PRESS RELEASE

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Quantum Communication with Zero-loss

Novel protocols that allow zero-loss transmission of information in quantum networks are being developed by scientists at Max Planck Institute of Quantum Optics

Quantum networks are composed of nodes which can transmit and receive quantum states by exchanging photons. Such networks can be used, for example, to send secret messages in a secure way, and to communicate more efficiently than in classical networks. Here it is important to achieve quantum communication between any of the nodes within the network. As reported by Prof. Ignacio Cirac, Director at Max Planck Institute of Quantum Optics (Garching, near Munich), Antonio Acín (ICFO-Institut de Ciencies Fotoniques, Spanien) und Maciej Lewenstein (ICREA-Institució Catalana de Recerca i Estudis Avançats, Spanien) (Nature Physics, advance online publication, February 25, 2007), the efficiency of a quantum protocol is highly dependent on how the nodes are displaced and how they are entangled with one another. Phenomena only afforded by quantum systems can be employed to design protocols that ensure zero-loss transmission of information between any two nodes even in networks of infinite extent.

One of the concerns of classical information theory is to find the optimum way for transmitting information between any two nodes (a kind of switch that is distributing the information) in a network. Here there are two main points to be observed: first, which and how many nodes have to be connected with one another (it would be too expensive to link all of them) in order to guarantee transmission; second, by how many and by which ways the message is sent in order to ensure complete transmission, because not all channels are perfect (i.e. there is noise).The rules selected for a certain network are fixed in a so called protocol.

Similar questions are entailed in designing quantum networks, in which the nodes are represented by quantum systems. Here, transmitting quantum information from node A to node B (this process being termed teleportation) requires that the two nodes are entangled with one another. (The entanglement of two quantum systems means that their properties are perfectly correlated and hence mutually dependent.) Just as in classical information theory, when the protocols are designed in accordance with the configuration of the nodes, quantum information theory is also concerned with finding the optimum protocol for special configurations of quantum networks in order to transmit information over long distances with zero loss (even in the limiting case of quantum networks of infinite extent).

A quantum network is an ensemble of nodes between which, with a certain probability, is a connection, i.e. they exhibit a certain degree of entanglement. It is therefore necessary to create efficient protocols that maximise the probability of achieving maximum entanglement between any of the nodes. The protocols developed bv Cirac and coworkers resort to the concepts of classical information theory (percolation theory), but they substantially enhance their efficiency by enlisting and utilising quantum phenomena.

One such example is applying repeaters in classical networks to prevent the exponential decay of the signal with the number of nodes. There is no direct analogue to this in quantum information theory.

But quantum mechanics affords much more possibilities of manipulating the nodes, - i.e. the quantum bits - in order to obtain the information completely.

The fundamental difference to classical systems is that in a quantum network it is no longer necessary to consider the channels and nodes separately. Rather one regards the network as a single quantum state shared by the nodes and then optimises no longer the entanglement of any two nodes but the global entanglement distribution.

It is also possible under these conditions, as Cirac et al. show, for different protocols to lead to very different probabilities of achieving maximum entanglement between different nodes. For some special cases (one- and two-dimensional networks with special regular geometry), however, the scientists obtain protocols that are distinctly superior to classical percolation protocols. For the case of a one-dimensional chain the optimum protocol was found: even under conditions where the signal would decay exponentially in a classic system, it is possible to achieve zero-loss transmission of quantum information. (Quantum repeaters may thus be regarded as simple quantum networks allowing quantum communication over long distances).

The calculations show that the system passes through a kind of phase transition with respect to the degree of entanglement: below a certain threshold value for the degree of entanglement the percolation, i.e. transmission from A to B, is zero; above this value the percolation assumes a certain fixed value that is now independent of the distance between the nodes,

The entanglement distribution in a quantum network thus defines a frame work in which statistical methods and concepts such as classical percolation theory quite naturally find application. This leads to a new kind of phenomenon, viz. an entanglement phase transition. There is a “critical” minimum entanglement necessary to establish a perfect quantum channel over long distances. By investigating such entanglement and percolation strategies further scientists hope to achieve protocols that ensure zero-loss transmission of information even in quantum networks that are more sophisticated. [O. M.]

Original work:

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