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

ICFO researchers demonstrate the transmission of entanglement between matter and light over tens of kilometers through optical fiber in Barcelona.

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As the efforts towards the realization of powerful quantum computers and quantum simulators continues, there is a parallel program aimed at attaining the quantum analogue t the classical internet. This new quantum network will provide ultrasecure, quantum-saf cybersecurity and, eventually, be devoted to the exchange of qubits, the unitary elements o quantum information and the language of quantum computers. It will in fact provide a ne over which different quantum computers could connect, like classical processors ar connected in cloud computing

An up-front choice for the future quantum internet infrastructure is, in fact, the existin telecommunication network, which provides an almost ubiquitous channel over which ligh can travel very large distances with limited absorption. Because of this low absorption and it 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, whil the attenuation of light in optical fibers is compensated by light amplifiers placed every ten of km within these fibers. However, the transfer of quantum information, that is quantu communication, requires much more sophisticated means

Quantum bits are still encoded in light, specifically single photons, but this quantu encoding cannot be amplified because the rules of quantum mechanics prevent this: if yo try to amplify the quantum econding, you seriously damage the information contained in th 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 t e internet: th**quantum repeater**. ?

As light amplifiers ensure connectivity between distant locations, so will quantum repeater allow for long distance communication by distributing entanglement between them Entanglement is an exclusively quantum property of two objects which show correlation that cannot be reproduced through classical means, and it is one of the primary component for quantum communication. It can be used to transfer quantum information, for examp e through quantum teleportation between two nodes of a quantum repeater syste . One way of establishing remote entanglement between two nodes is through dire t transmission: an entangled pair of photons can be generated, with one staying put while t e other travels to the other location. This means that the latter needs to be compatible wi h optical fibre transmission, while the former needs to be stored in a quantum memory, leadi g to entanglement between light and matte . Now, one needs a set of quantum repeaters to pair several of these nodes to achie e long-distance entanglement between quantum memories. A promising architecture for the e quantum repeater nodes relies on pairing the spontaneous generation of photon pairs, a process known as spontaneous down-conversion (SPDC), with an external quantum memor . This is the approach that researchers at ICFO have taken. In the study published inOptica Quantum, **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 fibre**.

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 tw fibres which 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 50km, 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 kms in a fiber optic cable even in a metropolitan area. So, 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 into 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 straight line.

There, they installed a telecom detector to measure the arrival of photons which came through one of the fibres, while the other fibre 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** and a new laboratory is available a the Collserola tower within the context of the QNetworks and EuroQCI Spain projects, for th realization of an entangled state of remote quantum memories. The realization of a lon distance backbone for entanglement distribution between quantum memories is also one o the main goals of the Quantum Internet Alliance (QIA), the leading European effort in th realization of the quantum internet of which ICFO is a main partner

The results of this study**ï¿½namely the transmission of light-matter entanglement over fibe s 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 coreï¿½**as Samuele Grandi comments, researcher at ICFO and co-first author of the study.

As ICREA Prof. at ICFO Hugues de Riedmatten concludes ï¿½**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 networksï¿½.**

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Reference: Transmission of Light-Matter Entanglement over a Metropolitan Network, Jelena V. Rakonjac, Samuele Grandi, Soren Wengerowsky, Dario Lago-Rivera, Felicien Appas, and Hugues de Riedmatten, Optica Quantum **1**, 94-102 (2023).

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