SeQUeNCE – Simulator of Quantum Network Communication

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QUANTUM NETWORK APPLICATIONS: DISTRIBUTED COMPUTATION

- Connecting small quantum processors allows solving larger problems:

- Distributed computing possible with exponentially less communication:

  Promise: Hamming distance $n/2$ or 0
TELEPORTATION NETWORK APPLICATIONS

- Connected quantum sensors, accurate clock synchronization, secure delegated Quantum computing
- Bandwidth, latency and security requirements vary
- These applications require long-distance communication
- Multiple repeaters and entanglement generators are used
QUANTUM TELEPORTATION AT CQE

Optical table demonstrating the principles of quantum teleportation in the Awschalom Lab (University of Chicago and Argonne)

Quantum teleportation allows transmission of quantum states between two network hosts (Argonne and Fermilab)

P11.00008 : Characterization of epitaxially grown Er doped Y2O3 for quantum optics applications
ENTANGLEMENT SWAPPING

- Distribution of entangled photons only between NN
- Stored in QR memories until they are consumed
- Optional purification techniques to improve quality
- ES used to obtain long-distance entanglement
- Achieved by BBM on the appropriate pairs of photons
- Communicating measured Pauli Frame to the end hosts

1. Entanglement generation:

2. Bell basis measurement:

3. Pauli Frame determination:
MULTI-NODE QUANTUM NETWORK ARCHITECTURE

- Reconfigurable quantum nodes
  - Memory, photon pair source, BSM unit
- Coherent quantum materials and photonics
  - Long coherence memory, classical control of photon
- Control plane determines role and action of nodes
CONTROL PLANE

- Quantum nodes integrate with control plane via FPGA & fast I/O
- Layered control plane stack – lowest layer controls hardware, highest layer provides service to applications
- Routing – identify route, perform entanglement swapping, communicate Pauli frame
- SeQUeNCe will be used to verify the correctness of the control protocol implementation
SIMULATOR OF QUANTUM NETWORK COMMUNICATION (SeQUeNCe)

- Modularized discrete event simulator with a scheduler
- Simulates quantum communication at photon-level
- Other simulators:
  1. A. Dahlberg & S. Wehner, SimulaQron—a simulator for developing quantum internet software
  3. B. Bartlett, "A distributed simulation framework for quantum networks and channels"
DISCRETE EVENT SIMULATION OF TELEPORTATION

- DES models the operation of a system as a discrete sequence of events in time
- Simulation jump in time from one event to next
- Events generated upon a request or at the end of a certain activity
- Event is associated with a time and a function to invoke
SAMPLE QUANTUM NETWORK TOPOLOGY
**TOPOLOGY REPRESENTATION**

**End-host snippet:**
- Only have one neighbor
- Properties of quantum and classical channel
- Number of quantum memories

**Repeater snippet:**
- It have 2 neighbors
- Properties of quantum and classical channels
- Number of quantum memories is a multiple of number of quantum links
SUMMARY

- Majority of prior work focuses on point-to-point quantum communication
- CQE aiming to experimentally realize a multi-node network architecture
- Systematic design that leverages experience from traditional networking
- Classical control software to enable rapid experimental progress
- Discrete event simulator to verify scalability, performance of the network
- Quantum networks rely on early generation hardware components
- SeQUeN Ce to quantify benefits, understand value of improvements
- SeQUeN Ce to verify correctness, understand security of network designs
THANKS… QUESTIONS?