ITP Lab Intelligent Transmission & Processing Laboratory

Imperial College London

# 2024 Annual Report


**Intelligent Transmission and Processing Laboratory**

**Imperial College London**


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## Contents

## 1. About the Laboratory

The Intelligent Transmission and Processing Laboratory (ITP Lab) was established in 2020 by Professor Geoffrey Ye Li when he joined the Communications and Signal Processing Group, Imperial College London. The ITP lab focuses on the fundamental theories and trending applications of machine learning in signal processing and wireless communications.

### 1.1. Director of the Laboratory

**Dr. Geoffrey Ye Li** (FREng, FIEEE) is a Chair Professor at Imperial College London, UK. Before joining the College in 2020, he was a Professor at Georgia Institute of Technology, USA, for 20 years and a Principal Technical Staff Member with AT&T Labs – Research (previous Bell Labs) in New Jersey, USA, for five years.

He made fundamental contributions to orthogonal frequency division multiplexing for wireless communications, established a framework on resource cooperation in wireless networks, and introduced deep learning to communications. In these areas, he has published over 700 journal and conference papers in addition to over 40 granted patents. His publications have been cited over 74,000 times with an H-index of 126 according to Google Scholar. He has been listed as a Highly Cited Researcher by Clarivate/Web of Science almost every year.

Dr. Geoffrey Ye Li was elected to Fellow of Royal Academy of Engineering (FREng), IEEE Fellow, and IET Fellow for his contributions to signal processing for wireless communications. He won 2024 IEEE Eric E. Sumner Award, 2019 IEEE ComSoc Edwin Howard Armstrong Achievement Award, and several awards from IEEE Signal Processing, Vehicular Technology, and Communications Societies.

### 1.2. Research Vision of the Laboratory

Prior to the era of artificial intelligence and big data, wireless communications and signal processing primarily followed a conventional research route involving problem analysis, modeling, calibration, tuning, and empirical verification. However, this methodology often encountered limitations when dealing with large-scale problems and managing complex, dynamic data, resulting in inefficiencies and limited performance in real-world operations. As such, modern wireless communications and signal processing have embraced the revolutionary impact of artificial intelligence (AI) and machine learning (ML), giving birth to more adaptive, reliable, efficient, and intelligent end-to-end systems and algorithms. The long-term research vision of the ITP Lab is to seek the performance improvement and resource efficiency of wireless data transmission and information processing by leveraging explainable, reliable, and sustainable machine learning theories and methods; see Figure 1. Explainable machine learning, including techniques such as feature engineering and mechanism modeling, aims to render ML models transparent, interpretable, and accountable. Reliable machine learning, encompassing aspects such as adaptivity, robustness, and generalization, focuses on making ML models robust, accurate, and capable of generalizing well to new data. Sustainable machine learning, addressing concerns such as energy efficiency, privacy and security, and fairness and bias, aims to develop ML models with minimal negative impact on the environment and society.

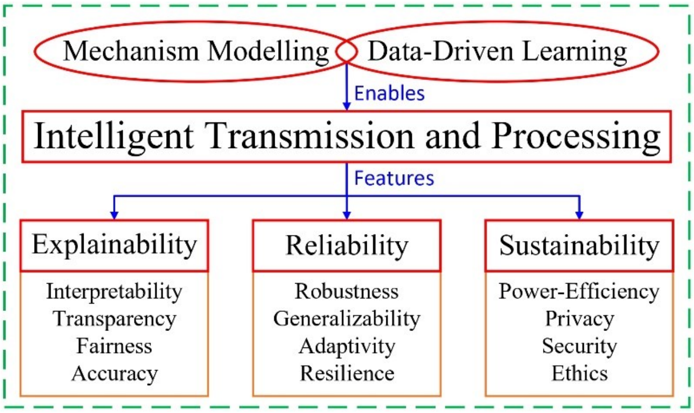


Figure 1: The long-term research vision of the ITP Lab is to seek the performance improvement and resource efficiency of wireless data transmission and information processing by leveraging explainable, reliable, and sustainable machine learning theories and methods. For details, see [1].

## 2. Achievements Summary of the Year

This year, the ITP Lab continues to demonstrate its leadership in research excellence and global engagement.

First, we are thrilled to share that Prof. Geoffrey Ye Li, the director, was elected as a Fellow of the Royal Academy of Engineering (FREng), Class of 2024, in recognition of his outstanding contributions to wireless signal processing, transmission, and standardization. In addition, Prof. Li received the 2024 IEEE Eric E. Sumner Award for his groundbreaking work on frequency-domain communications, including orthogonal frequency division multiplexing (OFDM). Moreover, he was also recognized as a 2024 World's Most Influential Scientific Mind (i.e., Highly Cited Researcher) by Thomson Reuters, underscoring the far-reaching impact of his research.

Second, the ITP Lab played a central role in organizing reputed international conferences. In September 2024, we successfully hosted the 2024 IEEE International Workshop on Machine Learning for Signal Processing (MLSP 2024) in London, UK, where Prof. Li served as General Co-Chair, Dr. Shixiong Wang as a Publicity Co-Chair, and Mr. Kaidi Xu as the Webmaster. Earlier in May, Prof. Li acted as the Technical Program Co-Chair for the 2024 IEEE International Conference on Machine Learning for Communications and Networking (ICMLCN 2024) in Stockholm, Sweden. Looking ahead, Prof. Li has been appointed as General Co-Chair for the upcoming 2025 IEEE Workshop on Signal Processing and Artificial Intelligence for Wireless Communications (SPAWC 2025) to be held in Surrey, UK.

Third, the ITP Lab consistently achieves significant advancements in research productivity, with 9 first-authored papers [1]-[9] and over 25 coauthored papers published in leading journals such as IEEE Transactions on Wireless Communications, IEEE Communications Magazine, IEEE Transactions on Signal Processing, IEEE Transactions on Pattern Analysis and Machine Intelligence, and Mathematics of Operations Research. We also contribute to international conferences, presenting 6 first-authored papers [10]-[15] and 2 coauthored papers at reputed events, including the 2024 IEEE Vehicular Technology Conference (VTC 2024), 2024 IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC 2024), 2024 IEEE International Workshop on Machine Learning for Signal Processing (MLSP 2024), and 2025 IEEE Conference on Computer Communications (INFOCOM 2025), etc. In addition, several first-authored preprints have been published on ArXiv.

Fourth, the laboratory invited five prominent scholars to deliver talks, including Prof. Christos Masouros (University College London), Prof. Shenglong Zhou (Beijing Jiaotong University), Prof. Wei Zhang (University of New South Wales), Prof. Wei Yu (University of Toronto), and Prof. Zhu Han (University of Houston). These interactions enriched the ITP Lab's intellectual ecosystem and fostered collaborative opportunities.

Fifth, the laboratory welcomed two new postdoctoral researchers, Dr. Jingzhi Hu and Dr. Zhenzi Weng, who bring fresh perspectives to the vibrant research environment of the ITP Lab. Additionally, the lab hosted two visiting students, Mr. Jiawei Cao from the University of Electronic Science and Technology of China, from December 2023 to June 2024, and Ms. Shan Sha from Beijing Jiaotong University, from December 2023 to December 2024, further enhancing its international reach and influence.

As the year concludes, the ITP Lab reflects with pride on its achievements and looks forward to continuing its mission of advancing knowledge in signal processing and machine learning for wireless communications. The dedication and contributions of its members ensure that it remains at the forefront of innovation and excellence.

## 3. Individual Achievements of Members

**Dr. Shixiong Wang** works on signal processing and machine learning for wireless communications and sensing (WCS). His is particularly concerned with uncertainty quantification and robustness treatments for WCS problems. In 2024, his first-author paper titled "*Robust waveform design for integrated sensing and communication*" (ISAC) [2], which takes into consideration the uncertainty of channel matrix in ISAC waveform analysis and synthesis, has been published in IEEE Transactions on Signal Processing (TSP). Three reviewers gave highest ratings in TSP, i.e., "Very Novel" and "Significant", which endorses the scientific values of the paper. Moreover, in response to the invitation from Huawei Technology, he wrote a review paper titled "*Machine learning in communications: A road to intelligent transmission and processing*" [1] as the first author, which profoundly discusses the connotations of "Intelligent Transmission and Processing", as well as its technical challenges and practical considerations. The paper has been published in Communications of Huawei Research. In addition, he published a first-author conference paper titled "*Distributionally robust outlier-aware receive beamforming*" [13] in IEEE MLSP 2024, which addresses the outlier issue in wireless transmission and processing. Besides the three published papers above, he also has three first-author preprints on ArXiv, including 1) "*Distributionally Robust Receive Beamforming*", currently under revision at IEEE Transactions on Signal Processing; 2) "*Robust Beamforming with Application in High-Resolution Sensing*", currently under submission to IEEE Transactions on Signal Processing; and 3) "*Uncertainty Awareness in Wireless Communications and Sensing*", to be submitted to IEEE Communications Magazine.

In 2024, Dr. Shixiong Wang also led the Work Package 4 (WP4) of the TUDOR project. He attended 2 plenary meetings, organized 16 WP4 regular meetings, served as the lead editor for 4 WP4 deliverables, and served as a reviewer for 9 WP4 deliverables. He works on transceiver design for integrated sensing and communication for the WP4 of the TUDOR project.

**Mr. Kaidi Xu** focuses on using federated reinforcement learning to train multiple agents for wireless communication systems, obtaining more efficient resource allocation policies. In 2024, Kaidi has two accepted papers on this topic [4], [5]. In detail, Kaidi improves the existing FedGiA approach (an inexact ADMM-based federated learning algorithm) by incorporating the second moment of gradients, and proposed a new method called PASM. He proves that the PASM algorithm is guaranteed to converge to stationary points of the underlying optimization model. Experiments show that PASM can significantly outperform FedGiA and other baselines in scenarios of resource allocation for wireless communications.

Moreover, Kaidi proposes to improve the model aggregation step in neural network (NN) training by rescaling the NN parameters. This rescaling operation utilizes the node-wise-invariance of ReLU activated neurons. It does not change the network input-output map but aligns the models of all agents, and thus, lifts the aggregation steps. Simulation results show that the proposed algorithm improves both convergence speed and final performance compared to the baselines in V2X communication scenarios.

**Mr. Bowen Zhang** focuses on developing machine learning algorithms for parameter estimation in integrated sensing and communications. In 2024, he is interested in improving the detection accuracy of OFDM-based radar. To be specific, Bowen designs a mathematically interpretable Transformer by incorporating learnable parameters and dynamic dictionaries into the conventional 3D-OMP algorithm. The proposed 3D-OMP-Transformer achieves a higher resolution in parameter estimation than the widely used MUSIC and OMP algorithms. Bowen also shows the interpretability of his new method. This work is available online at ArXiv: Bowen Zhang and Geoffrey Ye Li, “White-box 3D-OMP-transformer for ISAC,” arXiv:2407.02251, July 2024. Bowen is also exploring the potential usage of large language models in ISAC, aiming to extend the multi-modality abilities of language models in wireless engineering.

**Mr. Ouya Wang** works on adaptive machine learning for wireless communications. In 2024, he proposes a new algorithm based on the alternating direction method of multipliers (ADMM), called batch ADMM (BADM), to train deep neural networks in a computationally more efficient way. The key innovation of BADM lies in its hierarchical data-splitting strategy, where training data is divided into batches and sub-batches, enabling efficient global parameter aggregation at the batch level and iterative updates of primal and dual variables using the sub-batch data. He and collaborators prove that BADM achieves a sublinear convergence rate under relatively mild assumptions. The performance of BADM is evaluated across diverse deep learning tasks. The work is available online at ArXiv: Ouya Wang, Shenglong Zhou, and Geoffrey Ye Li, “BADM: Batch ADMM for deep learning,” arXiv:2407.01640, June 2024.

Furthermore, Ouya presents a comprehensive review on few-shot learning (FSL) techniques for wireless communications. He classifies existing FSL techniques in wireless systems into two categories: 1) purely data-driven methods, where conventional AI-based FSL techniques are optimized for wireless applications, and 2) wireless domain knowledge-based methods, which integrate domain knowledge, such as classical signal processing algorithms, to reduce the complexity of system parameterization. As a case study, he specifically focusses on multiuser multiple-input multiple-output (MU-MIMO) precoding to demonstrate the advantages of the FSL to achieve fast adaptation in wireless communications. The work is available online at ArXiv: Ouya Wang, Hengtao He, Shenglong Zhou, Zhi Ding, Shi Jin, Khaled B. Letaief, and Geoffrey Ye Li, “Fast adaptation for deep learning-based wireless communications,” arXiv:2409.04302, September 2024.

**Mr. Yanzhen Liu** focuses on addressing two critical challenges in wireless communication systems: 1) the inefficiency of conventional methods in adapting to dynamic and unpredictable environments, and 2) the high energy consumption and computational demands of traditional machine learning models, which limit their practicality in real-world deployment. To tackle these challenges, Yanzhen proposes a new framework that leverages spiking neural networks (SNNs) to enable continuous learning in resource-constrained wireless environments. SNNs, inspired by biological neural systems, utilize event-driven processing and exhibit high energy-efficiency, making them particularly suited for wireless communication tasks.

In technical details, the framework introduces a two-level control algorithm to address the issue of catastrophic forgetting, a common problem in continuous learning systems. This algorithm effectively utilizes previously learned knowledge to facilitate adaptation to new environments, ensuring robust performance over time. Simulation results demonstrate the efficiency of the framework in key wireless communication tasks, including task-oriented semantic communications, MIMO beamforming, and OFDM channel estimation. The results show that the proposed framework significantly mitigates catastrophic forgetting. Furthermore, SNNs achieve comparable performance to conventional artificial neural networks (ANNs) while offering superior energy efficiency, highlighting their potential for deployment in resource-constrained systems. The corresponding paper is under preparation.

**Ms. Tianxin Wang** focuses on the design of federated learning algorithms and their applications in neural receivers. Online neural receivers face significant obstacles such as frequent retraining requirements and vulnerability to interference.

In 2024, Tianxin proposes federated learning solutions to overcome these issues, aiming to enhance training efficiency, generalization, and robustness of online neural receivers. To be specific, in [14], she designs a multi-cell personalized federated learning (PFL) framework to improve online generalization of neural receivers. This framework utilizes the technique of partial model aggregation to balance global and local learning, allowing each receiver to share a global representation while customizing its local head network. In [15], following the above methodology of collaborative learning, she designs a novel collaboration-graph-based PFL algorithm. An approximate generalization bound is derived to enable the optimization of collaboration graphs at the server without accessing raw data. As a result, neural receivers achieve robust performance even in highly heterogeneous and interference-included environments. The extended version of [15] is under preparation for the IEEE Transactions on Wireless Communications, titled "*GraphRx: Graph-Based Collaborative Learning among Multiple Cells for Uplink Neural Receivers*" and co-authored by Prof. Xudong Wang and Prof. Geoffrey Ye Li.

**Mr. Jiawei Cao** focuses on applying deep learning (DL) techniques to analog integrated circuit (IC) testing, aiming at improving testing efficiency and reducing testing costs [9]. The training data for this deep learning-based testing scheme is generated by legacy mathematical programming-based algorithms. Specifically, the optimal selection of stimulus signals and test circuits can be formulated as a 0-1 integer programming problem, which can identify the optimal test modules. Experimental results demonstrate that with the DL-based test method, the response of the selected test modules can map to analog IC specifications with high precision, while testing cost is reduced significantly.

**Ms. Shan Sha** focuses on algorithm design for decentralized federated learning (DFL), a method that allows multiple devices to train a shared model without a central server. DFL is a key branch of collaborative machine learning but often struggles with communication delays, computational limits, and reliability and trustworthiness issues. In 2024, Shan Sha aims to overcome these challenges to make DFL more efficient and secure. The main research problem she addresses is how to improve the speed and stability of DFL while maintaining the privacy and trustworthiness of the system. To solve this, she develops a new algorithm based on the inexact Alternating Direction Method (iADM). This algorithm uses a sparsity constraint on the shared model, enabling the use of one-bit compressive sensing (1BCS). Additionally, she proposes to add differential privacy measures to protect the data of each node, making the learning process more secure and trustworthy. Moreover, she provides strong theoretical justifications for the new algorithm, proving that it converges effectively and maintains privacy. Through various numerical experiments, she shows that the algorithm significantly improves communication and computational efficiency without sacrificing the reliability of the learning results. The corresponding paper is under preparation, titled "*Communication-Efficient and Private Decentralized Federated Learning*" and co-authored by Prof. Lingchen Kong, Prof. Shenglong Zhou, and Prof. Geoffrey Ye Li.

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