Quantum Information Science: The Way Ahead

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USAF QIS Strategy: Context

• Aspects of QIS are maturing beyond purely theoretical
  – Many engineering challenges remain
  – Still expect new concepts to emerge

• Known implications for USAF operational capabilities
  – Mid-term: timing and sensing
  – Far-term: computing, communications and networking

• AF S&T is informing and leveraging broader DoD, government, academic, industry and international efforts
Quantum-Enabled Air Force Capabilities

- Zero GPS Age of Data (aka error) with Entangled Clock Network with Quantum Repeaters
- Secure Encryption
- Tanker or Bomber
- Time Transfer - Complete Data Fusion Possible
- Carrier Strike Group
- Bunker/Tunnel Detection with Advanced Sensors
- Rapid Actionable Information with Quantum Computation of Data
- Long Duration Unaided Inertial Navigation
- Low Probability of Intercept Communications

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Quantum Capabilities for the AF
Quantum Information Science at AFRL

RD: Satellite-based Quantum Communication and Networking and Optical Channels (Gruneisen; NM)
RV: Position, Navigation, Timing (Metcalf, Olson, Robertson, Squires; NM)
RX: Diamond Color Centers, Materials, Supply Chain (Bissell, Eyink, Reed, Urbas; OH)
RY: Quantum emitters, Device fabrication (Lutwak, Bergfield, Usechack; OH)
AFOSR: 6.1 Basic Research funding in QIS (Metcalf; DC)
GPS precision in GPS-denied environments - Timing

Mid-Term Clock Objectives:
- Improved stability in static conditions
- Volume: 500 Liters

Long-Term Clock Objectives:
- Improved stability in dynamic conditions
- Volume: few Liters

Current Status:
- Stability: $10^{-9}$ sec/day (static conditions)
- Volume: 10 Liters

GPS timing updates – several times per day

Mid-term Concept

Long Term

High performance mobile clocks & networks distribute accurate timing

Fewer timing updates – mobile clocks hold time for weeks to a month

Chip-scale atomic clock

Space clock

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GPS precision in GPS-denied environments - Sensors

Current Status:
- 100's meters/hour
- Volume: 100 – 1,000 liters

Mid-Term Sensor Objectives:
- Reduced sensor noise
- Moderate volume

Long-Term Sensor Objectives:
- Quantum limited sensor noise
- Highly portable

GPS-like accuracy for >1 hr

GPS-like accuracy for multiple hours

Mid-term Concept

Today

Northrop RLG
WSN-7 INS for ships
(Strategic)
Quantum-enabled PNT Strategic Challenge

• “Five Eyes” international partnership
  – United States, United Kingdom, Canada, Australia, New Zealand

• Develop a challenge problem for navigation in GPS-challenged environments
  – Use of alternative PNT technologies including quantum sensors and clocks

• Goal – Demonstrate new capabilities in 2022 on a ship-board platform
Global Assured Communications: Satellite-based Quantum Networks

Mid-Term Payload Objectives:
• Key Rate: > moderate

Long-Term Payload Objectives:
• Entanglement Rate: > high (bright)

Current Status:
• Prototyping and field testing components
• Beginning payload studies

Global-scale entangled network demonstration

Quantum Key Distribution (QKD) Field Demo in Relevant Environment

Enables tamper-proof, point-to-point communication with immediate intrusion detection and day/night operation

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Global Assured Communications: Ground- and Air-based Quantum Networks

**Current Status:**
- Nodes: 2

**Mid-Term Node Objectives:**
- Nodes: > 3

**Long-Term Node Objectives:**
- Nodes: > 5

**Entanglement distribution testbed and proof-of-concept ad-hoc network capability**

**Mid-term Concept**

**Critical tech field demo of a multi-node, memory-based ground network connected to a UAV**

**Today**

- No memory available at network nodes

**Memory Node**

**Quantum Circuit**

**Fully-quantum transmission ensures data integrity throughout network and provides immediate intrusion detection**

**Investigate entanglement distribution between ground-to-ground and ground-to-air platforms**

**Field Site**

**UAV Field Site**

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Faster Algorithms for AF Needs: Quantum Computing and Algorithm Development

**Mid-Term QC Objectives:**
- Develop/test/evaluate algorithms to train neural networks

**Long-Term QC Objectives:**
- Develop advanced algorithms for machine learning, optimization, and material discovery on most-current commercial devices

**Have experienced algorithm team; partner with national testbed facilities to test algorithms on available devices**

**Current Status:**
- Investigate programming languages and available algorithms

**Coding to hardware – each system unique**

**IBM Experience User Interface**

**Today**

- Neural network
- Object recognition

**Optimization, faster training of neural networks, material discovery**

**Long Term**

- Form algorithm test and development team to test/vet commercial devices

**Commerially-available platforms**

- IBM
- IonQ
- Rigetti

**Optimization for multi-domain command and control**
Summary

• AF QIS strategy on pathway to enable game changing capabilities in 2035 timeframe
  – Mid-term outcomes: tech maturation for timing and sensing
  – Long-term outcomes: tech maturation for communications and networking; computing algorithms
  – Strategy includes partnerships, workforce development, supply chain
Questions?