SOCIETY FOR
SCIENCE & THE PUBLIC

Inform. Educate. Inspire.

---

Quantum Internet
Author(s): Peter Weiss
Source: *Science News*, Vol. 155, No. 14 (Apr. 3, 1999), pp. 220-221
Published by: Society for Science & the Public
Stable URL: http://www.jstor.org/stable/4011480
Accessed: 28/10/2010 11:46

---

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at http://www.jstor.org/page/info/about/policies/terms.jsp. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at http://www.jstor.org/action/showPublisher?publisherCode=sciserv.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

*Society for Science & the Public* is collaborating with JSTOR to digitize, preserve and extend access to *Science News.*

STOR®

http://www.jstor.org

# Quantum Internet

## The quirks of quantum mechanics may lead to better computer networks

By PETER WEISS

Feverish experimentation now under way in labs around the world may one day lead to quantum computers. These extraordinarily powerful calculating machines would employ as their bits not electric circuits but particles that obey the strange rules of quantum mechanics. These devices are years away at best—maybe decades, maybe more.

Scientists dare to dream, anyway—not only of quantum computers but also of linking them together into networks. The connections between the machines would operate on quantum mechanical principles, too.

Fueling those dreams is a growing ability to transfer delicate quantum information from one place to another. New experiments that stretch quantum mechanical effects across distances of kilometers are providing encouragement.

Theorists are fanning the flames as well. Studies of how such hypothetical networks would compare with conventional ones hint that greater computing power waits to be unleashed.

H. Jeff Kimble, an experimenter and theorist at the California Institute of Technology in Pasadena, foresees such networks having a widespread impact. "One could imagine a quantum Internet in the future," he says. It would be a more complex web than the one that currently spans the globe and would employ communication capabilities not possible with conventional technology.

"Such a network can do heroic things," he predicts.

Less than 2 years ago, scientists succeeded for the first time in making information appear to leap instantaneously from one place to another without passing through the intervening space. In independent experiments, scientists in two European laboratories transferred a characteristic of one photon—the elementary particle of light—to another photon via a technique called quantum teleportation (SN: 1/17/98, p. 41). Researchers say quantum teleportation will be an essential ingredient of both quantum computers and networks.

Teleporting a photon's state is the equivalent of sending just one quantum bit, or qubit, worth of information. Unlike a conventional bit, which must represent either 0 or 1, a qubit represents a mixture of 0 and 1 called a superposition. Only when a measurement is actually made, which destroys the superposition, is the qubit forced into a specific value.

While wonderfully versatile, a qubit still packs only one nugget of information. Recently Kimble and his colleagues have shown experimentally that quantum teleportation using light beams, made up of many photons, may be able to carry a great deal more information, enough perhaps to support practical computing.

Kimble's team and scientists from Aarhus University in Denmark and the University of Wales in Bangor shipped a characteristic of a pulse of light across a lab bench to another pulse a meter away. Although the distance is short, in principle the same technique could work over unlimited spans, Kimble says. The researchers described their experiment in the Oct. 23, 1998 Science.

"With our quantum scheme, we could take the whole output of a quantum computer and teleport it," says Christopher A. Fuchs, one of the Caltech researchers.

To achieve teleportation, scientists exploit another of the quantum realm's strange aspects. Known as entanglement, it creates a correlation between quantum objects that, in theory, persists no matter how far apart those entities become. The correlation arises because the objects occupy a joint quantum state. When the entanglement ends—because of a measurement, for example—the once-entangled states must adopt related values. Two formerly entangled photons would take on predictable characteristics—for instance, opposite values.

Kimble's team split a single laser beam to create an entangled pair of beams. One blazed into the sending station and the other into the receiving station. When a new pulse, which can be thought of as the message, interacts with the sending half of the original beam, entanglement requires that the receiving part be affected, too. In essence, the receiver gets a part of the message as quantum information via entanglement.

Teleportation also requires a classical transfer of information—in Kimble's experiment, along wires. By correctly combining the information from the wires and the beams, the scientists recreate the message at the receiving end.

Along the classical path, information flows no faster than the speed of light. So, quantum teleportation still obeys that universal speed limit.

Although light-based quantum-information processing seems promising, the quantum-Internet may not ultimately use light as its medium. Attempts to use photons as bits in rudimentary quantum-computing experiments have run into some serious snags. In an alternative pursued by some researchers, the quantum Internet might slosh more than blink.

A number of scientific teams are exploring quantum computing and communication using atoms in liquids manipulated via nuclear magnetic resonance (NMR). The technique is also used in medicine to make images of body parts. With strong magnetic fields and radio-wave pulses, NMR manipulates the spins of atomic nuclei.

In the Nov. 5, 1998 Nature, researchers from Los Alamos (N.M.) National Laboratory and the University of New Mexico in Albuquerque reported a short-distance example of teleportation. They transmitted a characteristic known as spin orientation from one atom to another within a molecule. The scientists manipulated molecules of trichloroethylene dissolved in chloroform.

"We've used different nuclei to transfer the information, not photons or electromagnetic fields. We're the first ones to do that," says Raymond Laflamme of Los Alamos.

In a manner analogous to the optical experiments, the researchers created a quantum conduit by entangling two atoms. Then, they allowed another atom, which carried the spin message, to interact with one of the entangled pair, automatically affecting the other via the quantum link.

Although no wires were involved, a classical ingredient was still present. A combination of radiofrequency pulses and quiescent periods guided the molecule into a final state that depends on the arrangement of spins caused by the initial message interaction. Those influences finally nudged the target atom into the message's spin state.

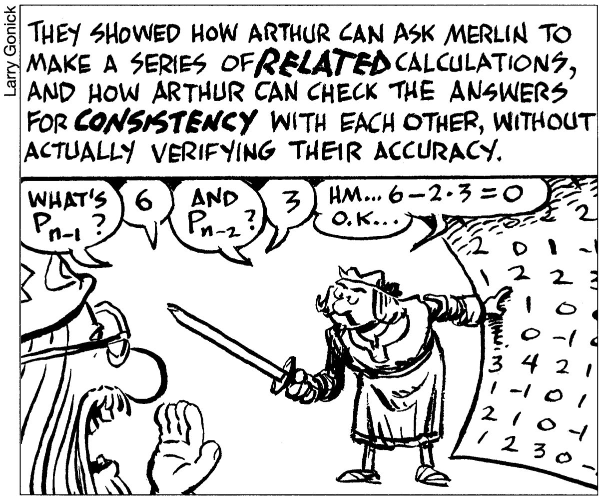
The Caltech and Los Alamos achievements are both "great experimental tours de force in learning how to control these things," says Charles H. Bennett of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y. Bennett is one of six theorists who in 1993 came up with the idea of quantum teleportation (SN: 4/10/93, p. 229).

Kimble, however, harbors grave doubts about the NMR experiment. "In my view, it's not a demonstration of teleportation, it's a simulation," he says. He contends that entanglements can't survive in the disorderly sea of molecules constituting a typical liquid. NMR proponents counter that Kimble and his fellow skeptics have chosen to ignore other analyses showing that entanglements can survive.

Teleporting across a molecule—or even a workbench—won't suffice for making practical networks. Researchers are building up to greater leaps, however, by testing the notion that entanglement has an unlimited range.

Wolfgang Tittel and his colleagues at the University of Geneva hold the world record for extending entanglement across space. Using existing optical fibers that had been installed for telecommunications, the scientific team split up entangled pairs of photons produced in Geneva and sent them on separate paths to Bellevue and Bernex, two villages outside Geneva (SN: 2/10/96, p. 90). The Swiss researchers used a different characteristic of photons than that transmitted in the teleportation experiments.

Measurements at the destinations determined that the quantum states remained correlated throughout the photons' journeys. In the May 1998 Physical Review A, the researchers concluded, borrowing a phrase from Albert Einstein, that the "spooky action at a distance" between their entangled photons does not break down across the 10.9 kilometers between the villages.



Larry Gonick

*Quantum networks could quickly determine whether Merlin's proof is valid.*

Scientists are planning to test longer entanglements. Anton Zeilinger of the University of Vienna says that his group is gearing up for experiments at distances beyond 20 km. He led one of the first experiments in photon teleportation more than a year ago, while at the University of Innsbruck in Austria. His newly established Vienna lab will collaborate on the project with the Geneva researchers and other scientists.

To go beyond entanglement, the Vienna researchers are also laying plans for the first teleportation of a photon's characteristics across kilometer distances, Zeilinger says.

Those experiments would follow on an achievement completed while he was still at Innsbruck but just reported in the Feb. 15 Physical Review Letters. The Innsbruck team simultaneously entangled three photons, with distances of roughly 20 centimeters between each of them.

It's not the first report of three-particle entanglement. Laflamme and his colleagues made that claim in a NMR experiment last year involving three atoms in a molecule (SN: 9/12/98, p.165).

The Innsbruck experiment, however, goes far beyond interatomic distances, albeit without coming close to practical network dimensions. Moreover, "the same procedure we used for 3 photons can now be generalized" to possibly as many as 10 photons, Zeilinger says.

Would quantum networks be worth the work that it will take to develop the quantum links that they will need? Theorists are probing how model networks might perform and comparing them with conventional, or classical, computer networks.

Each node of a quantum network would be a quantum computer. Such machines would calculate and perform logical operations using delicate strings of entangled qubits, each in a superposition of many states. So far no more than three-qubit, rough-hewn calculating experiments have appeared in labs. Not until that qubit number grows to thirty or forty and a robust technology emerges will quantum computers begin to make their mark, scientists say.

At that point, teleportation would provide the thread to tie the computers together. How far those threads might stretch remains to be seen. Tittel thinks 50 km is possible with current optical fiber technology.

If quantum computers start talking to each other, what would come next? Computer scientists have begun to address that question, although on a very abstract level.

In one sort of problem that they ponder, several very busy people try to arrange to meet for lunch. They let their computers, which know their jam-packed schedules, interact with each other in order to find a time slot in which all three people are free.

For conventional computers, researchers had already proved years ago that for schedules with some number, *n*, of time slots, no fewer than *n* bits would have to be exchanged by the machines. Early last year, however, a trio of computer scientists examined how quantum computers would solve the problem and reported that the number of bits needed would be significantly below *n*.

"By using quantum bits, rather than classical bits, you can save on communication," says Richard Cleve of the University of Calgary in Alberta, a member of the research team. For this particular problem, however, he notes, the quantum treatment requires more exchanges among the computers than a classical solution does.

An analysis of a more esoteric problem by Ran Raz of the Weizmann Institute in Rehovot, Israel, concludes that a quantum interaction saves on both the number of bits exchanged and the number of exchanges. Raz is scheduled to present his work in May in Atlanta at the 31st Annual Association for Computing Machinery's Symposium on Theory of Computing.

Another example of a possible quantum-network edge emerged at a January workshop on algorithms in quantum information processing at DePaul University in Chicago.

Some computing researchers study ways in which computers can evaluate the validity of mathematical proofs. In the interactive method, two computers, named Arthur and Merlin after the legendary king and sorcerer, have a chat. Merlin, who is wise but not always honest, presents the proof to Arthur. Limited both in brains and time, Arthur queries Merlin in an attempt to verify the proof.

Daunted by the proof itself, Arthur asks Merlin to carry out related calculations instead. By checking for consistency among Merlin's answers, Arthur can discern if the proof is valid.

In the case of conventional computers, the number of rounds of question-and-answer grows as the mathematical statement or equation under consideration becomes more complicated.

At the DePaul conference, however, John Watrous of the University of Montreal reported that a quantum Arthur and Merlin duo could determine the validity of the proof, no matter how convoluted its mathematical expression, in only two rounds of questioning. Watrous says that the finding rests on a widely accepted assumption that there is a certain type of complexity in the mathematics.

Watrous's new evidence of latent quantum network power has impressed Bennett. "This is another major step along the way," he says. For more than two computers, Watrous says, he expects a quantum approach also to yield a bonus, but he hasn't yet analyzed that situation in detail.

If researchers ultimately find ways to make quantum information leap far enough and wide enough, a quantum leap for networks may not be far behind. □