Quantum Internet: the Dawn of the Quantum Paths

Invited Paper

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ABSTRACT

The Quantum Internet – i.e. an heterogeneous network enabling quantum communications among remote quantum nodes by leveraging on quantum transmission channels in synergy with classical transmission channels – is attracting worldwide academic and industrial interest [1, 2, 3, 4, 5, 6, 7], given its potential of enabling applications with no counterpart in the classical Internet [8]. Indeed, the Quantum Internet, by transmitting qubits and by distributing entangled quantum states, comes with a whole new dazzling functionalities [9, 10].

In this context, while the information carriers and the transmission channels are treated quantum mechanically [9], the paths, i.e. the placement of the channels through which the carriers propagate through, are still treated classically [1, 11], obeying the laws of classical causality. However, this assumption can be generalized so that also the placement of quantum channels can be quantized [10, 12, 13, 14, 15, 16] in order to beat fundamental transmission bounds, which constituted up to now critical limitations in classical networks.

Such an unconventional placement of channels, referred to as quantum path, has been theoretically and experimentally verified. And it has been proven to be able to describe powerful setups not only for the transmission of both classical and quantum information [14, 15, 16], but also to distribute multipartite entangled states among remote nodes of a quantum network [13].

This paper aims at shedding light on the aforementioned genuine quantum phenomenon represented by the quantum paths and on the challenges and the open problems arising in harnessing its unconventional features within the Quantum Internet design.

CCS CONCEPTS

• **Networks** → **Network design principles**; **Network protocol design**.

KEYWORDS

Quantum Internet, Quantum Networks, Quantum Communications, Entanglement, Quantum Teleportation, Capacity, Quantum Capacity, Holevo Information, Coherent Information, Quantum Switch, Superadditivity, Superactivation, Causal Activation.

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