is the inventor of 16 granted patents (including a PCT patent authorized by US Patent and Trademark Office). He has received two Best Paper Awards in conferences, and two prize awards in natural sciences for research excellence by both China Institute of Communications and Chinese Institute of Electronics.

Brief description

This tutorial aims to provide a comprehensive overview of the state-of-the-art development in technology, regulation and theory for “Deep Learning Empowered Large-Scale Antenna Systems," and to present a holistic view of research challenges and opportunities in the coming area of next generation large-scale antenna systems. The overall tutorial is organized as follows: In Part I, we review the evolution of wireless communications and recent achievements in intelligent wireless communications, and present our motivations. In Part II, some DL methods are presented to improve the existing MIMO algorithms, such as channel estimation, CSI feedback, the compensation for nonlinear hardware, and the signal detection. In Part III, we try to deal with some conventionally unsolved MIMO problems with DL schemes. Specially, we utilize deep transfer learning and deep multimode learning to implement downlink channel and beam prediction. In addition, the idea of vision based intelligent communication is discussed here. In Part IV, we try to give some interpretation for DL based designs. In Part V, we apply DL for RIS systems. The key issues of RIS assisted communications is first shown. Then, we introduce the basic concepts of DL based channel extrapolation. Furthermore, we present some DL schemes to implement RIS channel acquisition and beam design under different RIS structures. In Part VI, we close the tutorial by listing the key challenges and future directions on the topic.

Outline

Part I: Background and research motivation

1. Evolution of wireless communications
2. Recent achievements in intelligent wireless communications
3. Overview of DL
4. Research motivation

Part II: DL to improve the existing MIMO algorithms

1. DL based MIMO channel estimation
2. DL based CSI feedback
3. DL based compensation for nonlinear hardware
4. DL based MIMO signal detection

Part III: DL for conventionally unsolved MIMO problems

1. DL for downlink channel prediction
2. DL based beam prediction
3. Deep transfer learning for downlink channel prediction
4. Vision based intelligent communication
5. Deep multimodal learning for channel prediction

Part IV: Interpretability of DL

1. Mechanisms of ReLU DNNs
2. Interpretation for DL based channel estimation
3. Interpretation for DL based data detection

Part V: Concrete application of DL in RIS communication

1. Key issues of RIS communications
2. The concept of DL based channel extrapolation
3. DL based RIS channel estimation and tracking
4. DL based RIS beam design and tracking

Part VI: Challenges and future directions

List of past tutorials given:

1. Shi Jin and Feifei Gao “Low-Cost Massive MIMO: From Theory to Practice,” in IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), New Orleans, March, 2017.
2. Shi Jin and Feifei Gao “Low-Cost Massive MIMO: From Theory to Practice,” in IEEE Global Communications Conference (GLOBECOM), Washington DC, December, 2016.
3. Shi Jin and Feifei Gao “Low-Cost Massive MIMO: From Theory to Practice,” in IEEE Vehicular Technology Conference (VTC) Spring, Nanjing, March 2016.

Related Publications:

[J1]. Yuwen Yang, Feifei Gao, Chengwen Xing, Jianping An, and Ahmed Alkhateeb, “Deep Multimodal Learning: Merging Sensory Data for Massive MIMO Channel Prediction,” IEEE J. Sel. Areas Commun., accepted, 2021.

[J2]. Qiang Hu, Feifei Gao, Hao Zhang, Shi Jin, and Geofrrey Ye Li, “Deep Learning for Channel Estimation: Interpretation, Performance, and Comparison,” IEEE Trans. Wireless Commun., accepted, 2021.

[J3]. Yuwen Yang, Feifei Gao, Zhimeng Zhong, Bo Ai, and Ahmed Alkhateeb, “Deep Transfer Learning Based Downlink Channel Prediction for FDD Massive MIMO Systems”, IEEE Trans. Commun.,vol. 68, no. 12, pp. 7485-7497, Dec. 2020.

[J4]. Qian Hu, Hao Zhang, Feifei Gao, Chengwen Xing, and Jianping An, “Analysis on the Number of Linear Regions of Piecewise Linear Neural Networks,” IEEE Trans. Neural Networks and Learning Systems, accepted, 2021

[J5]. Weihua Xu, Feifei Gao, Shi Jin, and Ahmed Alkhateeb, “3D Scene Based Beam Selection for mmWave Communications,” IEEE Wireless Commun. Lett., vol. 9, no. 11, pp. 1850-1854, Nov. 2020.

[J6]. Hongyuan Ye, Feifei Gao, Jing Qian, Hao Wang, and Geoffrey Ye Li, “Deep Learning based Denoise Network for CSI Feedback in FDD Massive MIMO Systems,” IEEE Commun. Lett., vol. 24, no. 8, pp. 1742-1746, Aug. 2020.

[J7]. Jieyu Liao, Junhui Zhao, Feifei Gao, and Geoffrey Ye Li, “A Model-Driven Deep Learning Method for Massive MIMO Detection,” IEEE Commun. Lett., vol. 24, no. 8, pp. 1724-1728 Aug. 2020.

[J8]. Yuwen Yang, Feifei Gao, Cheng Qian, and Guisheng Liao, “Model-aided Deep Neural Network for Source Number Detection,” IEEE Signal Processing Letts., vol. 27, pp. 91-95, 2020.

[J9]. Yuwen Yang, Feifei Gao, Geoffrey Ye Li, and Mengnan Jian, “Deep Learning Based Downlink Channel Prediction for FDD Massive MIMO System”, IEEE Commun. Lett., vol. 23, no. 11, pp. 1994-1998, Nov. 2019.

[J10]. Yuwen Yang, Feifei Gao, Xiaoli Ma, and Shun Zhang, “Deep Learning-based Channel Estimation for Doubly Selective Fading Channels,” IEEE Access, vol. 7, no. 1, pp. 36579-36589, Dec. 2019.

[J11]. Shun Zhang, Yushan Liu, Feifei Gao, Chengwen Xing, Jianping An, and Octavia Dobre， " Deep Learning based Channel Extrapolation for Large-Scale Antenna Systems: Opportunities, Challenges and Solutions," IEEE Wireless Commun., Accepted, Dec. 2020. Available : https://arxiv.org/abs/2102.12859

[J12]. Shunbo Zhang, Shun Zhang, Feifei Gao, Jianpeng Ma, and Octavia Dobre, "Deep Learning Optimized Sparse Antenna Activation for Reconfigurable Intelligent Surface Assisted Communication," IEEE Trans. Commun., Major Revision, Dec. 2020. Available: https://arxiv.org/abs/2009.01607.

[J13]. Meng Xu, Shun Zhang, Caijun Zhong, Jianpeng Ma, and Octavia Dobre, "Ordinary Differential Equation-based CNN for Channel Extrapolation over RIS-assisted Communication," IEEE Commun. Lett., Accepted, Mar. 2021. Available: https://arxiv.org/abs/2012.11794.

[J14]. Yindi Yang, Shun Zhang, Feifei Gao, Jianpeng Ma, and Octavia Dobre, "Graph Neural Network based Channel Tracking for Massive MIMO Networks," IEEE Commun. Lett., vol. 24, no. 8, pp. 1747-1751, Aug. 2020.