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Editorial:

Coordination of networking and computing: toward new information infrastructure and new services mode

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Computing, serving as the cornerstone of information processing, plays a pivotal role in the digital service era. The "network" and "computing," responsible for information transmission and processing respectively, traditionally belong to different stakeholders and have evolved separately. However, the recent trend toward the coordination and integration of computing and networks has garnered significant attention from both industry and academia. Concepts such as "computility network" and "computing force network" have emerged, and the International Telecommunication Union - Telecommunication Standardization (ITU-T) has initiated efforts to develop standards for the coordination of networking and computing (CNC), focusing on the architecture and framework. The coordination of computing and networks is poised to offer several immediate benefits:

1. It enables efficient resource scheduling over wide areas, leading to energy conservation. The "East Data for West Computing" national project launched by China in 2022 exemplifies this, promoting data processing and storage in the country's western regions where there is an abundance of energy, particularly renewable energy.

2. It facilitates the realization of computing power as a utility service, a vision articulated by artificial intelligence (AI) pioneer John McCarthy in the 1960s. The aim is to make computing power as readily available as household water and electricity, bridging the accessibility gap. This concept, termed "computility" by Dr. Ninghui SUN and his colleagues, is predicated on the network's ability to provide ubiquitous information processing capabilities.

3. It significantly improves user experiences. For instance, immersive communication, characterized by high bandwidth, low latency, frequent interaction, and substantial computing complexity, necessitates that both data transmission and processing should be considered in the assessment of quality of experience. The synergy between connectivity and computing allows for optimal trade-offs, such as the selection of

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suitable computing nodes and network transmission paths.

This special feature, including six papers—one perspective paper, one review paper, and four research articles, revisits the longstanding question of whether it is feasible to design the system as a networked supercomputer. Managing computing resources across end devices, edge clouds, and central clouds while optimizing trade-offs for end-to-end services is essential. This approach enables the exchange of computation for transmission, where enhanced computing power can compensate for the need for ultra-low latency in network transmission. Through strategic collaboration and integration, the network and computing can synergistically amplify their capabilities. To harness the aforementioned benefits, it is crucial to address three key aspects:

1. Identification of networking and computing requirements and resources involves determining the computing power and network transmission capabilities needed by applications. It is essential to understand how to identify and model these demands, especially for heterogeneous and distributed computing resources. The challenge lies in ensuring that raw data or processing logic can be efficiently allocated to use available computing resources.

2. Joint and timely awareness of computing and networking resources necessitates the collection of load information related to network or computing capacities. Due to differing monitoring approaches, computing power metrics often derive from information technology infrastructure components such as cloud services, virtual machines, or containers. In contrast, network connectivity metrics typically depend on end-to-end data path transmission measurements.

3. Coordinated scheduling of computing and networking resources requires systematic optimization to facilitate collaboration among end devices, edge computing, and cloud services. This involves establishing a unified "brain" for the network to enable a distributed computing system where resource providers collaboratively tackle multidimensional scheduling challenges.

In addition to these core aspects, the practical implementation of such systems may involve tasks such as application task decomposition. Furthermore, it is vital to assess whether network and computing resources can collaborate in the entire information lifecycle, including generation, transmission, processing, and consumption. In the context of digital transformation, CNC heralds a promising new research domain. Numerous challenges, as outlined above, await discovery and resolution.

The architectural design of the system is pivotal in realizing these new functionalities. Xiaoyun WANG et al. introduced the concept of computing-aware network (CAN), a novel framework that incorporates an awareness plane to facilitate wide-area computing and network coordination. This framework identifies three pivotal technologies: computing-aware traffic steering (CATS), elastic broadcast, and wide-area high-throughput transmission. The Internet Engineering Task Force (IETF) has initiated discussions on CATS to explore potential scenarios and architectural designs, although the application of computing information in routing requires further investigation. Elastic broadcast is tailored for one-to-many communication in wide area networks (WANs), essential for AI model training and inference across data centers. While high-throughput transmission is not a novel concept, its application in WANs poses challenges due to long-distance delays, packet loss, and server limitations.

Energy efficiency is paramount due to the environmental and cost implications of high power consumption. Federated learning, increasingly popular in recent years, requires energy-efficient approaches, especially in edge computing contexts. Kang YAN et al. provided a comprehensive survey on energy-efficient strategies in federated learning at the edge, including system and energy consumption models. They explored three categories of strategies, including learning-based, resource allocation, and client selection, and discussed several potential research directions for energy-efficient federated learning.

To effectively provide computing services or solve complex problems, a collaborative approach to task decomposition is necessary. This includes task offloading among user devices, edge networks, and cloud data centers, fostering collaboration across cloud–edge–device infrastructures. Xiaojun BAI et al. differentiated tasks into delay-sensitive and delay-tolerant categories, employing a continuous-time Markov chain to model the system. Their research highlighted a

trade-off between average delay and blocking rate, with efforts focused on optimizing the access threshold for edge network buffers.

When dealing with multiple computing and network resource providers, selecting the appropriate provider is crucial for task completion. Yuexia FU et al. used a reputation model based on the beta distribution function to evaluate the credibility of resource providers and introduced a performance-based reputation update model. This approach was formulated as a constrained multi-objective optimization problem, with feasible solutions identified through a modified fast and elitist non-dominated sorting genetic algorithm. Their extensive simulations confirmed the validity and effectiveness of their model in enhancing user satisfaction and resource utilization.

The essence of CNC lies in the joint consideration of computing and network resources for resource allocation. Xueying HAN et al. developed an intelligent resource allocation method that integrates deep reinforcement learning with graph neural networks. This method addresses the challenge of routing in a computing force network by optimizing both network and computing resources across various network topologies, even with structural changes.

In various scenarios and fields, the synergy between computing power and networking is vital. Yizhuo CAI et al. focused on enhancing communication efficiency of federated learning in six-generation networks, examining both traditional and peer-to-peer federated learning architectures. They demonstrated that optimizing computing power scheduling based on a real-time resource status can significantly improve the performance.

The papers in this special feature cover various aspects of CNC, whether in Internet Protocol (IP) or cellular networks like the fifth-generation mobile communication technologies. This feature has garnered substantial support from both academic and industry sectors but remains in its infancy. Many questions and technical directions warrant further detailed investigation.

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