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Transmitting entanglement between light and matter in the metropolitan network of Barcelona

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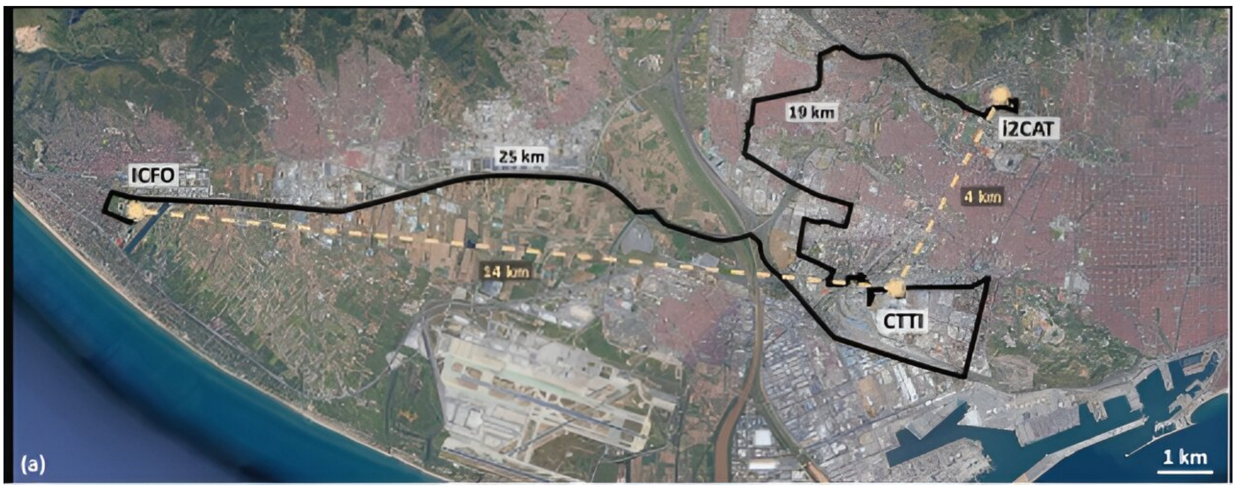

Measurement of non-classical correlations between remote locations. Map of the metropolitan area of Barcelona, with the three locations highlighted: ICFO, where the memory and SPDC source are located; CTTI, where the two optical fiber segments are connected; i2CAT, where the idler photons are detected. Credit: ICFO

As the efforts towards the realization of powerful quantum computers and quantum simulators continue, there is a parallel program aimed at attaining the quantum analog to the classical internet.

This new quantum network will provide ultrasecure, quantum-safe cybersecurity, and eventually will be devoted to the exchange of qubits, the unitary elements of quantum information, and the language of quantum computers. It will, in fact, provide a net over which different quantum computers could connect like classical processors are connected in cloud computing.

An up-front choice for the future quantum internet infrastructure is, in fact, the existing telecommunication network, which provides an almost ubiquitous channel over which light can travel very large distances with limited absorption. Because of this low absorption and its high speed, light is a great candidate as an information carrier, be it classical or quantum.

Bright laser light can be readily used to transfer classical information on the internet, while the attenuation of light in optical fibers is compensated by light amplifiers placed every ten km within these fibers. However, the transfer of quantum information—quantum communication—requires much more sophisticated means.

Quantum bits are still encoded in light, specifically single photons, but this quantum encoding cannot be amplified because the rules of quantum mechanics prevent it; if you try to amplify the quantum encoding, you seriously damage the information contained in the photons. Thus, the amplifiers used in classical networks cannot be used for quantum bits. This means that a radically new technology is needed to build a quantum version of the internet: the quantum repeater.

As light amplifiers ensure connectivity between distant locations, quantum repeaters will allow for long distance communication by distributing entanglement between them.

Entanglement is an exclusively quantum property of two objects that show correlations that cannot be reproduced through classical means, and it is one of the primary components of quantum communication. It can be used to transfer quantum information, for example, through quantum teleportation between two nodes of a quantum repeater system.

One way of establishing remote entanglement between two nodes is through direct transmission: an entangled pair of photons can be generated, with one staying put while the other travels to the other location. This means that the latter must be compatible with optical fiber transmission, while the former must be stored in a quantum memory, leading to entanglement between light and matter.

Now, one needs a set of quantum repeaters to pair several of these nodes to achieve long-distance entanglement between quantum memories. A promising architecture for these quantum repeater nodes relies on pairing the spontaneous generation of photon pairs, a process known as spontaneous down-conversion (SPDC), with an external quantum memory.

This is the approach that researchers at ICFO have taken. In a new study appearing on the *arXiv* preprint server, Jelena Rakonjac, Samuele Grandi, Soren Wengerowsky, Dario Lago-Rivera, and Felicien Appas, led by ICREA Prof. at ICFO Hugues de Riedmatten demonstrate the transmission of light-matter entanglement over tens of kilometers of optical fiber.

In their experiment, they generated pairs of photons, where one is emitted at the telecommunication wavelength of 1436nm, while the other is emitted at 606nm, compatible with the solid-state quantum memories used, realized in special crystals doped with rare-earth atoms.

They then tapped into the metropolitan network of Barcelona, connecting their system to two fibers that ran from ICFO, in Castelldefels, to the Telecommunication Centre of Catalunya (CTTI), en

Hospitalet de Llobregat. By connecting both centers, they created a ring of 50 km, sending the photons all the way to downtown Barcelona and back to ICFO.

With this, they demonstrated that after a full round-trip of 50 km, the light generated in the lab maintains its quantum features without substantial decrease, showing that the photonic qubits do not manifest decoherence when traveling tens of km in a fiber optic cable, even in a metropolitan area. In short, quantum light left the lab, and it was ultimately detected back at its origin.

However, quantum communication requires using and verifying entanglement between remote locations, where entangled photons are detected in locations well-separated in space and time. Moving in this direction, the researchers extended their network to include a new node, this time located at the i2CAT foundation, a building in Barcelona, about 44 km from ICFO through the local optical fiber network and 17 km in a straight line.

There, they installed a telecom detector to measure the arrival of photons that came through one of the fibers while the other fiber was connected to a transducer, which turned the electrical signal of the detector into light and sent it through the optical fiber line.

This way, the information could be conveyed back to ICFO with high precision, even though the photon was detected about 17 km away. Moreover, they used the same transducers to send synchronization signals between the two nodes of this basic network, where the generation and detection of quantum correlations were fully separated between two independent yet connected nodes.

The experiment validated the system used by the researchers to generate light-matter entanglement and has proven to be one of the pioneering candidates for the realization of a quantum repeater node, the enabling technology for long-distance quantum communication. Proof-of-principle demonstrations have already been realized in the lab, and the group is now working on improving the performance of both the memory and the source.

Moreover, the researchers have partnered with Cellnex (Xarxa Roberta de Catalunya), and a new laboratory is available at the Collserola tower within the context of the QNetworks and EuroQCI Spain projects for the realization of an entangled state of remote quantum memories.

The realization of a long-distance backbone for entanglement distribution between quantum memories is also one of the main goals of the Quantum Internet Alliance (QIA), the leading European effort in the realization of the quantum internet of which ICFO is a main partner.

The results of this study, "namely the transmission of light-matter entanglement over fibers deployed in a metropolitan area, are the initial stepping stone towards the realization of a full-fledge quantum internet, with our source and memory quantum node at its core," comments Samuele Grandi, a researcher at ICFO and co-first author of the study.

As ICREA Prof. at ICFO Hugues de Riedmatten concludes, "Light-matter entanglement is a key resource for quantum communication and was demonstrated many times in the laboratory. Demonstrating it in the installed fiber network is a first step towards realizing a test-bed for quantum repeater technologies in the Barcelona area, preparing the ground for long-distance fiber-based networks."

More information: Jelena V. Rakonjac et al, Transmission of light-matter entanglement over a metropolitan network, *arXiv* (2023). DOI:

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