Acknowledgements

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Forward

This document contains the panelist presentations, out-brief charts, and discussion notes from the GSAW 2014 Session 11C Working Group titled “Current and Future Ground Systems for CubeSats.”
Outline

• Session Goals
• Presenters/Panelists
• Key Points
• Conclusions
• Way Forward
• Appendix A: Presentations & Notes
• Appendix B: Detailed Working Group Discussions
Working Group Outbrief

Ground System Architectures Workshop

Session 11C
Current and Future Ground Systems for CubeSats

Catherine Venturini, The Aerospace Corporation
Thom McVittie, NASA Jet Propulsion Laboratory-CalTech
Session Goals

- Understand what makes a CubeSat Mission different from a ground system perspective?
- Identify key Misconceptions about CubeSats.
- What are the CubeSat issues that affect ground systems today?
- What are the ground system issues that would affect future CubeSat missions?
Ground System Architectures Workshop

Presenters/Panelists

• Dr. Charles Norton – NASA JPL-CalTech (See Charts Appendix A)
  – Technology maturation mission in development
  – Constellation concepts, mission concepts for beyond LEO
• Mr. Bryan Klofas – SRI International (See Charts in Session 9)
  – Communications, RF issues
• Major Dave Illsley – NRO (No charts)
  – Government reference architecture
  – Acquisitions & ConOps (CubeSats as part of bigger mission architectures)
• Dr. Jamie Cutler – University of Michigan (See Charts Appendix A)
  – Bridging Student Education, Innovative Research & Entrepreneurial Vision
  – Future ground system needs
Key Points

- Large diverse & vocal community (we learned a lot)
- Real need for the community to come together to address key issues
  - CubeSat “unique” characteristics that drive Ground Systems
    - Number of CubeSats, bandwidth/power, development schedule
    - Mission ConOps Driven
  - Ground System Cost
    - Are CubeSat contact costs any cheaper than traditional sats?
  - New operations concepts
    - Keeping the ground system relevant from a technology and user-needs perspective
  - Where do standards make sense?
  - How do we share and leverage ground capabilities within the community? Are we at a tipping point?
• Definite interest in continuing the conversation
• CubeSats are rapidly increasing in complexity and capability
• Operational needs require us to think about 3 families of CubeSats
  – Government, Research/University, Commercial
• Certain aspects of ground systems are ripe for standardization
  – Ground Station Scheduling/planning
  – Ground Station to MOC interfaces
• Cost/Benefit for different ground system strategies isn’t well understood
  – Federated support
  – Build your own
  – Commonality across the three families
Way Forward

• Present key points and conclusions at other venues to gather additional feedback e.g. Space Ops 2014, Cal Poly CubeSat Developer Workshop

• If there is enough interest, continue the working group conversation
  – Establish focused topics for discussions
  – Identify action items or goals for the group

• Don’t want to reinvent the wheel
  – Support the Small Sat/CubeSat community
  – Integrate with ongoing efforts
Appendix A: Presentations & Notes

Charles Norton – JPL
Major Dave Illsley – NRO
Dr. Jamie Cutler – University of Michigan
Brian Klofas – SRI
Jonwa Kim – SMC/XR
Lyle Abramowitz – Aerospace Corp.
Lt Alan Frazier – SMC/XR
Paul Blanchard – L3 Communications
Presentation:
*Current and Future Ground Systems for Cubesats*

Dr. Charles Norton
Jet Propulsion Laboratory
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Notes: Dr. Charles Norton, NASA JPL-Caltech

• JPL Presentation
  – **IPEX**: Produce near-real-time data products
  – **Grifex**: high frame-rate focal plane tech validation
  – **RACE**: Science observations flight test towards using constellations for atmospheric measurements
  – **Isara**: 100 Mbps Ka band downlink in LEO
  – **LMRST**: radio transponder for calibration of DSN
  – **Inspire**: Interplanetary test bed for science and stereo magnetometry
  – **Luna Flashlight**: Solar sail reflector concept
  – **NEA Scout**: Astroid characterisation concept
  – **Relic**: ~30 vehicle constellation concept
  – **Sentinel**: Earth-Sun L5 space weather constellation concept
Notes: Major Dave Illsley, NRO (no charts)

• NRO CubeSat program office
• Cultural challenges
  – *CubeSats thought of as smaller versions of big satellites*
    • Big mistake, miss the potential
    • Need to use them properly
      – Acquisition process
      – Technology: Physical differences
      – Ground systems: CONOPS
    • How we use them
      • What’s the best use
  – Have to fight cultural issues
• Short acquisition timeline
  – Growing acquisition workforce
Notes: Major Dave Illsley, NRO cont.

• Next generation bus
  – Government owned design
  – Lawrence Livermore National Laboratory (LLNL) is the lead for development
  – Modular, scalable
  – Ready to compete for build in 2015

• Chicken-egg problem
  – Need to show capability
  – Real capability (regardless of mission) is strength in numbers

• CONOPS
  – Need to approach very differently
  – Can’t afford stove-pipe system
  – Have to look at differently
    • Command and control
    • Where we locate ground stations
• Audience Questions:
  – *Is anyone keeping track of CONOPS and rhythm to put together CONOPS and structure*”
    • Their office is working with OSL to follow processes before/during/after launch
    • Keeping track of details to see what is applicable
  – *Colony 2 ground architecture and what is going to be different?*
    • Colony 2 uses MC3 ground station nodes.
    • Like Colony 2, next gen bus would use UHF and S-band to use MC3
Presentation:

*Thoughts on Imagining the Future with CubeSats*

Prof. James W. Cutler  
University of Michigan  
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[http://exploration.engin.umich.edu](http://exploration.engin.umich.edu)

Notes: Dr. Jamie Cutler, University of Michigan

- Launch about 1 cubesat/year
- Peach Mountain retrofitting for tracking
  - *Upgrading 26 meter dish for deep space ops*
- CubeSat teams have to consider the end-to-end systems
- Need ground networks to support low-cost operations
- Modeling capacity and schedule of ground networks
- Federated networks using open source software
- Audience questions
  - *What is the orbital plan for launch?*
    - Yes, working with the launch provider. Must show deorbit plan.
Notes: Bryan Klofas, SRI International

• See briefing charts in Session 9
• Use the SRI Allen array in California
Notes: Jonwa Kim, SMC/XR

- SENSE launch November 19, 2013
- Going through LEO on-orbit checkout
- Pathfinder for SMC operational CubeSats
- Using NRL Common Ground Architecture (CGA)
  - Blossom point antenna
  - Manzano antenna
  - Some AFSCN contacts
- 18 month contract award to delivery
  - Rapid acquisition not usually seen
- Spacecraft are complex vehicles compared to some educational systems
- 7-man crew doing ground ops for 2 vehicles, goal is to move to lights-out
- Lessons learned are being flowed into the NRO Colony 2 and next gen programs
Notes: Lyle Abramowitz, Aerospace Corp.

- Some problems with ground
- ORS-3 mission deployed 30 objects
  - *Considerable difficult to get TLEs*
  - *Took a couple of weeks*
- Perhaps put corner reflectors and/or beacons?
- People who had low-frequencies had the quickest acquisition
- As missions progress low-latency will be more desired
- Frequency management is a difficult process
  - *FCC is taking an interest in the debris problem and must document*
Notes: Lt. Alan Frazier, SMC/XR

- Using CGA
  - *Were able to change the ground software within one orbit pass*
  - *Very flexible system was beneficial*
Notes: Paul Blanchard, L3 Communications

- COTS Package in-control for ground station
  - GPS in factory
  - Inmarsat on-orbit
- Ground system
  - Cubesats could build
  - Pay too much
- Developed a pricing model for APL that reduced costs
  - Agreed to use the process as-is, no PDR, CDR
- University of Colorado using their product
- COTS packages can do 92-95 percent of requirements
Appendix B: Detailed Working Group Discussions

Discussion Charts and Notes:
Common CubeSat Myths
What makes a CubeSat Unique?
What is the role of Standards?
Do we need a Ground Reference Architecture?
How about Federation?
Common CubeSat Myths:

• Myth #1: “A CubeSat is a CubeSat is a CubeSat”
  – Panel and audience discussion presented a wide variety of CubeSat designs and missions.
  – Significant differences in:
    • Destinations (LEO, lunar, planetary?)
    • Configurations (singletons, constellations, swarms)
    • Capabilities (particularly in navigation/position, communications, propulsion)
    • Required Data Rates (1200 baud -> Mbits/sec)
    • Operational use (adhoc science -> time critical mission data)
      – Impact on the number of passes and predictability of data completeness & latency
    • Business Models (lowest possible individual cost -> sustained fleet operations)
  – Conclusions:
    • Operational needs require us to think about 3 families of CubeSats
      – Government, Research/University, Commercial
    • Need to understand which ‘market’ we are serving to size the capability to the different classes of mission
    • Mission Characteristics/ConOps has a major influence on determining which is the relevant family, e.g., flight qualifying an instrument might be classed as Research rather than government, regardless of the funding agency.
Common CubeSat Myths:

- Myth #2: “CubeSats are small things with low data rates that have little or no impact on our ground systems”
  - The number of CubeSats being launched is increasing rapidly, so significantly more spacecraft to contact and command/control.
  - While CubeSat missions can be short, many continue to operate after several years.
  - CubeSats require as much effort to track as a larger mission.
  - CubeSats may stress the Ground Stations more – lower power, smaller antennas.
  - CubeSats have highly constrained processing power which may put more of the work on the ground system. (planning, system management, safing and fault diagnostics, etc.)
  - CubeSat development schedules can be very short (e.g. NRO 18 months from idea to operations) which significantly reduces the amount of time to develop/customize, test and integrate the ground system.
  - CubeSats would likely be as highly specialized as possible, which would require the ground systems to be as flexible as possible.
  - CubeSats have more limited “self position reporting” capabilities and many have limited propulsion, which means the ground will need to perform traffic control functions.
Common CubeSat Myths:

• Myth #2 (cont.): “CubeSats are small things with low data rates that have little or no impact on our ground systems”
  – Conclusions:
    • CubeSats have a variety of characteristics that drive the capabilities/design of Ground Systems.
    • Potential areas where we need to rethink the Ground System’s role and capabilities:
      – Approaches to providing cost-effective communication infrastructure
        • Repurposing unused apertures and crowd-sourcing communications (particularly for receive-only)
        • Dealing with multiple CubeSats in the same beam
        • Opportunistic use of side-lobes and unused bandwidth. (second tier customer)
      – Rethinking how we schedule/request aperture time
        • Exchanges or market places
        • CubeSat Consortia
      – Approaches interacting between multiple apertures and the mission ops center
        • Commands via “pager-like” satcom, and downlink distributed via “bit torrent like” approach.
        • Rethinking the role of standards (Space Link Extension, Delay Tolerant Networking, etc.)
        • What are the security (confidentiality/integrity) needs?
      – Ability to rapidly tailor and test Ground System to meet short development cycles.
      – Role of Ground Systems in providing innovative command/control to get more out of the CubeSat.
What makes CubeSats unique?

- NASA getting over the idea that CubeSats are university only
  - Trying to plan for future post-TDRSS world
  - What are the capacities and data volumes for the future
  - Would take 15 years to build out the infrastructure
  - How can we commoditize sections of the ground to drive innovation and volume

- Recap
  - Relative cost of operations

- Ground system driven by mission requirements
- Bandwidth and power are limiting factors for CubeSat missions and is a big consideration when selecting a ground system solution
Afternoon Discussion Topics*

• What are the key issues from a ground system perspective to better support current and future CubeSat missions?
  – Security for future CubeSat missions
  – Communication licensing and spectrum allocation
  – Identify and track (e.g. lessons learned from recent launches)
  – Coverage, priority, & scheduling (e.g. spacecraft emergencies)
  – Information sharing & access
  – Usage of standards - interoperability and reuse
  – Proprietary vs. government reference architecture
  – Enabling development of new technology

• How to “share” or leverage current ground capabilities within community?
  – Federated vs. stand alone communications approaches
  – Scheduling and management of contacts
  – Buying shared contact time
  – Changes to support higher data rate communications

*Topics highlighted were selected by audience vote.
Topic: Usage of Standards

• Question:
  – What are the areas where standards may be beneficial?
    • Flight/ground?
    • Ground station to Mission Ops Center (MOC)?
    • Within the MOC?
    • Across Missions?
Flight/Ground Standards

- CCSDS standards (framing, packetization, on-board messaging, etc.) not usually picked for CubeSats
  - Considered by some as being too “heavy weight”
  - CubeSats grew up in the “IP in space era” and CCSDS only recently starting to adapt its framing standards to supporting IP encapsulation.
- As CubeSats need to access shared mission infrastructure (agency level communications resources, COTS tools, etc.) we may need to revisit the role of standardized interfaces
  - CubeSats can’t ask for a unique interface without incurring a large cost.
  - Need to revisit where standards exist, and whether there is a need/business case for making the transition.
- Universities may not have experience using CCSDS, both organizations could benefit from re-opening the discussion.
Ground Station to Mission Ops Standards

• Standards for how users:
  – *Schedule & configure contacts and aperture time*
    • University of Michigan has a proposed XML standard
    • CCSDS Service Management spec is also a possibility
      – Also the CCSDS Orbital Ephemeris Message
  – *Collect and transport command and data*
    • GENSO (focused on small UHF receivers)
    • CCSDS Space Link Extension – extending frame services from stations to MOC via IP

• Concerns:
  – *Standards need to be very lightweight and easy to adopt.*
    • Any potential for open source implementations?
  – *GENSO was a good start, but the standardization process made it difficult to use/adopt.*

• Seem to be several good candidates, but need to understand how the standards (and the standardization process) would interact with the faster and sometimes looser CubeSat development approaches.
Within the MOC Standards

- Standards for how users:
  - *Connect various components of the MOC*
    - Messaging bus – such as GMSEC
  - *Configure the MOC for a mission*
    - XML telemetry and command dictionary formats
      - CCSDS/OMG XTCE
        - Tailoring for GovSat (several GSAW sessions)
        - ESA & JPL/GSFC also tailoring for their own needs
  - Hope is to make COTS more readily adaptable for CubeSat missions
Cross Mission Standards

• Tracking/Position information
  – Currently difficult to understand/predict location of your CubeSat and it’s neighbors.
  – Large systems generate their own TLEs after launch
    • Predicts from the launch vehicle or communications providers
    • CubeSats are often secondary payload and don’t same same level of information from flight vehicle or primary mission.
  – GPS/self-reporting can be difficult – problems with the Z-axis
  – Unique messages require more resources to handle, a standard scheduling format or message would be helpful
  – TLEs are a standard format, but there isn’t a common standard for how to obtain them.
    • Could benefit from JSPOC standardization

• ‘Registry’ of vehicles planned for launch
  – Enables neighborhood predictive analysis
  – Space debris
  – “Air traffic control”-like capabilities
Cross Mission Standards (cont.)

- Standardized CubeSat mission information & common parameters
  - Goal is to make information sharing and data mining/analysis across missions easier
  - Industry groups working to get GEO folks sharing data, also useful for LEO.
    - Single event upset information
    - Communications/coverage gaps
    - Common definition & access to science data
  - Lots of information being collected/maintained by individual organizations, but very difficult to share. No single group to coordinate making any of this happen.
    - Aerospace Corp. doing internally
      - Only so much data that can be collected
      - Keeping up with recent launches is a challenge
    - SRI keeping a communication table
    - St Louis University has on-line database
  - Concern: if we share out data – others will make money off of us or scoop our results.
  - Needs
    - Define and prioritize the information that needs to be shared
      - Look at the CubeSat standard definition (currently version 12)
    - Identify an organization/consortia that can lead/champion the standardization activity
    - Develop/adopt a standard for data sharing
      - Look at the Maritime AIS standard for data sharing and ID as an example
        - Provides location and maneuver capability
Standards Wrap-up

• Identified several areas which are ripe for standardization. Agreed that we should focus on the interfaces.
• Particularly interest in
  – *Ground-Station to MOC*
    • Contact scheduling, tracking and ephemeris exchange
    • Data exchange standards
  – *Cross-Mission areas.*
    • CubeSat mission registry
      – *What happened to the CubeSat Launch Portal?*
    • Sharing common interest data
• Need to work with community to further refine:
  – *Identify the high payoff points for standardization*
  – *Impediments to data sharing*
  – *Look at the lessons learned from previous standardization efforts*
  – *Determine the right forum to discuss*
    • Suggestion that this be brought up at the CubeSat Developer Conference in April
Topic: Reference Architectures

• Questions:
  – Do we need a reference architecture for CubeSat Ground Systems?
  – If so, who should lead?

• A reference architecture gives a common set of capabilities across the family of vehicles
  – Helps us understand the capabilities we need in common and where we diverge (boutique versus commodity)
  – May provide a basis for reusability and interoperability

• Concerns:
  • Risk is to attempt to cover too many customers with the standard
    – Which families do we consider?
  • Do we allow a marketplace to develop around a standard?
    – Does this take away the ability of vendors to innovate?
    – Will proprietary information make evolution slower/more difficult?
  • Will the speed of change in a reference architecture be able to keep pace with the rapid evolution of CubeSats?
    – How rapidly should the standard evolve
    – Technology changes rapidly, CubeSats launch ~6 months
Reference Architectures cont.

• How to go forward?
  – Need to identify the interoperability points between ground station architectures
    • This would allow different agencies to service each others missions (e.g., provide a federated architecture)
    • Need to address issues such as the wide variation in Security concerns.
  – Look at existing efforts
    • Openstack being worked by larger spacecraft
    • From the university perspective the ground system is released as open source
      – The barrier to entry is fairly low
      – Objective is to get as many ground stations available
  – Who should lead?
    • Observation that we need one group to lead this forward and the community will follow.
    • Government – current focus on next generation bus. Advantage is that it has the funding and organization to manage any changes. But may not be nimble enough.
    • “Build it and they will come” approach is attractive, but …
      – GENSO built it, but once deployed it was out of date
      – Can you react fast enough to make it work out
    • Potentially a good role for an independent agent (maybe the FFRDC community?)
Topic: Moving to a Federated Architecture

• CubeSats have a lot of common needs, but also some that are very unique.

• A federated architecture could allow a lot of flexibility in how missions use common infrastructure while supporting their mission unique needs
  – *Different networks may have different needs for information*
  – *Different operations tempos are supported*
  – *Different scheduling software in use*
  – *Even if schedule standards in place sharing could be difficult*
  – *A market for contacts may be helpful*
  – *Universities barter for time now*
  – *Currently assume the MOC handles the spacecraft details*

• Does the University want to run the ground system?
  – *Should be operated as a service*
  – *No dedicated funding to make this happen*
  – *Are groups that would support if funding were available*