

Artificial Intelligence-Enabled ISAC in 6G Radio Access Networks: A Brief Survey

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Abstract—We present a brief survey of the role of Artificial Intelligence (AI) in empowering Integrated Sensing and Communication (ISAC) within 6G Radio Access Networks (RANs). It accentuates how AI optimizes resource allocation, enhances sensing-communication fusion, and empowers adaptive network architectures. Key issues and future directions are also reviewed to guide the development of intelligent and robust 6G systems.

Index Terms—AI, ISAC, RAN, 6G.

I. INTRODUCTION

The evolution of wireless communication systems from 5G toward 6G envisions not only boosted data rates and connectivity but also the unification of multiple functionalities, namely sensing, communication, and artificial intelligence (AI). Among the core advancements in this trajectory is the aggregation of sensing and communication into a unified framework referred to as Integrated Sensing and Communication (ISAC). When AI is utilized within this paradigm, it enables smart, adaptive, and efficient Radio Access Networks (RANs), allowing new capabilities and performance enhancements. This survey details the state of AI-enabled ISAC technologies in RANs, covering technical foundations, optimization frameworks, and open research challenges.

II. AI-ENABLED ISAC TECHNOLOGIES IN RANs

This section presents state of AI-enabled ISAC technologies within the intelligent framework of RANs, as illustrated in Fig. 1.

A. AI-Driven System Optimization and Multiple Access Techniques

AI is playing a revolutionary role in optimizing modern ISAC-assisted RANs, improving signal processing, resource allocation, and user access methods. One remarkable advancement is the application of AI to Rate-Splitting Multiple Access (RSMA), which enhances sensing precision, communication efficiency, and network security, energy savings in cognitive radio environments. By deploying multi-block beamforming optimization frameworks, AI allows the joint design of transmit and echo beamformers, leading to improved secure energy efficiency. Optimization approaches, namely semi-definite programming, majorization-minimization, and successive convex approximation make these complex, non-convex problems controllable and solvable via iterative algorithms [1]. Multiple Access (MA) techniques remain central in ISAC systems by managing time, frequency, power, and spatial resources

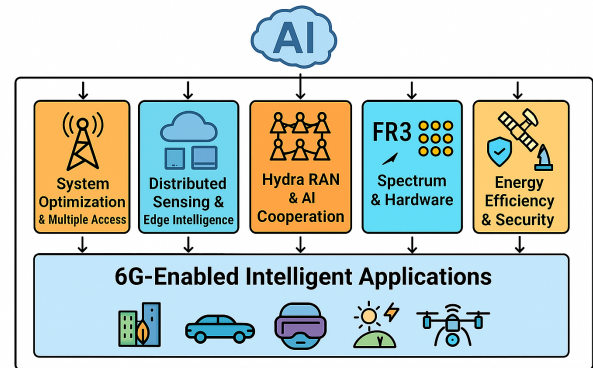


Fig. 1. An integrated framework for AI-assisted ISAC technologies in 6G RANs.

across devices. When integrated with AI, these schemes adaptively optimize channel estimation, receiver design, and power control in real-time. Moreover, they support the unification of sensing, communication, and computing tasks, which is essential for future intelligent applications such as semantic communication and virtual/augmented reality. Thus, AI not only boosts operational efficiency but also equips RANs to manage the increasing complexity and multifunctionality of 6G wireless networks.

B. AI Techniques for Distributed Sensing and Edge Intelligence

Distributed sensing at the network edge faces limitations due to wireless channel constraints and multi-access interference. To address this, AI-powered over-the-air computation (AirComp) enables multiple devices to simultaneously transmit and fuse sensing data by exploiting waveform superposition. A more advanced variant, AirPooling, introduces adaptive pooling functions, namely averaging and maximization, exploiting intelligent pre- and post-processing, improving both accuracy and latency [2]. Spatial AirComp extends this further by aligning sensing tasks with communication subcarriers based on spatial sparsity and channel diversity. AI algorithms handle the complex task of power allocation and task pairing using mixed-integer optimization techniques accelerated by tree-pruning and greedy heuristics. These innovations significantly reduce computation errors and improve sensing outcomes,

exhibiting the potential of AI to merge sensing and communication efficiently at the network edge [3].

C. Advanced Architectures: Hydra Radio Access Networks and AI-Driven Cooperation

Next-generation Radio Access Networks (RANs) are evolving into adaptive systems capable of fusing diverse services and technologies. The hydra RAN (H-RAN) model exemplifies this by using AI to orchestrate sensing and communication through shared data, models, and decisions across distributed components. Multi-sparse input and multi-task learning approaches enable seamless transitions among sensor and radio units (SRUs), ensuring reliable connectivity even in blockage scenarios. Simulations show that AI-driven cooperation in H-RAN can achieve up to 93% spectral efficiency and significantly reduce blockage, highlighting AI's role in creating agile and resilient 6G networks [4].

D. Spectrum and Hardware Considerations in AI-Enabled ISAC

As 6G evolves into higher frequency bands like FR3 (7–24 GHz), AI is essential for managing joint sensing and communication across complex propagation environments. Channel insights on path loss and delay spread guide the AI-driven design of massive MIMO and beamforming architectures. Alongside spectral advances, intelligent hardware like Reconfigurable Intelligent Surfaces (RIS) dynamically adjusts phase shifts and beam patterns using metaheuristic AI optimization. These innovations improve signal quality and sensing accuracy without raising power demands, enabling intelligent and energy-efficient ISAC operations [5].

E. Energy Efficiency and Security in AI-Enabled ISAC Networks

Energy efficiency is crucial in dense, sensor-rich ISAC networks. AI helps design green communication by jointly optimizing beamforming and signal splitting to cut power use while enhancing security and sensing accuracy. Power-domain non-orthogonal multiple access (NOMA), supported by machine learning, reduces user exposure and ensures scalable access [6]. AI also strengthens network security by refining rate splitting and beamforming to resist eavesdropping, boosting both secrecy and sensing reliability in AI-RAN systems [1].

F. AI-Enabled Network Adaptability and Intelligence

Future 6G ISAC-enabled RANs will rely on AI to enable self-configuring, adaptive networks that learn from traffic patterns and optimize end-to-end performance. These networks incorporate intelligent surfaces, edge-cloud architectures, and non-terrestrial links like drones and satellites. AI analytics enhance responsiveness, security, and reliability, even under dynamic conditions [7]. Furthermore, AI enables seamless integration of terrestrial and non-terrestrial systems, promoting ubiquitous connectivity. Emerging "green AI" approaches aim to balance performance with sustainable energy use across the entire network infrastructure.

III. OPEN CHALLENGES AND FUTURE DIRECTIONS

Despite rapid progress, AI-enabled ISAC in RANs faces several unresolved challenges. Efficient AI models are needed for deployment in resource-limited environments without causing latency or overhead. Real-time tradeoff management between sensing, communication, energy, and security remains complex. Privacy-preserving AI methods are essential to secure distributed data in federated learning setups. Achieving interoperability across vendors requires standardized ISAC-AI frameworks. Integrating heterogeneous technologies such as RIS, massive MIMO, and distributed sensing into a unified, AI-driven system is still an open research frontier. Finally, ISAC networks must be resilient to dynamic environments, including channel variations, mobility, and blockage. Addressing these issues demands sustained collaboration among academia, industry, and standard bodies.

IV. CONCLUSION

AI-enabled ISAC represent a revolutionary paradigm shift in RANs, promising enhanced environmental awareness, improved spectral efficiency, robust security, and energy-efficient operations. Persistent research on AI-driven optimization, cooperative multi-access schemes, advanced propagation management, and hardware-software co-design will be essential to unlock the revolutionary potential of this convergence for 6G and beyond.

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