Toward a Communications Satellite Network for Humanitarian Relief

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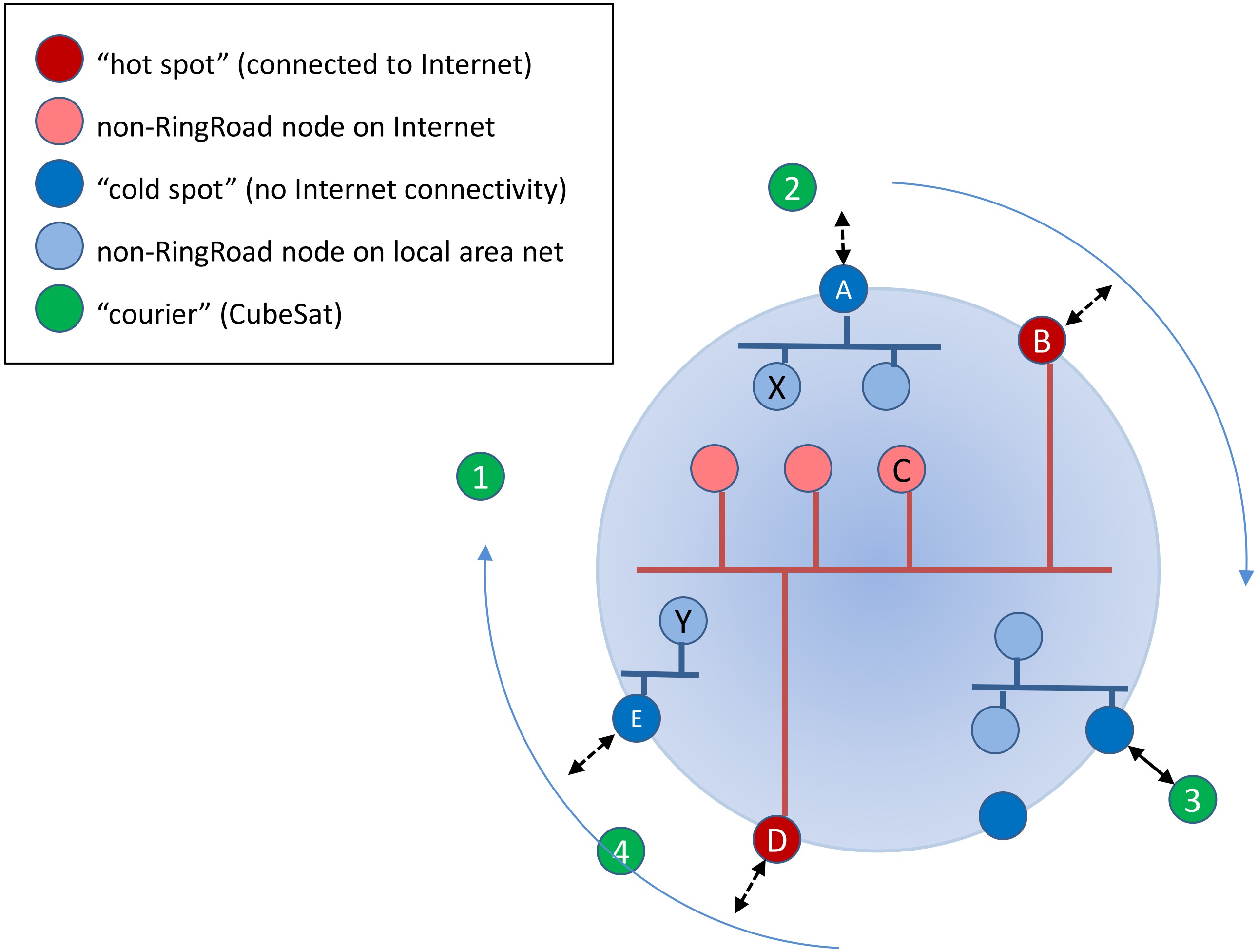
Ring Road Proposal

- A communications satellite network service at minimal cost:
  - Use CubeSats (or other "picosatellites") to reduce hardware and launch cost.
  - Use Delay-Tolerant Networking (DTN) to ensure reliable data transmission.
  - Deploy large numbers of satellites in low-Earth orbit, without cross-links, providing non-conversational but continuous data exchange service to most of the inhabited surface of Earth.

Technical Overview

- Integrate isolated communities with the Internet via wireless communication between base stations and satellites.
- Satellites as “data mules”: satellite receives data from an isolated base station, stores it in memory, and physically carries it until contact with an Internet-connected base station enables data to be forwarded – and vice versa.
- DTN protocols automate data mule functionality, providing routing and Quality of Service.


"hot spot" (connected to Internet)
non-RingRoad node on Internet
"cold spot" (no Internet connectivity)
non-RingRoad node on local area net
"courier" (CubeSat)
2
A
B
X
1
C
Y
E
3
4
D

Applications

- Disasters warnings, requests for relief
- Relief worker communications, search and rescue
- Disease control, weather forecasts
- Fish and game migration data, commodity pricing
- Distance learning, email, research queries
- Acquisition of data from remote sensors

Low Cost

- Key design concept: epistolary communications, not conversations. Accepting relatively long latency (round trips in minutes instead of seconds) enables:
  – Communication via low-Earth orbit, much less costly than geostationary satellites
  – Communication without crosslinks, higher bandwidth at lower cost

Incremental Deployment

- No cross-links, so each Ring Road satellite functions independently as a data transfer device.
  - A single satellite would implement the service, but at extremely long round-trip latency and a very low data rate.
  - The addition of each satellite incrementally increases the capacity of the network and reduces round-trip latency.
- Service can begin with the initial launch. No need to deploy the entire network at once.
- Any single satellite failure would diminish capacity only slightly, and replacement would be inexpensive.

CubeSat Overview

- 10cm x 10cm x 10cm cubes, up to 3 per spacecraft
- Powered by solar cells.
- Passive attitude control.
- Designed for aerospace engineering education.
- Kits sold online, e.g., by Pumpkin Space Systems.

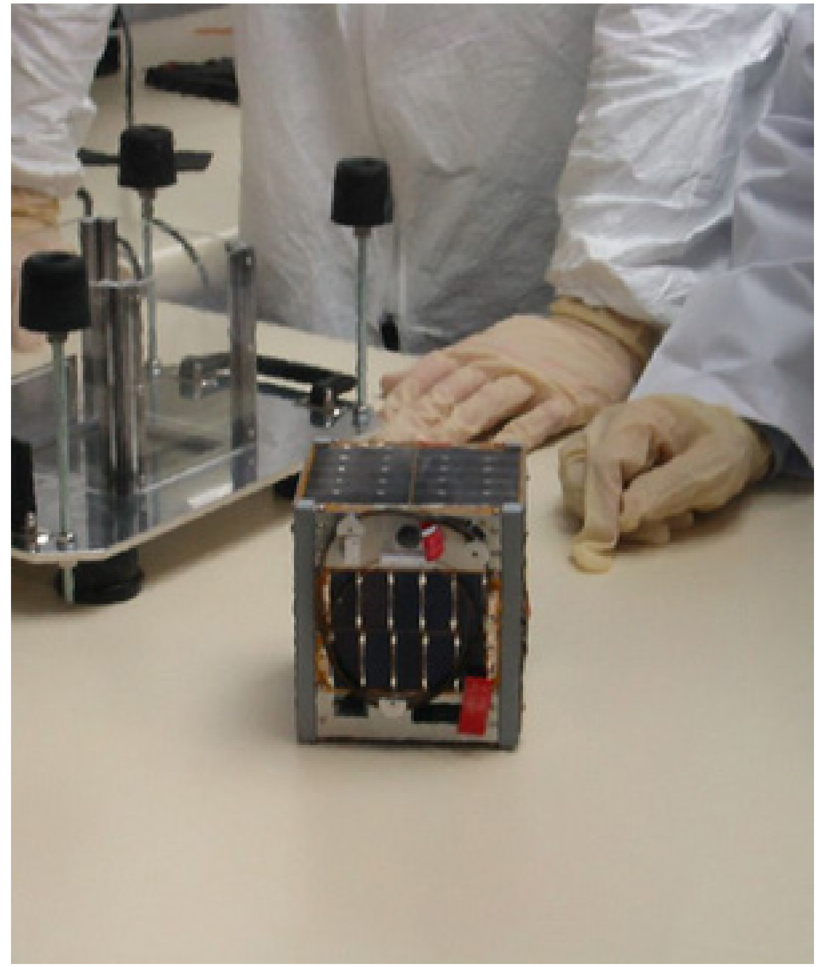


Photo used by permission: http://www.cubesat.org

CubeSat Recent Developments

- February 2010: U.S. National Reconnaissance Office contracts with Boeing Phantom Works for up to 50 triple-unit CubeSats.
- July 2010: India's Polar Satellite Launch Vehicle deploys two student-built CubeSats: Tisat 1, StudSat.
- February 2011: NASA selects 20 small satellite projects to fly as auxiliary cargo aboard rockets planned for launch in 2011 and 2011.
- August 2011: NASA announced 3rd CubeSat Launch Initiative, for launches planned for 2012, 2013, 2014.

DTN Overview

- Originally conceived in 1998 as network protocol for an Interplanetary Network (more recently termed the “Solar System Internet”).
- Scope broadened to terrestrial applications in 2002 with formation of DTN Research Group. Products:
  - RFC 5050 Bundle Protocol
  - RFC 5326 Licklider Transmission Protocol
  - RFC 6257 Bundle Security Protocol
- Standardization in progress within the Consultative Committee for Space Data Systems.

DTN Overview (2)

- Features:
  - Operating parameters are generally asserted rather than negotiated, to avoid delays due to long round-trip times.
  - Retransmission of lost data is performed at the point of data loss, within the network, rather than end-to-end.
  - Data packets ("bundles") are retained in router storage if an outbound route isn't available at the time they are received. Explicit time-to-live eventually clears non-routable bundles out of the network.
  - So physical conveyance of stored data, via "mules", is automatically integrated into network operations.

DTN Recent Developments

- Successful 4-week demonstration on the EPOXI spacecraft in deep space (about 100 light seconds from Earth) in October 2008.
- Continuous operation on the International Space Station, in low-Earth orbit, since July of 2009.
- Testing of Bundle Security Protocol on links between secure mission operations centers began in 2010.
- Research into enhanced Contact Graph Routing and DTN Network Management is under way at multiple laboratories in the U.S., Europe, and Japan.

Constellation Size

- Near-circular low-Earth orbits at inclination of about 50 degrees; altitude about 500 km.
- So radius of satellite visibility is somewhat greater than 1000 km.
- Maximum separation of satellites is at the equator, which is about 40000 km, so 10 orbital planes are needed.
- Propose 15 satellites per orbital plane, total target constellation size of 150 spacecraft.

Network Capacity

- Satellites at 500 km altitude travel at about 7.8 km per second, an orbital period of 90 minutes; 16 orbits per day. Any single satellite will be in view of any single base station for about 256 seconds per orbit.
- S-band transceivers can transmit at 230 kbps, could upload up to 7.2 MB during a single satellite contact.
- Up to 20 contacts of max. length per orbit, so 144 MB could be inserted into the network per satellite per orbit, 2.25 GB per satellite per day.
- For 150 satellites, 337.5 GB per day. This is 4 MB per second, 32 Mbps. But suppose it's only <u>16 Mbps</u>.

Deployment Cost

- Estimated assembly cost per satellite: $100,000.
  - Total satellite assembly cost for network: $15 million.
- Estimated launch cost per group of three CubeSats: $200,000.
  - Total launch cost for network: $10 million.
- 20 contacts per orbit for 150 satellites would require 3000 base stations; 1500 if one-half of the covered surface is unoccupied. Estimated cost per base station, including S-band radio modem: $2000.
  - Total base station cost for network: $3 million.

Service Cost

- Suppose network lifetime is 5 years and operating cost is $1 million per year. Total lifetime cost of the network is $15 + $10 + $3 +$5 = $33 million.
- At 16 Mbps, total lifetime traffic is about 300 TB. Mean cost of transmission is less than $0.11 per MB.
- Commercial satellite services (as of late 2009):
  - WCC (Iridium reseller) about $1/minute at 2400 bps, about $60.00 per MB.
  - Tempest Telecom (INMARSAT reseller) RBGAN service is $5.25 to $11.60 per MB, BGAN service from $3.59 per MB.

Conclusion

- We think the Ring Road concept has the potential to deliver access to information resources in the Internet – reliably and securely, though at relatively long latency – to most of the inhabited surface of Earth, at extremely low cost.
- Support for the day-to-day information needs of communities lacking Internet infrastructure.
- Support for emergency communications in the event of infrastructure failure in a disaster.

Backup slides

SERVICE COST COMPUTATION

- 230 kbps x 256 sec/contact = 7.1875 MB/contact
- x 20 contacts per orbit = 143.75 MB/orbit
- x 16 orbits per day = 2300 MB/day per satellite
- x 150 satellites = 345000 MB/day total for network
- Divide by 2 to account for uninhabited surface: 172500 MB/day total for network
- x 365 days per year = 62,962,500 MB per year total
- x 5 years = 314,812,500 MB over life of network
  - About 300 TB over life of network
- $33,000,000 / 314,812,500 = about $0.105 per MB

The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.