Jet Propulsion Laboratory
California Institute of Technology

Technical Issues in Implementing DTN in a Flight Software Architecture

Amalaye Oyake{@jpl.nasa.gov}

Jet Propulsion Laboratory
California Institute of Technology

Introduction

- The Delay Tolerant Networking is an approach to computer network architecture that seeks to address the technical difficulties for communicating in environments which lack continuous network connectivity.
- In a DTN, asynchronous variable-length messages (called bundles) are routed in a store and forward manner between participating nodes over a heterogeneous network.
- Examples of nodes in challenged environments include submarines and spacecraft in deep space.
- For the spacecraft environment, all of the enabling technology is available today.

Enabling Technologies

- **Software defined radios (Electra, etc) – already in use.**
- **Fixed UHF master sequence and request profiles.**
- **Proximity-1 protocol – already in use.**
- **Ephemeris information:**
  - **Navigation and Ancillary Information Facility (NAIF).**
  - **http://naif.jpl.nasa.gov**
- **FSW DTN implementation (ION).**
  - **VxWorks implementation - completed in Oct 2006*.**
- **Station Allocation Files to tell us when DSN stations are available.**
- **Licklider Transmission Protocol (LTP) – completed Aug 2007*.**

DTN for Flight Software Applications

- VxWorks is the primary real time operating system used for developing spacecraft FSW at JPL.
- DTN provides a standard method of end to end communication between these disconnected entities.
- An RTOS (VxWorks/RTEMS) implementation would enable more sophisticated spacecraft communication.
- Goal: Port Linux implementation of DTN to an onboard RTOS implementation (VxWorks and RTEMS).

Porting Steps and Issues

- Resolving discrepancies between Linux and VxWorks
- Combine object files into one large object file and load file into VxWorks
- Issue: Reallocation does not fit into 24 bits: Some architectures have instructions that use less than 32 bits to reference a nearby position in memory. Recompile the object file using the appropriate "long call" option, -mlongCallOption.
- Differences in TCPIP implementation between VxWorks and UNIX (adding routing, DNS, net mask).
- Big and Small Endian issues resolved.
- Unprotected Memory Model of Real Time Systems.

Porting DTN to VxWorks

- Underlying code (ici, icix, dgr) ported from Linux to VxWorks. Platform independent layer created.
- For AMS ~ Ported the expat XML parser from Linux to VxWorks, in order to load the AMS MIB XML file.
- Enabled Pthreads, NFS, routing tables, TCP send and receive buffers.

Porting DTN to VxWorks

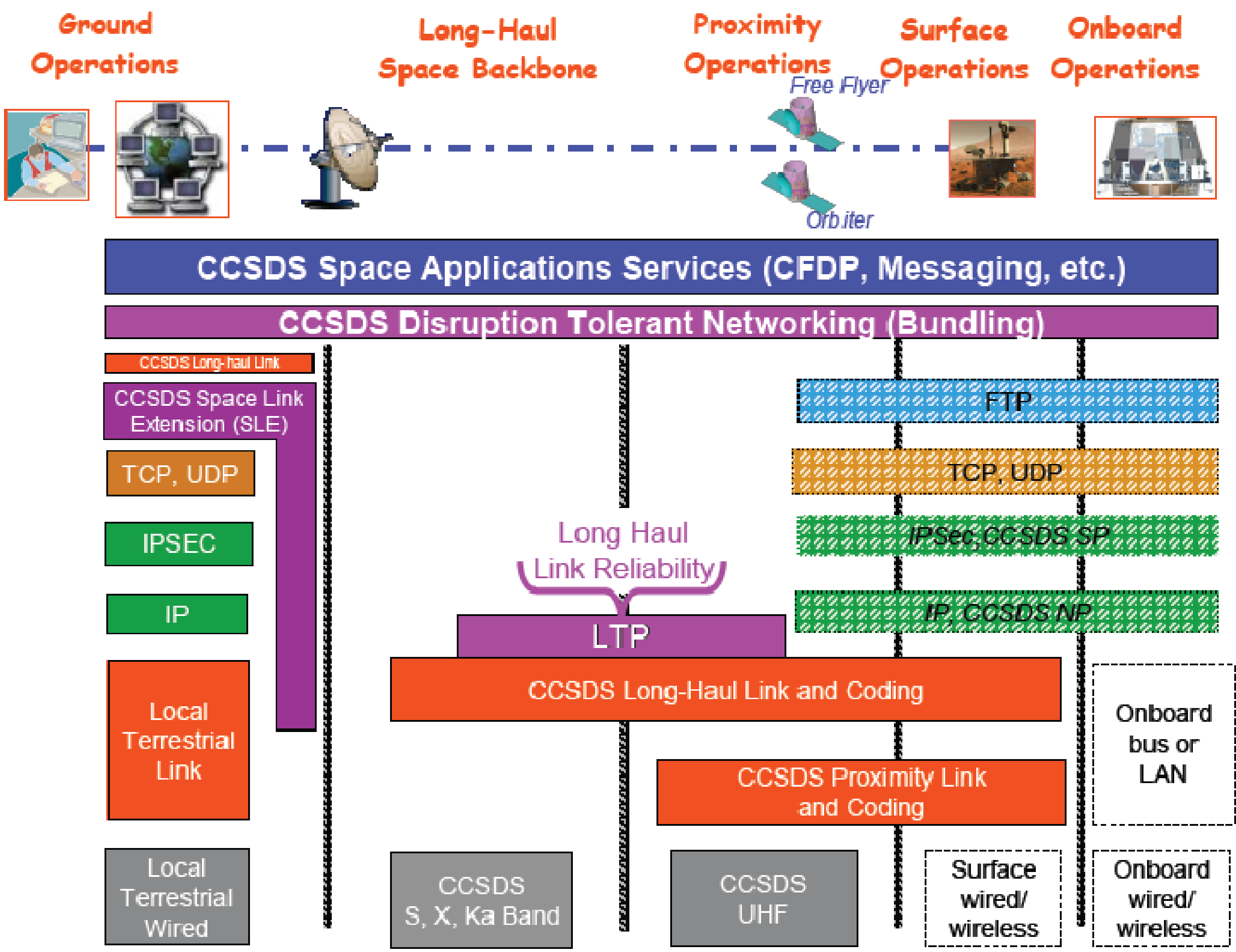
- **Aligning wall clock and free running clock on the VxWorks board.** ***This was a huge issue, which was only exposed after hours of testing. If the clocks are not set up correctly, functions like pthread_cond_timedwait will fail. The clocks are aligned by aligning the tick count and clock settings tickGet(), clock_settime(CLOCK_REALTIME, &now), etc***

- **Enabled time slicing so that threads of equal priority do round robin scheduling (kernelTimeSlice(int X)). Failure to do this causes functions like pthread_cond_timedwait to block.**

- **For precision timing you may want to use the high precision clocks of the BSP. In VxWorks you can enable TIMESTAMP in config.h and configAll.h (both places).**

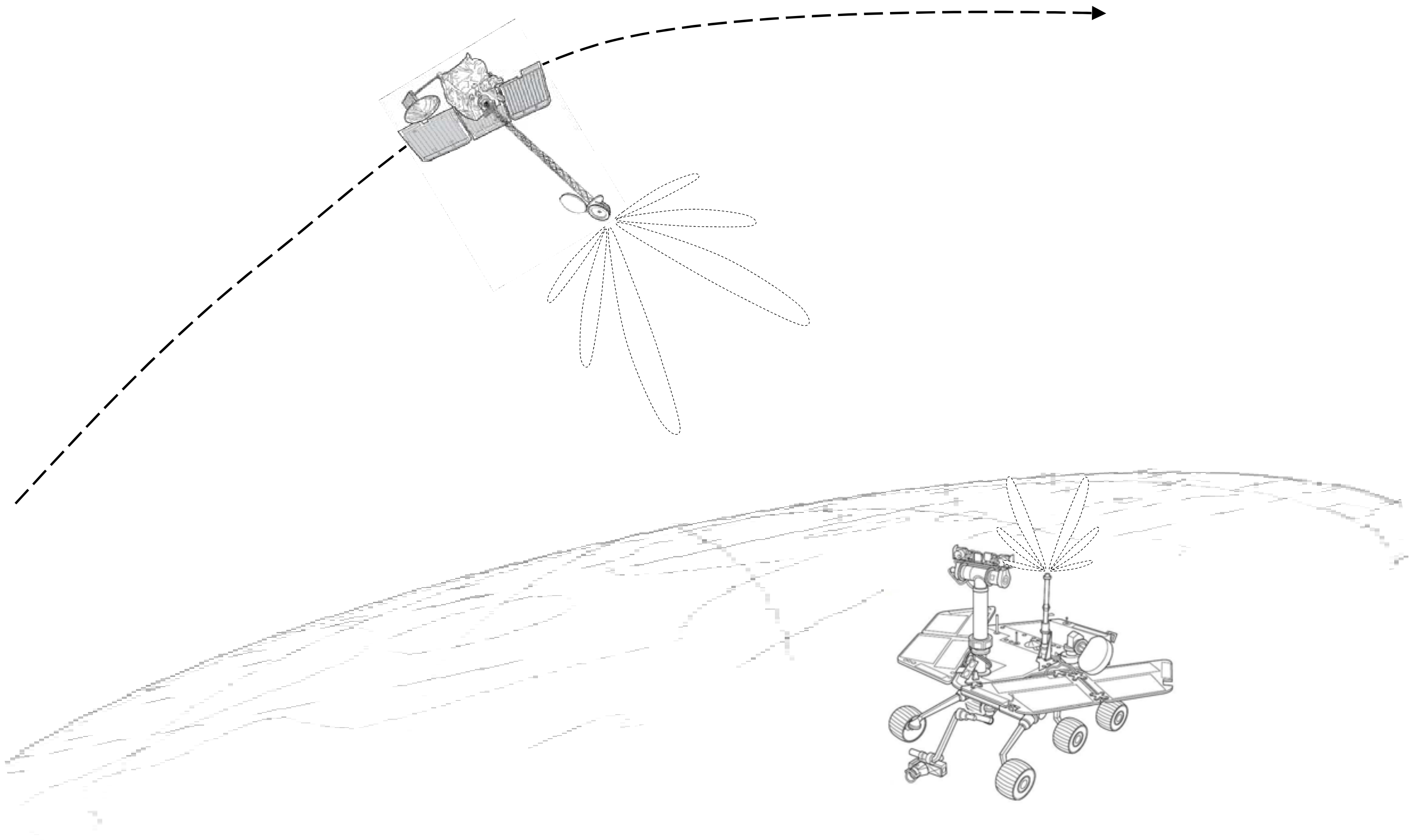
DTN Operational Scenarios

JPL – October 2006



Source: Wallace Tai, JPL

Scenario 1: Autonomous Relay Operations



Scenario 1: Autonomous Relay Operations

Enabling technologies include:

- **Software defined radios (Electra, etc).**
- **Fixed UHF master sequence and request profiles.**
- **Prox-1 protocol handshake and bundle transfer.**
- **Ephemeris information may not be needed.**
- **FSW DTN implementation (ION).**
  - **VxWorks implementation completed in Oct 2006.**
  - **RTEMS (used by ESA) implementation in progress.**

Scenario 1: Autonomous Relay Operations
Fixed UHF Master Sequence And Request Profiles

- **UHF communication occurs during opportunistic communication windows, which may occur several times a day/sol.**

- **The UHF communication profile contains information such as *pass ID, window id, transition start time, duration of communication, max elevation of orbiter, data volume (forward and return links), down link rate, coherent/non coherent communication, Is this pass a command pass?, shall the pass be requested?, communication start time,* etc**

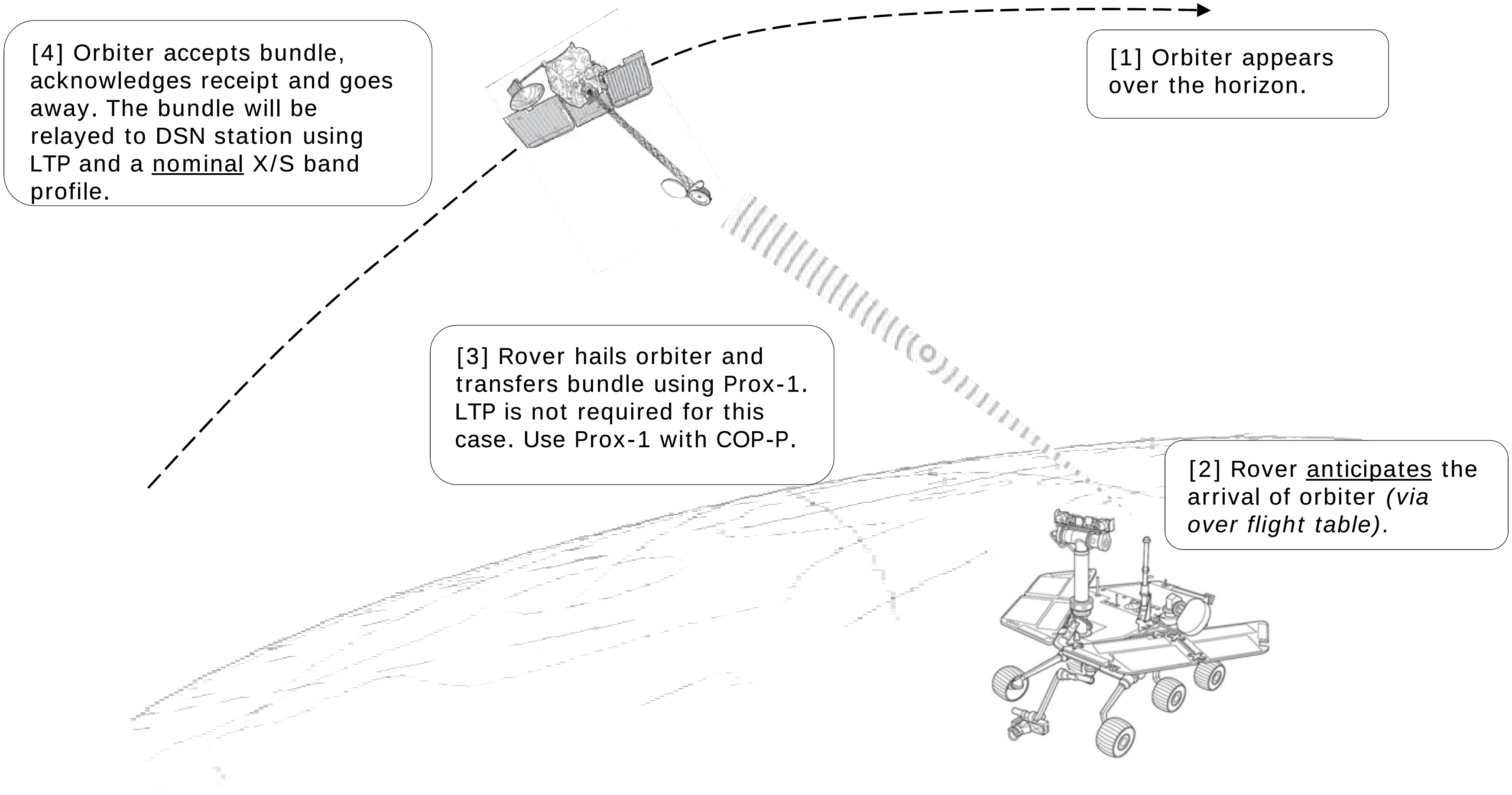
- **Create a set of standard UHF profiles**
  - **Skip Sol, Nominal, High Priority and Emergency profiles.**
  - **Table driven profiles.**

- **Only one element (the ground element) may need to know when the orbiter is overhead. At most the rover will need to do a turn to maximize communication link.**

Scenario 1: Autonomous Relay Operations
Proximity-1 Protocol

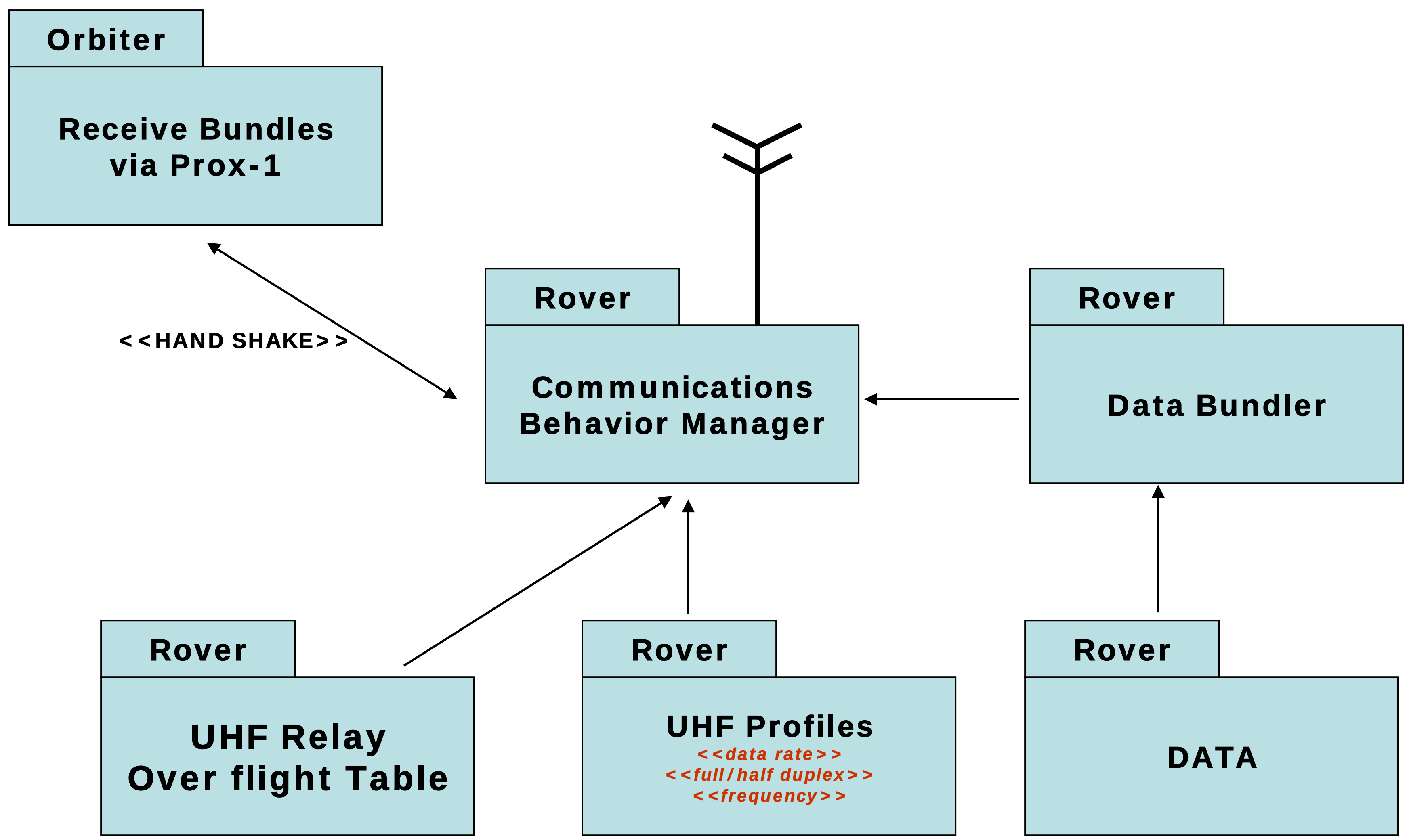
- **Use Proximity-1 and COP-P protocol using the Electra UHF radio.**
- **Proximity-1 is a short haul delivery protocol designed to establish a two-way communications link between a lander and an orbiter, negotiate data rate and communications mode, and reliably deliver data during short orbiter-to-surface contacts.**
- **COP-P provides reliability by retransmitting lost or corrupted data to ensure delivery of data in sequence without gaps or duplication over a space link.**

Scenario 1: Autonomous Relay Operations



Amalaye Oyake, January 2007 ... keywords DTN, LTP

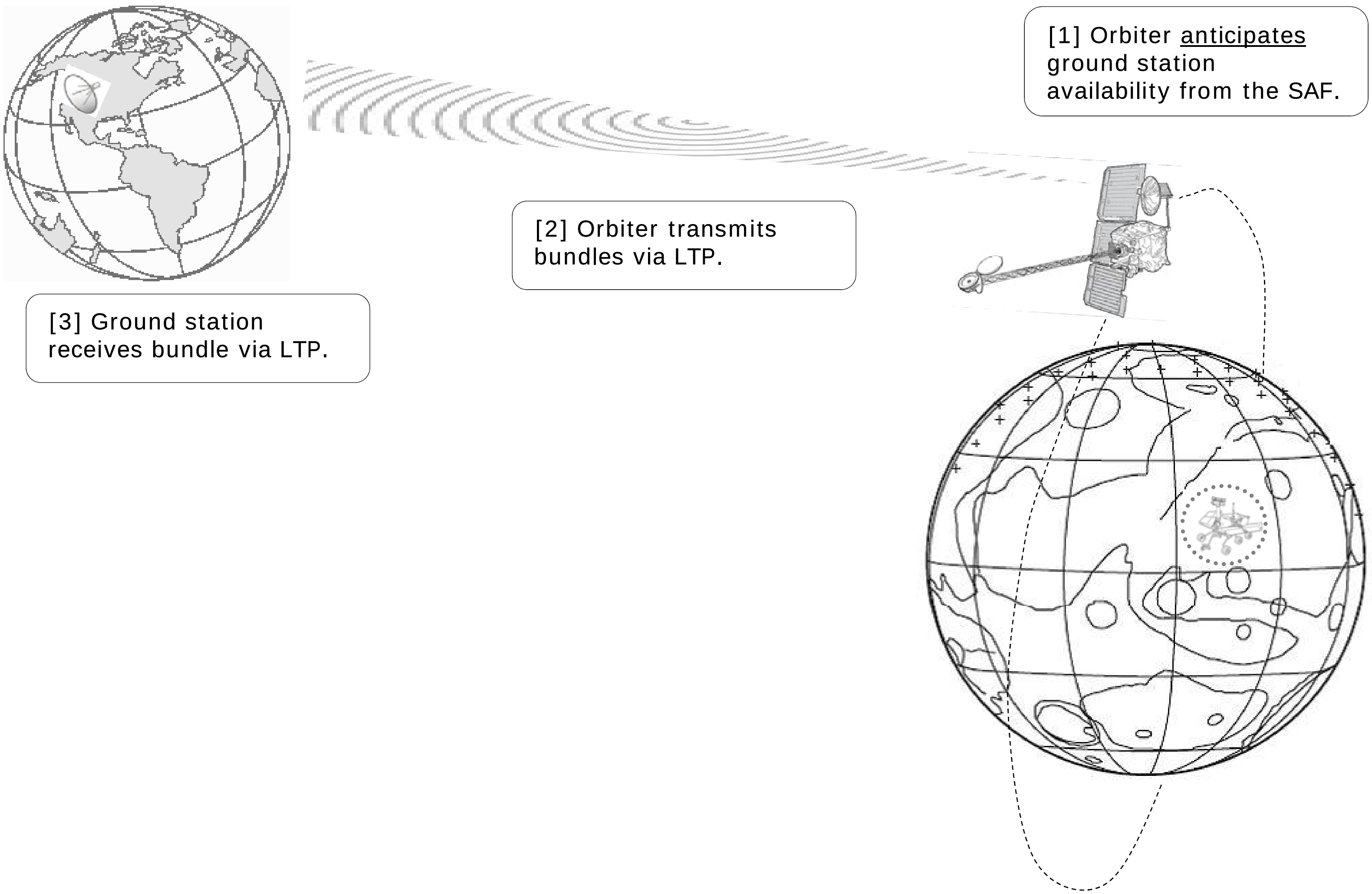
Scenario 1: Autonomous Relay Operations
Lander-Orbiter Software Implementation



Scenario 1: Autonomous Relay Operations Other Issues

- The Orbiter will accept as many bundles as its bucket can accept, it must not buffer overflow.
- Does the bundle protocol handle buffer overflow on the receiver side?
- Bundle Protocol metadata has a slightly higher priority than the Bundle Protocol data.

Scenario 2: Autonomous Deep Space Communications



Scenario 2: Autonomous Deep Space Communications

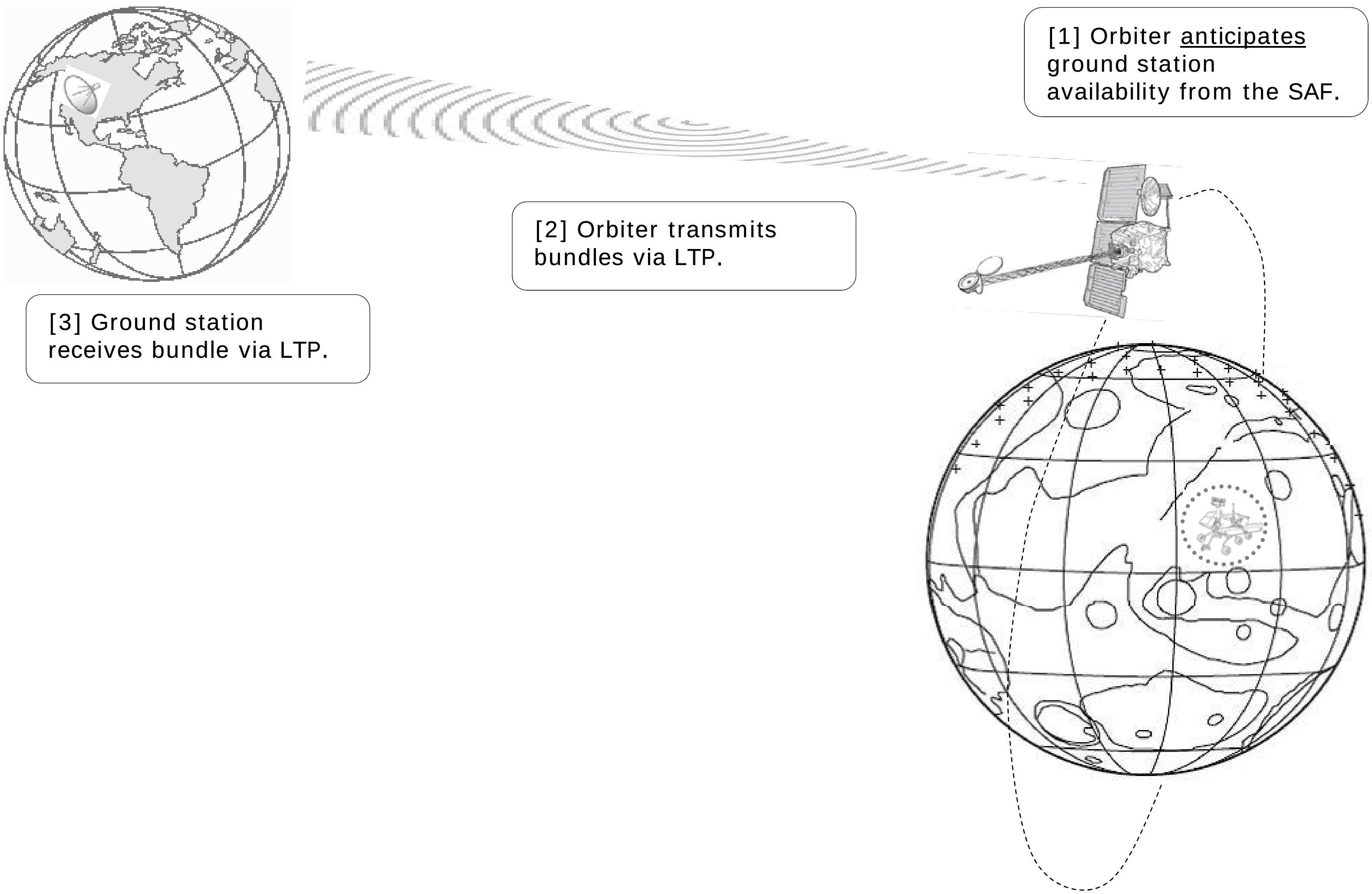
Enabling technologies include:

- Licklider Transmission Protocol (LTP) which is a point-to-point protocol aimed mainly at deep space long-haul links. LTP is seen as a protocol that underpins bundling, so that bundles are transported over LTP on long-haul links.
- FSW DTN implementation (ION).
  - VxWorks implementation completed in Oct 2006.
  - RTEMS (used by ESA) implementation in progress.
- Station allocation files (SAF) – orbiter knows when ground stations are available.
- Ephemeris information needed for instrument pointing. NAIF library provides this.
- Fixed X/S/K band communication profiles.

Scenario 2: Autonomous Deep Space Communications

- Given updated station availability (via the SAF), the orbiter knows when ground stations are available.
- The spacecraft points it high gain antenna to earth and begins radiating (via NAIF).
- The spacecraft begins forwarding bundles via LTP.
- The ground station receives bundles it's LTP proxy.
- The station acknowledges receipt of the bundles.
- Data is then purged from the orbiter <u>automatically</u>.

Scenario 2: Autonomous Deep Space Communications



The Licklider Transmission Protocol

- The Licklider Transmission Protocol (LTP) aka *Long-haul Transmission Protocol* is designed to provide retransmission-based reliability over links characterized by extremely long message round-trip times and/or frequent interruptions in connectivity.

- LTP is named in honor of JCR Licklider , one of the pioneers of ARPANET who envisioned having interplanetary links a long time ago.

- Communication in interplanetary space is the most prominent example of this sort of environment, and LTP is principally aimed at supporting "long-haul" reliable transmission over deep-space RF links.

The Licklider Transmission Protocol

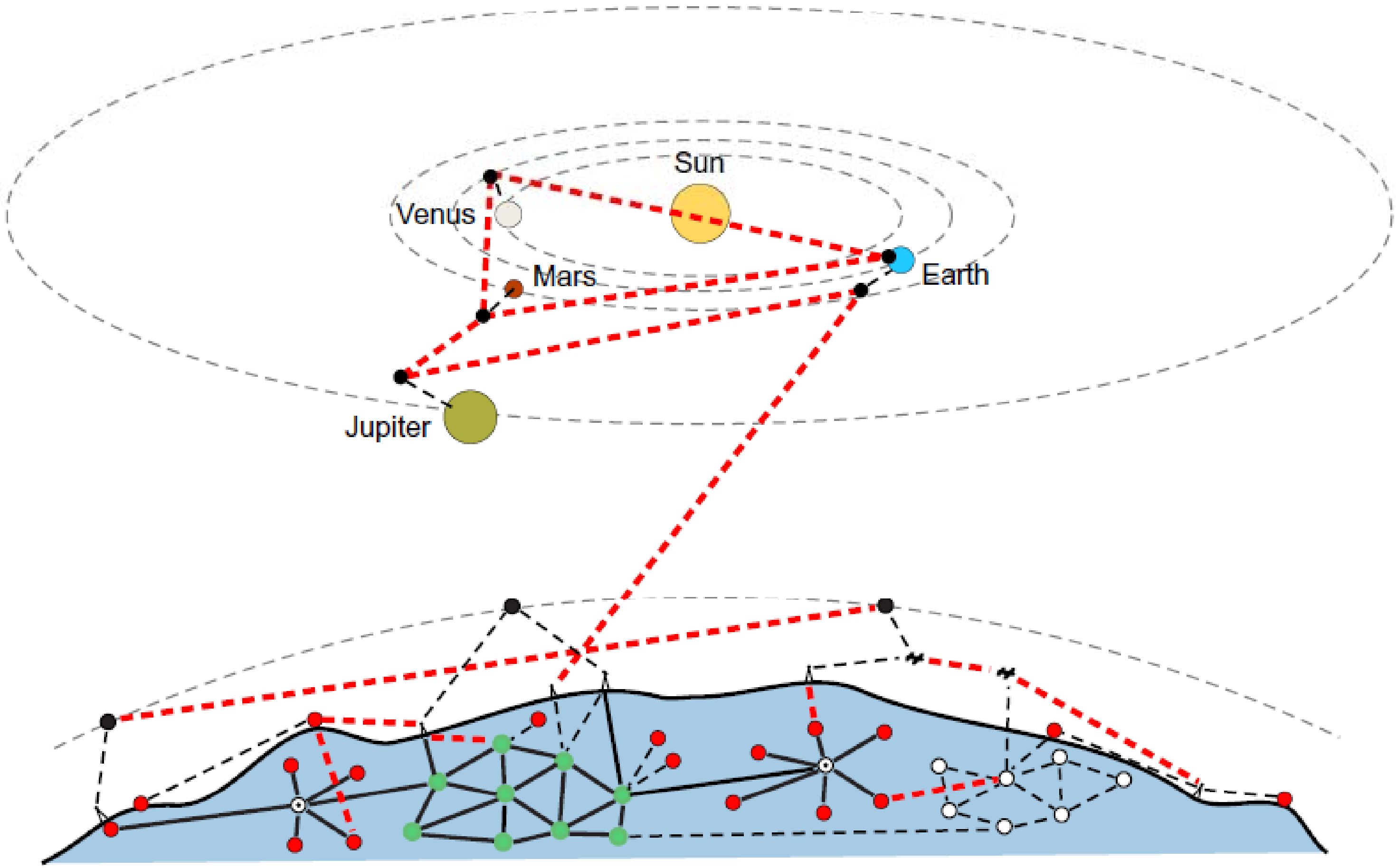
- LTP is designed to provide retransmission based reliability of data transmissions over deep-space RF links. In the bundling protocol stack designed by the Delay Tolerant Networking Research Group DTNRG , it serves as a reliable datalink convergence layer for deep-space links.

- Deep-space links have many constraints constraints: Extremely long signal propagation delays, on the order of seconds, minutes, or hours rather than milliseconds. Frequent and lengthy interruptions in connectivity. Low levels of traffic coupled with high rates of transmission error. Meager bandwidth and highly asymmetrical data rates.

- These environmental characteristics - long delays, low and asymmetric bandwidth, intermittent connectivity, and relatively high error rates - make using unmodified TCP for end to end communications in the IPN infeasible.

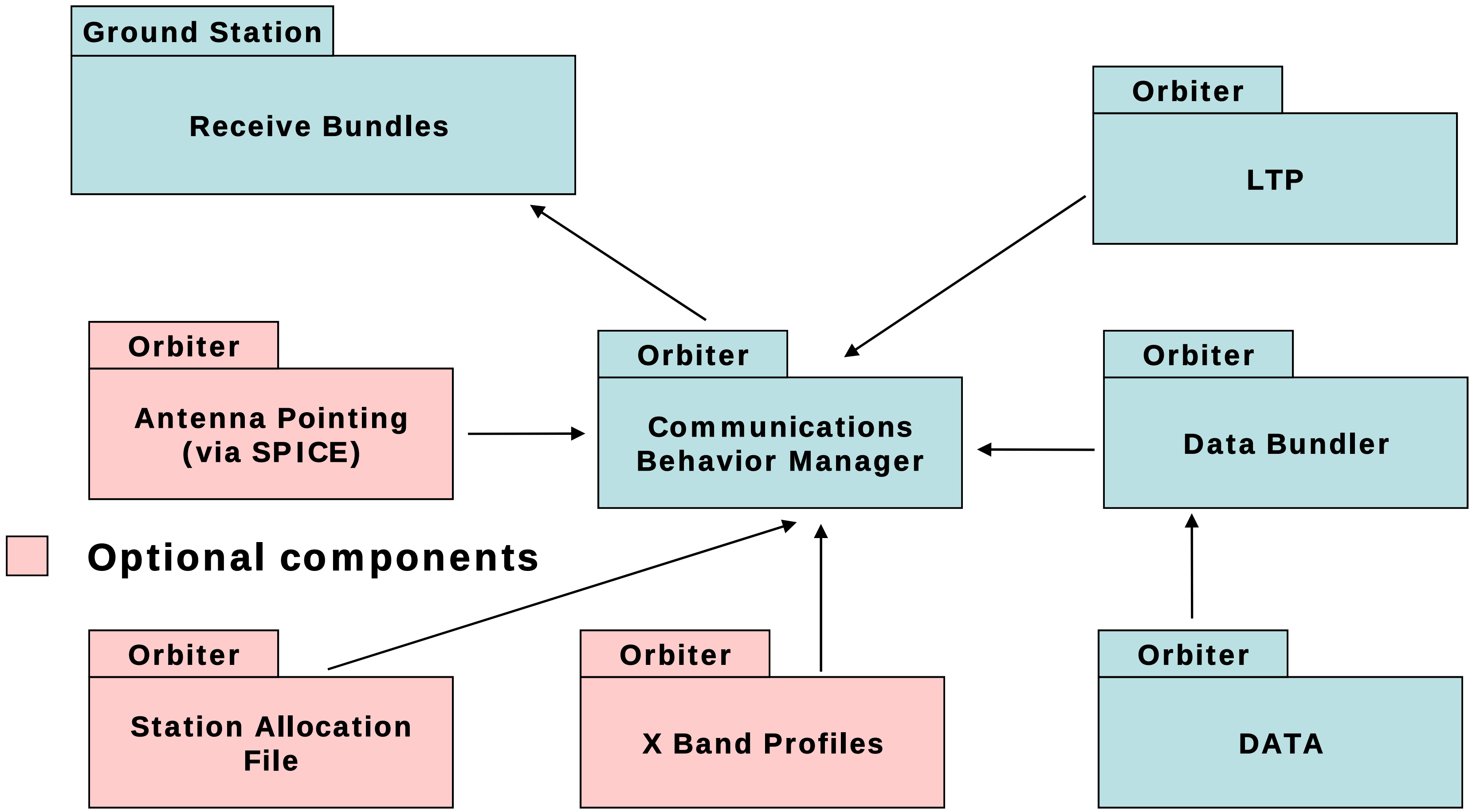
DTN Routing

- We are experimenting with a dynamic routing system for deep space links

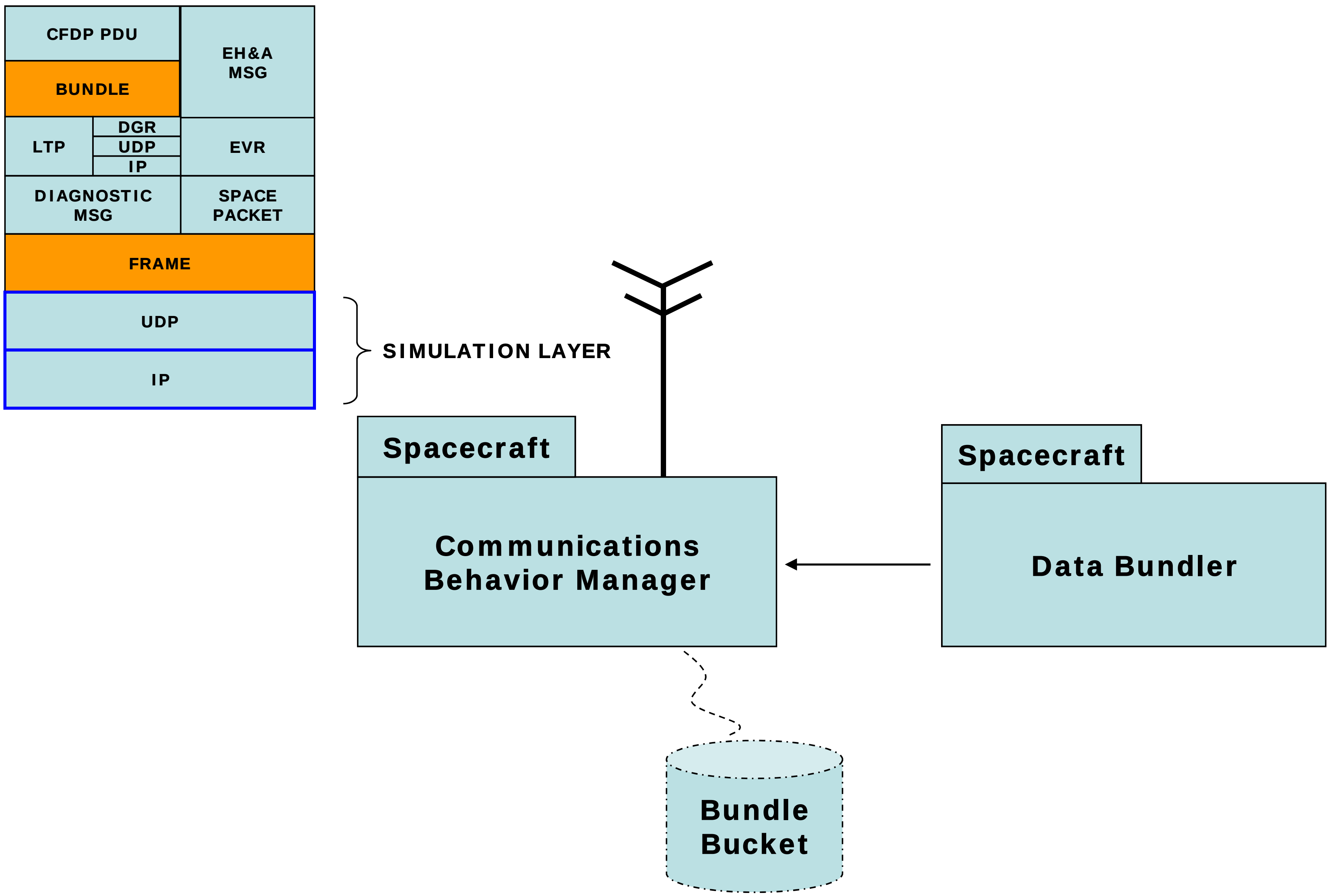


Source: DTN TUTORIAL, Warthman et al

Scenario 2: Autonomous Deep Orbiter-Ground station Implementation



Flight Software Architecture



Amalaye Oyake, January 2007 ... keywords DTN, LTP

Current Use of DTN
NASA Glenn Flight Experiment

- NASA Glenn and SSTL are developing and demonstrating DTN in a LEO flight environment in support of NASA specific needs for Earth Observation and Science.
- Other partners include Universal Space Networks, General Dynamics, Cisco, Air Force Space Battle Lab, Army Space & Missile Defense Battle Lab, Japan Manned Space Missions
- A DTN agent will run onboard SSTL's UK-DMC Satellite, which uses RTEMS as its operating system.
- Goal is to demonstrate DTN Protocols in Space by 9/2007

Current Use of DTN
NASA Glenn Flight Experiment