Architecture Study of Space-Based Satellite Networks for NASA Missions

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Traditional NASA Mission

- Stovepipe Architecture – Mission Specific
- Optimized from application to RF
  - Efficient, but not flexible
- Ground Infrastructure
  - Dedicated or
  - Highly Scheduled
- Store and Forward Systems
  - Requires Onboard Storage
  - Requires High-Speed Space to Ground Transmission
- Relay Satellite (TDRSS)
  - Highly Scheduled

Future NASA

- Network Centric Architectures and Operation
  - Interoperability between missions
  - Support of multiple missions
- New Architecture Concepts
  - Shared Satellite Resources
  - Shared Ground Infrastructure
  - Direct to PI Data Distribution
  - Remote Control of Experiments
  - Coordinated Science (Sensor Webs)
- Emerging Technologies
  - Software Radios
  - Phased Array Antennas
  - Media Access
  - Authentication, Authorization and Accounting
  - Encryption

Design Philosophy

- Volume Production
  - Iridium and Globalstar
- Willing to trade optimization for flexibility and interoperability
- Use existing techniques and technologies available in the communication and computing industries
  - Examples
    - COTS intellectual property
    - Standard Interfaces
    - Commodity protocols
  - Results
    - Reduced time to deploy
    - Reduced cost
    - Reduced risk

Myriad of Ground Stations

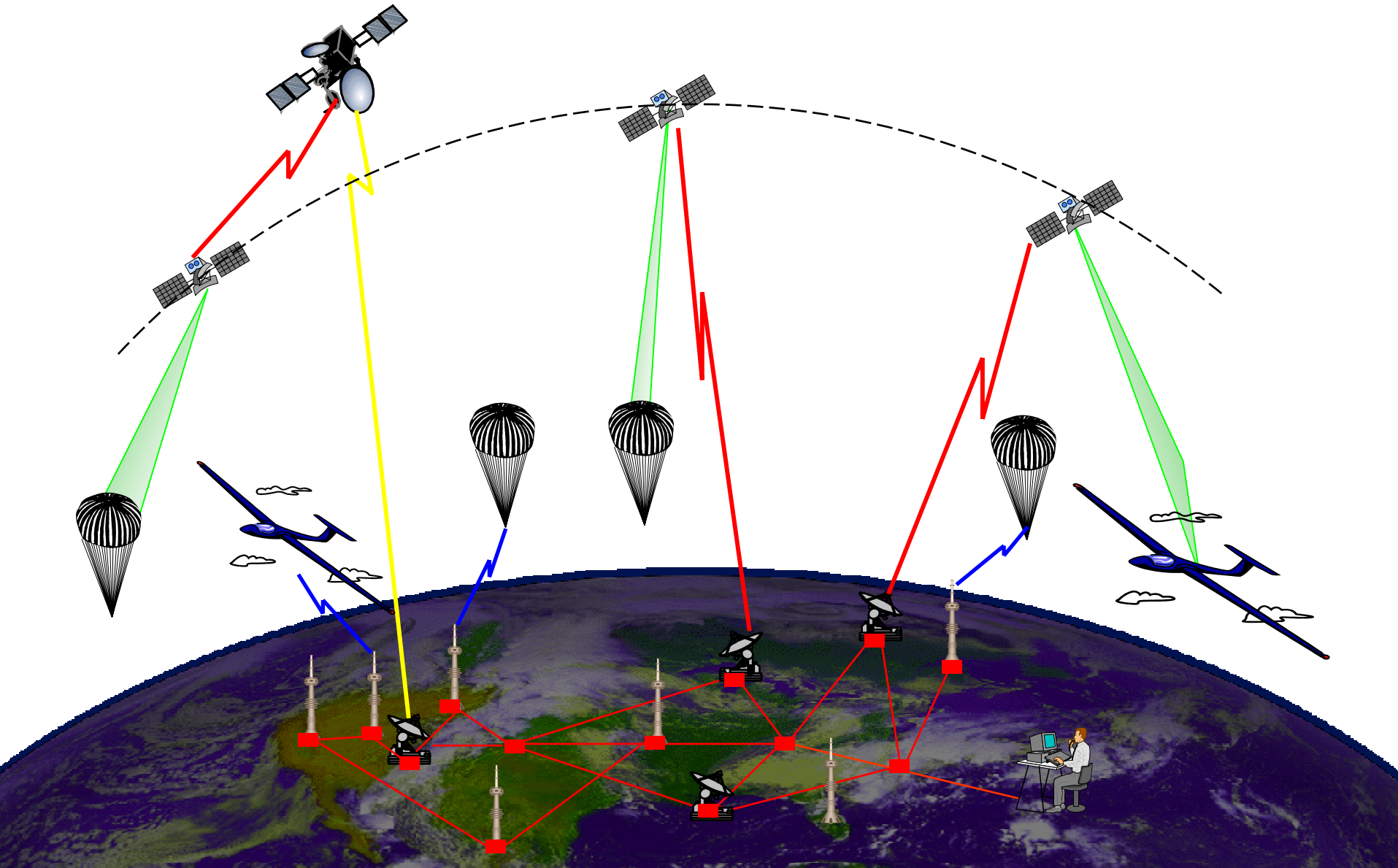
- Feasibility
  - Technically, Economically and Politically
- Volume Production of Satellite and Earth Stations
- Shared Infrastructure = Shared Cost
- Evolve and Grow
  - Scalable
- Allows for greater flexibility in choice of orbits

Myriad of Ground Stations

Fully Meshed Sensor Web

- Evolving Web
  - Flexible must be built in
  - Unable to optimize for the unknown
  - Pre-engineering not possible
    - Communication paths will vary
    - Time delays will vary
    - Available bandwidth will vary
    - Link Characteristics will change instantaneously
  - Utilizes all of the emerging technologies

Fully Meshed Sensor Web



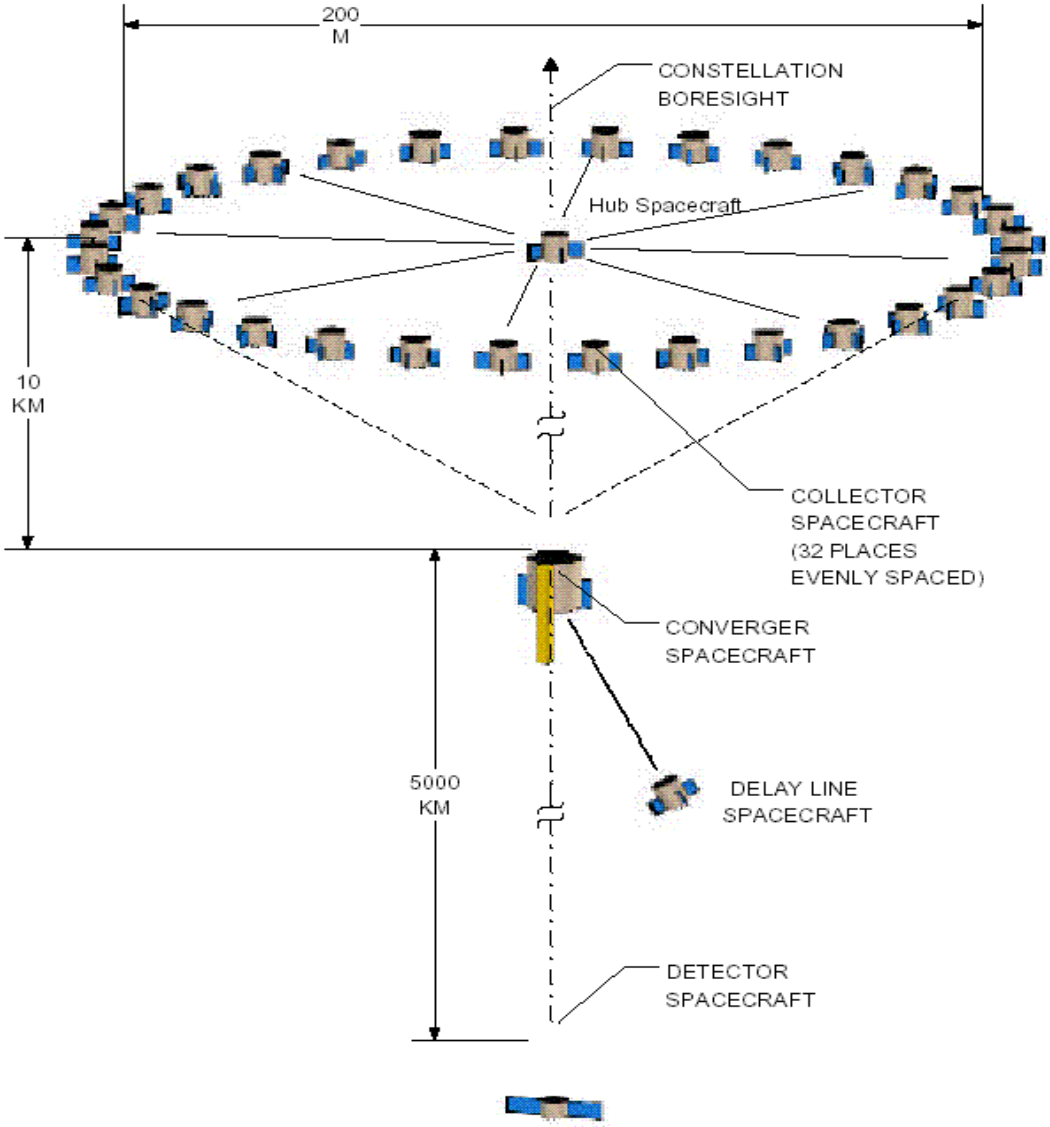
Key Technologies for Sensor Webs

- Standard Media Access Techniques
  - Starting point for communication
    - What antennas, frequencies, modulations schemes
    - Where am I and where will I be (if possible)
      - Orbits are deterministic (ephemerous data)
      - Aircraft and balloon tracks are not.
    - AAA
- Programmable modems or software defined radios
- Directional tracking antennas
- Routing Techniques
- Secure networking over shared infrastructure

Formation Flying Constellations

- Entire constellation performs and one unit
  - Tendency to be more mission specific
    - Less flexibility, lose volume production gains except for common parts.
- Some science may not be possible by single spacecraft
- Multiple spacecraft may reduce risk
  - Provides redundancy
  - Reduced launch costs
  - No single point of failure – depending on architecture
    - Except ---- the mother ship (reach back in ad hoc networks)

Formation Flying Constellations



Key Technologies for Formation Flying Constellations

- Overall architecture and distribution of processing
  - Mother ship (hub-spoke) or peer-to-peer?
  - Self-healing, self configuring?
- Types of communication that needs to take place between spacecraft
  - Command, Control, Timing and Positioning
  - Science data
- Media Access Technology
  - Can one architect the constellation design so at to reused existing media access techniques and radio technologies?

Reconfigurable Radios

- Utopian Solution
  - Single radio sends and receives multiple waveforms at any data rate and any frequency
  - Modulation and coding scheme automatically sense and adapt to link characteristics.
    - Need starting point, restarting point and protocol for adaptation
- Manual Reconfiguration
  - Not practical in large dynamic sensor web
- Reality
  - Multiple links will probably have their own radio
    - Greatly eases securing links
  - Data rates and frequency limit the degree of reconfigurability that is possible and practical.

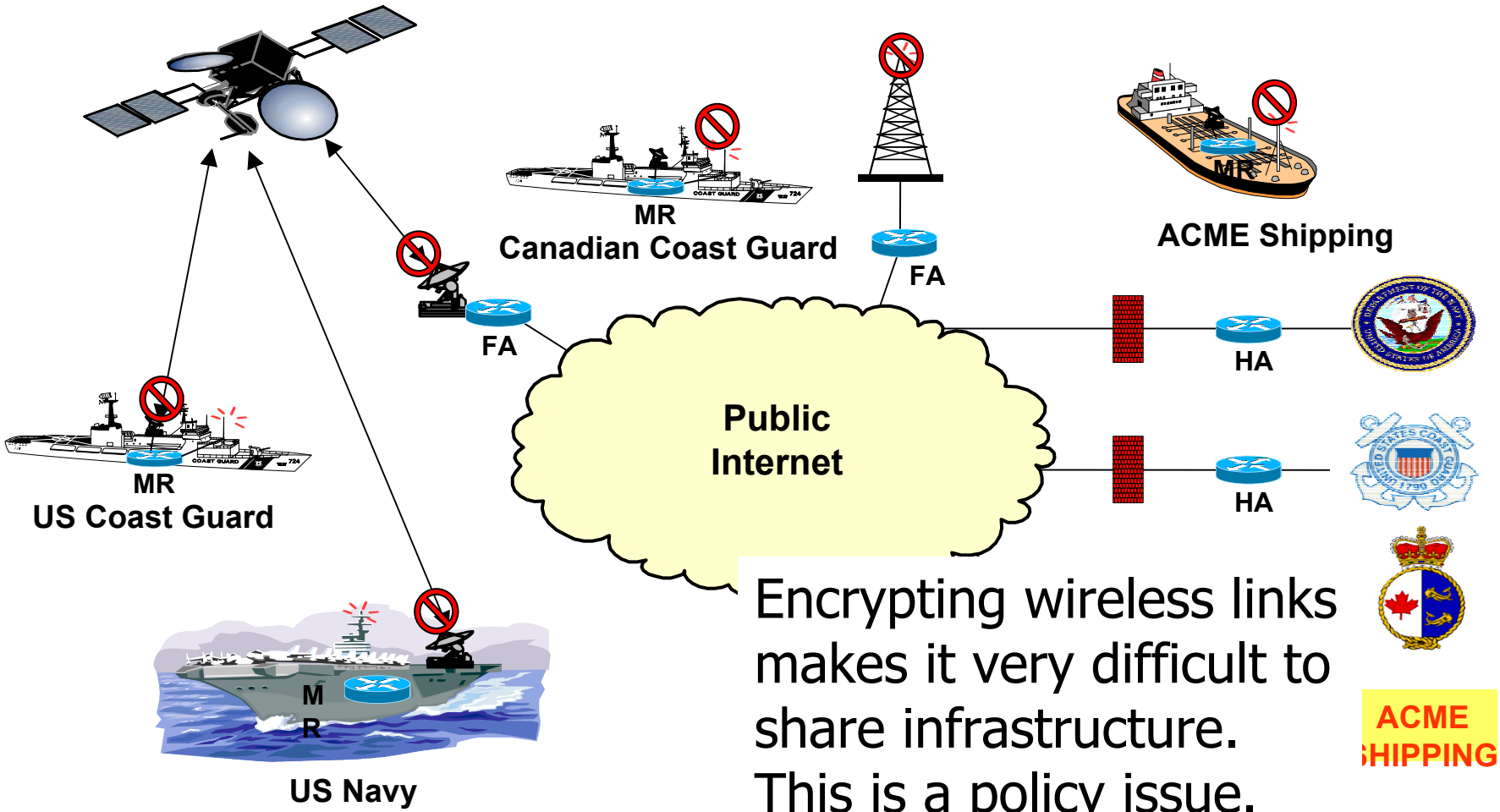
AAA and Encryption

- Authentication
  - Are You who you say you are?
- Authorization
  - What resources are you permitted access to?
    - Use of the network?
    - Command and control?
    - Access to experimental data?
- Accounting
  - How much of the resources did you use? $$$
- Encryption
  - Secures Data (used for security and/or privacy)
  - Possible to hide (somewhat) the secure network
  - Does not replace AAA
- How does one validate certificates and load and manage keys in space-based networks – particularly when isolated from the ground infrastructure?

Routing in Mobile Network

- Routing Protocols
  - Convergence time
  - Will one ever be allowed to inject routes into another's network?
- Mobile-IP and Networks in Motion (NEMO)
  - Allows entire networks to roam
  - Can be nested (reduces bandwidth utilization)
  - Security and route optimization do not mix well
- Ad hoc Networking
  - Self Configuring and dynamically reconfigurable
  - Most space based networks are not truly ad hoc
    - Orbits are deterministic
    - Reach back implies structure
  - Need development of layer-2 radio and media access to support ad hoc networking.

Shared Network Infrastructure

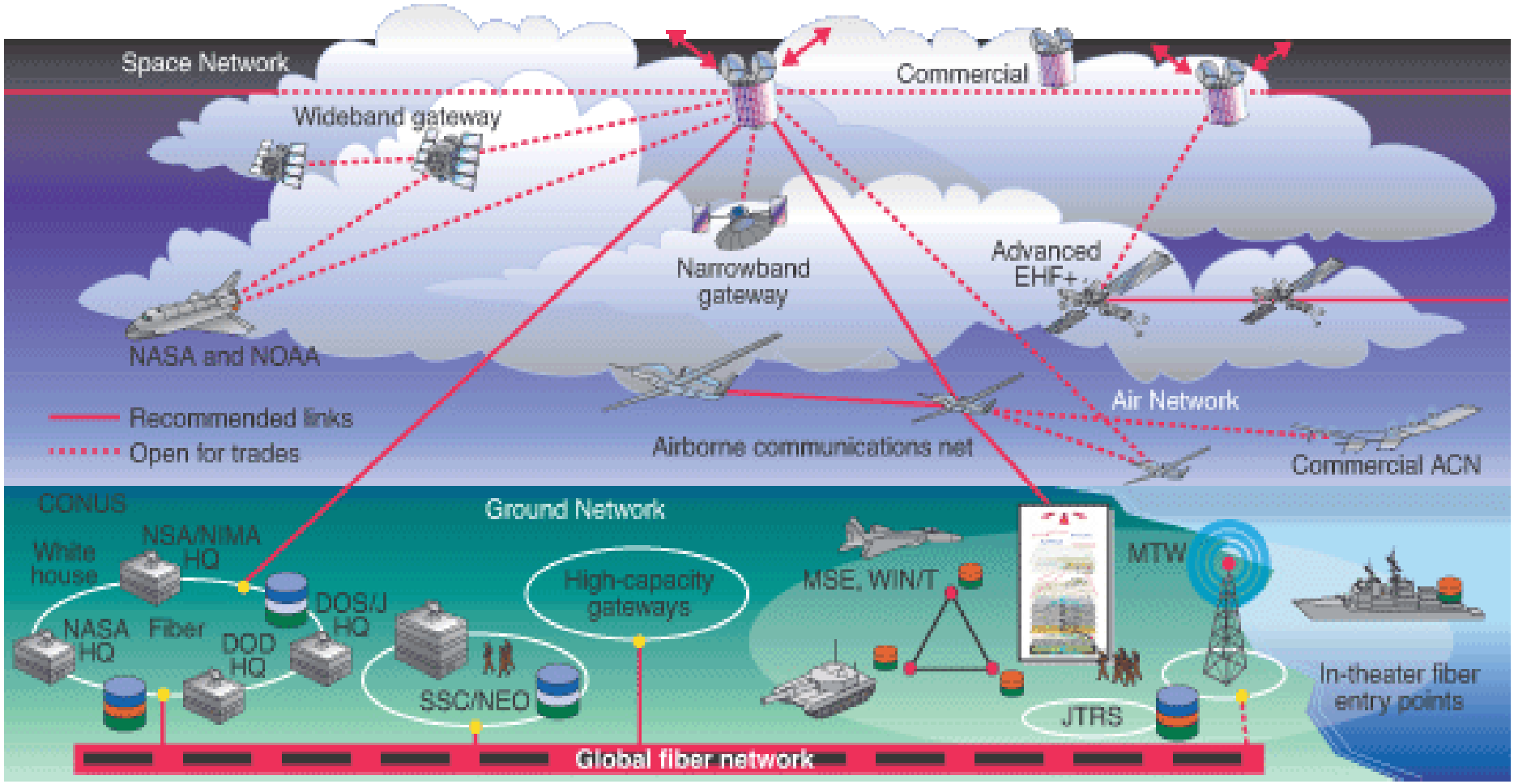


Autotuning Reliable Transport Protocols

- Desire to fully utilize available links
- Maintain Fairness
- Observe and support Quality of Service
- End-to-End Link due to mobility and crossing networks
  - Instantaneous path delay
  - Instantaneous bandwidth variation
  - Instantaneous BER variation
- Need and End-to-End solution due to End-to-End Encryption

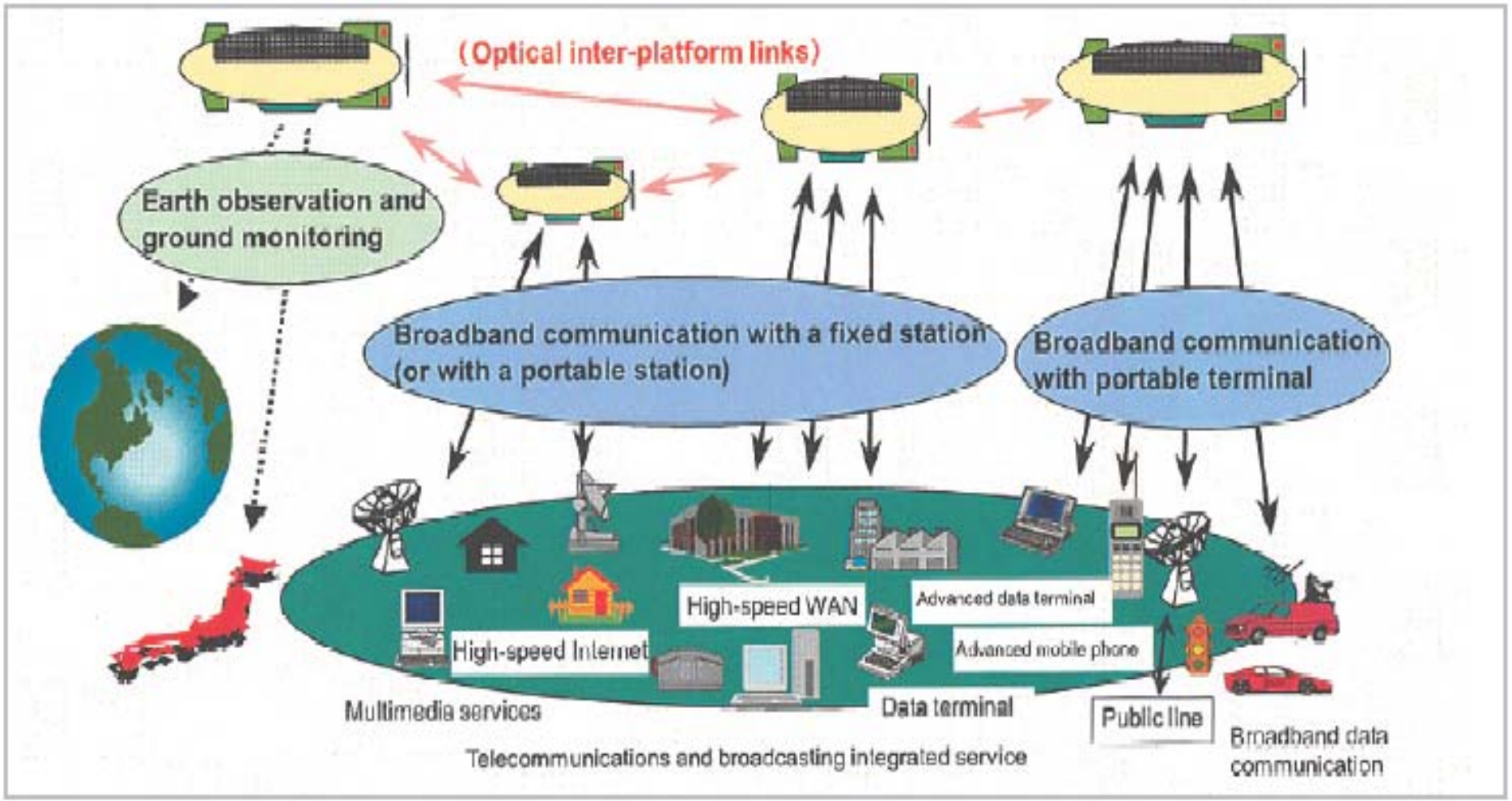
Conclusions/Recommendations

- Many pieces are in place to begin deploying a space-base network that can support multiple science endeavors and share network infrastructure
  - Mobile-IP, Software Radios, AAA, Directional Tracking Antennas
- Start now.
- Keep it simple and flexible.
- Learn as we go.
- Address the political issues and policies through demonstration and deployment.
- The sensor web networks will evolve with as technology evolves and we learn.
- The same technologies and techniques that apply to space-based networks apply to the military and aeronautical networks.



Crosslink Magazine - Future U.S. Military Satellite Communication Systems
Glen Elfers and Stephen B. Miller
http://www.aero.org/publications/crosslink/winter2002/08.html

Stratospheric Platforms – These Are Coming Soon



Refernece: Ryu MIURA and Masayuki OOD: "R&D Program on Telecom and Broadcasting System Using High Altitude Platform Stations," Journal of the Communications Research Laboratory Vol.48 No.4 2001