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Looking at the Quantum Internet

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Abstract

The future of the Internet and of computer communication goes through modern physics. Using the new properties of quantum mechanics, various research laboratories around the world are building prototypes of "quantum networks," a new way that uses some quantum physics principles to deliver information packets. Thanks to the quantum network, in the near future our data will be able to travel on the Internet at very high speed, also greater than the speed of light. Independent research groups have already been able to demonstrate the entanglement of photons on fiber optic networks in China and Canada. The result can be considered as the first step towards the realization of quantum telematic networks on a metropolitan scale and the connection at large distances of future computers based on quantum physics. But the quantum computer will be such a powerful system that can even damage the security of our systems and networks as we know them today, as well as to personal privacy, already threatened by current network rules.

Key words: Internet, Quantum Physics, Quantum Network, Teleportation, Entanglement, Quantum Information, Security, Education.

Introduction

The quantum network develops the current classical network utilizing the principles of quantum communication and computation. Quantum data are basically composed of photons (*britannica.com*, 2017) that, by exploiting quantum properties, are able to convey the information on a particular quantum state of a system.

The basis of communication in a quantum network is referred to as 'qubits' (quantum bits), the quantum analogue of the classical 'bits'. Qubits are the elementary information blocks that have a much greater versatility than the bits of a classical computer network. Classic bits can only assume a definite value: 0 or 1 (on - off, open - closed, white - black, etc.), while qubits are characterised by the ability to assume superposed values of the two extremes. For example, a qubit can be 0 or 1, but also 10% of 0 and 90% of 1, 20% of 0 and 80% of 1, and so on. In the first case of the example, this means that when we measure the value of a qubit, we have 10% of probability that it is 0 and 90% of probability that it is 1.

Then the great advantage lies in the fact that quantum computers are able to 'simultaneously' process all classic results, thus making the calculation exponentially faster than its conventional counterpart. Data is transmitted using the physical characteristics of atoms for which it is possible to identify two well distinct electronic excitation states, the equivalent of the 0 and 1 values of classical computation. When these atoms are stimulated, for example through a laser, they release a photon that conveys the information, in the form of energy bound to a particular quantum state, and transmit it to another atom as soon as it affects the latter, reproducing the quantum state of the original atom.

For a better understanding of the rest of paper, we shall briefly summarize some important features of quantum reality:

a) *the collapse of the wavefunction*: in quantum mechanics a wavefunction, initially in a superposition of several possibilities, 'collapses' after an observation and then appears to be reduced to a single state. The collapse is one of the two processes by which quantum systems evolve in time; the other one is the evolution of the system through the Schrödinger equation;
b) *non-locality*: it is referred to the '"action at a distance"; an object is "interested without being physically in mechanical contact with another object." We have a non-local interaction between objects that are spatially separated;
c) *non-separability*: an experience occurred in the past between two subatomic particles creates between them a kind of 'connection'; the behaviour of one instantaneously affects the other, regardless of the distance that separates them. The "instant communication" is connected with the technical term "quantum entanglement" and is considered one of the greatest mysteries of the human knowledge;
d) *entanglement*: it is a physical phenomenon that occurs when pairs (or groups) of particles are generated or interact in such a way that the quantum state of each of them can not be described independently from the other one, even when the particles are separated by an extremely large distance;
e) *teleportation*: it is the process of instantaneous transport of matter through the space from place to place at speeds equal to or greater than the speed of light. It is one of the major research subjects among physicists around the world who work in the field of quantum mechanics (Di Sia, 2017).

Experiments

As happened for the Internet, the first quantum network prototypes have been made by the government agency of the US Department of Defense in charge of the development of new technologies for military use "DARPA" (*darpa.mil*, 2017). Currently also other research institutes and university institutions are making similar prototypes. Realising a reversible information exchange, it has been shown that it is possible to exploit the entanglement for medium distance information transmission. This phenomenon confirms the possibility of creating an entire quantum Internet.

Two atoms are connected using an optic fiber cable on which the photons are transported to carry the information. Whenever one of the two atoms is solicited with a laser light, it emits a photon that can carry its qubit of information. The polarisation state of the atom is 'trapped' and transported by the photon to the other atom without any variation; the second atom, hit by the photon, assumes the same polarisation as the first one, thus receiving the sent qubit of information (Ritter, et al., 2012). As source of photons we have a chip with a component that allows the passage of the current through semiconductor materials to which micro-inclusions of other semiconductor materials (quantum dots) are added, and photon emission is obtained by excitation of the material molecules.

Two independent research groups have been able for the first time to demonstrate the photon entanglement on optic fiber networks in Hefei, China, and Calgary, Canada. The result can be considered as the first step for the realisation of quantum telematic networks on a metropolitan scale with large distance connection for future computer based on quanta (Yao, et al., 2012; Valivarthi, et al., 2016; Northup, & Blatt, 2014; Stute, et al., 2013).

The communication between entangled quantum states has been shown in the last few decades for many particles, atoms and even for photons. In addition to providing the basis for quantum communication networks, this technology could be integrated almost naturally with that of quantum computers. According to the analysis of the IT sector, conventional computers may be getting closer to the limits of their development; the miniaturisation of the microchips, on which the growth of computing power for many decades has been based, has now reached the physical limits of the micro-world. Nanotechnology is helping a lot in this way, but even in this case there are size limits that will cause big problems (Di Sia, 2014; Di Sia, 2015).

Superfast quantum network and unthinkable calculation potential

The ambitious goal is to convey information at the speed of light by exploiting the particular laws of quantum mechanics; photons, the light particles, travel at the highest speed currently known on the Earth. All information about the quantum state of an atom are 'written' on photons; the optic fiber drives the light particles in the specific direction.

Quantum teleportation has been for years at the center of major research interests because it could have huge implications on many problems of national security such as banking, military and citizens privacy. The system allows the sending of encrypted messages that are impossible to decipher, and in the future could put in communication the quantum computers. The first applications are in the military and financial communication world, but in a few years it could change the entire Internet network. History is not new in giving surprises; nothing was known about the first web communications made at the European Organization for Nuclear Research, commonly known as CERN in Geneva, then the Internet changed the world.

Traditional computers are demonstrating their limits in terms of power and computing, highlighting an increasing inadequacy to perform some tasks. IT giants such as Google, Intel, IBM and Microsoft are investing huge resources (billions of dollars) in the development of quantum technologies. Quantum computing allows the overcoming of the physical and structural limits of existing systems; the expectations of this new technology are important, even though it is difficult to predict its real computer applications.

D-Wave Systems aim to propose its quantum computing service through cloud services (*dwavesys.com*, 2017); IBM is launching its "Q program" (*ibm.com*, 2017), which would provide paid quantum computing services, public cloud platforms, for applications in areas such as material science, quantum dynamics, financial and economic modelling.

Also in relation to computational optimisation, a central function in many activities, the related problems are difficult to solve with traditional computers, because the analysis of a large number of possible solutions is required (for example the quality of results offered by online search engines and of Internet-sponsored products). Quantum algorithms will also dramatically improve medical diagnoses and advance artificial intelligence, molecular engineering, nanotechnologies, material science, astronomy, finance, logistics, and cyber-security.

Use of teleportation

One of the main objectives will be the ability to send quantum signals not only through photons, but also by 'teleportation', without having to go through optic fibers; information disappears on one side and re-appears on the other one. In essence, the information does not move from the sender to the receiver, but disappears near the sender to re-appear instantaneously near the receiver.

At present, these applications are still science fiction, but there are more and more scientists working on them. It could thus break the 'speed of light limit', opening a new era of communications, with unimaginable consequences.

Quantum teleportation could be the future of the internet. For example, in the field of mobile phone, it should arrive in around 2020 the 5G (wikipedia.org, 2017), the fifth generation technology. It will deliver better performance and speeds than the current 4G / IMT-Advanced technology. But in the case of optic fiber information transported by photons, or with teleportation, the performance would be far beyond.

Security and dangers: problems to deal with

Given its extraordinary potential, quantum calculation will be powerful enough to allow any confidential information to be encrypted. At present, the encryption of sensitive data is done with the help of keys, the reliability of which is based on the difficulty in factorising them. Current computers would take centuries before finding a solution that will take a few seconds for a quantum computer.

This new technology will be able to break the full current cryptographic infrastructure, with retroactive effect to encrypted information in the past years. The day the quantum computer becomes reality, this ocean of information (private and secret) will be readable as an open book.

On the one hand, therefore, any possible future quantum Internet may be very safe, as the information can not be intercepted in any way. However, the contrary may also happen, if the system will be managed by bad organizations, secret agencies or unreliable governments.

Even the impact on younger generations, so involved in the Internet phenomenon and so sensitive to extreme situations, could lead to unforeseeable consequences if not correctly and properly managed (Di Sia, 2016).

Conclusions

The quantum network is one of the major challenges of modern physics. The so far achieved results demonstrate the possibility of integrating existing telematic networks with the potential offered by the laws of quantum mechanics.

If the quantum Internet will be realized in the near future, it could be complementary to the current Internet, as it is much more expensive and complex to realise and, therefore, perhaps not convenient to use for the most extensive online activities.

The quantum computer will be such a powerful system that can be even damaging to the security of our systems and networks and for younger generations, if not adequately controlled.

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