Quantum communication__Quantum memory

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***Abstract*— …**

***Keywords*— …**

I. FASTER?!

Factoring a number into its prime roots is one of the hardest mathematical computation inquiries. The truth is that our security is actually based on the amount of effort, time and energy we spend to solve a NP problem. RSA cryptosystem which is now widely applied for asymmetric encryption is based on the factoring problem.

$$e.d \overset{\varphi(n)}{\equiv} 1$$
$$\varphi(n) = (p-1).(q-1).$$

Here the calculation of "d" without knowing {p, q} requires great deal of time which makes RSA algorithm secure.

Quantum computers can solve factoring problems much faster than any advanced kinds of classical computers.

Quantum computers are not genuinely faster than classical computers, but for problems such as factoring, they may be faster.

We describe Qubits (quantum bits) using quantum state

$$|\varphi> = \cos\frac{\theta}{2}\ |0> \ + e^{i\Phi}\ \sin\frac{\theta}{2}\ |1>$$

So as you can see for describing a qubit (for example here for Bloch sphere representation we need two numbers), which means by having "n" particles we can store 2^n numbers. So what are we waiting for?

The real problem arises in the level of measurement. Measurement seems quite a straightforward concept in classical mechanics but in quantum mechanics measurement is a little bit tricky.

When measuring a quantum state, it evolves into a new post-measurement state which is:

$$\rho' = \frac{1}{P(a_k)}\ P_{a_k}\ \rho\ P_{a_k}$$

It turns out that using quantum computers with parallel algorithm would bring just one of all solutions with specific probabilities and the system would collapse to a state relating to that specific solution.

So far, it turns out that applying quantum methods can reduce the increase rate of difficulty from exponential growth into polynomial growth.

Yet frankly even a quantum computer can solve some NP Problems such as factoring and P problems (which can be solved efficiently by a classical computer). hence a large group of NP problems and NP complete problems need an exponential time to be solved even by a quantum processor.

II. MORE SECURE!

Security is in the nature of a Qubit as if you can measure a Qubit only once due to the fact that every quantum state collapse into its post measurement state after being measured.

The first Quantum communication protocol, QKD, was based on a shared key which lead to low efficiency. But QSDC & DSQC protocols which were proposed in the year 2000-2003 in contrary to QKD didn't demand for any shared key.

QSDC (Quantum Secure Direct Communication) and DSQC (Deterministic Secure Quantum Communication) are averagely divided into two different group first those based on entanglement and second those based on single photon.

DSQC protocol doesn't require a shared key instead it is based on choosing a photon from some random photons which has been sent to you from the sender. You can send your encoded secret message plus other checking messages to the sender. After publishing of the checking message property sender can check whether the backward channel is safe or not.

Quantum Communication over Long Distances

I. Quantum Memory:

Long distance quantum communication is dramatically attached to quantum storage problem.

When we think of classical computers we think of connecting blocks each functioning an important role for instance control unit, CPU, etc. one of the most important part of each classical computer is memory. In the matter of information processing having a memory is essential as well as in Quantum information processing.

In the field of Quantum information there are two different kinds of QMs. First the photonic Quantum memory and the solid-state Quantum memory.

Photonic Quantum memory: In photonic Quantum memory we are dealing with atoms and electrons. The interaction between light and matter focuses on transition between different quantum state.

Solid-state Quantum memory: solid-state quantum memory as it is clear by its name utilize matters with crystal or lattice structure. For example, graphite can be used as symmetric lattices.

Because of superposition property of a qubit, every qubit has a potential of two outcomes thus we can process more information than the total number of particles existing in the whole universe! Miracle isn't it?!

But the bitter truth is quantum mechanics is not as simple as you might think. As discussed earlier measuring a system would change the system state from a superposition state into a post measurement state.

II. Electromagnetically induced transparency:

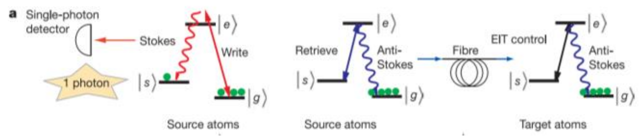
When we are talking about quantum memory it means on demand storage. The storage time is usually in the order of μs but for atomic ensemble this time can be in the order of ms.

For each quantum memory design, we need both protocol and the medium. one of the protocols for QM implementation is EIT method which is short for electromagnetically induced transparency.

From quantum networks to quantum repeaters or any other applications, the ability to control photonic signals throw atomic ensembles is so crucial in this major.

Let me set the scene for you, imagine there exist a "source ensemble" and you want to stimulate a photonic signal and consecutively propagate it throw other ensembles called "target ensemble" and finally store it in one specific one.

Picture from Ref [.]



By using an initial signal, "write signal" you can force atoms to move from the state |g>, their initial state which is the so called ground state, into the state |e>, the excited state. After that due to Raman scattering atoms start to moderately go to state |s> and thereby producing "stokes". You can detect them using a photonic detector.

Here comes the important part which is "retrieve" signal. But before that I'd like to talk about optical pumping.

❖ Optical Pumping

Consider the same scenario but not just for one excited atom. instead of having a retrieve signal now you have a pumping signal which continuously pump atoms from the state |s> to the state |e> so after a while the signal would be transparent because there is no atom left to absorb the light. This was a very abstract explanation of optical pumping according to my understanding.

Let's get back to where we left after applying the retrieve signal now the excited atom in the |e> state will go back to its initial state which was |g> and as a result the anti-stoke signal will be generated. Before taking care of the rest lets evaluate the system so far.

We can control the anti-stoke light properties by changing the retrieve laser. We can tune the frequency, direction and intensity of the retrieve laser.

In calculating the efficiency, we have to consider background noise. These unwanted quest made the detection of a signal photon so much harder which means more than one atomic excitation would be needed.

By increasing the power of EIT control signal, the bandwidth will increase and instead of having a small transparency window, there will be two separate line with much larger bandwidth.

III. Autler-Townes splitting:

In this method reversible transfer between the photonic and spin components of the system is mediated by the evolution of the polarization.
As signal is propagating throw medium it is totally or partially absorbed by the ATS peaks and the coherence which was carried by the incident signal map onto spin excitation.
Here one has to pay attention that carrying the coherence means that the coherence of the system should be conserved throw the process due to the fact that the information of the system is rely on the total correlation in the system.
The EIT and Raman schemes rely on the adiabatic elimination of the atomic polarization on the other hand the ATS schemes relies on the excitation of the atomic polarization.

IV. Photon echo Quantum memory:

Quantum communication which based on direct transmission of entanglement is limited to 100km distances.
Quantum memories can store entanglement, or purified entanglement in one segment until pure entanglement has also been established in the adjacent sections.

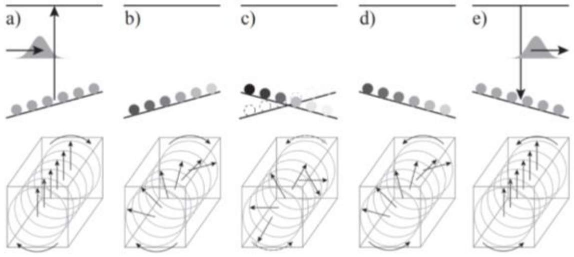
storage time: affects the maximum transmission distance

efficiency: determines the rate with which entangled states can be generated over long distances

high fidelity: essential for preserving the initial entanglement of the qubit with another qubit

photon echo memory is a system which controls the material in a way to transmit the exact photon as it absorbs. Its emitters have wide range of frequencies hence when the light will be absorbed it would force emitters to align with its field. Due to their frequency, when emitters want to come back to their same phase gap, they would create the same photon.

Photo from Ref []



Explanation of some terms

"**Homogeneous broadening** affects every individual molecule in the ensemble in the same way. If you could take a spectrum of just one molecule (which can be done in some situations) the transition would still have the same width.

Inhomogeneous broadening results from different molecules having slightly different resonant frequencies because they are in slightly different local environments within the liquid or solid.

Broadening:
Broadening in laser physics is a physical phenomenon that effects the spectroscopic line shape of the laser emission profile.

Time-bin encoding:
Time-bin encoding is a technique used in Quantum information science to encode a Qubit of information on a photon. Quantum information science makes use of Qubits as a basic resource to bit in classical computing.

Stark effect:
The Stark effect is the shifting & splitting of spectral lines of atoms and molecules due to the presence of an external electric field. It is the electric field analogue of the Zeeman effect, where a spectral line is split into several components due to the presence of the magnetic field. Although initially coined for the static case, it is also used in the wider context to describe the effect of time-dependent electric field.

Spatial coherence:
Spatial coherence is a strong correlation between the values of electric field at different points in the beam profile.

Temporal coherence:
Temporal coherence, by contrast, is a correlation between the electric field values at a single point, but at different time intervals.

Optical depth:
In physics, optical depth or optical thickness is the natural logarithm of the ratio of incident to transmitted radiant power through a material.

V. AFC

The future of quantum network requires encoding quantum states into photons, transmitting them over networks' nodes and also being able to store quantum states in any node. Quantum information science has so many applications including:

1) Computational power
2) Key sharing
3) Precision in measurement

After measuring quantum state, we gain information in terms of density matrices. We can earn information about crucial properties such as:
AFC:
Which is short for atomic frequency comb. A frequency comb is a periodic spectrum which its frequency lines are placed according to this formula:
$f_n = f_0 + n f_r$
Another application for frequency comb is synchronization of atomic clocks.

III. CONCLUSION

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