The Internet of Satellites:
A C&DH Software Framework Built on Open
Internet Standards and Software

Jesse Coffey
Smallsat 2016
Logan, Utah
Capable Cubesats

● Powerful Processors with Small Form Factors
  ○ Beaglebone Black, Raspberry Pi, etc.
● Ethernet Connectivity
  ○ Internal IP network
● Open Source tools
  ○ Massive user base
  ○ Exponentially increases speed of development
● You can now “Fly your Laptop”
Satellite Local IP Network

- Ethernet Switch
- Payload
- Payload
- SW Payload
- Flight Computer
- Radio
- Serial Payload
“Under the Hood” - System Architecture
System Architecture

- **Linux Base**
  - Custom linux build tailored to the Beaglebone
  - Familiar platform for developers
  - Massive user base to provide open source tools and support
System Architecture

- **Core Bus Firmware**
  - Hardware Interface
    - "bent-pipe"
  - CCSDS Spacepacket standard
    - Ubiquitous in current flight software and groundstations
  - Lowest level interface
  - High TRL base
System Architecture

- **Python Library**
  - Open Source - On our GitHub
  - Library for interfacing with the Core Firmware
    - CCSDS Spacepackets
  - Can be used directly to build Python payload applications
    - event-driven applications
    - service based
System Architecture

● **HTTP server**
  ○ High Level
  ○ Internet standards:
    ■ ReSTful API
    ■ JSON data format
  ○ Exposes most common Core functionality

● **Advantages to Payload Developer**
  ○ Familiar protocol
  ○ Wide native or library HTTP support:
    ■ Java, Python, JavaScript, C/C++, C#, ...
  ○ API retains backward-compatibility through hardware upgrades
  ○ Data interchange is standard & intuitive (JSON)
System Architecture

- **Multiple Levels of Abstraction**
  - Low level control and direct access to the Core
  - High level interface for ease of access and development
Example Payload: Antarctic Observation

● **Mission:**
  ○ Support antarctic base research with aerial footage at high temporal resolution.

● **Tasks:**
  ○ Take pictures of area around arctic base
  ○ Process pictures during orbit to measure ice
  ○ Downlink data & satellite health when passing over ground stations in lower latitudes
Example Payload: Design

- **Hardware:**
  - Camera
  - Linux Computer for controlling camera and image processing
    - Raspberry Pi, Beaglebone Black, NVidia Tegra
  - SSD Drive for photo storage
- **Software:**
  - Pick your favorite language…. Let’s say C++
  - Open HTTP Library for communication with the Flight Computer:
    - libcurl - [https://curl.haxx.se/libcurl/](https://curl.haxx.se/libcurl/)
  - Open Source JSON library:
    - JSON for modern C++ - [https://github.com/nlohmann/json](https://github.com/nlohmann/json)
  - Open Source library for image processing:
    - OpenCV - [http://opencv.org/](http://opencv.org/)
Example Payload: Payload <---> Bus

- Check for pass over antarctic to take photos:
  - GET /gps/state
    - Response: {lat: 84, long: -44, altitude: 235}

- Request to point camera at targets:
  - POST /adcs/attitude

- Send data to flight computer for downlink on next pass:
  - PUT /payload-01/telemetry-downlink
    - Body: {measurement_1: 344, measurement_2: 874, …}

- Check for commands from ground to downlink raw data:
  - GET /payload-01 commands

- Send raw files to be downlinked:
  - PUT /payload-01/data-downlink
Example Payload: Payload <---> Bus

- Check for pass over antarctic to take photos:
  - GET /gps/state
    - Response: {lat: 84, long: -44, altitude: 235}

- Request to point camera at targets:
  - POST /adcs/attitude

- Send data to flight computer for downlink on next pass:
  - PUT /payload-01/telemetry-downlink
    - Body: {measurement_1: 344, measurement_2: 874, ...}

- Check for commands from ground to downlink raw data:
  - GET /payload-01/commands

- Send raw files to be downlinked:
  - PUT /payload-01/data-downlink

Data and Commands are human readable
Pumpkin Mission Architecture

User Programs \rightarrow HTTP \rightarrow Ground HTTP Server \rightarrow UDP/IP \rightarrow Ground Station

Payload \rightarrow HTTP \rightarrow Flight HTTP Server \rightarrow UDP/IP \rightarrow Flight Radio

RF
Example Payload: Ground Station <---> Ground Applications

- **Same Interface on Ground**
  - Payload data pulled into cloud database for analysis
  - Command/control remote from ground stations
  - Phone alerts about satellite health, pass information, etc. sent to dish operators & mission engineers.

- **Design an App for your satellite**
Development Status

● **Beta Release Ready:**
  ○ Core Bus Firmware
  ○ Python Libraries
  ○ HTTP/ReST Server Bus - Payload

● **In early development:**
  ○ Ground station HTTP server
Conclusion

- Powerful flight computers for Cubesats are here
- Adopt web standards for easy integration
- Modular and Open Source Systems speed up development
Thanks...

- Shaun Houlihan
- Austin Small
- James Womack
- Devlyn Nelson
Goals

● **Reliable**
  ○ Leverage as much flight heritage as possible
  ○ Compartmentalize mission specific code

● **Capable**
  ○ Fully utilize all onboard hardware
  ○ Allow access to all levels of the system

● **Compatible**
  ○ Fits into current systems seamlessly
  ○ Use widely adopted hardware/software standards

● **User friendly**
  ○ Provide multiple levels of abstraction
  ○ Enable everyone from novice to veteran developers
  ○ Open source
Pumpkin Mission Architecture