

Quantum Internet

Back before Aug. 6, 1991

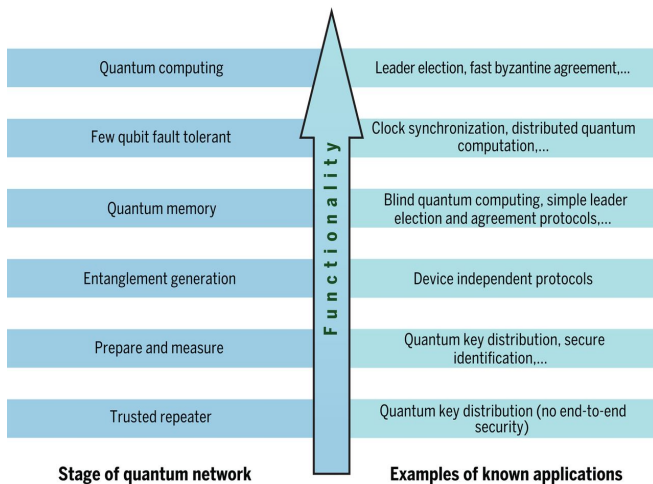
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Outline

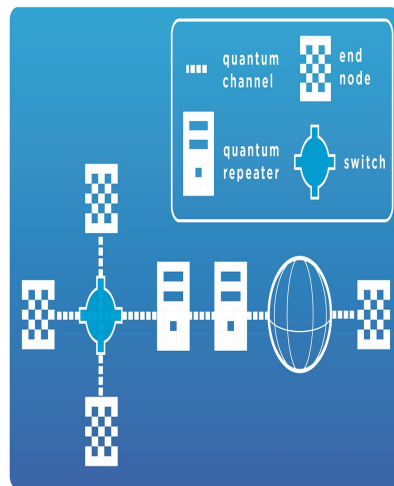
- 1 Why Quantum Internet?
- 2 Cavity QED: Quick and Dirty
- 3 Application: Single-Photon Generation on Demand and Reverse
- 4 DLCZ protocol
- 5 To the general case
- 6 Quantum Repeater
- 7 Conclusion: Challenges and Outlooks

Applications: broadly speaking [1]



Components:

- Quantum Node
- Quantum Channel
- Quantum Repeater (WiFi Extender)
- Switch



Advantage of Quantum Channel [2]

- Quantum Channel provides exponential increase in computational dimension
- $k2^n$ to 2^{kn} when we connect k n -bit quantum nodes
- Help to alleviate scaling and error-correlation problem
- Simulation of evolution of quantum many-body system
- "Spin-Spin" interaction of atoms simulated by quantum channel
- Help to solve the problem of percolation
- I.e can the liquid flow from the top of a cube to the bottom. When the cube has a cheese (Tom and Jerry type of cheese)like internal structure but some of the paths are blocked with probability p .¹

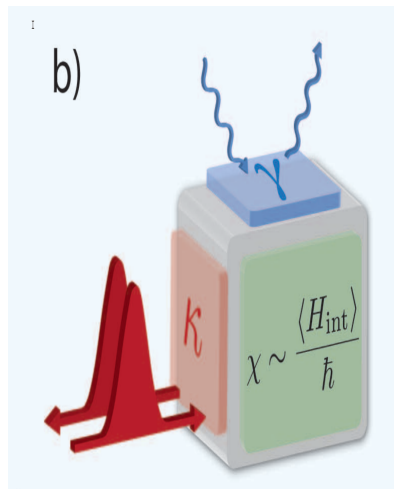
¹Percolation Theory from Wikipedia

Focus of this presentation: Quantum Channel

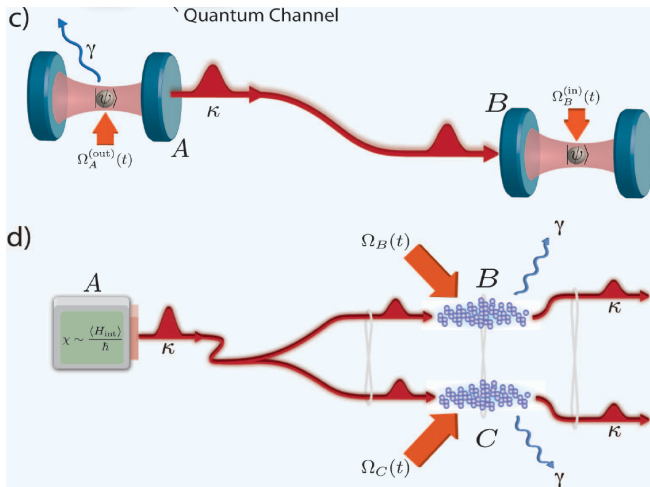
- Coupling of single photons and atoms w/ help of cavity QED
- Difficulty arises b/c photon-photon interaction cross-sections are tiny, i.e very unlikely to occur
- Quantum Information processing with atomic ensemble

Requirements for Physical Realization [2]

- Interaction between light and matter should be easily tunable
- Done through an interaction Hamiltonian $\langle H_{int}(t) \rangle \approx \hbar \chi(t)$
- Physical processes that controls (t) need to be robust in the face of **imperfections**?
- Mistakes can be efficiently detected and fixed
- Mathematically : $\chi \gg \kappa \gg \gamma$



Realization Examples [2]

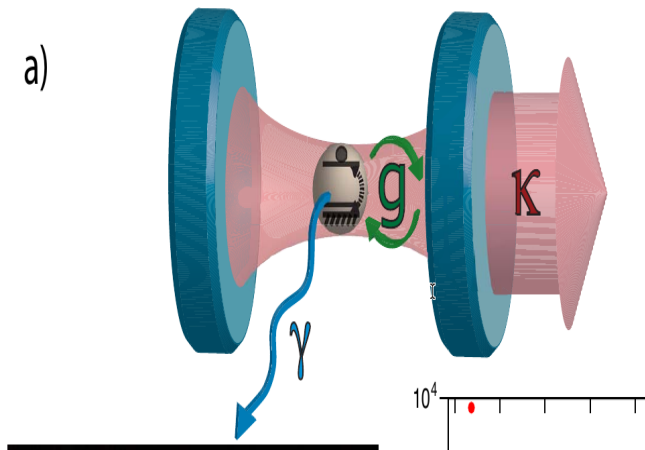


Terms ²[2]

- V_m : mode volume, approximately the volume of resonator, defines spatial confinement. **Debated definition**
- Quality factor: roughly defines how long the light lives in the cavity
- $\vec{\epsilon}$: polarization vector
- $\vec{\mu}_0$: transition dipole moment, how strong does the atom feel a EM wave with certain polarization
- $g = \sqrt{\frac{|\vec{\epsilon} \cdot \vec{\mu}_0|^2 \omega_C}{2\hbar\epsilon_0 V_m}}$
- γ : atomic decay rate to modes other than the cavity mode
- κ : decay rate of cavity mode
- $n_0 \approx \gamma^2/g^2$: photons required to saturate the intracavity atom
- $N_0 \approx \kappa\gamma/g^2$: number of atoms required to have appreciable effect on intracavity field

²Mode Volume and Quality Factor

Illustration

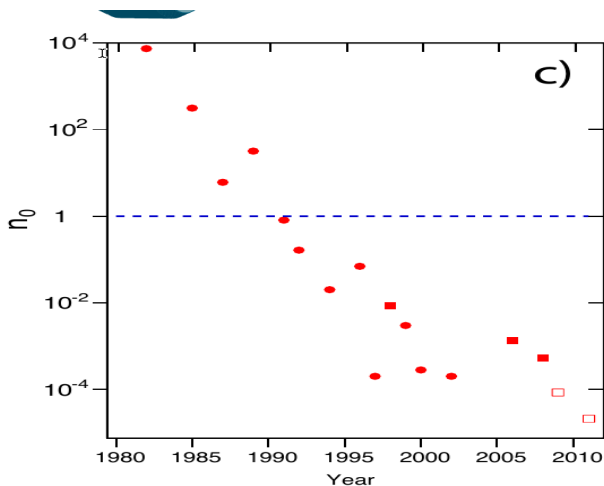


Strong Coupling regime [2]

- Require $(N_0, n_0) \ll 1$
- Could achieve in microwave domain with a Rydberg atom and a high Q superconducting cavity
- In optical domain: use high-finesse optical resonator and atomic transition with large $\vec{\mu}_0^3$
- Better confinement of atom will also help, it reduces V_m

³Finesse

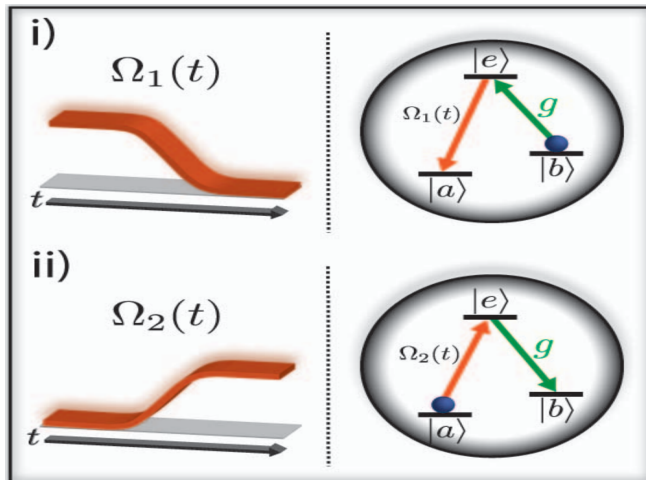
Progress



How we send bits classically

- OK, it's a diagraph, watch yourself if interested
- Video, watch it!

Illustration

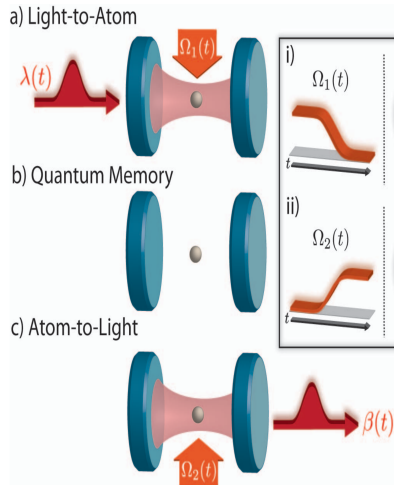


How we do it

- Mathematically $|a\rangle |0\rangle \leftrightarrow |b\rangle |1\rangle$
- Notation is $|\psi_{atom}\rangle |\phi_{Fock}\rangle$
- Dark State $|D\rangle = \cos\theta |a\rangle |0\rangle + \sin\theta |b\rangle |1\rangle$
- $\cos\theta = [1 + \frac{\Omega(t)^2}{g^2}]^{-1/2}$
- Need to modify $\Omega(t)$ adiabatically for **coherent absorption and creation of photon?**
- Intermediate transition $|b\rangle \rightarrow |e\rangle$ strongly coupled to a mode of optical cavity of energy $\hbar g$

Importance

- Could serve as Quantum Memory
- Optical field as a superposition of 0 and 1 Fock state sent through fiber
- Use the control field $\Omega(t)$ to store the superposition information into atoms



Extend to have entanglement [2]

- Allow the control field to have different polarization over time
- May entangle the state of atom with the polarization state of a flying photon call it p_1
- p_1 is not emitted by the atom, you are just entangling it with the atom, could have came from the emission process of another atom, thus having the state info of that atom.
- Apply another control field to disentangle the atom with p_1 and emit another photon p_2 which is in turn entangled with p_1
- No pics :(, the source file does not allow access, fuck

- Your Input needed

- Ben and Chase plz help

References I



Stephanie Wehner, David Elkouss, and Ronald Hanson.
Quantum internet: A vision for the road ahead.
Science (80-.), 362(6412), 2018.



H. J. Kimble.
The quantum internet.
Nature, 453(7198):1023–1030, 2008.