A Study on Programmable Resource Management Infrastructure Technology with Guaranteed Application Performance

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***Abstract*—This paper proposes a performance-guaranteed programmable resource management infrastructure framework to satisfy the performance requirements of various hyper-connected services in a 6G network environment. Focusing on integrated virtualization of networking and computing resources, orchestration, and in-network offloading technologies to overcome the limitations of existing network infrastructure, it examines domestic and international technology trends and standardization activities. Furthermore, it discusses the applicability to various industrial fields and implementation strategies, presenting directions for building a QoE-based network infrastructure in the 6G era.**

Keywords*—6G, programmable infrastructure, resource virtualization, orchestration, offloading, QoE

I. Introduction

In the 6G network environment, various hyper-connected services, such as XR-metaverse, holographic communication, and remote surgery, will emerge, requiring complex and fluid performance quality and rapid, continuous connectivity between users. However, due to limitations such as existing class-based, bandwidth-centric quality assurance methods, 5-tuple-based QoS provision, and computing latency, it is difficult to guarantee the actual quality of experience (QoE) for 6G service users with the current network infrastructure alone. Consequently, problems arise, such as the inability to understand resource configurations commensurate with required quality, or the inability to adaptively respond to dynamically changing resource requirements with manual policy-based scaling [1], [2].

To address these limitations and meet 6G application performance requirements, the development of resource management infrastructure technologies that explicitly communicate requirements through standardized interfaces, organize resources into virtualized logical resource pools, and enable dynamic allocation, reconfiguration, and application offloading based on requirements is essential. Based on this need, this paper comprehensively analyzes domestic and international trends, standardization status, and application fields of 6G performance-guaranteed programmable resource management infrastructure technology, and proposes an integrated infrastructure model for this purpose.

II. Related Work

A. Domestic Technology Trends

In anticipation of the advent of the 6G era, Korean academia and government-funded research institutes are researching network and computing resource management technologies from various perspectives. As part of the 6G core technology development project, they are conducting research on "End-to-End Ultra-Precision Network Technology Development" [3], [4]. Through the "Development of AI-Based Intelligent Edge Networking Technology" [5], they are conducting research to optimize the configuration of infrastructure resources and provide a dynamic service environment tailored to specific situations. Furthermore, they are developing a system to provide a common research infrastructure for virtual network services to domestic small and medium-sized enterprises (SMEs) by leveraging efficient network resource management and optimization technologies.

Academia has developed AccelTCP, a CPU computation offloading acceleration technology based on user-mode TCP and SmartNIC, to overcome the performance limitations of existing kernel-based network stacks. They have developed a zero-wait socket assist technique that utilizes end-host transmission delay prediction results and socket buffer size information to meet application target transmission delays. They also proposed a mobile offloading system that offloads specific tasks to servers for low-performance smartphones. We are also actively conducting research to effectively manage and distribute computing resources scattered across networks, including optimizing wired and wireless network resource management based on edge computing and dynamic resource allocation technology that considers the importance of tasks and latency requirements in edge cloud environments.

B. Overseas Technology Trends

Overseas, leading computing companies such as Intel, HPE, and Samsung Electronics are developing composable infrastructure architectures and standard protocols to address the complexity and cost issues of existing data centers and maximize the flexibility and scalability of computing infrastructure. An Intel-led consortium proposed CXL, an open interconnect standard protocol for efficiently connecting infrastructure resources such as CPUs, GPUs, and memory, in 2020 to address bandwidth and latency issues arising in high-performance computing environments. An HPE-led consortium also proposed the Gen-Z open interconnect standard protocol in 2020, establishing the concept of memory-centric computing to maximize ultra-low latency connectivity and resource distribution flexibility among infrastructure resources. Global industries are actively exploring ways to integrate networks and computing resources to provide network quality for future application services such as XR, AI, and the metaverse through efficient and flexible resource configuration, optimized performance, and data processing.

C. *International Standardization Trends*

Several international organizations are also discussing network functions and architectures that can meet the complex performance requirements of the 6G era.

The IETF COINRG (Computing in the Network Research Group) is working on standardizing in-network computing, which enables computing tasks within networks. It studies the concepts and architecture of future network technologies that enable networks to perform not only data transmission but also data processing and analysis. Research is also being conducted on problem definitions, application cases, requirements, security considerations, and programmable network technologies [11].

The ETSI F5G (Fixed 5th Generation) is standardizing technologies to deliver ultra-high speeds, ultra-low latency, and ultra-reliability through fiber-optic technology, aiming for the fifth generation of wired networks. It is exploring key characteristics such as eFBB (Enhanced Fixed Broadband) for ultra-high-speed optical networks, FFC (Full Fiber Connection) for expanding fiber-optic connectivity, and GRE (Guaranteed Reliable Experience) for ultra-low latency and high reliability [12].

3GPP XRM (XR and Media Service) is currently working on standardizing XRM to support media services in 5G networks. Research is underway on multimodal transmission to efficiently process and synchronize diverse data formats, including audio, video, and haptics, and 5G system information disclosure technology to provide network status information to applications [13].

D. *Application Areas*

This 6G performance-guaranteed programmable resource management infrastructure technology can be applied to various fields, including hyper-realistic interactive communications and high-quality vertical industries, to ensure end-to-end quality for future 6G services.

1) *Network Infrastructure Business Sector*

Performance-guaranteed programmable infrastructure can be utilized as an innovative platform that converges telecom and IT, providing customized network and computing solutions. Specific examples include:

- Customized enterprise network solutions combining wide area networks (WANs) and the cloud
- High-quality network service solutions requiring high-bandwidth, high-capacity networking and computing resources for VR, AR, XR, and interactive holograms
- Quality-guaranteed SD-WAN solutions, network-based integrated hyper-cloud solutions, application performance offloading edge solutions, etc.

2) *Application Service Business Sector*

By leveraging advanced network functions through performance-guaranteed network interfaces, it is possible to develop customized, high-quality services and provide differentiated, high-value services. Key application areas include:

- Real-time streaming: cloud gaming, live broadcasting, etc.
- Telemedicine: remote surgery, real-time medical image transmission, etc.
- Augmented and virtual reality (AR/VR) applications
- High-reliability services: emergency medical care, smart factories, smart logistics, etc.

III. Proposed Infrastructure

6G performance-guaranteed programmable resource management infrastructure technology enables dynamic configuration and reconfiguration of networking and computing resources through a performance-based programming interface to deliver customized performance requirements for various hyper-connected services in a 6G network environment. Fig.1 illustrates the programmable integrated infrastructure model, which enables real-time resource expansion and adjustment based on service-specific QoE demands. Key core technologies are as follows:

- Performance-optimized virtualization technology for integrated virtualization of networking and computing resources, programmable resource allocation, and dynamic automatic scaling.
- Application performance-guaranteed resource orchestration technology for collaboration between application terminals, distributed edge devices, and the cloud, integrated resource operation, and complex flow coordination of application services.
- Application performance-guaranteed in-network offloading technology for application service offloading, application flow synchronization, and terminal network access and control.

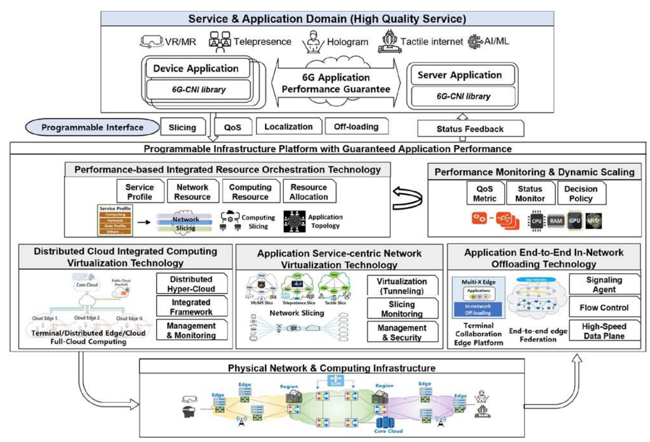

Fig. 1. Programmable Infrastructure Concept Diagram with Guaranteed Application Performance

A proposed structure for the successful development and commercialization of 6G performance-guaranteed programmable resource management infrastructure technology could include the following steps:

- Establishing a customized network quality-guaranteed infrastructure with ultra-high performance, ultra-low latency, and ultra-reliability required for 6G hyper-connected services.
- Maximizing resource efficiency and improving user quality of experience (QoE) through the development of integrated virtualization and dynamic operation

technologies for networking and computing resources.

- Securing technological leadership through participation and contributions to international standardization organizations.

Key research and development areas include the following:

- Development of core technologies for performance-customized virtualization: Integrated virtualization of networking and computing resources and dynamic automatic scaling mechanisms.

- Development of core technologies for application performance-guaranteed resource orchestration: Collaboration and complex flow coordination between application terminals, distributed edge devices, and the cloud.

- Development of core technologies for application performance-guaranteed in-network offloading: Application service offloading and flow synchronization, and terminal network control. - Concept verification and demonstration environment construction: Implementation of a testbed environment and performance verification based on actual 6G service scenarios (XR, telemedicine, etc.).

IV. Conclusion

This study investigated and analyzed domestic and international technology and standardization trends related to performance-guaranteed programmable resource management infrastructure, as well as its applicable fields. Furthermore, it examined the concept, configuration technology, and implementation strategy of 6G performance-guaranteed programmable resource management infrastructure. The evolution of 6G services demands intelligent, application-aware infrastructure. The performance -guaranteed programmable infrastructure framework proposed in this paper can provide a flexible and standardized solution to address these demands. This technology is expected to enhance the QoE of future 6G services and have a tangible impact across high-value-added industries. Through future research and development and international standardization cooperation, we aim to develop this technology into a feasible next-generation infrastructure technology.

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