Quantum Information Technology:
Entanglement, Teleportation and Quantum Memory

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Applications of Entanglement

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Accomplishments

- Developed cavity and atom loading techniques for quantum internet (with S. Shahriar, J. Shapiro.)
- Developed techniques for quantum positioning and clock synchronization (with V. Giovannetti, L. Maccone.)
- Developed techniques for cryptographic ranging (with V. Giovannetti, L. Maccone.)
- Developed dispersion cancellation techniques for clock synchronization (with V. Giovannetti, L. Maccone, N.C. Wong.)
- Showed impossibility of clock synchronization using degenerate entanglement (with V. Giovannetti, L. Maccone.)
- Developed techniques for enhancing quantum channel capacity via entanglement.
- Showed how entanglement allows one to attain the ‘quantum speed limit’ (with V. Giovannetti, L. Maccone.)

Quantum speed limits and entanglement-enhanced channel capacity

Summary of existing results on quantum speed limits.

Heisenberg quantum speed limit:

$$\Delta t_H \geq \pi\hbar/2\Delta E$$

Margolus-Levitin quantum speed limit:

$$\Delta t_H \geq \pi\hbar/2E$$

Combined quantum speed limit:

$$\Delta t \geq \mathrm{Max}(\pi\hbar/2\Delta E, \pi\hbar/2E)$$

N unentangled systems

$$E_N = NE$$

$$\Delta E_N = \sqrt{\Delta^2 E_1 + \Delta^2 E_N} \approx \sqrt{N} \Delta E$$

So unentangled systems fall short of the quantum speed limit unless all the energy is concentrated in a single subsystem.

Why entanglement helps:

Entanglement states have $\Delta E_N = E_N = NE$

Example: entangled states for quantum positioning.

$$|\psi\rangle = \int \psi(\omega) |\omega\rangle_1 \ldots |\omega\rangle_N .$$

Use of entangling dynamics to enhance channel capacity

A single broadband channel has capacity $\approx \sqrt{P/\hbar}$

Where $P = E/t$ is the channel power.

As a result, N unentangled channels have capacity $\approx N\sqrt{P/N\hbar} = \sqrt{N}\sqrt{P/\hbar}.$

By contrast, if an entangling dynamics is allowed for the channels, they have a capacity

$$\approx N\sqrt{P/\hbar}.$$

- By comparison, super-dense coding gives a factor of two enhancement, but only with pre-existing entanglement.
- The Kholevo-Schumacher-Westmoreland theorem suggests that enhanced capacity cannot be obtained without entangling dynamics.
- Entangling channels require N-mode nonlinearities and are likely to be difficult to realize.

Future Directions

- Developing protocols for quantum cryptography (with J. Shapiro, A. Smith.)
- Investigating quantum internet protocols (QTCPIP, etc.)