The QEYSSat Mission: Demonstrating Global Quantum Key Distribution Using a Microsatellite

26th Annual Small Satellites
August 13-16, 2012

I. D’Souza, D. Hudson, C. Evans, E. Choi – COM DEV Ltd.
T. Jennewein – Institute for Quantum Computing, University of Waterloo
K. Sarda – Space Flight Laboratory, University of Toronto
QEYSSat: Quantum EncrYption and Science Satellite

- Used to create a quantum link to space
  - individual polarized photons sent from ground to microsatellite
- Demonstrate global quantum key distribution
- Provide platform for long distance entanglement science

- Characterize & optimize the quantum link
- Demonstrate satellite re-keying
- Allow testing of multiple quantum source types
  - single photons / faint laser pulses
  - entangled photons (quantum correlations)
Quantum Satellite Proposal

- **Studies Performed to date:**
  - 2010 Governmental Institution Study on QKD downlink approach.
  - 2010-2011 CSA Study: mission using uplink allows global QKD and science
  - CSA support for advancing the Technical Readiness Levels
  - CSA project for development of key technologies (pointing/tracking)
  - Can be built with all-Canadian industrial partnerships
  - Launch in 3 to 5 years feasible

- **CSA Contractor, COM DEV Mission Lead, IQC Principal Investigator (Thomas Jennewein)**
What is Quantum Key Distribution (QKD) ?

- Closes the security loophole of encryption key distribution
  - Security rests on the laws of nature (Uncertainty Principle)
- Key is encoded in quantum states (polarizations of single photons) sent from Alice to Bob
- Eavesdropping impacts quantum state
  - Estimation of bit errors indicates security
  - Security of key is quantifiable
- Secure key does not exist prior to transmission and processing of quantum signal
  - Only known by Alice and Bob

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Basis Bit</th>
<th>Polarization Bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>→</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>↑</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>↓</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>←</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Why Go to Space?

- Maximum quantum link on ground cannot surpass 300 km to 400 km with optical photons
  - Quantum memory & quantum repeaters under development but not expected for perhaps decades
- Quantum Key Distribution (QKD)
  - Distance limits for secure key generation (path length)
  - Provide global coverage for encryption key users
- Fundamental Tests of Quantum Mechanics - Entanglement
  - Distance limits for Bell test (separation of two detectors)
  - Relative speed of entangled photons (effects of relativity)
  - Effect of gravity gradient on entanglement
Key Distribution Concept

- The satellite generates one secure key with Station A, then a second secure key with Station B.
- Unsecure information about the combination of the two keys, allows one station to determine the key of the other:
  - Bitwise comparison of two keys calculated \((D = \text{XOR}(A,B))\)
  - \(D\) transmitted to one station (e.g., Station B) which calculates Key A \((A = \text{XOR}(D,B))\)
  - Stations A and B use Key A to encrypt their communication.
System Overview
Quantum Link Requirements

• Photon detection rate
  – Must provide key generation rate which demonstrates a useful operational system
  – Link budget defines receiver aperture size, detector sensitivity, and pointing alignment

• Polarization measurements
  – Polarization maintaining optics
  – Alignment of polarization reference frame between satellite and ground station

• Data logging
  – High speed recording of photon reception times
  – Clock alignment to correlate sent and received times

• Acquisition, Pointing, and Tracking
  – Receiver telescope must find and track the quantum source
  – Receiver and transmitter actively track a beacon target for fine pointing
Recent Work – Optical APT

- Payload fine pointing subsystem
- Selection of optimum design for pointing correction mechanism
- Demonstration of concept feasibility
  - Link budgets for beacon target
  - Impact of pointing mechanism on quantum signal
  - Integration of system in payload
Payload Accommodation on AIM Bus

- Secondary mirror extends outside nominal AIM envelope
- CoM in target range for launch requirement
- ADCS upgrades required
- Payload integrated and tested independently
- Volume available for small secondary payload
Conclusion

- Implementation of satellite-based QKD will provide encryption key distribution with unconditional security on a global scale
- A microsatellite mission to demonstrate long-range QKD is feasible with current technology and reasonable budgets
- The proposed QEYSSat mission would
  - Demonstrate the feasibility of space-based QKD and retire risk
  - Provide a platform for fundamental quantum physics experimentation
  - Provide data on the quantum link in order to optimize a future operational system