Delay Tolerant Networking and Cubesats

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Introduction to Delay Tolerant Networking
DTN is a suite of protocols. It extends the terrestrial Internet to form a “Solar System Internet”.

The terrestrial Internet works by connecting multiple individual links into an end-end path using Internet Protocol (IP) routers. The end-end path is always available, delays are short (a few milliseconds) and error rates are very low. The animation below demonstrates a terrestrial Internet.

The “IP” of the Solar System Internet is the Bundle Protocol (BP), which is the core of the DTN suite.

The Solar System Internet works by connecting multiple individual hops into an end-end path with Bundle Protocol (BP) routers. A hop may use IP or any other protocol. The end-end path is rarely available owing to disruptions and outages of individual links, delays are potentially very long as a consequence of Solar System geometry (minutes to days) and error rates are often high.

- The BP routers work in a store-and-forward mode where data are held until the next hop becomes available.
- BP often uses “Custody Transfer” to improve network efficiency – a BP router accepts custody of incoming Bundles, thus allowing the previous hop to clear its buffers.

The Bundle Protocol therefore forms an Overlay Network. It can run over IP where IP is available, or it can run directly across individual links. The animation below demonstrates an IP network with the bundle protocol overlaid.
Comparison of Packet Delivery in Different Networks

- This video demonstrates how a network with DTN overlaid can improve transmission of the packets.
- The video shows the difference between TCP/IP, UDP/IP and Bundle Protocol (BP).
Why is DTN important?

- DTN is a game-changing internetworking technology that allows the reach of the *IP-based Internet* to reach out into the *highly stressed* communications environments at its edges:
  - Public emergency networks
  - Tactical military
  - Mining, nuclear plants
  - Remote area communications
  - Space missions

- Highly secure – powerful data protection was built-in from the start

- DTN development started in NASA in 1998 in response to a DARPA initiative to develop an “Interplanetary Internet”. Since the mid-2000s worldwide DTN development has been led by NASA and is approximately 50% complete. Basic open source DTN core protocols are getting close to reaching international standards, but the ancillary protocols required to operate a network (routing, network management, security, key management, etc.) need further development and testing

- NASA has a “Core Team” of experts across the Centers who have led DTN development for the past decade, plus “DTN Advocates” at the Centers who assist with pickup of DTN by spaceflight missions and external organizations. *NASA is the world leader in DTN.*
• **Interoperability and Reuse**
  – A standardized open-source* DTN protocol suite enables interoperability of multi-organization communication assets and also allows re-use of the same communication stack for future projects. Interoperability with NASA’s partner agencies greatly expands the opportunities for new, collaborative missions to emerge.

• **Improved Operations and Situational Awareness**
  – The DTN store-and-forward mechanism along with automatic retransmission provides more insight into events during communication outages and significantly reduce the need for manually commanded communications operations by automating communication in the context of the contact schedule.

• **Space Link Efficiency, Utilization and Robustness**
  – DTN enables more reliable and efficient data transmissions resulting in more usable bandwidth. DTN also improves link reliability by having multiple network paths and assets for potential communication hops.

• **Security**
  – The DTN Bundle Security Protocol allows for authentication and encryption, even on links where not previously used.

• **Quality of Service**
  – The DTN protocol suite allows for many priority levels to be set for different data types, ensuring that the most important data is received ahead of less important data.

  ❖ [http://sourceforge.net/projects/dtn/?_test=b](http://sourceforge.net/projects/dtn/?_test=b)
DTN is a Suite of Protocols

- Licklider Transmission Protocol (LTP)
  - Provides retransmission-based reliability over links characterized by extremely long message round-trip times and/or frequent interruptions in connectivity
- Contact Graph Routing (CGR)
  - Enables dynamic selection of data transmission routes in a space network based on DTN. This dynamic responsiveness in route computation should be significantly more effective and less expensive than static routing, increasing total data return while at the same time reducing mission operations cost and risk
- Compressed Bundle Header Encoding (CBHE)
  - Developed to improve DTN transmission efficiency by further reducing the number of bytes used by convergence-layer adapters to represent EIDs in the primary blocks of bundles
- Extended Class of Service (ECOS)
  - Extends the class of service definitions to allow for a more granular approach
- Bundle Security Protocol (BSP)
  - Provides the mechanisms to authenticate the source as well as protect the integrity and confidentiality of the data
Example Operations Scenario
Problem

• Future space missions will include features that cannot be accommodated by today’s link layer based communications
  – Multiple spacecraft
  – Intermittent connectivity and long light-time delays
  – Data flow across multiple hops and potential paths
  – Spacecraft that need to communicate without Earth in the loop (e.g., a lander and orbiter)

• This complex topology will require a network layer in the space communications protocol stack to provide reliable routing and forwarding of data

• TCP/IP cannot support this type of network because it requires a point to point path and low latencies at all times to work. Delay/Disruption Tolerant Networking is the effort to solve this problem.
Operations Scenario

CGR shows upcoming AOS with ground site and Satellite starts connection. Connection Lost. Data buffered on board. Connection Restored. Transmitting data and receiving commands.

Pre-staged command is uplinked and first telemetry bundle in downlinked. Telemetry bundles continue to be transmitted. Bundles automatically queued onboard. Command Center online. Bundles now sent to Command Center.
Scenario Analysis

- What made this different for operations?
- Satellite operations can be performed in a “light’s out” mode
  - The operator did not have to command the data downlink it was automatic using the onboard system with contact graph routing
    - Can be used to completely automate passes especially overnight and through weekends
  - The operator did not command data retransmits. LTP and BP with custody transfer requested missing data
  - The operator did not have to be online. The operator used the DTN command queue to have them automatically sent
  - Allows operators to support multiple vehicles easier
Example End-to-End Implementations
Example Implementation (Combined Science Downlink)

CubeSAT

For the DTN implementation to work the satellite would need to be running the DTN protocols.

LTP provides added link assurance for the RF portion of the transport. For this example science data is transmitted using the CCSDS File Delivery Protocol (CFDP) over the Bundle Protocol. Vehicle Commands and Health & Status are built directly into bundles.

Command AP
DTN Bundle
LTP
AOS Frame

Ground Antenna Site

Ground Antenna Site provides a first level check of the frames to insure delivery to the ground. It also provides the broker between the Mission Operations Center and the CubeSAT.

Ground Antenna Site

S Band

Mission Operations Center

Received the bundles from the antenna site and extracts the satellite health and status for operations team. Distributes payload and other data to remotes. Sends the command packets to the antenna site for uplink.

Mission Operations Center

End Point
Puts data to storage as files
Uses custody transfer

Control Room
CMD & TLM App
Gets Bundles
Does CFDP file recombine

Remote User
CMD & TLM App
Gets Bundles
Does CFDP file recombine

Remote Users

For analysis.
Commands can be built and sent to MOC for uplink to satellite. Bundles as well as other methods of delivery (such as an operations support portal) can be used for mission analysis and support.
Example Implementation (Separate Science Downlink)

CubeSAT
For the DTN implementation to work the satellite would need to be running the DTN protocols.

LTP provides added link assurance for the RF portion of the transport. For this example science data is transmitted using the CCSDS File Delivery Protocol (CFDP) over the Bundle Protocol. Vehicle Commands and Health & Status are built directly into bundles.

To meet the science delivery requirement a second X-band connection is used for downlink. (Example would be large files and limited storage)

<table>
<thead>
<tr>
<th>Command AP</th>
<th>CCSDS Packets (H&amp;S Data)</th>
<th>CFDP (Science Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTN Bundle</td>
<td>DTN Bundle</td>
<td>DTN Bundle</td>
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<td>LTP</td>
<td>LTP</td>
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<tr>
<td>AOS Frame</td>
<td>AOS Frame</td>
<td>AOS Frame</td>
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Ground Antenna Site

Ground Antenna Site provides a first level check of the frames to insure delivery to the ground. It also provides the broker between the Mission Operations Center and the CubeSAT.

Mission Operations Center

Receives the bundles from the antenna site and extracts the satellite health and status for operations team.

Distributes payload and other data to remotes.

Sends the command packets to the antenna site for uplink.

Remote Users

Receives the data for analysis.

Commands can be built and sent to MOC for uplink to satellite.

Bundles as well as other methods of delivery (such as an operations support portal) can be used for mission analysis and support.
References
References

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMS</td>
<td>Asynchronous Message Service</td>
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<tr>
<td>BP</td>
<td>Bundle Protocol</td>
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<td>BSP</td>
<td>Bundle Security Protocol</td>
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<td>CBHE</td>
<td>Compressed Bundle Header Encoding</td>
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<td>CCSDS</td>
<td>Consultative Committee for Space Data Systems</td>
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<td>CFDP</td>
<td>CCSDS File Delivery Protocol</td>
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<td>CGBA</td>
<td>Commercial Generic Bioprocessing Apparatus</td>
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<tr>
<td>CGR</td>
<td>Contact Graph Routing</td>
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<td>CU</td>
<td>University of Colorado Boulder</td>
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<td>DARN</td>
<td>DTN Academic Research Network</td>
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<td>DEN</td>
<td>DTN Engineering Network</td>
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<td>DRTS</td>
<td>Data Relay and Tracking Satellite</td>
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<td>DSN</td>
<td>Deep Space Network</td>
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<td>DTN</td>
<td>Delay (Disruption) Tolerant Networking</td>
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<td>ECOS</td>
<td>Extended Class of Service</td>
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<td>EO-1</td>
<td>Earth Observing Satellite - 1</td>
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<td>EPOXI</td>
<td>Extrasolar Planet Observation and Characterization Deep Impact Extended Investigation</td>
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<td>ESOC</td>
<td>European Space Operations Center</td>
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<td>HOSC</td>
<td>Huntsville Operations Support Center</td>
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<td>IOAG</td>
<td>Internet Operations Advisory Group</td>
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<tr>
<td>ISS</td>
<td>International Space Station</td>
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<td>LTP</td>
<td>Licklider Transmission Protocol</td>
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<td>MCC</td>
<td>Mission Control Center</td>
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<td>MSFC</td>
<td>Marshall Space Flight Center</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NEN</td>
<td>Near Earth Network</td>
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<td>SCan</td>
<td>Space Communications and Navigation</td>
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<td>SISG</td>
<td>Space Internetworking Strategy Group</td>
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<td>SSI</td>
<td>Solar System Internet</td>
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<td>TCP/IP</td>
<td>Transmission Control Protocol/ Internet Protocol</td>
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<td>TDRS</td>
<td>Tracking and Data Relay Satellite</td>
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<td>TKSC</td>
<td>Tsukuba Space Center</td>
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<td>WG</td>
<td>Working Group</td>
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