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6G autonomous radio access network empowered by artificial intelligence and network digital twin

Key words: 6G; Network autonomy; Native artificial intelligence; Network digital twin; Service-based radio access network

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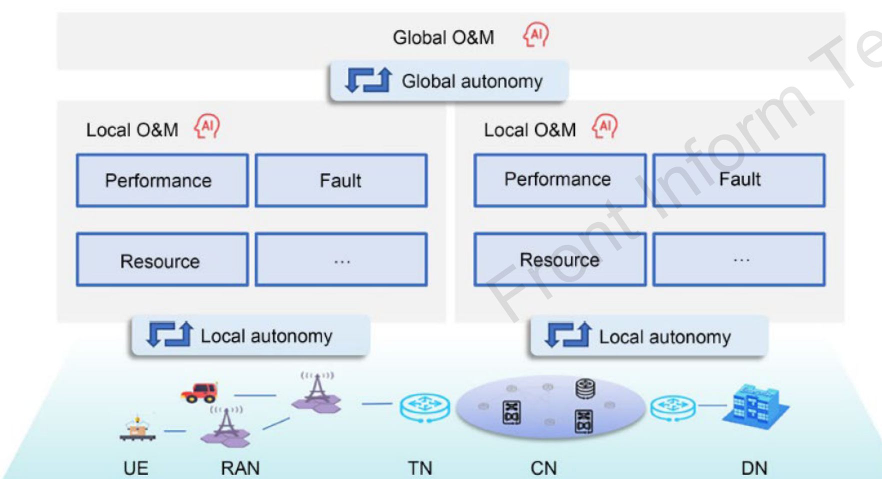
Background

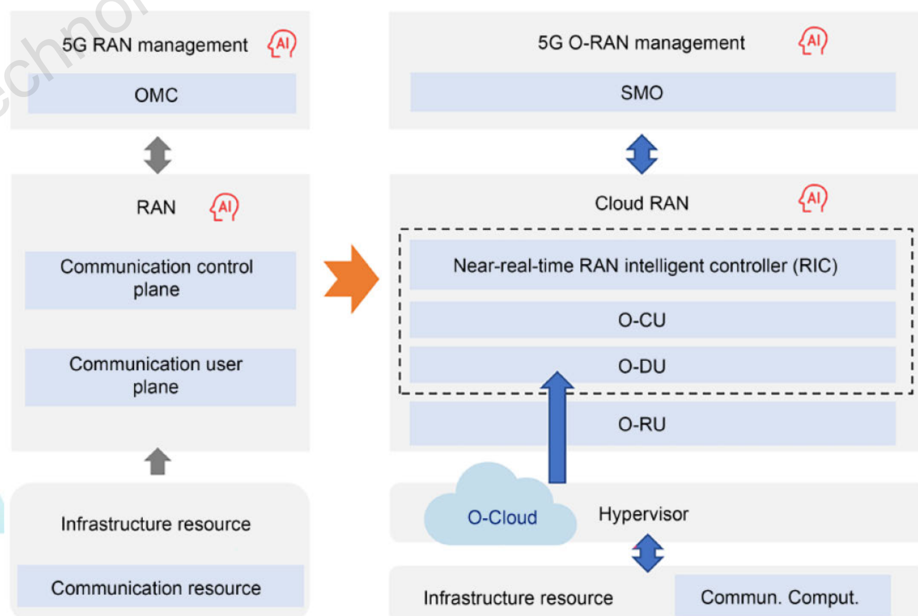
- 5G faces the challenges of network efficiency, complexity, and cost, making it difficult to support flexible, on-demand, and low-cost deployment, operation, and maintenance.
- The continuous emergence of new applications, new technologies, and new infrastructures in 6G network accelerates network intelligence and digital transformation, where high-level autonomy will become an inevitable trend.
- 6G networks require the integration of communication, computing, big data, AI, and other technologies to support fragmented applications from various industries, with the challenge being how to achieve seamless integration of these technologies.
- In the face of large-scale deployment and high energy consumption, reducing energy usage through AI and network intelligence, while ensuring green and low-carbon network development, is a critical challenge for the future.

Development of network autonomy

- Both centralized and distributed network management architectures are used for current operations and maintenance.
- As network management evolves towards intelligence, automation, and data-driven approaches, AI and digital twins are introduced to enhance network autonomy. At the same time, the openness of network architecture is increased (e.g., O-RAN).



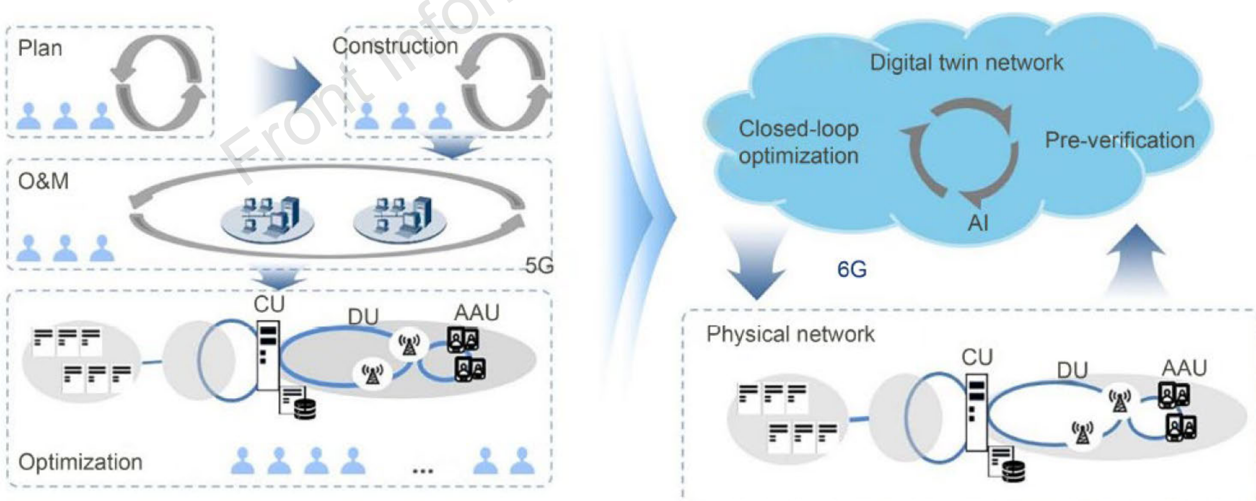
Network management architecture



A reference architecture for an O-RAN

Drivers for 6G autonomous RAN

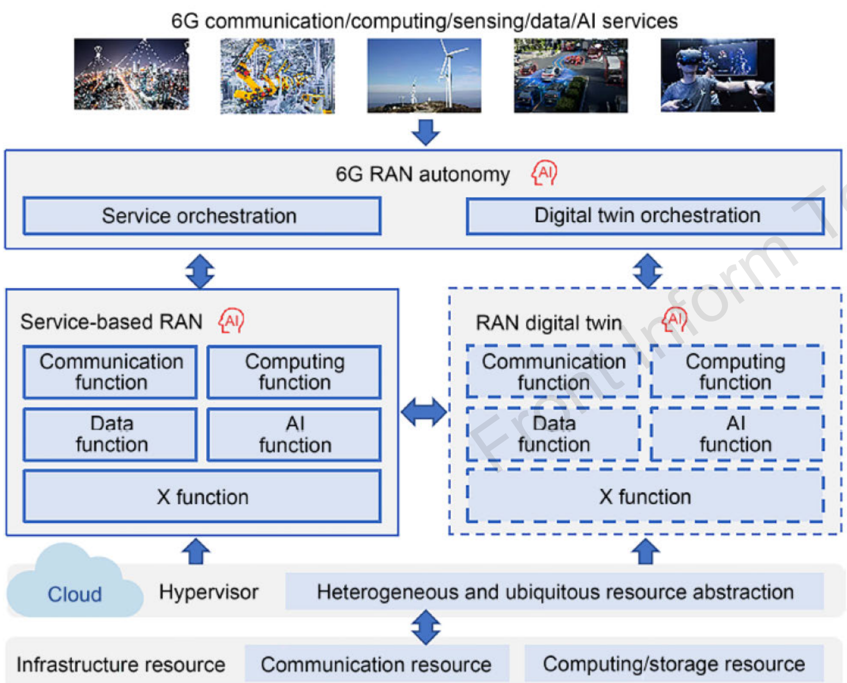
- **Fast response to diverse use cases:** 6G will enhance traditional mobile capabilities and introduce new ones, such as ubiquitous connectivity, AI integration, sustainability, and advanced positioning.
- **O&M in advance:** 6G will enable proactive maintenance through unified management based on NDT, shifting from high-cost event handling to cost-efficient O&M.
- **Intent-driven O&M:** Intent-driven O&M introduces automation to enhance agility, predictive maintenance, and alignment with business goals, improving network efficiency and reliability.



Shifting from high-cost event handling to low-cost O&M in advance

Function architecture of 6G autonomous network

The architecture integrates service-based capabilities as a foundation, native intelligence as a high-performance engine, and DT as a low-cost environment to enhance adaptability, self-management, and efficiency of network.



Service-based: Single- to multi-element differentiated services

End-to-end servitization enables flexible NF combinations and efficient orchestration to meet differentiated network requirements.

DT: Post-processing to low-cost preemptive intervention

Requiring NDT to create low-cost virtual environments that predict future network states and validate AI-driven decisions.

Native intelligence: external to native, scenario- to capability-driven

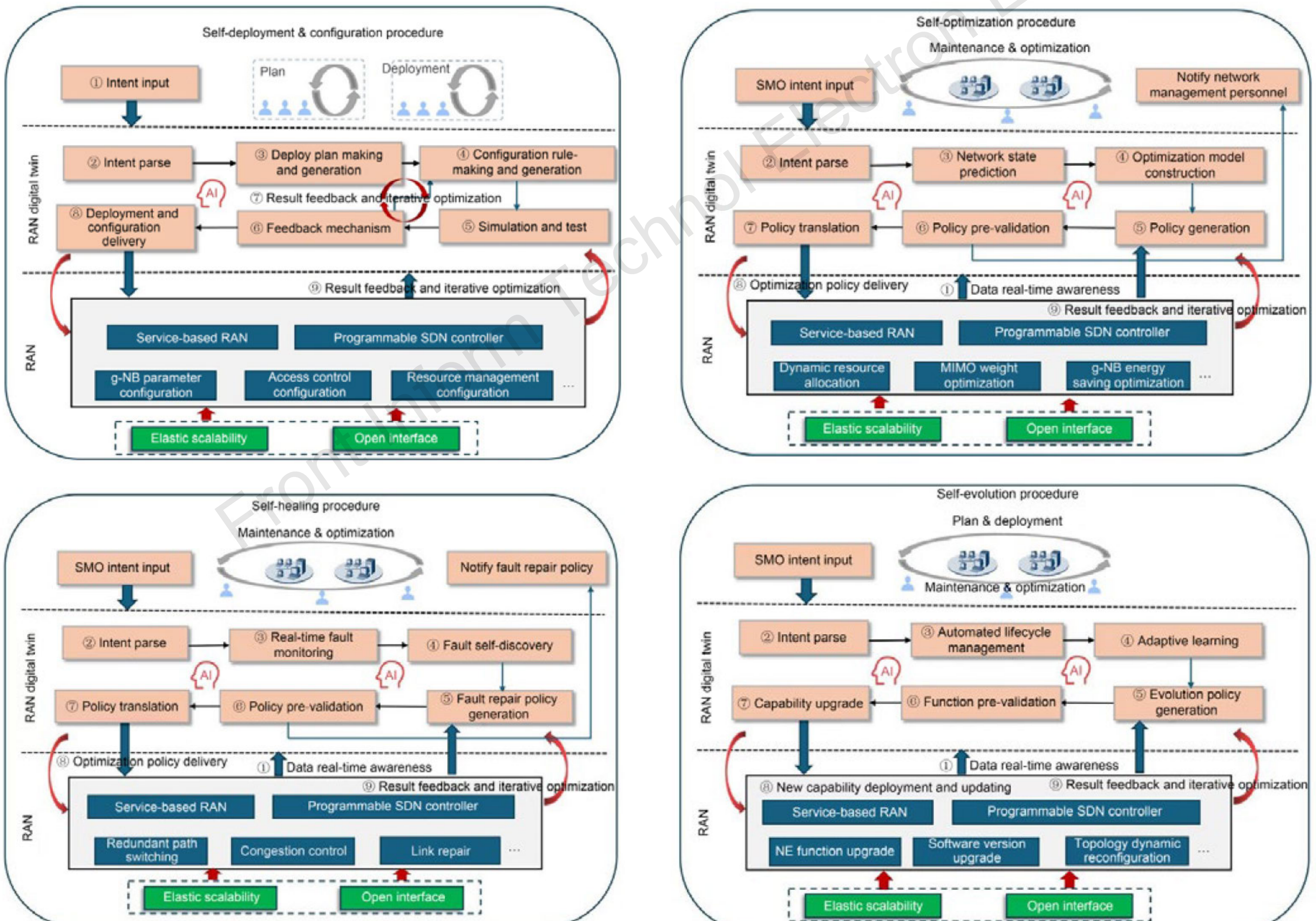
Building a native AI supply system to improve decision-making efficiency while ensuring the quality of AI decisions.

Cloudification of underlying resources: Silos to collaboration

Heterogeneous hardware clouding enables flexible resource use and on-demand scheduling of communication, computing, and intelligence.

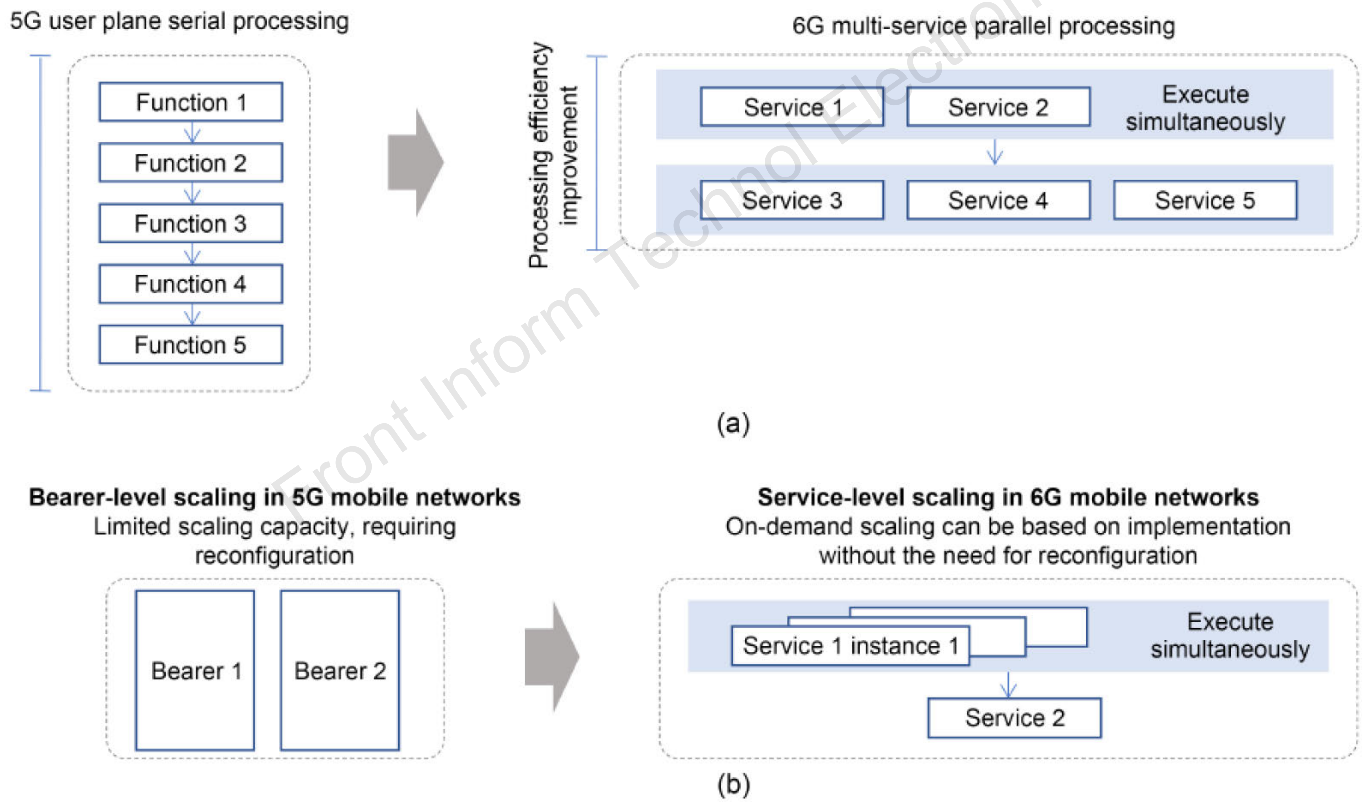
Autonomous network

- Parsing user intentions based on intent-driven technology, generating, optimizing, and pre-validating configuration and policies based on DTN to achieve self-configuration and self-optimization.
- DTN generates and pre-validates fault policy based on intent to achieve self-healing, and enables self-evolution through full lifecycle management and adaptive learning.



Cloud-native and service-based architecture

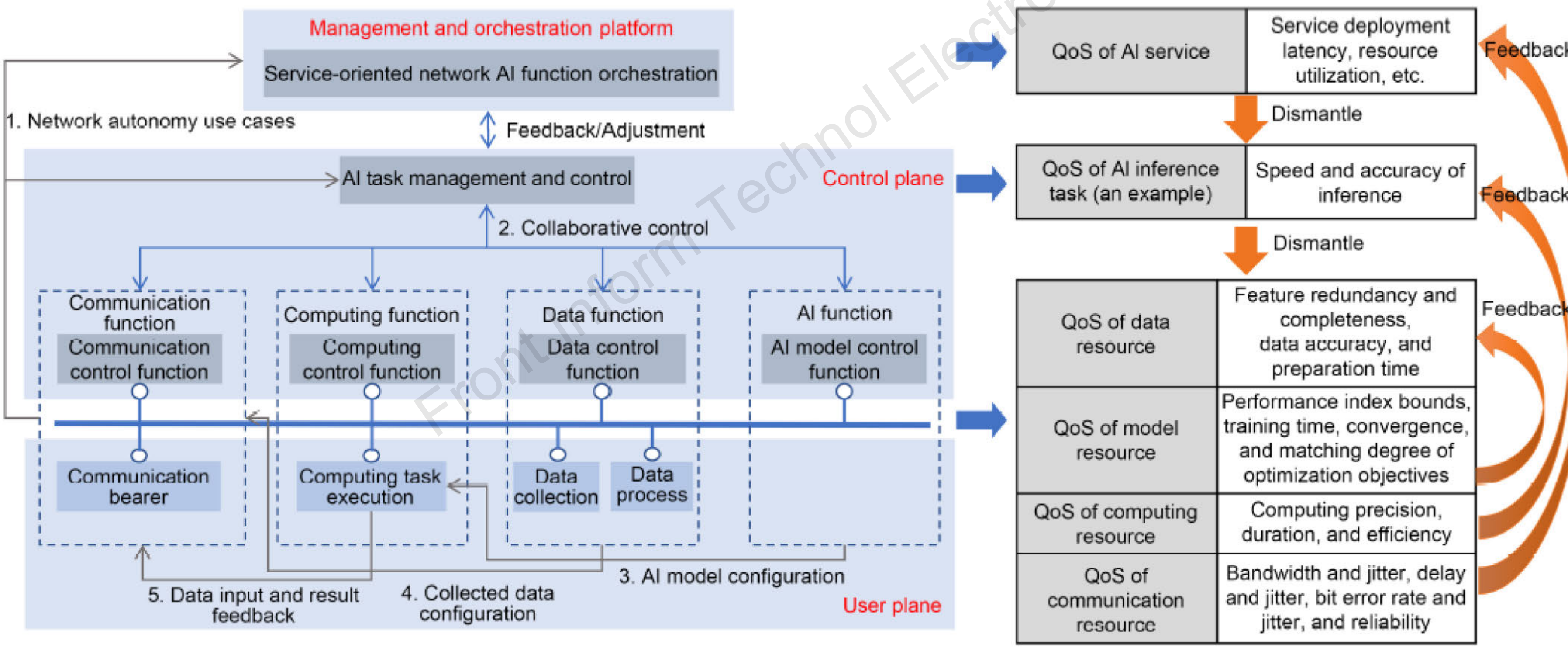
Based on cloud-native technologies, it decouples traditional single-BS functions into control and user plane services, enabling flexible, on-demand network capabilities and enhancing industry adaptability through service-based interfaces.



Use case of service-based radio access network (RAN)

AI: evolution from case-driven and add-on to native

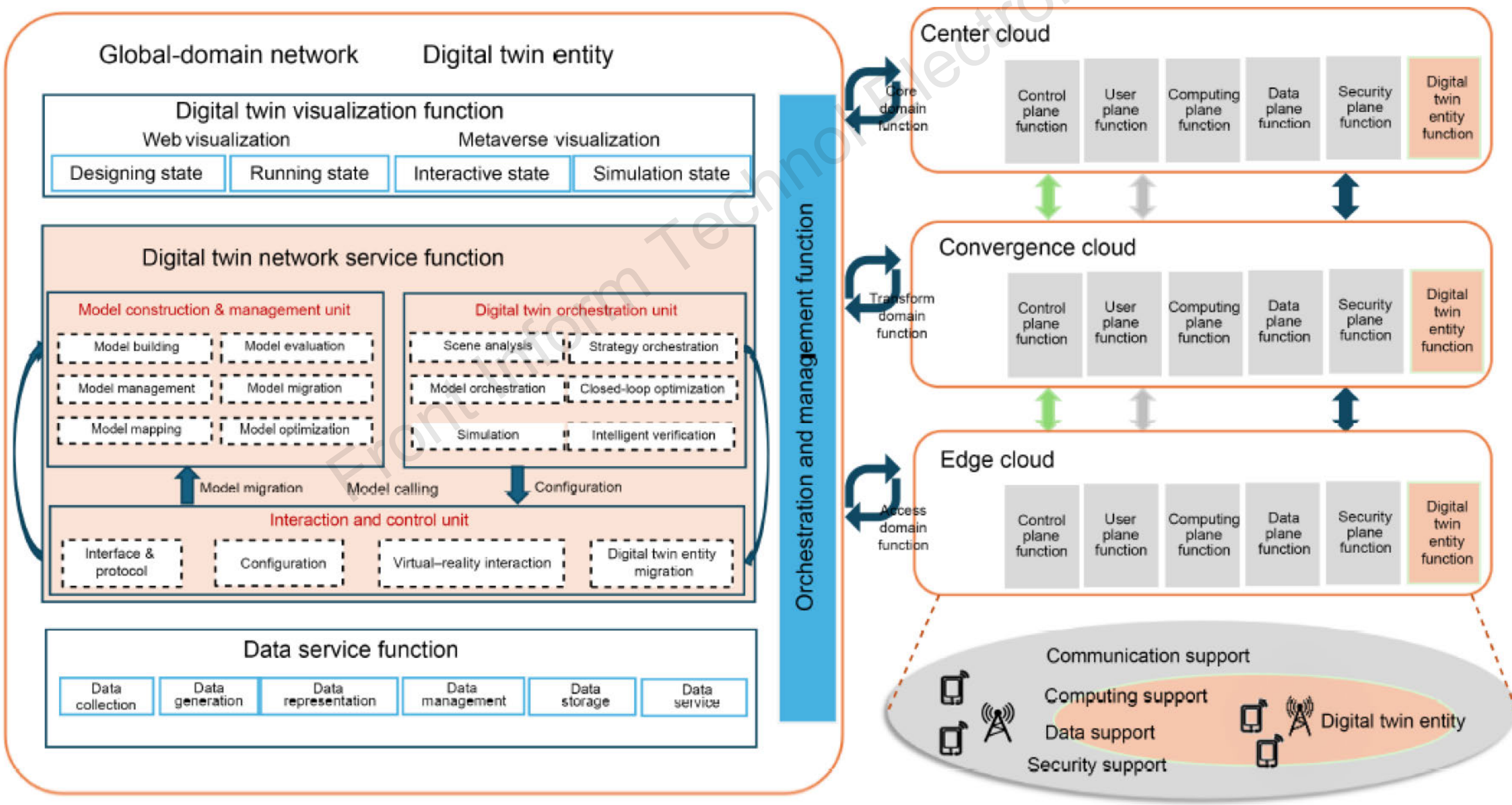
Based on the aforementioned design principles and simplified intelligent network architecture, a cloud-based, service-oriented, and layered control framework is proposed herein for 6G networks with native AI capabilities.



6G native AI network framework

Network digital twins

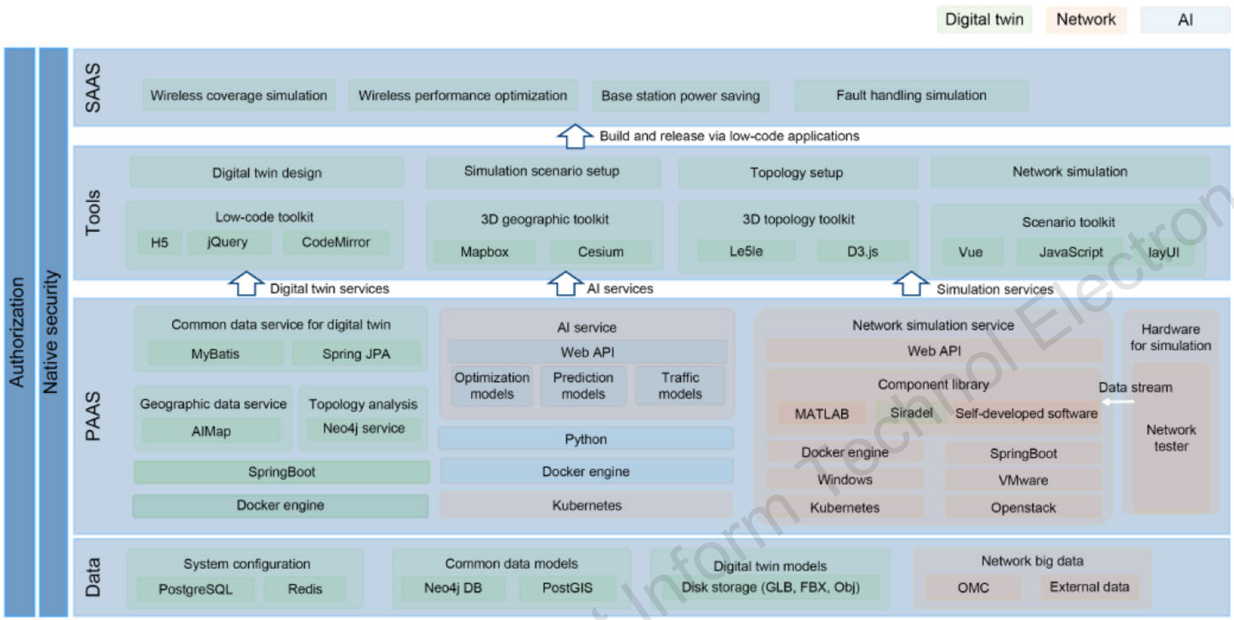
NDT enables real-time interaction and virtual-real mapping by modeling the physical network across multiple dimensions, enhancing simulation, optimization, and control. A new “centralized control + distributed autonomy” framework is proposed.



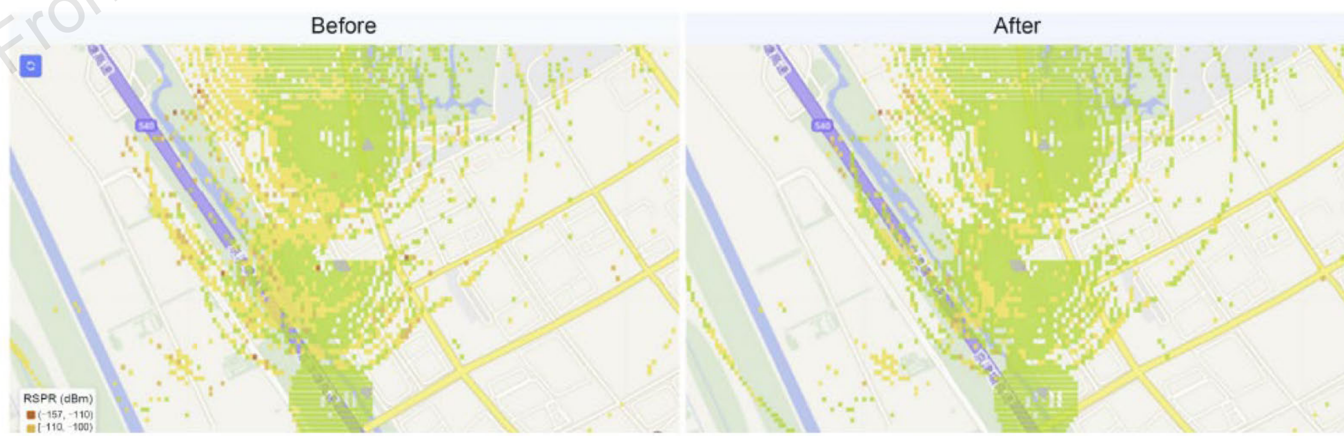
Network digital twin (NDT) framework

Prototype and trial

The DTN prototype is designed for highly complex enterprise-level applications, adopting a layered and modular approach to ensure scalability, flexibility, and maintainability.



Implementation of the DTN prototype



Comparison of RSRP in the area before and after optimization using MIMO weight optimization prototype

Research challenges and open issues

- **Splitting and definition of services:** Lack of a well-defined efficient service splitting algorithm, large number of NF splits in the 5G core network service-based architecture, and performance loss caused by service splitting in RAN.
- **NetGPT:** Designing NetGPT is challenging due to the significant differences between network autonomy tasks and NLP tasks, and NetGPT will bring various challenges in areas such as network transmission, storage, computation, and energy consumption.
- **Efficiency and accuracy of digital twin modeling:** The accuracy, simulation efficiency, and real-time performance of existing modeling methods cannot meet the requirements for high-precision DTN modeling, and whether high-order modeling or LLM can be used to achieve this is still under investigation.
- **Heterogeneous hardware selection, management, and scheduling for AI computing:** RAN’s diverse deployment scale and scattered scenarios create a high demand for performance-driven heterogeneous hardware, requiring further research on efficient, cost-effective, and energy-saving hardware platforms with enhanced heterogeneous resource management.

Guangyi LIU received his PhD degree from Beijing University of Posts and Telecommunications, Beijing, China, in 2006. He is currently a chief scientist for 6G at the China Mobile Communication Corporation (CMCC), a founding member and co-chair of the 6G Alliance of Network AI, and a vice chair of the THz Industry Alliance in China and the Wireless Technology Working Group of the IMT-2030 (6G) Promotion Group supported by the Ministry of Information and Industry Technology of China. He has been leading 6G research and development with the CMCC since 2018. He led the research and development of 4G's evolution to 5G at the CMCC from 2006 to 2020. He acted as a spectrum working group chair and project coordinator of LTE Evolution and 5G eMBB for the Global TD-LTE Initiative from 2013 to 2020 and led the industrialization and globalization of TDLTE evolution and 5G eMBB.