Crystal quantum memories for quantum communication

September 19 2013

Credit: Silvie Lindemann from Pexels

Research into the strange phenomenon known as quantum entanglement - once described as 'spooky' by Albert Einstein - could revolutionise ICT over the coming years, enabling everything from ultra-fast computing to completely secure long-distance communications. EU-funded researchers are carrying out cutting-edge work on quantum technologies, with one team recently demonstrating a key breakthrough in extending the range of quantum communications.

In essence, quantum entanglement occurs when particles such as photons or electrons interact physically and then become separated but remain intimately connected, even if they are thousands of kilometres apart. It defies our common sense instincts and experience of the physical world, but one particle located in Tokyo, if measured by an observer, would exhibit the exact qualities of its entangled counterpart in Brussels.

A pair of quantum systems using photons in an entangled state can be used as a quantum information channel to perform computational, communication and cryptographic tasks that are impossible for classical systems. And, crucially for communications purposes, because the photon pairs are intrinsically linked, they provide complete security and fidelity - as when one photon is measured it reveals with absolute certainty what the other photon would reveal if measured. In addition, if the signal were intercepted by a third party it would immediately be detected, as the entanglement would have to be broken in order to intercept the message. Once the entanglement is broken, it cannot be restored. These properties open up a whole new world of applications.

'Applications of quantum technologies are still in their infancy. Hence, it is likely that we are not yet aware of most future applications,' notes Professor Nicolas Gisin of the Group of Applied Physics at the University of Geneva in Switzerland. 'These future applications of quantum technology would probably look like magic to people who are around today.'

Quantum computing could allow us to solve a query - in code-breaking for example - by looking at all possible input combinations at the same time. Whereas current computers could take years to investigate every possible input combination, in the quantum computer they are all tested at once. And quantum entanglement might permit instantaneous communication, or even allow us to teleport solid objects from one place to another.

Prof. Gisin and a team of researchers from four European countries - France, Germany, Sweden and Switzerland - have taken an important step forward in making that magic happen. Their work is expected to contribute to the development of commercial applications for quantum communications technology within the next 10 years.

Working on the 'Quantum repeaters for long distance fibre-based quantum communication' (QUREP) project, with the support of EUR 1.9 million in funding from the European Commission, the consortium has made important steps towards a quantum repeater that can boost quantum signals across greater distances, bringing long-distance quantum communication closer to reality.

Quantum communication has already been proven possible over short distances, but the means to separate entangled photons by greater distances reliably had been lacking until now. The QUREP researchers have made important strides toward solving the problem by developing key components of a quantum repeater. The quantum repeater is similar to the repeaters used in standard communications today and its role is to boost an incoming signal and repeat it on the other side, so the signal does not lose its strength as it travels.

'Quantum repeaters are the elementary building blocks of long-distance quantum communications. They require the ability to distribute entanglement over tens of kilometres, quantum memories and entanglement swapping by joint measurements on two photons. We concentrated on quantum memories, which represent the biggest challenge,' Prof. Gisin explains. 'Results are very encouraging, though it is clear that a lot remains to be done to bring this technology to a level suitable for industrialisation.'

The team developed solid-state quantum memories from rare-earth ion doped crystals, which absorb a photon on the input side of the signal and emit a new photon with identical entanglement properties on the other side.

'The bandwidth of quantum memories is a great challenge,' Prof. Gisin notes. 'Our quantum memories have a bandwidth relatively large compared to alternative approaches. Nevertheless, they are limited to some hundreds of megahertz (MHz). Hence, developing sources of entangled photons with compatible bandwidths and high stability was one of our challenges. Overcoming it, we could demonstrate entanglement between two of our quantum memories.'

In tests, the team was able to send a signal photon to the crystal to be stored, while the other photon, known as the idler, was kept behind. The signal photon could then be detected at a laboratory 50 metres away from the Group of Applied Physics, which when measured, revealed with absolute certainty the outcome of the measurement of the idler photon.

'Using large ensembles of ions greatly simplifies the coupling between the photons and the memory, both for storing and retrieval. And we work at about 3 kelvin, a temperature rather easily reached and compatible with the best superconducting single-photon detectors,' Prof. Gisin says. 'There are not too many projects that can bring together all of the technologies and know-how necessary to demonstrate quantum repeaters and that is something that QUREP certainly achieved.'

However, for the technology to move out of the lab and into real-world applications, several key challenges still need to be overcome.

'Challenges that remain are longer memory times (up to one second), higher efficiencies (up to 80 %) and still more efficient signal sources. Even then, there will still be a great engineering challenge to have everything working together,' Prof. Gisin acknowledges.

Members of the consortium, which includes leading research institutes and companies, plan to continue their research into quantum repeaters and may look at commercial spin-offs from their work further down the line.

For commercial applications to materialise, the QUREP coordinator foresees the need for a feasibility demonstration of a quantum repeater for direct communication, as well as a fine analysis of simplifications, industrialisation and lower development and manufacturing costs.

'I believe this is all feasible, but still requires quite some time for physicists,' he says. 'The gap between academic research and industry is huge. I believe we made great step towards bridging this gap, though a second step of similar amplitude is still needed before an engineering project could develop a product. In the first step, the one conducted during QUREP, we have identified precisely the challenges that remain to be overcome and identified promising paths to overcome them.'

More information: quantumrepeaters.eu/

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