A Near-Term Quantum Computing Approach for Hard Computational Problems in Space Exploration

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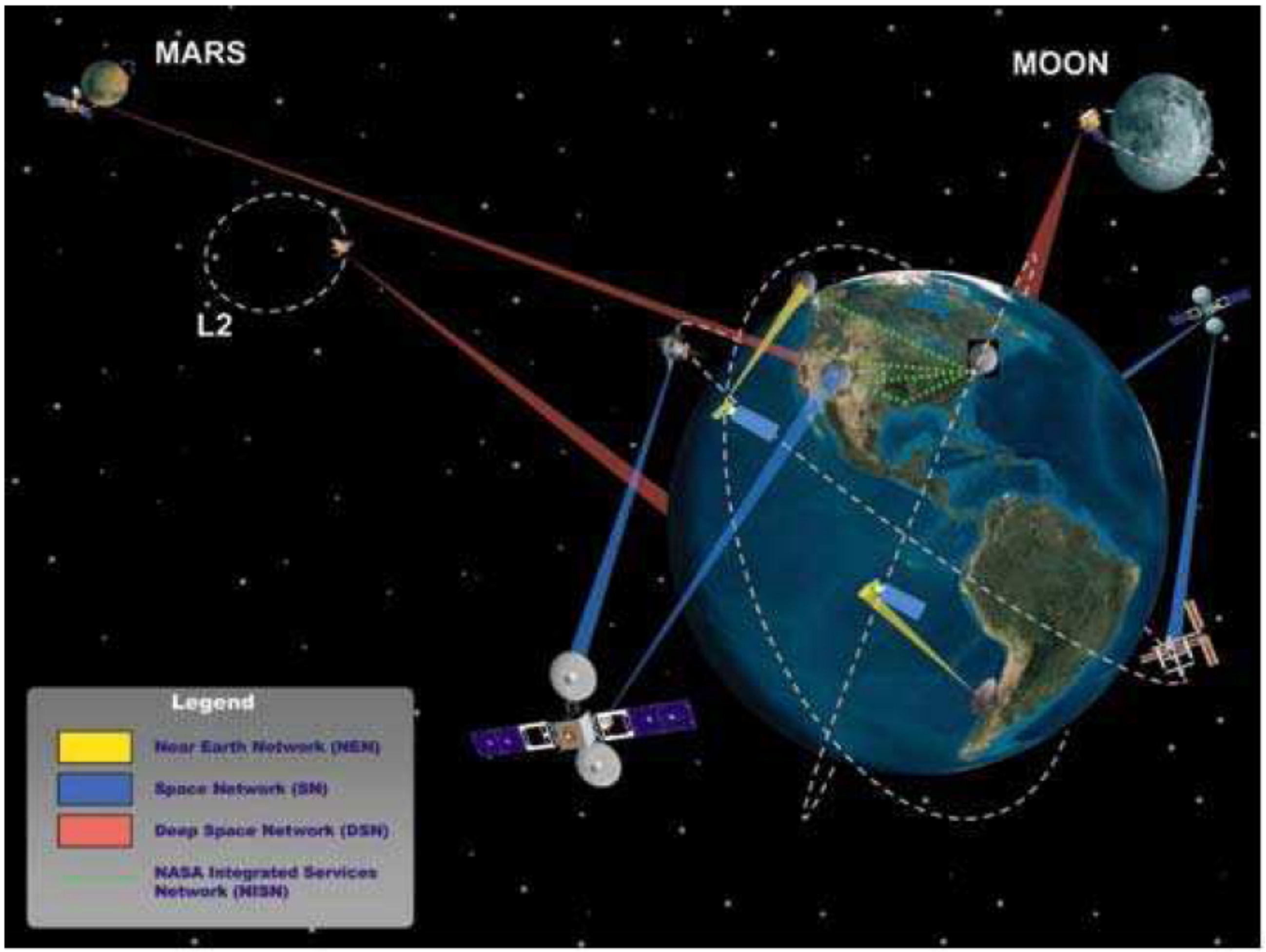
Three components of the NASA Integrated Services Network

- ❑ Near Earth Network
- ❑ Space Network,
- ❑ Deep Space Network



1. Communication delays
2. Limited travel speed
3. Severe space environment
4. Earth gravity well
5. Mission complexity

Robotic missions would be preferable…….

- Complexity of manned missions is often greater than robotics missions

  a. Safety issues, need for life-support technologies , harsh space environments (radiation exposure , etc)
  b. Limited mission duration (with small travel velocity this limits haw far we can reach)

- Robotic missions need to become more intelligent:
  a. operational autonomy
  b. distributed coordination –algorithms for cooperation between unmanned autonomous systems
  b. optimal management of resources
  c. Robustness and reliability

Quantum computer in space that can be located on planetary orbiter and supporting autonomous operations on planter surface through the communication link

Examples:
precision landing , system navigation, terrain mapping , etc

Mission operations

- Planning and scheduling – optimal strategies or action sequences in which various constraints associated with normal operation must be satisfied at all times.
    a. Augmented planning capabilities to support crew autonomy, ISS operations, deep space missions, autonomous robots and unmanned vehicles

- Decision making –computerized generation of conclusions and decisions, as well as model identification, from available data, using the laws of physics, logical, mathematical, and statistical techniques
    a. Launch abort sequences

- **High payload price, limits on space mission resources , computational power , etc.**
  It will be good if we can “pre-compute as much on Earth as possible.

Data-driven approaches

a. QC could provide better algorithms for analysis of training data available on Earth to identify parameters of learning algorithms that will perform in Space operations on classical machines:
   classification, clustering, supervised and unsupervised learning, data segmentation , feature identification and matching, pattern recognition

b. Early warning system from the data stream communicated back to earth anomaly detection algorithms could indicate incipient failure model long ahead of time.

Model based approaches

a. Mode Identification and Mode Reconfiguration :

continuously analyze input from sensors and known control variables to identify a particular hardware mode and whether it deviates from normal behavior. The latter attempts to adjust controls to achieve original high-level goals even if undesirable transitions due to malfunction do take (propositional logic).

d. Problems in fault tree analysis:

isolating the most likely cause of malfunction, finding the most likely combination of basic events that would lead to top event. Computing the probability of top events given a vector of probabilities of basic events is NP-hard in general case

Example:

minimum cut set , the smallest subset of basic events that would result in system failure.

Major intelligent system domains to address Space Exploration Issues

1. Data Analysis and Data Fusion
2. Planning and scheduling
3. Decision making
4. Distributed coordination

Prescription

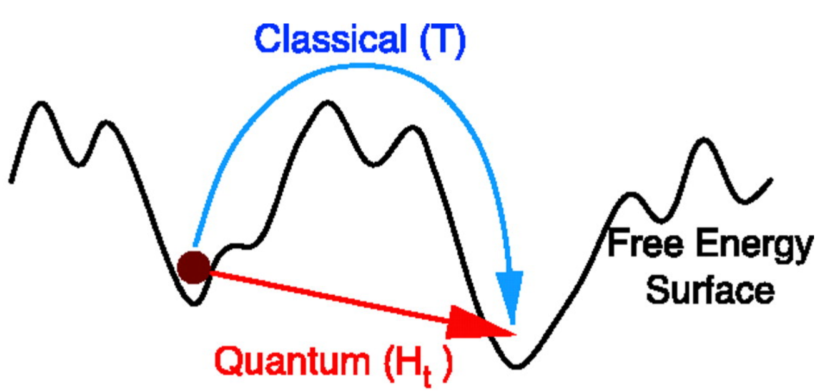
Develop quantum annealing machines….

Do not look for perfect qubits :

- ❖ t_{gate} /T_2 =0.1- 0.5
- ❖ No error correction
- ❖ Can ‘loose” some qubit in the process of calculation
- ❖ Temperature is grater then the many-body gap
- ❖ Have tools at hand for space tomography at intermediate times

Do not think too much about the computational complexity issues:

try to empirically determine the properties of the ensemble of instances that are suitable for quantum computation



$$H = -\Gamma \sum_i \sigma_i^x - \sum_{\langle ij \rangle} J_{\langle ij \rangle} \sigma_i^z \sigma_j^z$$