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Editorial:

Theory and techniques for "intellicise" wireless networks

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With the acceleration of a new round of global scientific, technological, and industrial revolution, the next generation of information and communication technology, i.e., 6G, will inject new momentum into industry transformation and upgrading, as well as into economic innovation and development. This will subsequently promote a global industrial integration. Wireless communication will be ubiquitous in all areas of future society, supporting novel applications with various performance requirements, such as immersive- or interactive-experience applications requiring a large bandwidth, autonomous driving and vehicle-to-everything applications requiring ultra-high reliability and ultra-low latency, and applications for industrial Internet requiring massive machine-type connectivity. Facing the challenges of the post-Moore and post-pandemic era, wireless communication needs breakthroughs in network architecture to improve the intelligence, security, robustness, bandwidth, and heterogeneity. With this background, several important tendencies have emerged in the development of 6G wireless communications:

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1. Future wireless networks will evolve from "human-to-human" communications into intelligent "human-to-machine" communications.

In addition to enabling communications among humans, future wireless networks will be able to support close connections among humans and machines. The behavior and intent of humans will be sensed and communicated to machines that will accordingly adjust their operations. Typical scenarios include smart building, intelligent transportation, mixed reality (MR), and others.

2. Network nodes will evolve from carrying out only traditional communications to carrying out communication, sensing, computation, management, and caching in an integrated manner.

To meet the diverse service requirements of mobile MR, intelligent transportation, industrial Internet of Things, and other areas, future networks will possess multiple functionalities. For example, by sensing human head position, pre-caching necessary content, and rendering high-quality images, network nodes can provide fully immersive MR experiences. In addition, with artificial intelligence (AI), network nodes can manage multi-dimensional resources in an on-demand fashion, where intent-driven network management and control can be realized.

3. Network architecture will focus on collaborations between the cloud and the network edge, which will become more heterogenous.

To shorten latency and alleviate the backhaul/fronthaul burden, the network edge must collaborate with the cloud. The first method of collaboration is that the cloud finishes AI model training and then deploys AI models into the network edge, which supports the so-called edge intelligence. In the second method, users demanding high throughput are served via a cloud radio access mode, while users requiring ultra-low latency can benefit from edge computation and caching. As for architecture heterogeneity, future networks are envisioned to incorporate unmanned aerial vehicle (UAV) networks, satellite communication networks, and dense cellular networks, bringing three-dimensional and hierarchical network coverage.

In short, the evolution of existing 5G technologies and the development of 6G need to address more stringent and diverse application scenarios, a more strict energy constraint, and the orchestration of multi-dimensional resources. These challenges call for an *intellicise* wireless network operation paradigm, where "intellicise" is a new adjective that we coin, standing for intelligence-endogenous and primitive-concise. Built upon the integration of AI and next-generation networking technologies, an intellicise wireless network continually explores and exploits new intelligent primitives, e.g., semantic base (Seb) in semantic communications, proactively takes systematic entropy reduction as the global optimization objective, adaptively reshapes the core models of information systems, and ultimately endows itself with endogenous intelligence and primitive conciseness.

In this context, the journal *Frontiers of Information Technology & Electronic Engineering* has organized a special feature on the theory and techniques for intellicise wireless networks. This special feature covers information theory, architecture design, and intellicise wireless networks for achieving air-space-ground-sea integration, resource management, hardware testbeds and platforms, as well as related applications. In addition, this feature is intended to provide a review of advancements and future research directions in the research field of intellicise wireless networks. After a rigorous review process, six papers have been selected for this feature, including one review article and five research articles.

Yaohua SUN and his collaborators undertook a comprehensive literature review in terms of the architectures, key techniques, and experimental platforms of intelligent wireless networks. Specifically, they first introduced an intent-driven wireless network, an autonomous driving network, an O-RAN reference architecture, and other elements. Then, they presented a deep discussion on AI-driven network slicing, intent perception, intelligent operation and maintenance, AI-based cloud-edge collaborative networking, and intelligent, multi-dimensional resource allocation. To fill the gap between theoretical study and practical implementation, they further surveyed recent progress in developing experimental platforms to demonstrate the benefits of network AI.

Intellicise Internet-of-Things (IoT) networks can provide ultra-low-power communication connecting numerous miniaturized devices, for which, however, traditional software-defined radio (SDR) platforms are insufficient, making fast algorithm implementation and evaluation difficult. Fei XIAO and her collaborators provided an ultra-low-power SDR design to meet ultra-low-power or even battery-free requirements. The core idea is to use μW-level backscatter in the design instead of power-hungry active RF chains. An evaluation was conducted with different modulation schemes, and a data rate of 100 kb/s was reported with less than 200 μW of power consumption.

Equipped with a large number of reflection elements, intelligent reflecting surfaces (IRSs) can generate desired reflection beams and create favorable propagation conditions, a promising technique for intellicise networks. Yu ZHANG and his collaborators proposed to integrate IRSs into cloud radio access networks to further enhance capacity and coverage. They investigated a scenario with multiple IRSs deployed between the users and remote radio heads, and developed a successive convex approximation approach to handle the non-convexity of an uplink sum-rate maximization problem under fronthaul capacity constraints. Via the proper design of user transmit beamformers, IRS passive beamformers, and compression noise covariance matrices, the cloud radio access network (C-RAN) uplink rate can be significantly improved.

Edge AI plays a vital role in enabling intellicise networks to support complex and dynamic tasks in an industrial wireless environment. Chi XU and his collaborators adopted multi-agent deep reinforcement learning (DRL) to orchestrate the computation and communication resources of both industrial devices and edge servers with each device being seen as a self-learning agent. Compared to a traditional DRL approach, their proposal was shown to achieve better adaptation to the computation capacity of edge servers, data size, computation resources required, and the number of industrial devices.

The coverage of intellicise networks can be greatly extended with UAVs. However, interference between terrestrial links and UAV-ground links can degrade the performance of the whole network. To address this, Jing GUO and her collaborators used the coordinated multipoint (CoMP) technology to mitigate the interference in a three-dimensional, multilayer UAV-terrestrial heterogeneous network (HetNet). A rigorous analytical study was conducted using stochastic geometry theory, resulting in a tractable mathematical framework for coverage probability evaluation. Its accuracy was further validated via numerical results.

To better support applications with stringent requirements, such as virtual reality (VR), multidimensional resource management is essential. In this field, Chenxi LIU and his collaborators presented a mobile, VR delivery framework where both uplink and downlink transmissions were considered. They characterized the round-trip latency of the VR service and revealed its dependence on communication, caching, and computation resource allocation. Then, they proposed a simple yet efficient optimization algorithm to minimize round-trip latency, while satisfying practical constraints on caching, computation capability, and transmission capability in the uplink and downlink. Numerical evaluations illustrated that the proposed algorithm can effectively reduce the round-trip latency compared with various benchmarks.

Overall, a broad spectrum of current research topics relevant to the theory and techniques of intellicise wireless networks is covered in this special feature, from software-defined-radio hardware and beamformer design, to AI-driven resource orchestration, network coverage performance analysis, multidimensional resource management, and others. We hope that this collection of diverse but interconnected topics will be beneficial to those with an interest in intellicise networks or in related areas.

Finally, we would like to express our special gratitude to the authors and reviewers for their support and valuable contributions to this special feature, the editorial staff, and the Editors-in-Chief Profs. Yunhe PAN and Xicheng LU.

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