Tortoise and Hare: Ways of Thinking About Mission Communications

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DTN Is Here

- Delay-Tolerant Networking (DTN) technology has matured over the past twelve years.
  - Internet RFCs: 4838 (Architecture), 5050 (Bundle Protocol [BP]), 5326 (Licklider Transmission Protocol [LTP]).
  - Registered Uniform Record Identifier schemes: $dt\text{n}$, $ipn$.
  - Open-source (SourceForge) implementations: $dt\text{n}$, $dt\text{n-ION}$.
  - Many research studies, theses and dissertations.
  - In continuous operation on the International Space Station since July of 2009.
So Why Isn’t It On Your Laptop?

- There’s more to do, still – standardizing network management and routing in particular.
- Mainly, though: **where are the applications?**
Is DTN a Niche Technology?

• DTN enables network communication when round-trip message latency – “delay” – is high, right?
  – But signal propagation latency is negligible on Earth and in Earth orbit, where almost all communication happens. Is DTN only useful in deep space?
  – Well, no, round-trip message latency is also caused by link disruption. But do we need a general solution for this? Why not just do some intensive engineering on the dodgy links: application-layer proxies, PEPs, TCP tweaks (BIC)?

• What can I do with DTN that I can’t already do in the Internet? What’s the “killer app” for DTN?
Toward an Answer

• There’s a good answer to that question, but to reach it we may need a new perspective on DTN.

  Forget about delay for a moment: think of DTN as networking that is relentless.

• To be robust enough to use in interplanetary space, it has to be.

• If your home Internet Service Provider often returns transient “server not found” messages (mine does), you could seek a better ISP – or you could use DTN.
But wait…

- Isn’t the Internet already “relentless”? Wasn’t survivability what Paul Baran was aiming in 1964 – a network with enough redundancy and resilience to withstand even a nuclear attack?

Figure courtesy of Defense Advanced Research Projects Agency.
Sure....

• ....but consider the nature of the redundancy:
  – The Internet is built on connections, continuous conversational data exchanges over end-to-end paths.
  – Multiple cross-links in the Internet enable a connection to switch immediately from one end-to-end path to another when a link is lost.
  – So in the Internet, connections are explicitly preserved. This implicitly preserves the data moving through the network.
Internet Robustness

• The Internet backbone of buried optical fiber cables is highly redundant and robust. However:
  – Tier 3 networks are not always as robust as the backbone.
  – ISPs’ networks can be shut down by just throwing circuit breakers for a few key routers, as in Egypt in January 2011.
  – Wireless links extend the scope of the Internet but are far more fragile.
• When end-to-end paths become impossible, connections can’t be preserved.
• Losing the connections causes data to be lost.
DTN Robustness

- In DTN there is no connection concept:
  - DTN is built on discontinuous atoms of data, bundles, that flow between topologically adjacent network nodes whenever transmission opportunities arise.
  - Multiple contact intervals between pairs of adjacent nodes enable each bundle to flow toward its destination in its own way, in its own time.
  - But between transmission opportunities, the bundles reside persistently and securely in nodes’ local storage.
  - So the data themselves are explicitly preserved.
The Difference

• **Data preservation in DTN is explicit rather than implicit.** It is supported directly, by protocol design, rather than indirectly by infrastructure design. It is enacted in the general case, rather than only in the special case of connection preservation.

• What makes this possible is that DTN is based on a general model of *asynchronous* communication, of which the Internet’s connection concept – a type of *synchronous* communication – is a special case.
Communication Structures

• Connections are conversational, synchronous structures, like phone calls:
  – Both communicating entities are concurrently engaged.
  – Latency in the exchange of data between the entities is minimal and predictable.

• Message (e.g., bundle) exchange is an epistolary, asynchronous structure, like sending postcards:
  – The communicating entities may or may not be concurrently engaged; no constraint.
  – Latency in the exchange of data may or may not be minimal and predictable; no constraint.
The Robustness of Asynchrony

- You can always use conversational infrastructure for successful epistolary communication – e.g., you can take turns reading postcards aloud over the phone. But the reverse doesn’t work.

- Epistolary communication is the general case: the conditions required for its success are a proper subset of the conditions required for the success of conversational communication.

- Since it’s less demanding, it succeeds in a larger number of operational scenarios. It’s more robust.
This Is Nothing New

- Humans have used both asynchronous and synchronous communication for thousands of years.
The Conversational Model

- Conversational communication is “closed-loop”:  
  - Say something.  
  - Wait for the response.  
  - Hear the response.

- This was the earliest communication: it began when humans acquired spoken and gestural language.

- It was only possible between people who were in the same place at the same time.

- But the bandwidth was very high.
The Epistolary Model

- Epistolary communication is “open-loop”:
  - Write a message and have it carried to another person.
  - Do other things while the message is carried and delivered, and a response message is returned.
  - Receive the response message.
- This began at the start of civilization, when written language was invented.
- It made communication possible across thousands of miles or hundreds of years.
- But the bandwidth was low: originally, limited by walking speed.
A Dynamic Balance

• The balance between reliance on the conversational and reliance on the epistolary is always changing:
  – With geographical expansion, round-trip time (signal propagation latency) increases and the role of asynchronous communication increases.

  Empires were operated by courier and postal systems.

  – With improvements in technology, round-trip latency decreases and the role of asynchronous communication decreases.

  The telegraph made the Pony Express obsolete.
Communications Technology Timeline

Conversational, Synchronous
--speaking
-telegraph (~1833)
-telephone (~1877)
-radio (~1897)

Epistolary, Asynchronous
-writing
-ship (~1825)
-roads
-railroad (~1825)
-magnetic tape (1928)
-communication satellite (1960)
-Internet (1971)
-CD-ROM (1985)
-USB flash drive (2000)
-DTN (2007)

Signaling (smoke, mirrors)

Horse domesticated

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The Conversation Explosion

• Telegraphy: signaling by electricity.
• Telephony: audio telegraphy – speech by electricity.
• The design of Internet was inherited from telephony, though based on managing connections by packet switching instead of circuit switching.
• Many Web applications replace what you would otherwise do by telephone.
The Age of the Epistle

• But even in the era of the telephone we still rely on asynchronous communication – now more than ever:
  – Answering machines, voice mail.
  – Email.
  – Facebook.
  – Twitter.

• And as we expand into the solar system, the historical pattern re-emerges: with this immense geographical expansion, round-trip times again increase and we need DTN.
Tortoise and Hare

When a connection is possible:
When connections aren’t always possible:
Relentless Communication

- DTN is that tortoise, that keeps on working no matter what happens in the network – except that it does not have to be slow when conditions are good:

800 Mbps on a Gigabit Ethernet, sending 4-MB bundles*.  

*Courtesy of The Mitre Corporation
Where Can DTN Help?

• If DTN is the latest step in the evolution of epistolary communication, what does that tell us it’s best for?

• What have we always used postal systems for?
  – Transmission of data that must reach its destination, eventually.
  – Transmission of data that would be difficult to re-transmit from the source in the event of data loss.
  – Transmission of policy – information that enables the recipient to make correct decisions locally, instead of asking some central authority to make those decisions.
Applying DTN (1 of 2)

- Internet applications, not suitable for DTN:
  - telnet, ssh, Skype
  - most Massively Multi-player Online Games
  - interaction-intensive e-commerce, e.g., stock trading

- DTN applications already contemplated:
  - e-mail (Internet e-mail is already delay-tolerant)
  - file transfer (e.g., CCSDS File Delivery Protocol)
  - non-instant messaging (e.g., CCSDS Asynchronous Msg Svc)
  - policy-driven Web browsing (e.g., World Wide Web Offline Explorer [WWWOFFLE])
Applying DTN (2 of 2)

- DTN applications that nobody’s working on (I think):
  - Transmissions of formal agreements, documents of record.
  - Transmissions from security cameras.
  - Transmissions of backup data.
  - Time-tagged state information, for managing confidence-weighted situational awareness displays.
Conversational communication is great for hands-on, interactive control – like running a power plant or piloting a UAV. But you can’t use it to direct entities who are not in continuous contact.

Humans and machines who venture outside of the Internet blanket must make operating decisions autonomously, using the best available information.

DTN-based distribution of policy and status is the best available technology for supporting operational autonomy.
...As In Deep Space

• So we’re back where we started – sure, we need DTN for interplanetary space – but maybe with a perspective on how that relates to problems closer to home.
• Now to get it running on my laptop...