

Large Language Models for Intelligent Wireless Communications

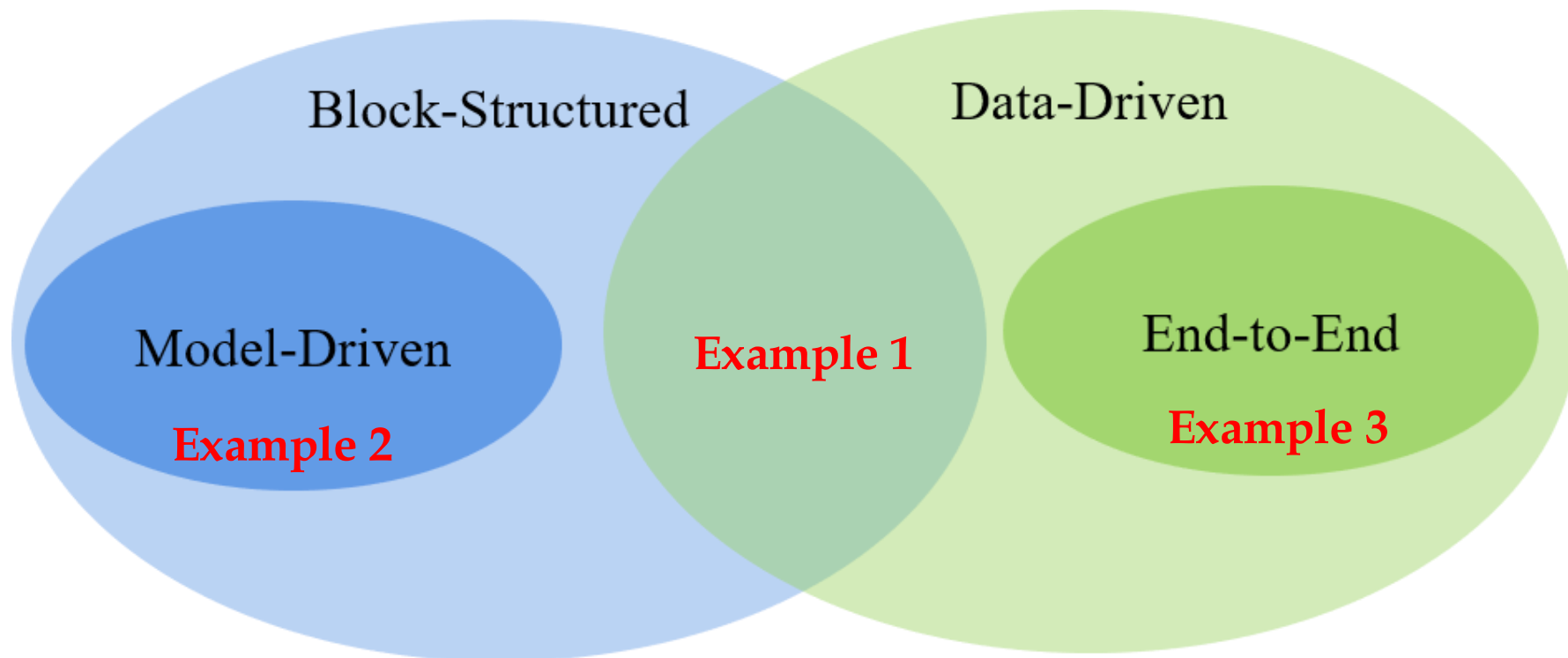
Professor Geoffrey Ye Li
Department of Electrical and Electronics Engineering
Imperial College London
London, UK

Contributed by
Prof. Le Liang, Southeast University
Prof. Hao Ye, University of California, Santa Cruz

Outline

- I. **Motivation**
- II. Adapting LLMs to Wireless Tasks
- III. Wireless Foundation Models
- IV. Agentic LLMs for Wireless Communication
- V. Challenges and Opportunities

DL in Physical Layer Communications



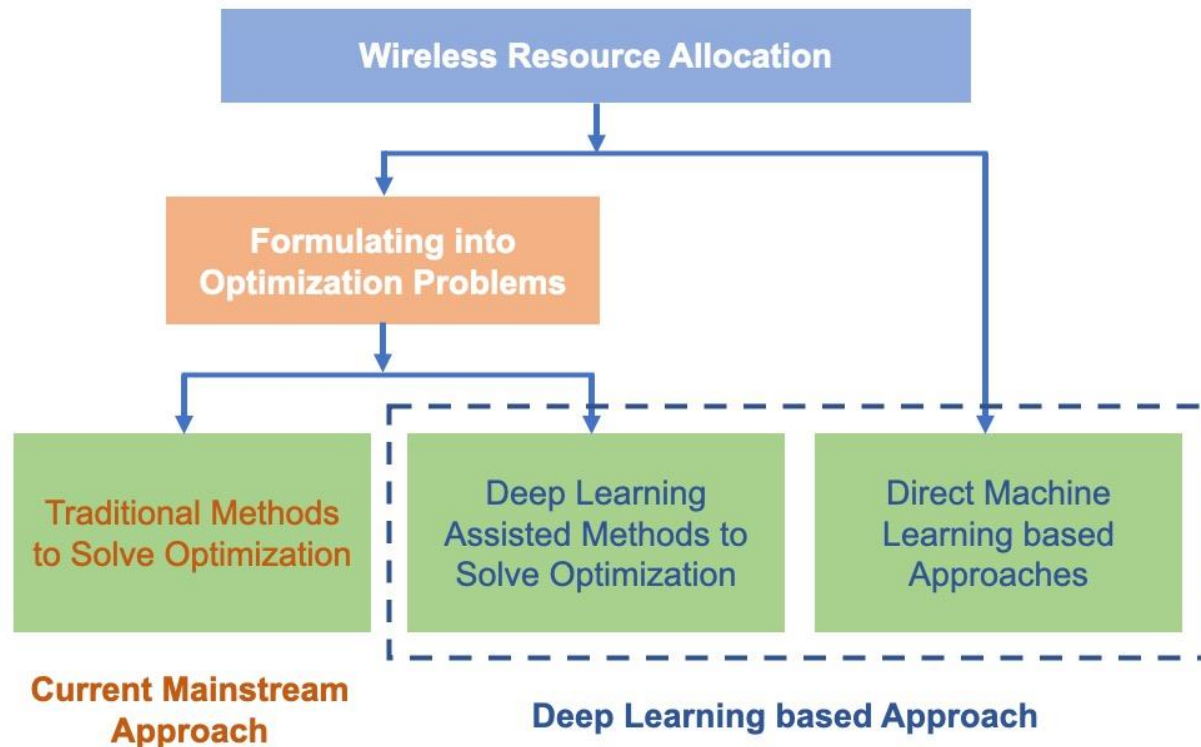
Z.-J. Qin, H. Ye, G. Y. Li, and B.-H. Juang, "Deep learning in physical layer communications," *IEEE Wireless Commun.*, vol. 26, no. 2, pp. 93-98, April 2019. **(2022 IEEE ComSoc Fred W. Ellersick Prize Paper Award)**

Example 1: H. Ye, G. Y. Li, and B.-H. F. Juang, "Power of deep learning for channel estimation and signal detection in OFDM systems," *IEEE Wireless Commun. Lett.*, vol. 7, no. 1, pp. 114 – 117, Feb. 2018.

Example 2: H.-T. He, C.-K. Wen, S. Jin, and G. Y. Li, "Model-driven deep learning for MIMO detection," *IEEE Trans. Signal Process.*, vol. 68, pp. 1702-1715, March 2020.

Example 3: H. Xie, Z. Qin, G. Y. Li, and B.-H. Juang, "Deep learning enabled semantic communication systems," *IEEE Trans. Signal Process.* vol. 69, pp. 2663-2675, 2021, Apr. 2021. **(2023 IEEE SPS Best Paper Award)**

DL for Wireless Resource Allocation



- L. Liang, H. Ye, G.-D. Yu, and G. Y. Li, "Deep learning based wireless resource allocation with application in vehicular networks," *Proc. IEEE*, vol. 108, no. 2, pp. 341-356, Feb. 2020.
- H. Ye, G. Y. Li, B.-H. F. Juang, "Deep reinforcement learning based resource allocation for V2V communications," *IEEE Trans. Veh. Tech.*, vol. 68, no. 4, pp. 3163-3173, April 2019.

Why LLMs for Intelligent Communications?

- **Limitations of Traditional AI Models**
 - Limited generalization
 - Task-specific architectures
 - Inefficiency in handling cross-task reasoning
- **Advantages of Large Language Models (LLMs)**
 - Adaptability
 - Scalability
 - Zero-shot learning ability

LLMs for Intelligent Communications: Challenges

- **Challenges**

- Modality gap (**HD, structured, modality-specific in wireless**)
- Inference overhead (**instant response & EE in wireless**)

- **Three Complementary Directions**

- Adapting LLMs to specific wireless tasks
- Wireless foundation models (**balance generality & efficiency**)
- Agentic LLMs for wireless communication (**self-organizing & adaptive networks**)

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Adapting LLMs to specific wireless tasks

□ Challenges:

- Modality gap between the natural language and the wireless data
- How to unleash the ability of LLMs?
- How to fine-tune the LLMs?

□ Two Examples

- Physical-layer signal processing

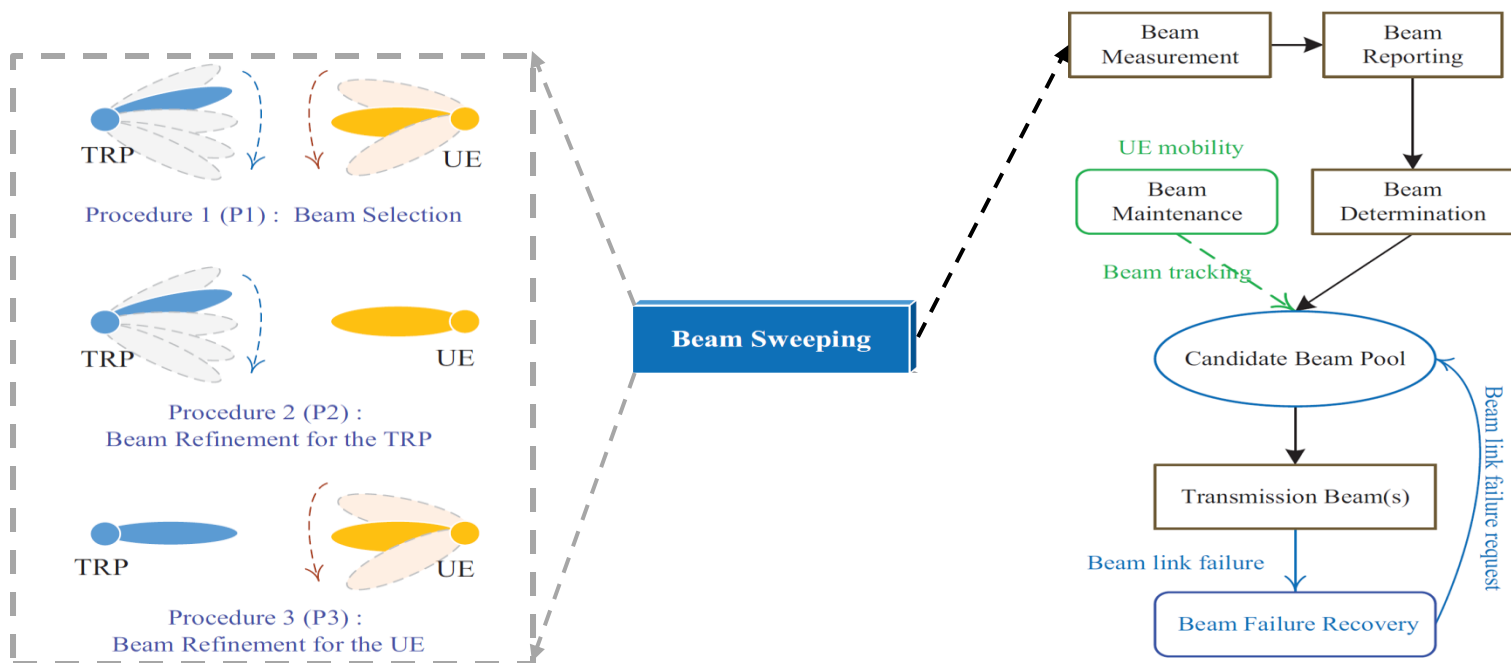
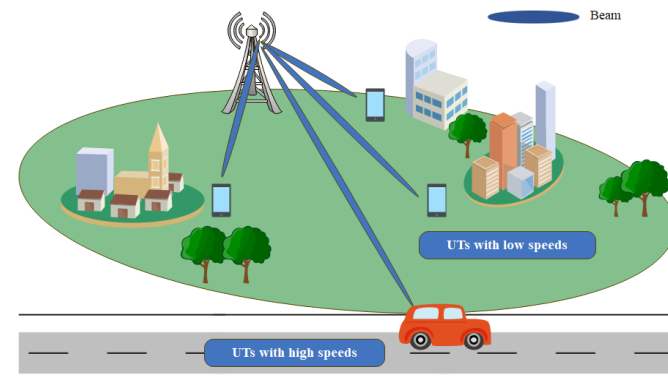
Y. Sheng, K. Huang, L. Liang, P. Liu, S. Jin and G. Y. Li, "Beam prediction based on large language models," *IEEE Wireless Commun. Lett.*, , vol. 14, no. 5, pp. 1406-1410, May 2025

- Semantic communication

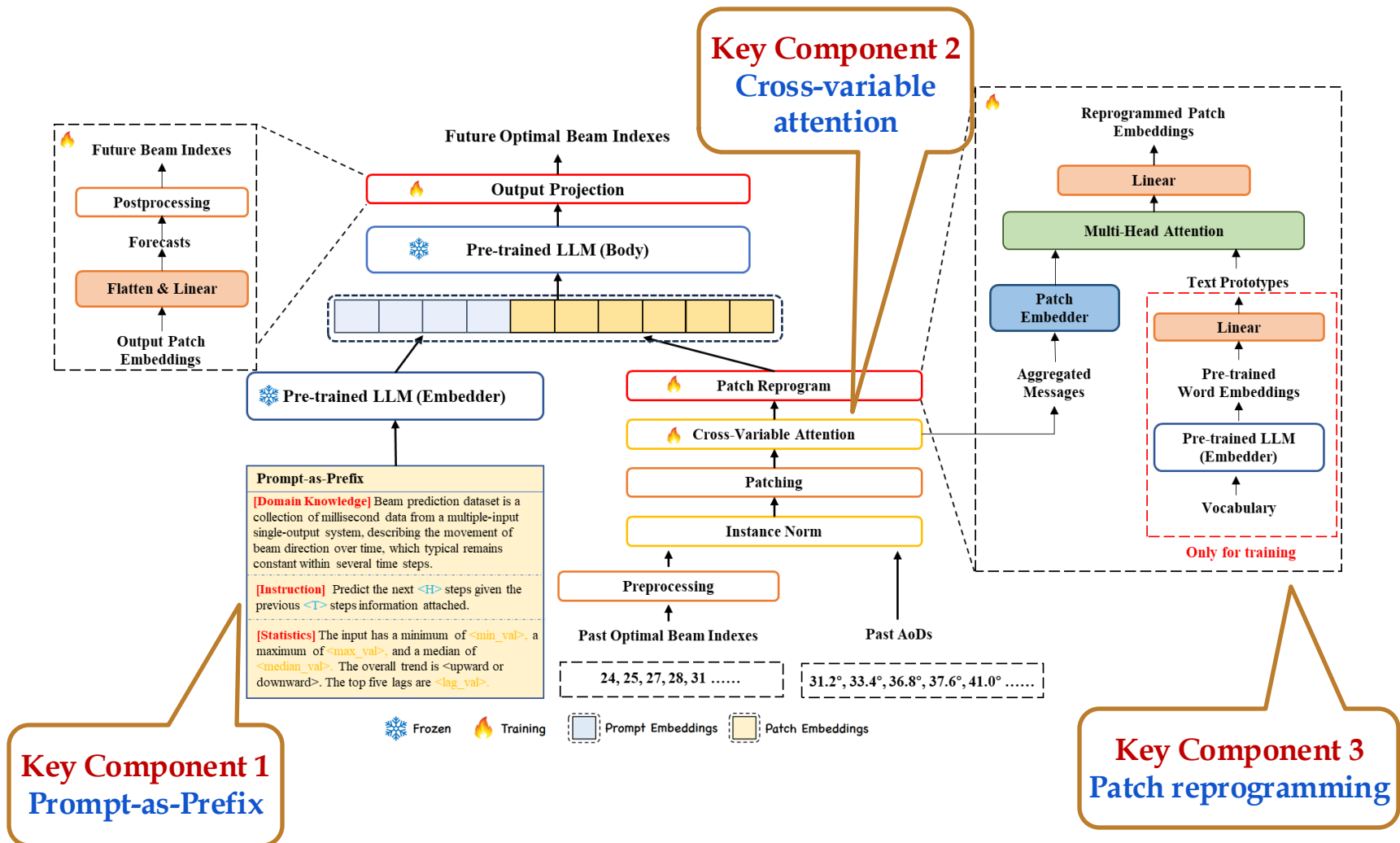
Z. Weng Z. Qin, and G. Y. Li, "Large model empowered streaming semantic communications for speech translation," *IEEE Wireless Commun. Lett.*, , early access

Beam Prediction based on LLMs: System Model

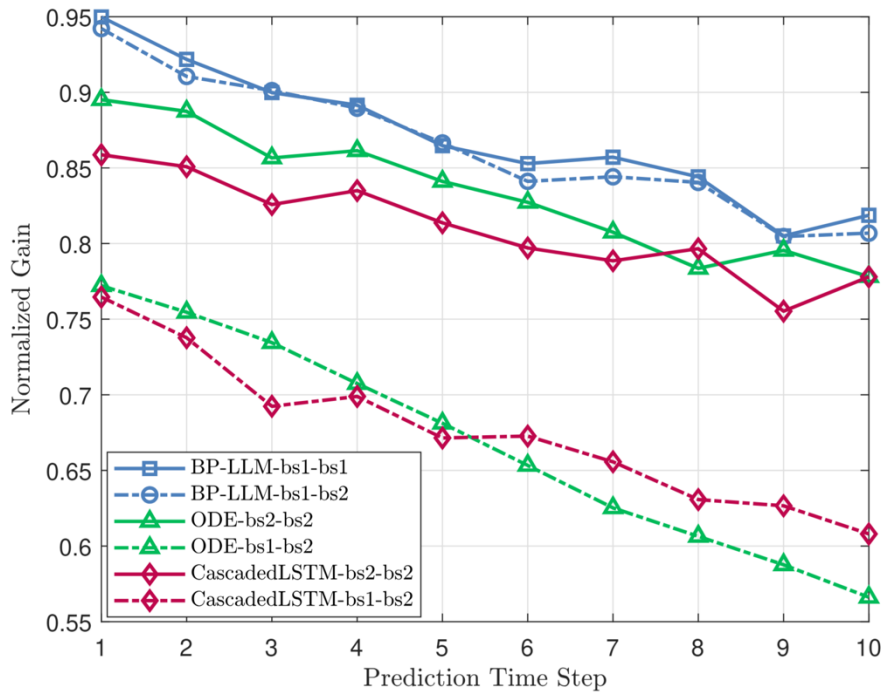
- Steering vector for base station (BS) with a uniform linear array (ULA)
- Discrete Fourier transform (DFT) codebook
- Objective: maximizing the beamforming gain



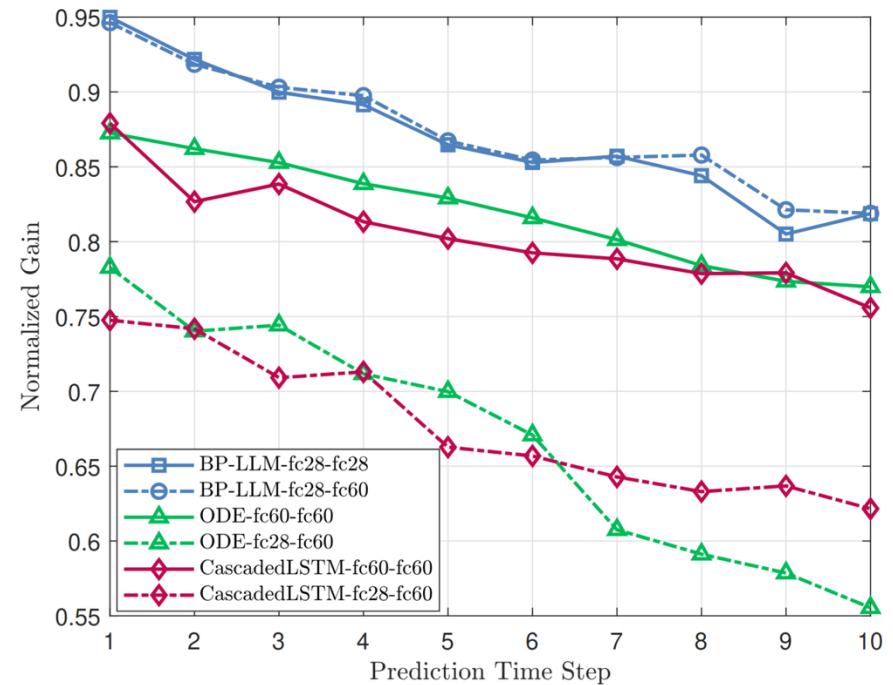
Beam Prediction based on LLMs: Architecture



Beam Prediction based on LLMs: Performance



Compared with baselines under
the **mismatched BS settings**

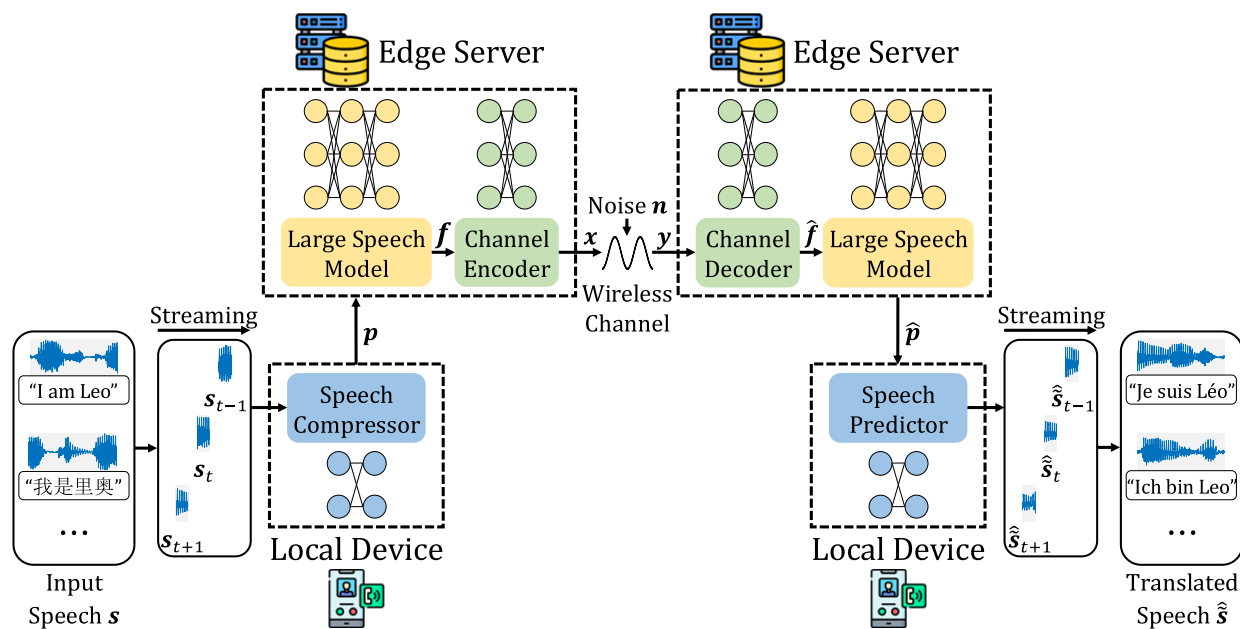


Compared with baselines under
the **mismatched center frequency**

Best performance with strong robustness to different scenarios!

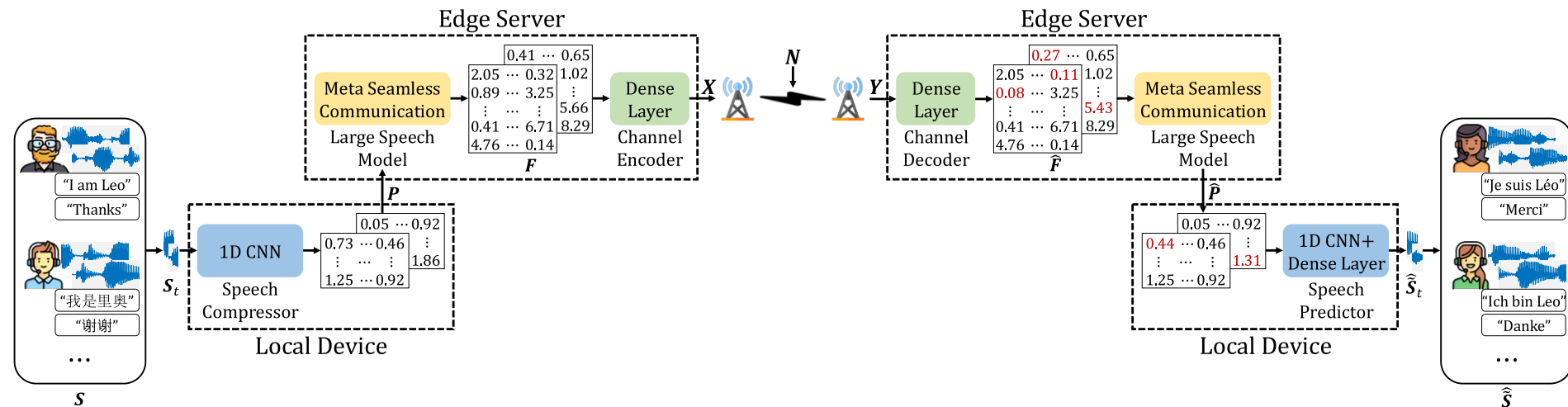
Semantic Communication: Multilingual Streaming Speech Transmission

- Support multiple languages translation
- Edge-device collaborative framework
- Enable streaming transmission to reduce latency



Semantic Communication: Multilingual Streaming Speech Transmission

- **Speech compressor:** Obtain low-dimensional features
- **Edge server:** Perform complicated semantic extraction
- **Channel coding:** Mitigate channel effects
- **Speech Predictor:** Reconstruct translated speech



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Why Wireless Foundation Models?

□ Limitations of Adapting LLMs for Communication:

- Large parameter size
- Slow training and inference speed
- Redundant linguistic knowledge

□ Advantages of Wireless Foundation Models:

- Smaller parameter size
- Quicker training and inference speed
- More domain-specific knowledge

Wireless Foundation Model: Predicting ...

□ Task I: Channel Prediction

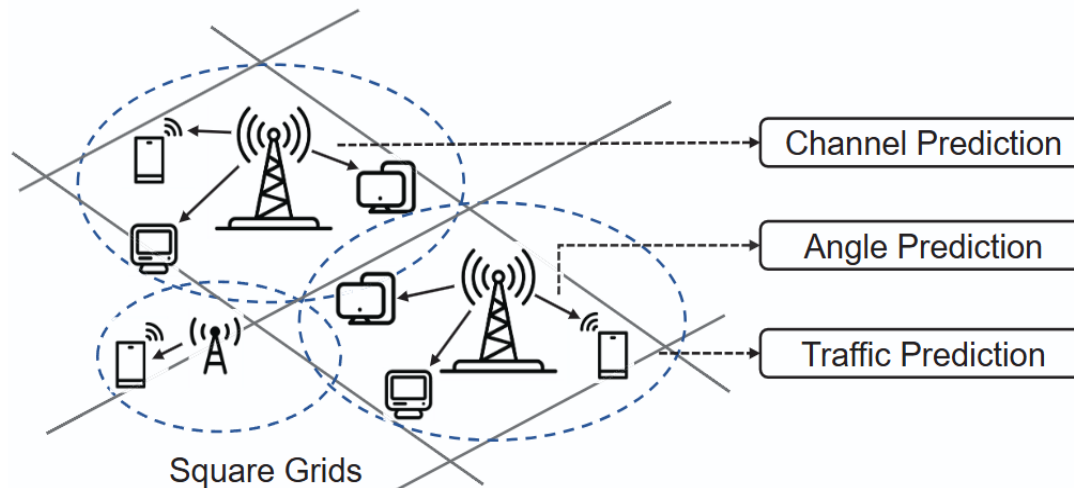
Downstream tasks: Resource Allocation, downlink communication

□ Task II: Angle Prediction in ISAC

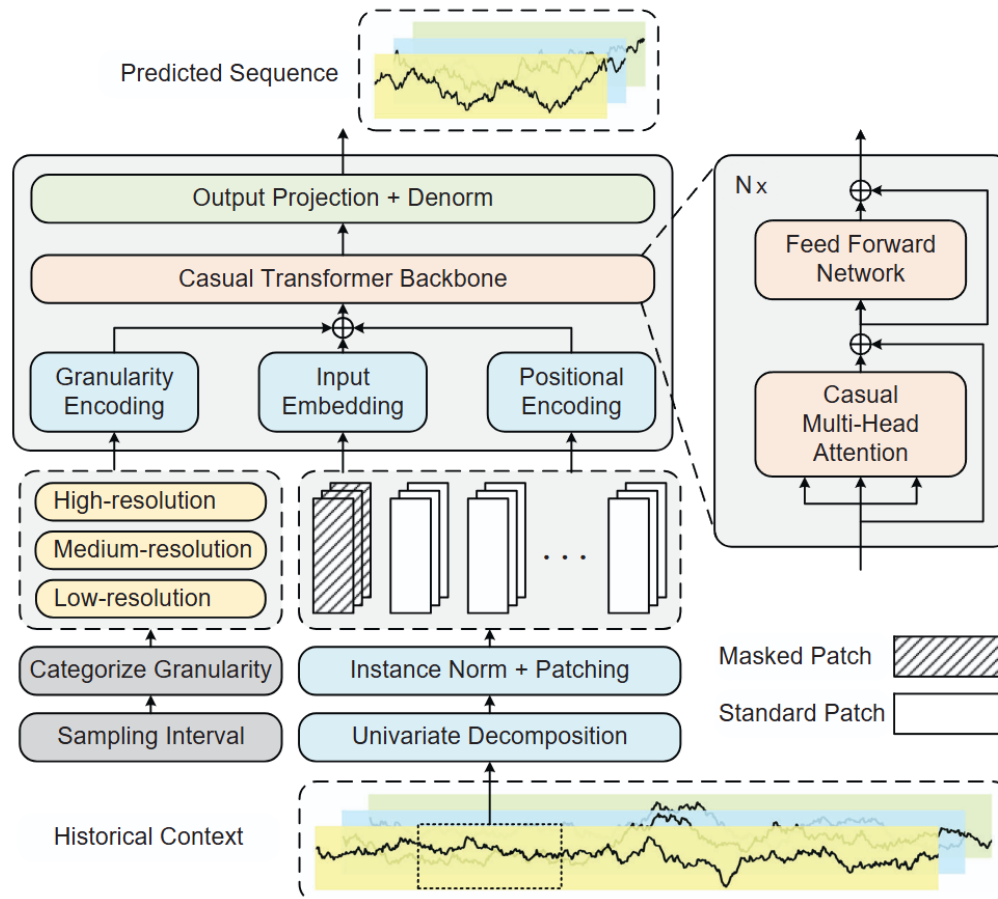
Downstream tasks: Predictive beamforming

□ Task III: Traffic Prediction

Downstream tasks: BS sleeping control, load balancing



Wireless Foundation Model



□ Data Processing

- Univariate decomposition
- Instance Normalization
- Patching

□ Model Architecture

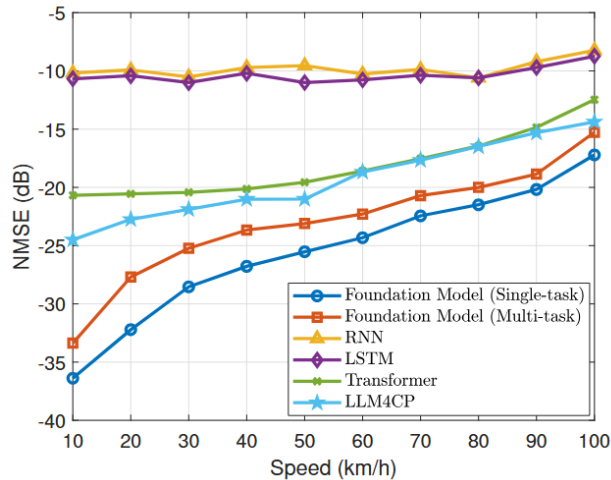
- Input embedding
- Positional encoding
- Granularity encoding
- Causal Transformer

□ Learning Algorithm

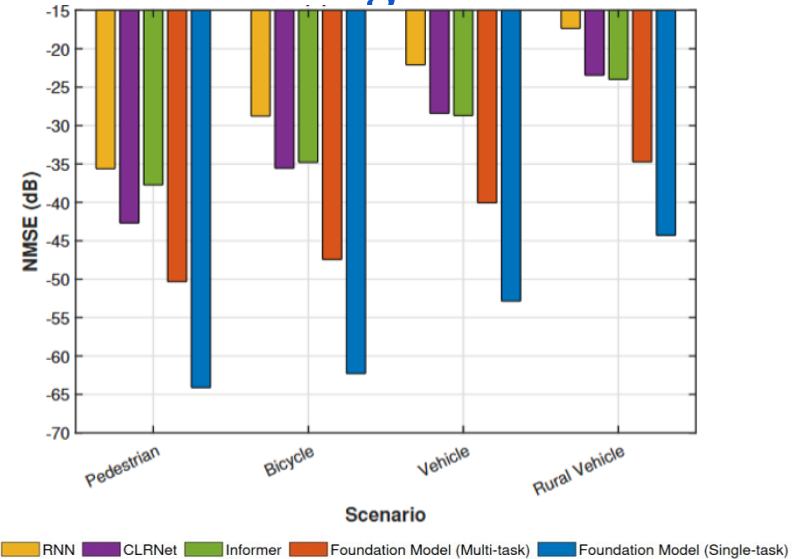
- Patch masking
- Loss function

Wireless Foundation Model: Performance

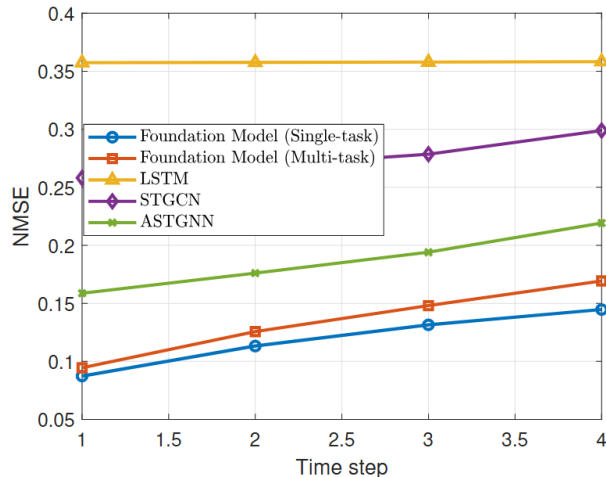
Task I: Channel Prediction



Task II: Angle Prediction



Task III: Traffic Prediction



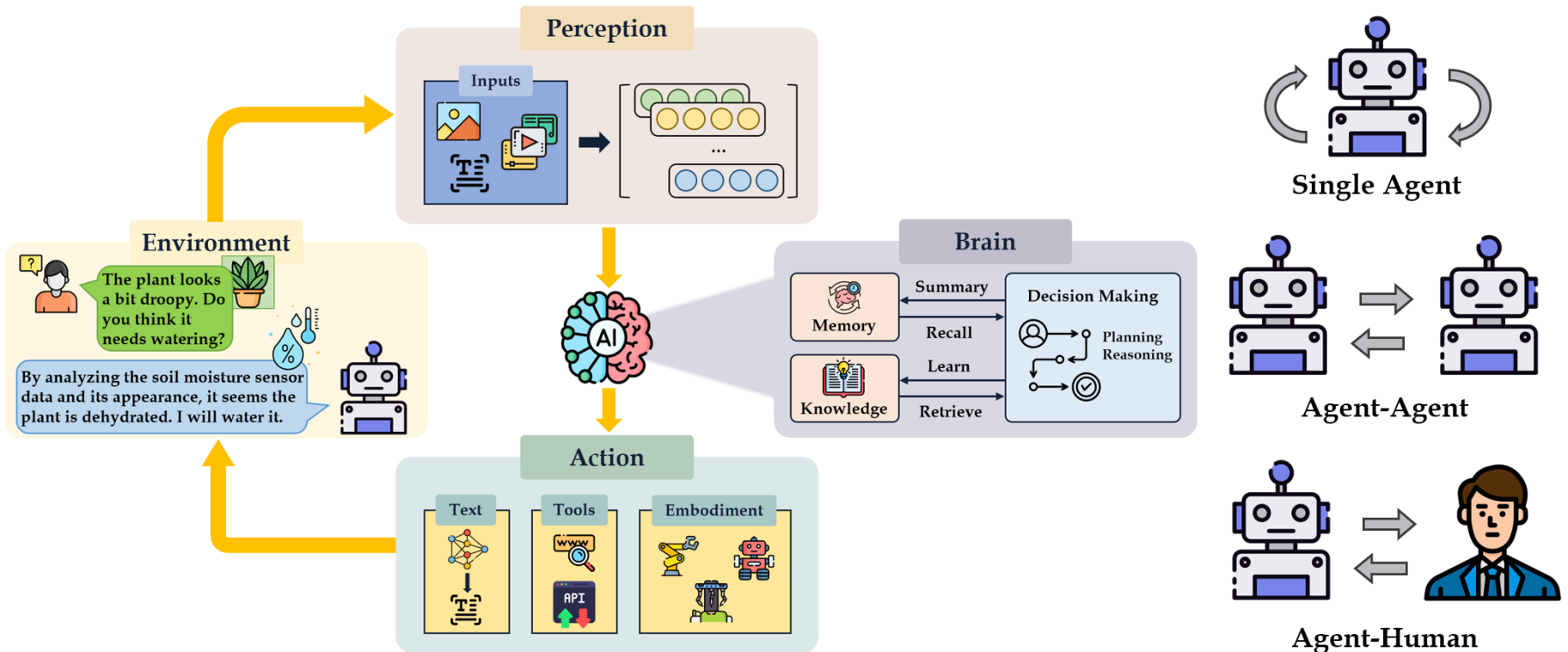
- Best performance across different tasks
- Better performance when finetuned on individual tasks

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Agentic LLMs: Advantages

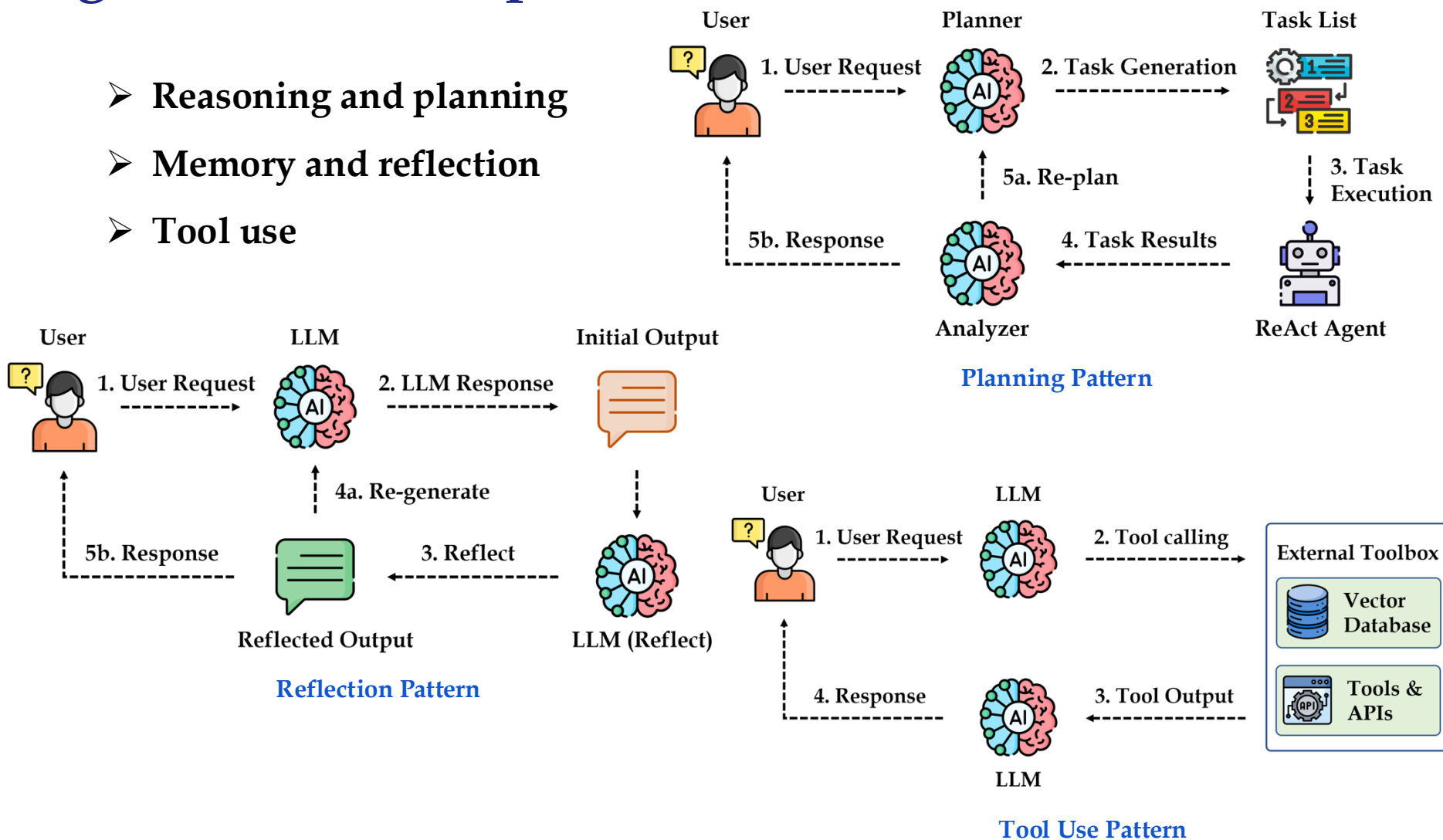
- Perceive, reason, act autonomously in dynamic environments.
- Unlock greater Intelligence, flexibility, adaptability, and autonomy for diverse wireless tasks.



Picture from: [1] Z. Xi, W. Chen, X. Guo, W. He, Y. Ding, B. Hong, et al., "The Rise and Potential of Large Language Model Based Agents: A Survey," *arXiv preprint arXiv:2309.07864*, Sep. 2023.

Agentic LLMs: Capacities

- Reasoning and planning
- Memory and reflection
- Tool use



An Example: Agentic LLMs for Wi-Fi 8

□ Background:

- Wi-Fi 8 new feature: multi-AP coordination in OBSS scenarios, mitigating inter-BSS collisions
- Coordinated mechanisms: Co-TDMA, Co-SR, etc.

OBSS: Overlapping basic service sets **Co-TDMA:** Coordinated time division multiple access
Co-SR: Coordinated spatial reuse

□ Our Agentic LLM-based approach:

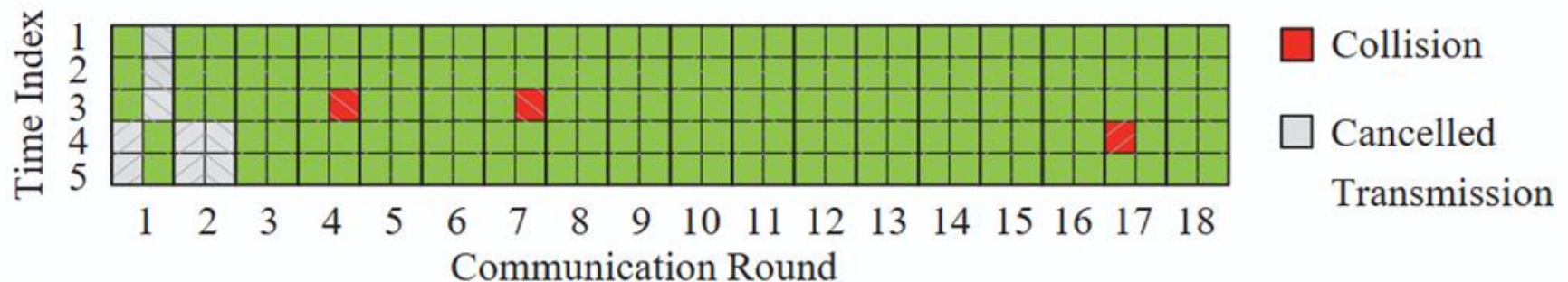
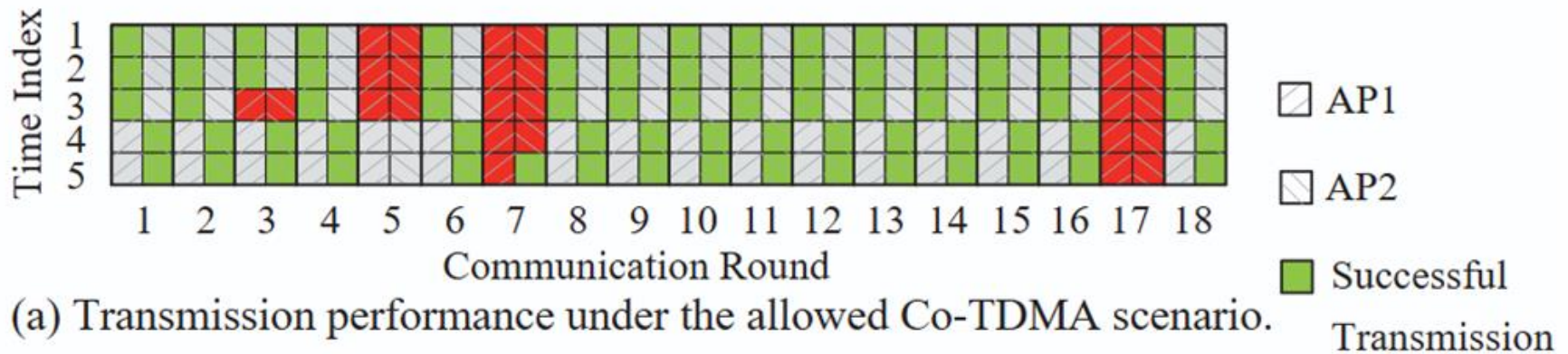
- APs modeled as agents
- Natural language conversations among agents for information exchange

□ **Goal:** Agents autonomously learn cooperative channel access strategies through conversations and reasoning

An Example: Performance for Wi-Fi 8

➤ Simulation Results:

Agents can derive interference-aware optimal strategies across diverse topologies.



Note: The two columns in each round represent the transmission status of 2 APs, respectively.

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Challenges and Opportunities

We have shown

- LLMs exhibit remarkable generalization and zero-shot learning capability in wireless tasks, overcoming the long-standing issue of DL in wireless.
- Wireless foundation models strike desirable balance between model size/complexity and performance.
- Agentic LLMs empower self-improving/ adaptive communication protocols.

Further investigate

- Wireless foundation models to handle a variety of communication tasks
- Multimodal integration for enhanced communication performance
-