ITP Lab Intelligent Transmission & Processing Laboratory

Imperial College London

2025 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 83,350 times with an H-index of 131 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.

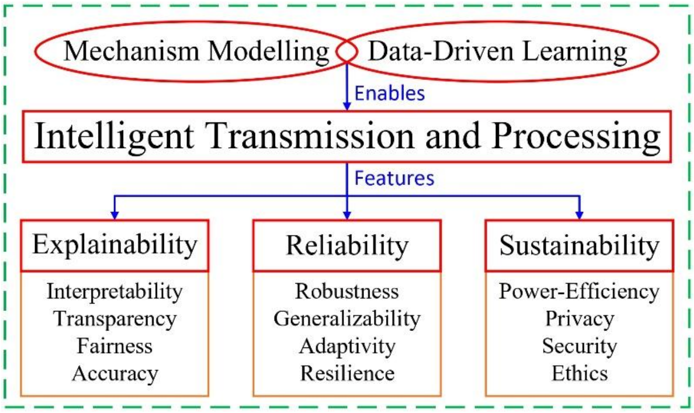

Figure 1: The long-term research vision of the ITP Lab is to seek the performance improvement and resource efficiency of wireless data transmission and information processing by leveraging explainable, reliable, and sustainable machine learning theories and methods.

2. Achievements Summary of the Year

This year, the ITP Lab has continued to demonstrate its strong commitment to research excellence and international engagement. We are pleased to report several notable achievements that reflect the lab's sustained impact and growing global presence.

First, we are delighted to announce that our paper, "*Preconditioned Inexact Stochastic ADMM for Deep Model*," has been accepted by *Nature Machine Intelligence*. In addition, Prof. Li received the 2025 IEEE Communications Society Best Tutorial Paper Award for his co-authored work, "*Reconfigurable Intelligent Surfaces for Wireless Communications: Principles, Challenges, and Opportunities*," published in *IEEE Transactions on Cognitive Communications and Networking* in September 2020. Furthermore, the book *Wireless Communications and Machine Learning*, co-authored by Prof. Li, has been successfully published by the Cambridge University Press.

Second, the ITP Lab continued to play a leading role in organizing high-profile international academic events. In July 2025, we successfully co-organized the *2025 IEEE Workshop on Signal Processing and Artificial Intelligence for Wireless Communications (SPAWC 2025)* in Surrey, United Kingdom. Prof. Li served as a General Co-Chair, while Dr. Shixiong Wang contributed as the Public Relations Chair and Technical Program Committee Assistant.

Third, the ITP Lab maintained strong research productivity, with 11 first-authored papers [1]-[11] and 15 co-authored papers published in leading journals, including *IEEE Transactions on Signal Processing*, *IEEE Transactions on Communications, IEEE Communications Magazine*, *IEEE Communications Letters*, *Nature Machine Intelligence*, and *Mathematics of Operations Research*. In addition, the lab presented 2 first-authored papers [12], [13] and 1 co-authored paper at major international conferences, including IEEE INFOCOM 2025, ICASSP 2025, and ICC 2025. Several first-authored preprints were also released on arXiv [14]-[19].

Fourth, the laboratory hosted two distinguished scholars for academic visits and seminars: Prof. Chenhao Qi from Southeast University and Prof. Jiangzhou Wang from Southeast University and the University of Kent. These visits further strengthened academic exchange and fostered new opportunities for collaboration.

Fifth, the ITP Lab welcomed five visiting students who have contributed to and benefited from its dynamic research environment: Mr. Zijian Cao (Southeast University, November 2024-November 2025), Miss Zixin Zhao (Sun Yat-sen University, July 2025-August 2025), Miss Yiqun Zhao (Academy of Mathematics and Systems Science, Chinese Academy of Sciences, December 2025-March 2026), and Mr. Chi-Wei Chen (National Taiwan University, May 2025-Jan 2026).

As the year draws to a close, the ITP Lab reflects with pride on its collective accomplishments and sustained momentum. With a strong foundation in signal processing and machine learning for wireless communications, the lab remains firmly committed to advancing frontier research and fostering impactful innovation in the years ahead.

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. This year, his first-authored paper titled "*Distributionally Robust Receive Combining"* [9] was published in *IEEE Transactions on Signal Processing*, where robust communication receiver design under various modelling and computational uncertainties was investigated. Another first-authored paper, "*Distributionally Robust Adaptive Beamforming*," [7] was also published in *IEEE Transactions on Signal Processing*, addressing robust sensing receiver design under diverse uncertainties. Moreover, his first-authored paper "*Uncertainty Awareness in Wireless Communications and Sensing*" [5] was published in *IEEE Communications Magazine*, where mature and emerging robust treatment approaches in wireless communications and sensing were reviewed. In addition, his first-authored preprint papers titled "*A New Particle Filter for Target Tracking in MIMO OFDM Integrated Sensing and Communications*" [14] and "*Robust Processing and Learning: Principles, Methods, and Wireless Applications*" [15] have been submitted to IEEE for consideration for publication.

In 2025, Dr Shixiong Wang co-organised the 2025 IEEE Workshop on Signal Processing and Artificial Intelligence for Wireless Communications (SPAWC 2025) in Surrey, United Kingdom, where he served as the Public Relations Chair and the Technical Program Committee (TPC) Assistant. Furthermore, under his leadership, the Work Package 4 (WP4) of the TUDOR project has successfully concluded.

Dr. Jingzhi Hu's research primarily focused on semantic communications, with particular emphasis on knowledge alignment between heterogeneous AI agents in generative semantic communication (GSC) systems. In 2025, he delivered several key contributions in this area. First, he designed a network-level knowledge alignment protocol based on knowledge distillation and low-rank adaptation, which fundamentally improves semantic communication quality across heterogeneous agent networks while enabling the transmission of expert knowledge at low overhead. The related paper, entitled "*Distillation-Enabled Knowledge Alignment Protocol for Semantic Communication in AI Agent Networks*" [11], was accepted by the *IEEE Communications Letters*, where multiple reviewers highlighted its strong novelty and potential impact. The project code has also been released as open source on GitHub. In addition, Dr. Hu investigated knowledge alignment for generative models under cloud–edge–device architectures, proposing a meta-word–assisted knowledge distillation framework and a transmission-level knowledge alignment method for JSCC codecs. This work has been released on arXiv [16] and submitted to IEEE Transactions on Image Processing (TIP), receiving positive reviewer feedback. Following constructive review comments, the manuscript has been substantially strengthened and is ready for resubmission. Furthermore, Dr. Hu led a visiting student (Ms. Zixin Zhao) in research on GSC for satellite video transmission. The proposed method achieves an additional 2.5 dB performance gain over existing semantic communication schemes and maintains video recognizability under channel error rates as high as 80%. This work has been submitted to IEEE ICC 2026, and an advanced neural architecture of GSC, featuring further enhanced robustness and fault tolerance tailored to satellite communication scenarios, has been designed and is currently under experiments.

Beyond his research contributions, Dr. Hu also co-supervised an undergraduate Final Year Project on advanced topics in continual learning, supporting the student in achieving a First-Class grade for the thesis. He further contributed to several group-level research proposals related to semantic communications, including applications to the MediaTek, CHEDDAR, and EPSRC projects, providing substantial support in technical planning and proposal preparation.

Dr. Ouya Wang focuses on developing fast adaptation techniques for deep learning-based wireless communication systems, enabling these systems to adapt efficiently across various scenarios. In 2025, Ouya has two accepted papers on this topic [2], [6]. In detail, Ouya developed two few-shot learning (FSL) frameworks for wireless transceiver design, both formulated as optimization problems solvable by well-known algorithms such as inexact ADMM. He demonstrates how the proposed FSL frameworks are used in OFDM receivers and beamforming for millimeter-wave systems. Numerical experiments show that the proposed frameworks outperform popular approaches like transfer learning and model-agnostic meta-learning. Moreover, Ouya presents a comprehensive review to discuss fast adaptation for deep learning-based wireless communications by using FSL techniques. 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.

Dr. Kaidi Xu focuses on federated learning for wireless communications. This year, Kaidi has submitted one paper on this topic, entitled "*Neural Collapse based Deep Supervised Federated Learning for Signal Detection in OFDM Systems*" [17]. In detail, Kaidi leveraged Neural Collapse (NC) solution to supervise hidden features among different clients to improve the aggregation efficiency. This learning framework is termed as NCDSFL. In addition, the NC solution for multi-binary classification problem, which is equivalent to multi-label classification problem, has been derived. Experiments show that the proposed algorithm has significantly faster convergence speed than baselines and thus less communication overheads in signal detection scenarios.

Mr. Yanzhen Liu focuses on applying neuromorphic computing paradigms to wireless signal processing. In 2025, his work progressed in two main directions. First, he completed a framework for deploying spiking neural networks (SNNs) in wireless environments, named Spiking Adaptive Communications (SpikACom). The framework supports continual learning in dynamic wireless settings and has been demonstrated on a range of challenging wireless signal processing tasks. These results highlight the capability of SNNs to address complex problems while achieving significantly reduced energy consumption. For technical details, see the preprint [18]. Second, he investigated the unique advantages of spike-based computing for robust learning in semantic communication. He found that the threshold-based firing mechanism can help filter noise and developed a regularization method that improves robustness without relying on training with noisy samples. In addition, he explored how the strong nonlinearity of spike-based computation can make models more resilient to gradient-based adversarial attacks. This work has been submitted to IEEE journals.

Mr. Zijian Cao focuses on the design of task-oriented semantic communication systems, particularly in the context of collaborative perception and autonomous driving. His research addresses key challenges such as efficient image transmission, semantic information compression, and physical-layer security and robustness, aiming to enhance the performance, adaptability, and security of communication systems.

In 2025, Zijian Cao focused on task-oriented semantic communication for stereo-vision 3D object detection in autonomous driving. Specifically, in [10], he proposed a framework that jointly extracts, compresses, and transmits 2D detection and optical flow semantics, significantly reducing transmission load while maintaining detection accuracy and improving communication efficiency. Additionally, he explored physical-layer security in semantic communication. In [3], he introduced a secure transmission framework that integrates semantic encoding, decoding, and beamforming to ensure task performance and security under eavesdropping conditions. These two works, "*Task-Oriented Semantic Communication for Stereo-Vision 3D Object Detection*" [10] and "*Physical-Layer Secure Transmission for Semantic Communication Systems*" [3], were published in IEEE Transactions on Communications (TCOM) and co-authored with Prof. Le Liang, Prof. Hua Zhang, and Prof. Geoffrey Ye Li. Moreover, Zijian Cao also conducted research on physical-layer robustness for semantic communication in collaborative perception for autonomous driving, and his paper "*Physical-Layer Adversarial Robustness in Semantic Communication for Collaborative Perception*" is currently under review.

Mr. Chi-Wei Chen focuses on the application of deep learning (DL) techniques to digital predistortion (DPD) for linearizing nonlinear power amplifiers (PAs) in wideband communication systems. While conventional DSP-based methods like the General Memory Polynomial (GMP) suffer from limited linearization performance, state-of-the-art DL models such as LSTM and GRU involve computational costs that are often unaffordable for edge devices. Chi-Wei proposes a hybrid DPD framework to balance high-fidelity linearization with low complexity. Specifically, based on the sequence properties, he develops an adaptive residual GRU model that integrates GMP-based structures to mitigate the PA memory effects. To further minimize the computational cost and enable parallelization, he introduces a multi-sample prediction scheme based on down-sampled sequences, achieving an additional 32% reduction in MAC operations. Experimental results on two open datasets demonstrate that this hybrid model significantly reduces complexity while maintaining superior EVM and ACLR performance. The corresponding paper is under preparation.

Ms. Yiqun Zhao's reserch mainly focuses on semantic theory for AI-driven communication systems. Her first-authored paper submitted to IEEE Transactions on Signal Processing (TSP), which is titled "*Semantic Rate-Distortion Theory with Applications*" [19], develops a rate-distortion framework for semantic compression. Most existing approaches focus on decoder-side estimation of meaning while overlooking inherent challenges like semantic ambiguity and polysemy. To bridge this gap, the work proposed a novel constraint of conditional semantic probability distortion within a realistic semantic communication model. This constraint effectively captures the essential features of practical semantic exchanges. Leveraging methods from rate-distortion-perception theory, the work established a theorem specifying the minimum achievable rate under both this new semantic constraint and a traditional symbolic fidelity constraint. A closed-form limit was derived for a specific semantic scenario. Experimental results demonstrate that bounding conditional semantic probability distortion simultaneously improves semantic transmission accuracy and bit-rate efficiency.

Ms. Zixin Zhao works on semantic communications and machine learning for wireless and satellite networks. Her research focuses on improving transmission robustness under low-SNR and high-error-rate conditions. In 2025, she submitted a first-author paper titled "*Enabling High Error Tolerance in Satellite Video Transmissions by Generative Semantic Communication*" to IEEE International Conference on Communications (ICC 2026), which investigates robust semantic video transmission over LEO satellite links. The results demonstrate clear performance advantages over conventional semantic communication methods in challenging transmission scenarios.

Mr. Zeru Fang focuses on spiking neural networks (SNNs) and compressed sensing for efficient signal processing in resource-constrained and edge scenarios. His research examines the limitations of conventional ANN-based reconstruction methods in terms of energy consumption and computational complexity and investigates event-driven SNN models as a more efficient alternative. He has studied compressed sensing theory, including sparse modelling and iterative reconstruction algorithms, and explored their integration with spiking neural computation. Preliminary simulations analyse reconstruction performance and convergence behaviour under different signal models, laying the groundwork for future research on SNN-based compressed sensing methods for edge intelligent systems.

Mr. Yangjing Wang focuses on foundation models and multi-agent collaboration for intelligent wireless networks. In 2025, he proposes a wireless domain foundation model (WDFM) for generalized instantaneous optimization, comprising upstream universal pre-training and downstream multi-task adaptation. Specifically, in the upstream phase, he constructs a multi-source heterogeneous dataset to train a task-agnostic universal foundational channel encoder (FCE) based on the MAE architecture, enabling robust and generalized channel feature extraction. For downstream adaptation, the pre-trained FCE is frozen and integrated into the WDFM, which adopts a non-autoregressive (NAR) framework featuring a hard-parameter-sharing backbone with multiple MLP task heads. Extensive experimental results demonstrate that the WDFM not only exhibits strong performance across all evaluated tasks but also shows excellent generalization to unseen scenarios. The corresponding paper is under preparation.

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