Quantum Communications and Networking


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Quantum communication researchers have achieved significant progress during the recent decades and quantum networking has shown promise in terms of improving the overall functional benefits of the Internet and enabling applications with no counterpart in the classical world. It is a breakthrough technology towards the unimaginable future. In a quantum network, the source and destination may be connected by quantum repeaters/routers for facilitating qubit transmissions. The quantum network of the future is envisaged to pervade the entire globe, relying on terrestrial components, satellites, airplanes, ships and other vehicles. It is anticipated that it will support nearly unconditional security, super-computing power, large network capacity — even at high velocity — and privacy.

In the current era, quantum networks are similar to the early stage of the classical Internet in the 1970s. However, they exhibit fundamentally different features, obeying the uncertainty principle, the non-orthogonal indistinguishable theorem, the quantum non-cloning theorem, entanglement and superposition. These constraining features make the design of quantum networks a challenging task. This Special Issue (SI) features recent and emerging advances in the areas of quantum communications and networking. Of the 54 submitted papers, 12 were selected for this issue. The selected articles cover the topics including architecture and framework, entanglement preparation, distribution, routing, transport, and deployment, and quantum networking applications.

To make the promise of quantum networking a reality, the entire network architecture and framework requires careful investigations. The first article, "The Quantum Internet: Enhancing Classical Internet Services One Qubit at A Time" coauthored by Angela Sara Cacciapuoti, Jessica Illiano, Seid Koudia, Kyrilo Simonov, and Macello Caleffi, sheds the light on the interplay between classical and quantum Internet and shows that the quantum Internet exhibits the potential of supporting and even ehancing classical Internet functionalities. The second article, "From Single-Protocol to Large-Scale Multi-Protocol Quantum Networks" contributed by Yuan Cao, Yongli Zhao, Jie Zhang, Qin Wang, Dusit Niyato, and Lajos Hanzo, conceives a practical protocol translation framework to support the migration from single-protocol to large-scale multi-protocol quantum networks, and further proposes a programmable multi-functional relay node architecture. The third article, "Quality of Service in Quantum Networks" by Claudio Cicconetti, Marco Conti, and Andrea Passarella, investigates the problems of quality of service (QoS) and the provisioning in the context of quantum networks. The fourth article, "Physics-Informed Quantum Communication Networks: A Vision Towards the Quantum Internet" coauthored by Mahdi Chehimi and Walid Saad, brings forth a novel analysis of the performance of quantum networks in a physical-informed manner, by relying on the quantum physics principles and presents a physics-informed quantum network framework.

The enabling technologies for quantum networking include entanglement preparation, distribution, routing, transport, and further network deployment. The fifth article, "An Asynchronous Entanglement Distribution Protocol for Quantum Networks" by Zhaoying Wang, Jian Li, Kaiping Xue, Shaoyin Cheng, Jianqing Liu, Nenghai Yu, Qibin Sun, and Jun Lu, presents an asynchronous entanglement distribution protocol which contains a custom weighted maximum matching algorithm and a reliable signaling interaction mechanism to avoid swapping conflict, respectively. The sixth article, "Adaptive and Efficient Qubit Allocation Using Reinforcement Learning in Quantum Networks" coauthored by Yanan Gao, Song Yang, Fan Li, and Xiaoming Fu, proposes a reinforcement learning algorithm to self-adaptively and cooperatively allocate qubits among quantum repeaters. The seventh article, "Quantum Networks with Multiple Service Providers: Transport Layer Protocols and Research Opportunities" coauthored by Maoli Liu, Jonathan Allcock, Kechao Cai, Shengyu Zhang, and John C. S. Lui, presents two network-oblivious transport layer protocols for enabling high fidelity communication and performing fault diagnostics. The eighth article, "On Topology Design for the Quantum Internet" coauthored by Ruozhou Yu, Rudra Dutta, and Jianqing Liu, investigates the deployment issue of quantum network, analyzes the entanglement distribution rate and end-to-end fidelity of popular quantum network topologies, and points out the limitations of the current approaches.

Applications are an indispensable area promoting the quantum communications and networks to come into true. The ninth article, "Hybrid Quantum-Classical Computing for Future Network Optimization" coauthored by Lei Fan and Zhu Han, proposes the hybrid quantum-classical computing paradigm and potential applications for network resource optimization. The tenth article, "A High-Resolution and Low-Cost Entangled Photon Quantum Imaging Framework for Marine Turbulence Environment" by Jingyang Cao, Wei Nie, and Mu Zhou, investigates high-resolution imaging in marine environment and designs an innovative underwater quantum imaging optical path for experimental verification. The last article, "Digital Twins Based on Quantum Networking" contributed by Zhihan Lv, Chen Cheng, and Houbing Song, proposes a channel encryption scheme and adaptive key residue algorithm based on quantum communications to ensure the security of digital twin-based industrial Internet of Things.

This SI has successfully addressed important topics in quantum communications and networking from the aspects of architecture, physics, networking, and applications. Besides these studies, there are still many open challenges in this area, such as how to efficiently schedule the entanglement generation and distribution?

How to design effective entanglement routing and swapping control mechanisms? How to achieve efficient resource allocation and avoid congestion control? Also, the deployment and application issues should be addressed more in the future.

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Biographies

Ruidong Li (lrd@se.kanazawa-u.ac.jp) is an associate professor at Kanazawa University, Japan. He received his Ph.D. degree in computer science from University of Tsukuba in 2008. He is the recipient of the best paper awards for IEEE ICC 2022 and IWCMC 2022. He serves as the vice chair of IEEE Internet Technical Committee (ITC), and served as chairs for several conferences, such as the general co-chairs for IEEE MSN 2021, CPSCom 2021, and TPC co-chairs for IWQoS 2021, IEEE MSN 2020. His research interests include quantum networks, metaverse, and future networks.

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