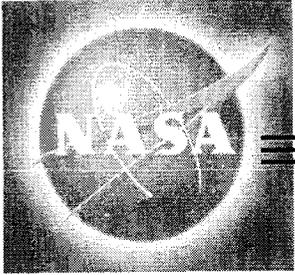


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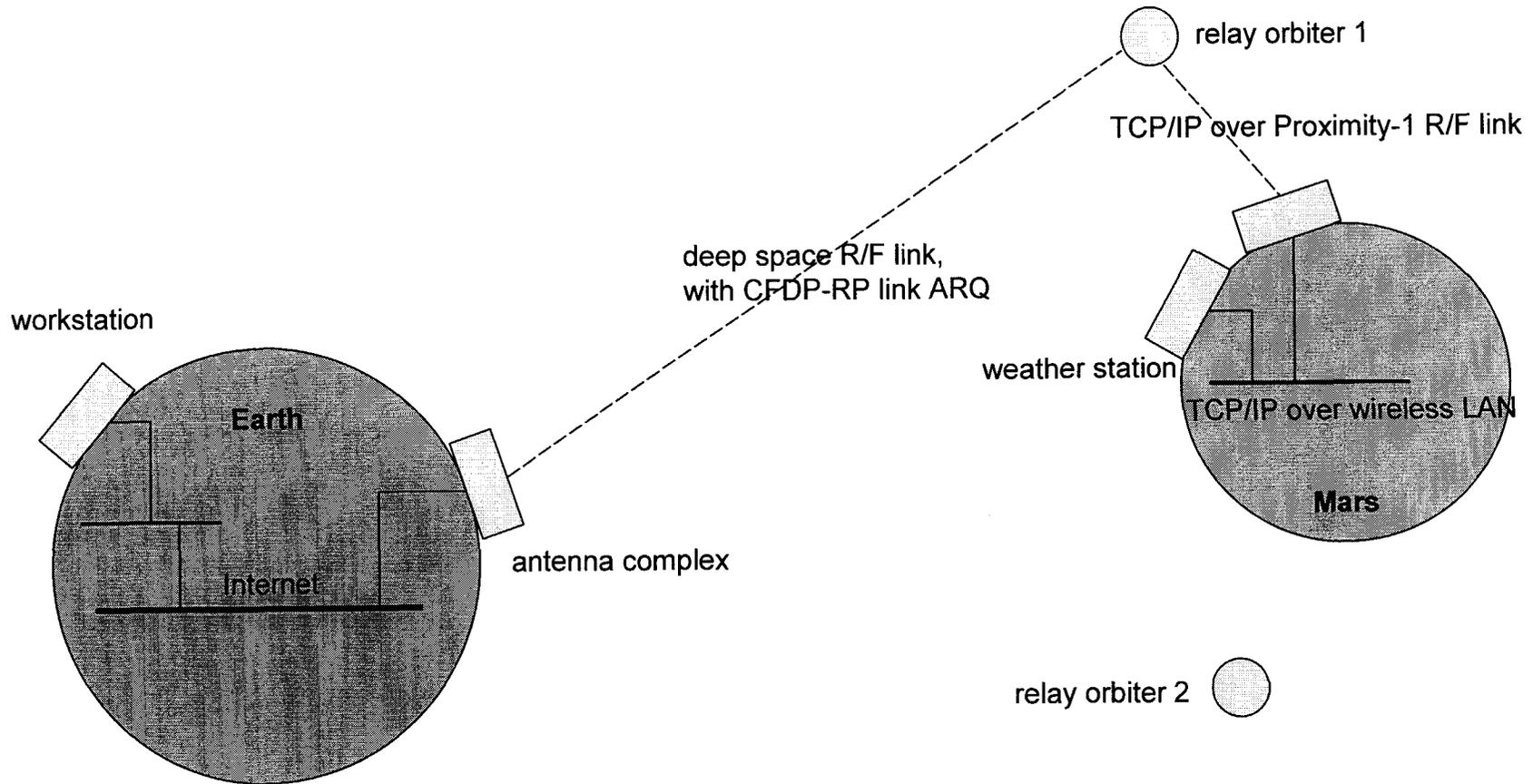
Delay-Tolerant Networking

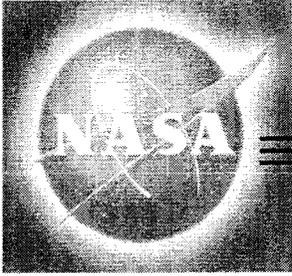
June 5, 2003



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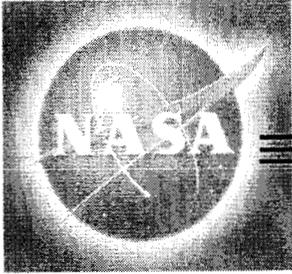
Scenario





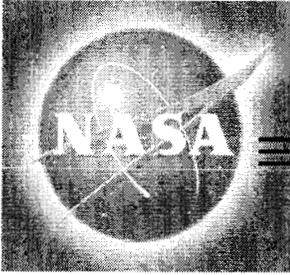
Why Not IP End-to-End?

- ◆ Problems with TCP:
 - ❖ Connection time (one round trip) may exceed duration of communication opportunity.
 - ❖ In-order delivery means data loss delays data arrival by at least one round trip.
 - ❖ Long round-trip times retard recovery from data loss (interpreted as congestion, reducing data rate).
- ◆ Problem with end-to-end ARQ (either TCP or application-layer ARQ over UDP): end-to-end retransmission requires original sender to retain retransmission buffer for an e-to-e round trip.



Why Not IP End-to-End? (cont'd)

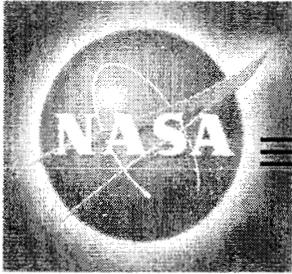
- ◆ Problems with routing protocols:
 - ❖ BGP uses TCP, performs poorly when TCP is unable to keep a connection established.
 - ❖ Route computation is based on probes and timeouts; loss of connectivity can result in premature timeout, thus a connectivity false negative.
 - ❖ Transient partitioning due to scheduled intermittent connectivity may be interpreted as loss of connectivity to the destination – no route can be computed at all.



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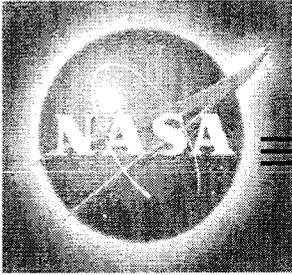
Alternative: Delay-Tolerant Networking

- ◆ Use protocols at all layers of stack that are best suited to each environment.
- ◆ Above them, provide an overlay network protocol that applications can use end-to-end.
- ◆ No end-to-end expectation of:
 - ❖ continuous connectivity; low or constant transmission latency; low error rate or low congestion
 - ❖ high transmission rate or symmetrical data rates
 - ❖ common name or address expression syntax or semantics; data arrival in transmission order



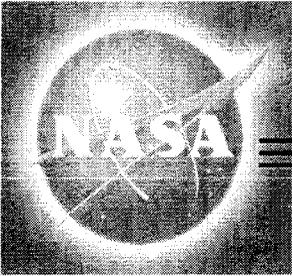
DTN Principles

- ◆ Postal model of communications.
 - ❖ Abandon telephonic model. Don't design for interactive conversation. When submitting a request, "bundle" with it the answers to all possible questions.
 - ❖ Overlay protocol is named "Bundling".
- ◆ Tiered functionality: rely on underlying "regional" protocols as heavily as possible, do the rest in Bundling.
- ◆ Terseness.



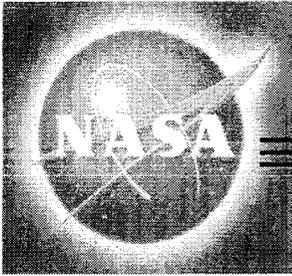
Tiered Forwarding

- ◆ Regional network protocols (e.g., IP) do local forwarding.
- ◆ Bundling does end-to-end forwarding across region boundaries. *Deferred transmission.*
- ◆ Bundle (message) source and destination IDs must include:
 - ❖ Region ID (meaningful to Bundling)
 - ❖ Regional endpoint ID (meaningful to the regional network protocol)
- ◆ Region IDs function as addresses.
- ◆ Regional endpoint IDs are names that are *late bound* to regional addresses upon arrival at the destination region.



Other Tiered Functionality

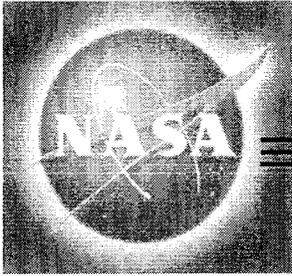
- ◆ Tiered routing:
 - ❖ Regional routing protocols
 - ❖ Contact-sensitive bundle routing
- ◆ Tiered ARQ:
 - ❖ Regional ARQ (e.g., TCP, CFDP's retransmission procedures)
 - ❖ Bundle-layer ARQ: custody transfer
- ◆ Tiered security:
 - ❖ Hop-by-hop bundle agent authentication at Bundle layer to protect infrastructure
 - ❖ End-to-end confidentiality, integrity at application layer



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Other Tiered Functionality (cont'd)

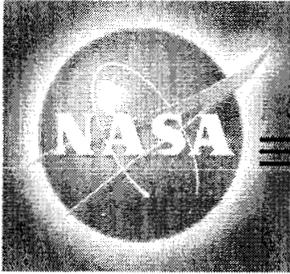
- ◆ Tiered congestion avoidance:
 - ❖ Regional protocols deal with regional congestion.
 - ❖ Bundle layer detects Bundling congestion, respond to it by invoking (tiered) flow control.
- ◆ Tiered flow control:
 - ❖ Regional flow control may be protocol-based (Internet) or managed, rate-based (deep space).
 - ❖ Inhibition of custody acceptance at Bundle layer.
- ◆ Tiered coding:
 - ❖ Regional coding:
 - ◆ Bundle header compression in adapters to regional protocols.
 - ◆ Other coding as needed is performed by regional protocols, possibly at multiple layers of stack.
 - ❖ Optional erasure coding at Bundle layer.



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Other Tiered Functionality (cont'd)

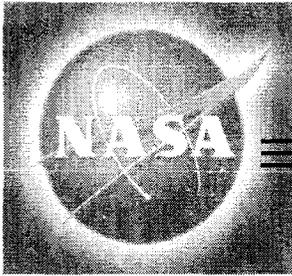
- ◆ Tiered fragmentation and reassembly:
 - ❖ Bundling fragments bundles from awareness of contact duration.
 - ◆ Proactive for scheduled or predicted contacts.
 - ◆ Reactive for opportunistic contacts.
 - ❖ Regional protocols do further fragmentation from awareness of (e.g.) MTU size.



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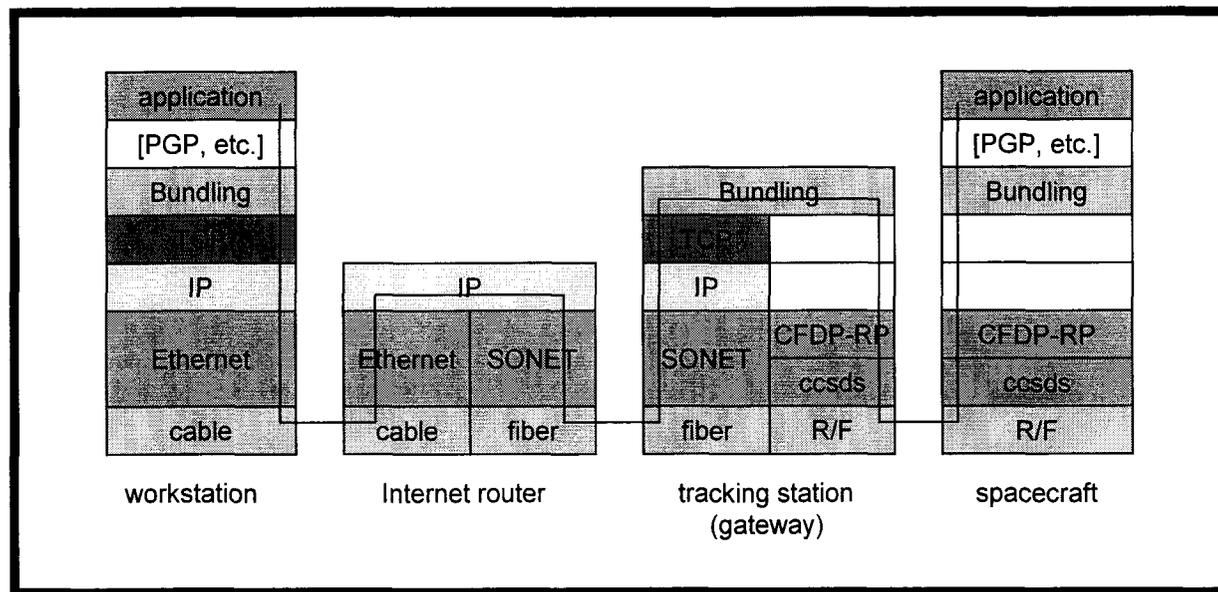
Other DTN Functionality

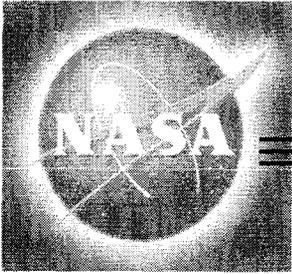
- ◆ Resilient delivery: destination service agent may not be running at the time a bundle destined for it arrives.
 - ❖ *Deferred delivery*: wait until destination starts.
 - ❖ *Reanimation*: start the destination, then deliver bundle to it.
- Postal service levels:
 - ❖ Priority levels: low, standard, high
 - ❖ Service notifications:
 - ◆ Notice of initial transmission, i.e., notice of mailing
 - ◆ Notice of delivery to the ultimate destination application , i.e., return receipt
 - ◆ Report of route taken, i.e., delivery record



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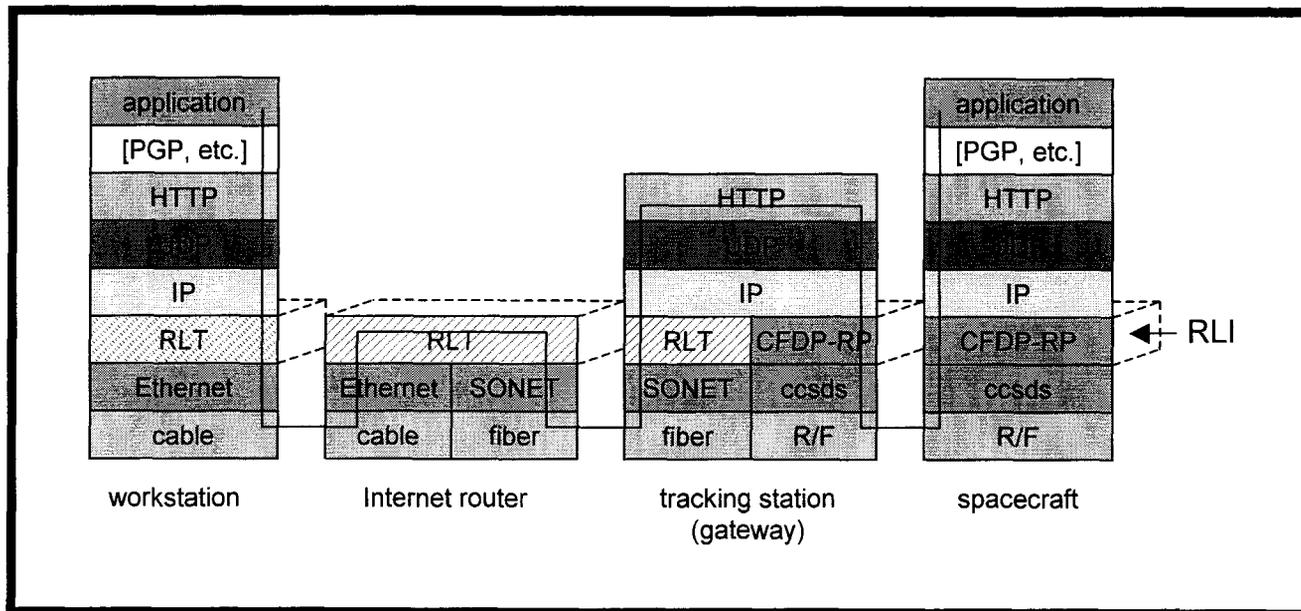
Example of Bundling Data Flow

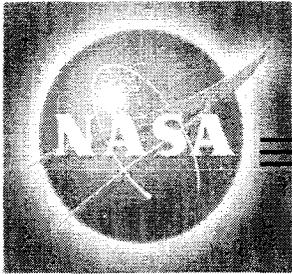




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Example of Tunneling/RLI Data Flow

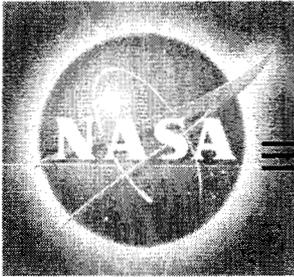




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Summary

- ◆ Emerging network configuration problems are difficult to handle by simply extending the Internet.
- ◆ Delay-Tolerant Networking generalizes the Internet architecture to address these problems in a simple, robust way.



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1. Interplanetary Internet: An Architectural Framework for Space Internetworking: Adrian Hooke
2. User Data Services for Internet Based Spacecraft Applications: Joe Smith
3. CCSDS File Delivery Protocol (CFDP): Tim Ray
4. Internet Protocol Based Standards for Spacecraft Onboard Interfaces: Joe Smith
5. Standard Spacecraft Interfaces and IP Network Architectures: Jane Marquart
6. Standard Transport and Network Capabilities: Bob Durst
7. Next Generation Space Internet: Standards and Implementation: Keith Scott
8. Secure Space Networking: Howie Weiss
9. Delay Tolerant Networking: Scott Burleigh
10. CCSDS Link Layer Protocol Suite: Greg Kazz

