Beyond cloning: Harnessing the power of virtual quantum broadcasting

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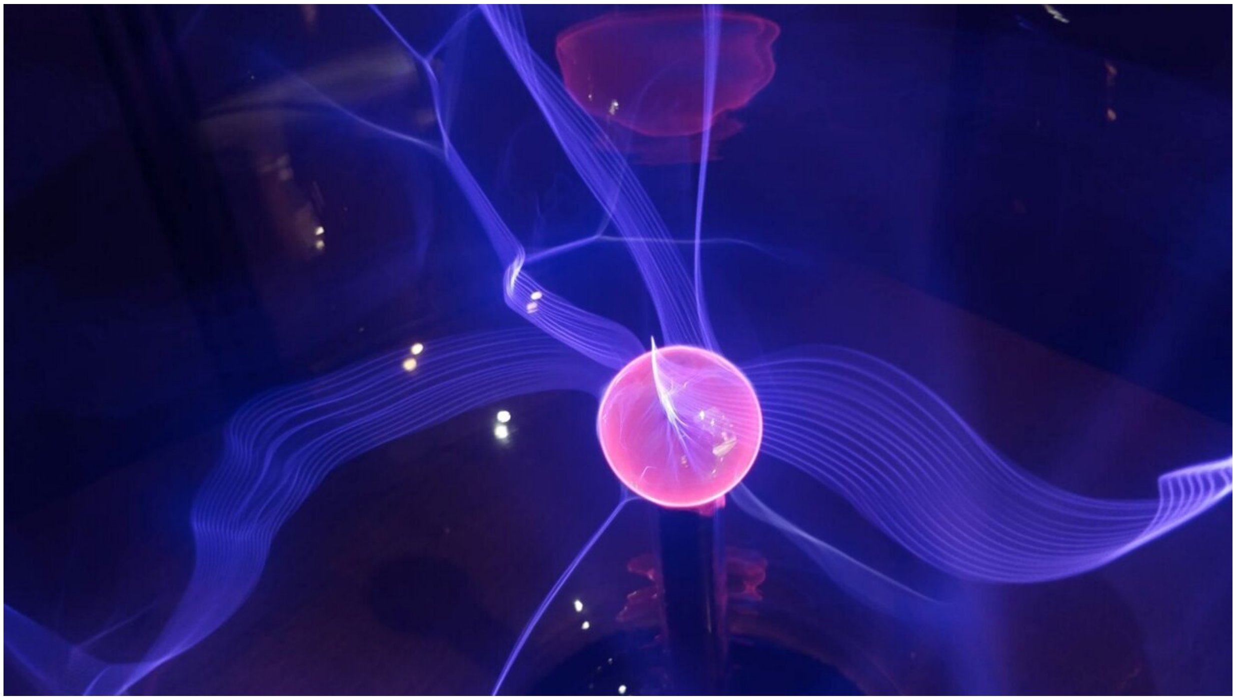

A virtual broadcasting map can have a significant impact on quantum information processing. Credit: Fractal Hassan/Unsplash

In a new study, scientists propose the concept of "virtual quantum broadcasting," which provides a workaround to the longstanding no-cloning theorem, thereby offering new possibilities for the transmission of quantum information.

The study, published in *Physical Review Letters*, outlines a virtual broadcasting map that creates correlated copies "virtually." Through a series of four theorems, the researchers establish the viability of this map, which allows for the creation of correlated copies of quantum states over time.

Further, the researchers demonstrate the robustness of the canonical framework, prove its physical approximation to the universal cloner, and detail how the map can be implemented.

Virtual quantum broadcasting promises to impact many fields of quantum information processing by leveraging time-based correlations, thereby avoiding the limitations imposed by the no-cloning theorem.

Why can't we copy and paste?

Quantum mechanics, while incredibly powerful, is built such that it prevents information from being replicated or copied. A quantum state encapsulates all the relevant information in the system and collapses or changes to one of the possible outcomes of the measurement when measured or observed.

It means that we can't copy the state since it needs to be measured to be able to do that. This principle is known as the no-cloning theorem. In simpler terms, you can't just copy and paste quantum information as you would with classical data.

This limitation poses a significant obstacle for quantum communication systems that rely on efficiently being able to transmit and reproduce quantum information.

The research team consisted of Prof. Arthur Parzygnat from MIT, Prof. James Fullwood from Hainan University, Prof. Francesco Buscemi from

Nagoya University, and Prof. Giulio Chiribella from the University of Hong Kong, who explained their motivation to Phys.org.

They were motivated by this problem presented by the no-cloning theorem. Their aim was to study the evolution of quantum states over time and understand what "correlation does not imply causation" meant for purely quantum states.

Virtual quantum broadcasting

"Our way around this was to introduce virtual quantum broadcasting channels, which, though not genuine physical processes, have many important applications in quantum information processing," explained Prof. Parzygnat.

Unlike traditional copying methods, which are prohibited by the no-cloning theorem, these virtual broadcasting channels or maps operate virtually, meaning they don't involve direct physical replication.

Instead, the map establishes correlations between different instances of a quantum state, effectively allowing for the transmission of information without violating the fundamental principles of quantum mechanics.

The virtual broadcasting map is unique and satisfies three simple axioms, which the researchers lay out in theorem 1. The axioms governing the virtual broadcasting map ensure consistency under changes in:

- The frame of reference.
- Symmetry between the receiving ends.
- The ability to copy classical information unaffected by decoherence.

These are the basic requirements of a virtual broadcasting map.

The researchers further prove (in theorem 2) that a physical approximation of such a map could be created using a universal cloner, a device that can make the most faithful copies of an arbitrary quantum state possible.

Next, the researchers show how the broadcasting map can be achieved by decomposition (theorem 3). It establishes that the map can be broken down into two operations:

- A measure-and-prepare protocol involves performing a virtual measurement on the quantum system to create a virtual performing a virtual measurement on the quantum system.
- Next, two copies of the virtual quantum state are generated based on the outcomes of the virtual measurement performed in the previous step.

Finally, they establish (in theorem 4) the equivalence between the action of a time evolution function and the action of the virtual broadcasting map on any arbitrary state. This implies that the virtual broadcasting map behaves like a time operation, allowing for the creation of correlated virtual copies of quantum states over time.

"The most appealing feature of this work is that the map is uniquely characterized by a simple set of natural requirements. That's why we call it canonical. Such a unique property, in turn, seems to point to a whole new part of quantum theory, i.e., its time-like structure, which is still largely unexplored," explained Prof. Buscemi.

Impact on quantum applications

By establishing a virtual quantum broadcasting theorem, the researchers have brought forth a host of new possibilities for quantum computing, quantum information, and quantum cryptography.

"One avenue I find particularly interesting, and which I am currently working on with Prof. Parzygnat, is how a virtually broadcast state can potentially encode the measurement statistics of two timelike separated measurements in a given laboratory," said Prof. Fullwood.

This phenomenon suggests that the virtually broadcast state, as outlined, captures not just the expectation values but also the probabilities of joint measurement outcomes.

This supports the interpretation of virtual broadcasting as a spatiotemporal process that mirrors the flow of quantum information over time, "similar to how spacetime encapsulates the evolution of space over time," added Prof. Fullwood.

The researchers also point out that virtual broadcasting reveals the hidden structure behind many quantum information technologies. Prof. Chiribella explains this with an example in the context of quantum communication, "A natural way for an eavesdropper to tap into a quantum communication channel is to attempt to copy quantum states."

"As it turns out, the best approximate way to copy the quantum state is to realize a physical approximation of our virtual broadcasting."

This understanding can enhance security measures in quantum communication by offering insights into potential eavesdropping techniques and their countermeasures.

The researchers point to us entering a new area of quantum theory previously considered unorthodox or off-limits, such as the direct measurement of accuracy in quantum devices, as allowed by the virtual broadcasting map.

"Perhaps the answers to many fundamental questions can be found here," concluded Prof. Buscemi.

More information: Arthur J. Parzygnat et al, Virtual Quantum Broadcasting, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.110203. On *arXiv*: DOI: 10.48550/arxiv.2310.13049

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