Guest Editorial >>>

Special Topic on Native Intelligence at the Physical Layer

Guest Editors

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The rapid evolution of wireless communication technologies, particularly with the advent of 5G and the impending transition to 6G, has underscored the need for innovative strategies to enhance the performance, reliability, and efficiency of communication systems. One such promising approach gaining significant attention is the concept of native intelligence at the physical layer (PHY). This forward-thinking concept integrates advanced algorithms and AI-driven solutions directly into the physical layer, transforming the way communication systems are managed and optimized in real time. The incorporation of native intelligence at the physical layer offers tremendous potential to meet the growing demands of future communication networks. By embedding artificial intelligence (AI) algorithms into the physical layer, these intelligent systems can autonomously adapt to dynamic channel conditions, thereby improving spectral efficiency, enhancing error correction, and ensuring robust communication even in highly challenging and fluctuating environments. Native intelligence is poised to become a crucial enabler for the advanced features promised by 6G networks, such as ultra-reliable low-latency communication, massive connectivity, and intelligent wireless ecosystems.

In this special issue, we aim to spotlight the latest advancement and research development in the field of native intelligence at the physical layer. We have invited high-quality submissions that explore the theoretical underpinnings and innovative use cases of AI in enhancing the physical layer of communication systems. The call for papers has garnered a series of excellent submissions, reflecting the growing interest and momentum in this emerging area. Following two rigorous rounds of peer review, the following seven papers are presented. These papers cover topics such as spatio-temporal channel state information (CSI) prediction for massive multiple input multiple output (MIMO), reconfigurable intelligent surfaces (RIS)-enhanced communication security, AI-based physical-layer authentication for 6G, rethinking source-channel coding, AI-native networks for 6G optimization, device activity detection in massive MIMO, and efficient primary synchronization signal (PSS) detection using convolutional neural networks (CNN), each demonstrating significant advancements in performance, security, and efficiency. The papers are organized as follows.

The first paper, titled "Efficient Spatio-Temporal Predictive Learning for Massive MIMO CSI Prediction", introduces a novel spatio-temporal predictive network (STPNet) that improves CSI prediction in massive MIMO systems. The STPNet model integrates both CSI feedback and prediction modules using deep learning techniques to capture spatio-temporal correlations. This approach improves the accuracy of CSI prediction, especially in scenarios with high mobility or feedback delays, outperforming traditional methods under various channel conditions.

The second paper, titled "RIS-Enabled Simultaneous Transmission and Key Generation with PPO: Exploring Security Boundary of RIS Phase Shift", investigates the use of RIS to enhance both communication security and transmission efficiency. The paper presents an integrated communication and security (ICAS) design that combines simultaneous transmis-

DOI:10.12142/ZTECOM.202501001
Citation (Format 1): YANG K, JIN S, XIANG L P. Native intelligence at the physical layer [J]. ZTE Communications, 2025, 23(1): 1–2. DOI: 10.12142/ZTECOM.202501001
Citation (Format 2): K. Yang, S. Jin, L. P. Xiang, "Native intelligence at the physical layer," *ZTE Communications*, vol. 23, no. 1, pp. 1–2, Mar. 2025. doi: 10.12142/ZTECOM.202501001.

sion and key generation (STAG). By optimizing RIS phase shifts through a proximal policy optimization (PPO) algorithm. The proposed system significantly improves security and convergence stability, demonstrating a 90% performance improvement in "one-time pad" communication compared with traditional methods.

The third paper, titled "Endogenous Security Through AI-Driven Physical-Layer Authentication for Future 6G Networks", explores the use of AI to enhance physical-layer security for 6G networks. The paper focuses on physical-layer authentication (PLA), leveraging the unique randomness and space-time-frequency characteristics of the wireless channel to provide secure identity signatures. The authors propose a graph neural network (GNN)-based PLA method that outperforms traditional authentication schemes in terms of accuracy, addressing emerging security challenges in 6G networks.

The fourth paper, titled "Separate Source Channel Coding Is Still What You Need: An LLM-Based Rethinking", challenges the conventional joint source channel coding (JSCC) paradigm and advocates for separate source channel coding (SSCC). The authors propose leveraging large language models (LLMs) for source coding and error correction code transformers (ECCT) for channel coding, showing that SSCC offers superior performance over JSCC. The paper provides an in-depth analysis of the compatibility challenges between semantic communication approaches and digital communication systems, demonstrating the efficiency of SSCC in modern communication contexts.

The fifth paper, titled "Exploration of NWDAF Development Architecture for 6G AI-Native Networks", explores the role of AI-native networks in 6G, focusing on the network data analytics function (NWDAF). The paper proposes a novel architecture that integrates real-time data collection, model training, and AI-driven decision-making to optimize network resource management. Through a vertical scaling use case on Kubernetes, the authors demonstrate the practical benefits of AI in improving network management and resource allocation, with the XGBoost model showing superior predictive performance.

The sixth paper, titled "Device Activity Detection and Channel Estimation Using Score-Based Generative Models in Massive MIMO", addresses the challenge of joint device activity detection and channel estimation in massive MIMO systems. The authors propose a score-based generative model for robust channel estimation, which adapts well to the complex and dynamic environments typical of massive MIMO systems. Simulation results show exceptional precision in channel estimation, with errors reduced to as low as −45 dB, and demonstrate high accuracy in detecting active devices. This method significantly improves the performance of network resource allocation and device activity detection in large-scale systems.

The seventh paper, titled "Efficient PSS Detection Algorithm Aided by CNN", proposes a fast PSS detection algorithm based on the correlation characteristics of PSS time-domain superposition signals. By incorporating CNN to estimate frequency offsets, the paper addresses potential accuracy issues caused by these offsets during the PSS detection process. The proposed method reduces computational complexity and improves communication speed, with simulation results demonstrating its effectiveness in enhancing PSS detection efficiency.

To conclude, we hope this special issue on native intelligence at the physical layer serves as a significant step forward in integrating intelligent algorithms directly into the physical layer of communication systems. Finally, we sincerely express our gratitude to all the authors and reviewers for their invaluable contributions, and we trust that the insights and innovations presented will inspire new directions for research and development in this exciting and evolving field.

Biographies

YANG Kun received his PhD from the Department of Electronic & Electrical Engineering, University College London (UCL), UK. He is currently a Chair Professor in the School of Intelligent Software and Engineering, Nanjing University, China. He is also an affiliated professor of University of Essex, UK. His main research interests include wireless networks and communications, communication-computing cooperation, and new AI for the wireless. He has published 500+ papers and filed 50 patents. He serves on the editorial boards of a number of IEEE journals (e.g., *IEEE WCM*, *TVT*, and *TNB*). He is a deputy editor-in-chief of *IET Smart Cities Journal*. He has been a judge of GSMA GLOMO Award at MWC Barcelona since 2019. He was a recipient of 2024 IET Achievement Medal and the 2024 IEEE CommSoft TC Technical Achievement Award. He is a member of Academia Europaea (MAE), a Fellow of IEEE, a Fellow of IET and a Distinguished Member of ACM.

JIN Shi received his BS degree in communication engineering from Guilin University of Electronic Technology, China in 1996, MS degree from Nanjing University of Posts and Telecommunications, China in 2003, and PhD degree in information and communications engineering from the Southeast University, China in 2007. From June 2007 to October 2009, he was a research fellow with the Adastral Park Research Campus, University College London, UK. He is currently with the faculty of the National Mobile Communications Research Laboratory, Southeast University. His research interests include wireless communications, random matrix theory, and information theory. He is serving as an area editor for the *Transactions on Communications* and *IET Electronics Letters*. He was an associate editor for the *IEEE Transactions on Wireless Communications*, *IEEE Communications Letters*, and *IET Communications*. Prof. JIN and his co-authors have been awarded the 2011 IEEE Communications Society Stephen O. Rice Prize Paper Award in the field of communication theory, the 2024 IEEE Communications Society Marconi Prize Paper Award, the IEEE Vehicular Technology Society 2023 Jack Neubauer Memorial Award, a 2022 Best Paper Award, and a 2010 Young Author Best Paper Award by the IEEE Signal Processing Society.

XIANG Luping received his BE degree (Hons.) from Xiamen University, China in 2015, and PhD degree from the University of Southampton, UK in 2020. From 2020 to 2021, he was a research fellow with the Next Generation Wireless Group, University of Southampton. In November 2021, he joined the University of Electronic Science and Technology of China (UESTC) and in September 2024, he joined Nanjing University, China as an assistant professor. In 2024, he was honored with the Xiaomi Young Scholar Award, and also co-founded the company Accelercomm. His research interests include native intelligence at wireless communication, end-to-end transmission technology, computer vision, and integrated sensing and communication transmission.