Researchers demonstrate promising method for improving quantum information processing

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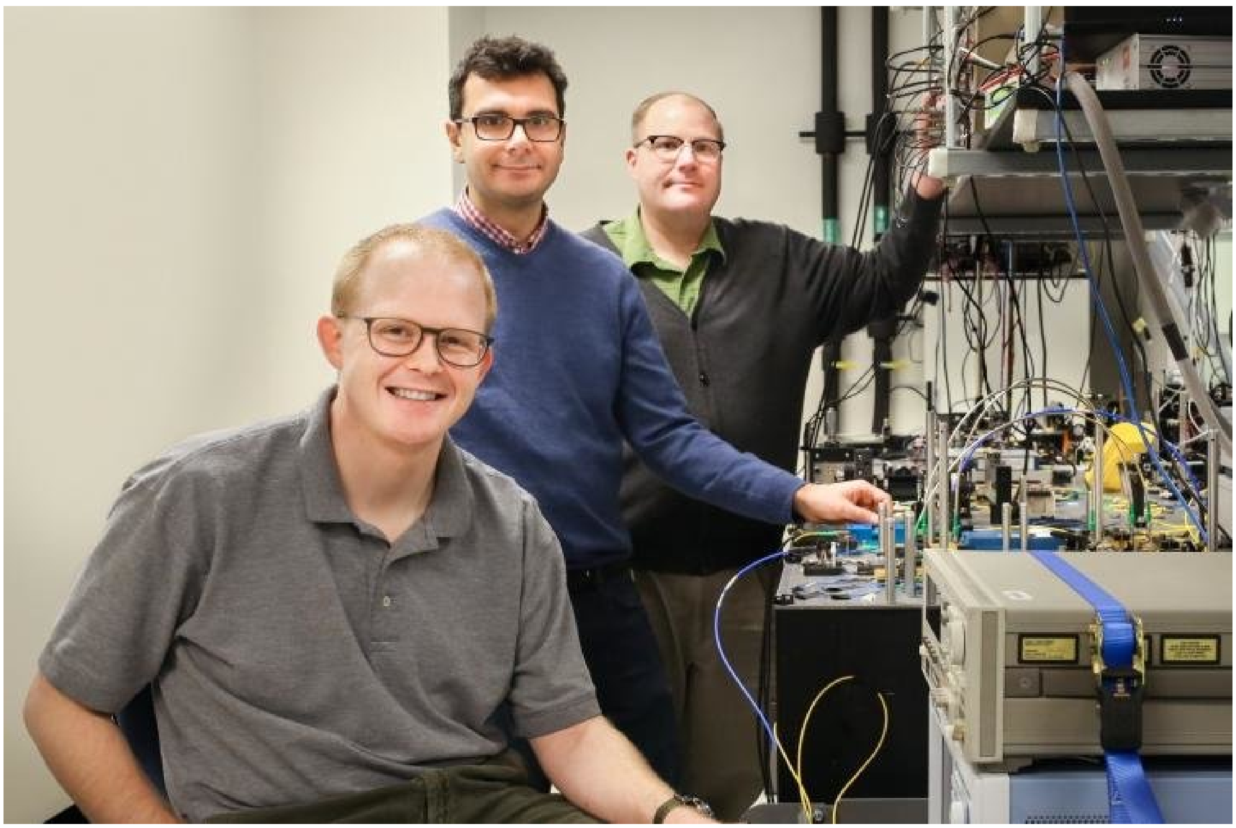

Joseph Lukens, Pavel Lougovski and Nicholas Peters (from left), researchers with ORNL's Quantum Information Science Group, are examining methods for encoding photons with quantum information that are compatible with the existing telecommunications infrastructure and that incorporate off-the-shelf components. Credit: Genevieve Martin/Oak Ridge National Laboratory, US Department of Energy

A team of researchers led by the Department of Energy's Oak Ridge National Laboratory has demonstrated a new method for splitting light beams into their frequency modes. The scientists can then choose the frequencies they want to work with and encode photons with quantum information. Their work could spur advancements in quantum information processing and distributed quantum computing.

The team's findings were published in *Physical Review Letters*.

The frequency of light determines its color. When the frequencies are separated, as in a rainbow, each color photon can be encoded with quantum information, delivered in units known as qubits. Qubits are analogous to but different from classical bits, which have a value of either 0 or 1, because qubits are encoded with values of both 0 and 1 at the same time.

The researchers liken quantum information processing to stepping into a hallway and being able to go both ways, whereas in classical computing just one path is possible.

The team's novel approach—featuring the first demonstration of a frequency tritter, an instrument that splits light into three frequencies—returned experimental results that matched their predictions and showed that many quantum information processing operations can be run simultaneously without increasing error. The quantum system performed as expected under increasingly complex conditions without degrading the encoded information.

"Under our experimental conditions, we got a factor 10 better than typical error rates," said Nicholas Peters, Quantum Communications team lead for ORNL's Quantum Information Science Group. "This establishes our method as a frontrunner for high-dimensional frequency-based quantum information processing."

Photons can carry quantum information in superpositions—where photons simultaneously have multiple bit values—and the presence of two quantum systems in superposition can lead to entanglement, a key resource in quantum computing.

Entanglement boosts the number of calculations a quantum computer could run, and the team's focus on creating more complex frequency states aims to make quantum simulations more powerful and efficient. The researchers' method is also notable because it demonstrates the Hadamard gate, one of the elemental circuits required for universal quantum computing.

"We were able to demonstrate extremely high-fidelity results right off the bat, which is very impressive for the optics approach," said Pavel Lougovski, the project's principal investigator. "We are carving out a subfield here at ORNL with our frequency-based encoding work."

The method leverages widely available telecommunications technology with off-the-shelf components while yielding high-fidelity results. Efforts to develop quantum repeaters, which extend the distance quantum information can be transmitted between physically separated computers, will benefit from this work.

"The fact that our method is telecom network-compatible is a big advantage," Lougovski said. "We could perform quantum operations on telecom networks if needed."

Peters added that their project demonstrates that unused fiber-optic bandwidth could be harnessed to reduce computational time by running operations in parallel.

"Our work uses frequency's main advantage—stability—to get very high fidelity and then do controlled frequency jumping when we want it," said Wigner Fellow Joseph Lukens, who led the ORNL experiment. The researchers have experimentally shown that quantum systems can be transformed to yield desired outputs.

The researchers suggest their method could be paired with existing beam-splitting technology, taking advantage of the strengths of both and bringing the scientific community closer to full use of frequency-based photonic quantum information processing.

Peters, Lougovski and Lukens, all physicists with ORNL's Quantum Information Science Group, collaborated with graduate student Hsuan-Hao Lu, professor Andrew Weiner, and colleagues at Purdue University. The team published the theory for their experiments in *Optica* in January 2017.

More information: Hsuan-Hao Lu et al. Electro-Optic Frequency Beam Splitters and Tritters for High-Fidelity Photonic Quantum Information Processing, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.030502

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