National Aeronautics and Space Administration



#### Creating an Interface to View Multi-Spacecraft Swarm Telemetry



#### Presenter: Elaine Zheng Other Authors: Daniel Cellucci and Steven Hu

1/30/2021

#### Speaker

#### **Elaine Zheng**

#### Software Engineering Intern NASA Ames Research Center ezheng2000@gmail.com



#### Distributed Spacecraft Autonomy (DSA)

https://gameon.nasa.gov/projects/distributed-spacecraft-autonomydsa/

1/30/2021

### Agenda

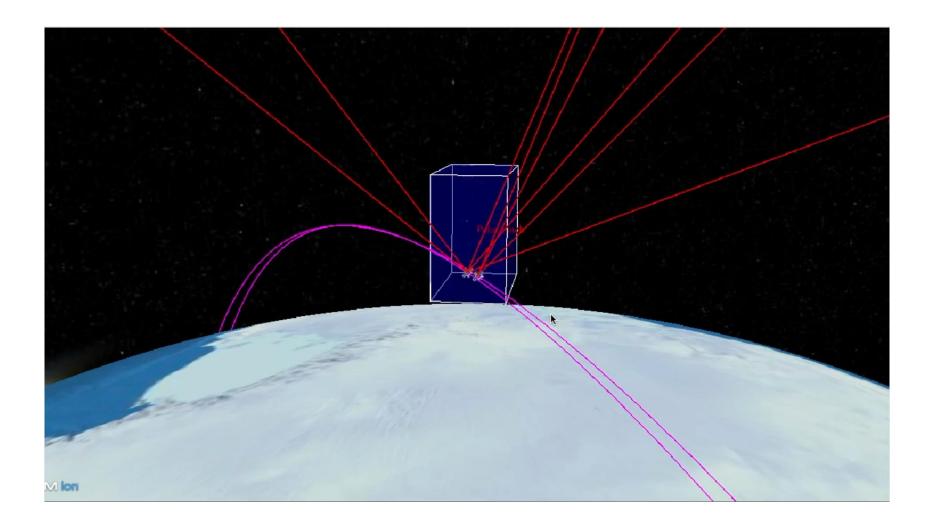
# About DSA Background Use Case Development

### About DSA

#### **Distributed Spacecraft Autonomy (DSA)**

- Software payload on Starling which is a 4 CubeSat NASA mission to develop and advance space swarm technologies
- Goal is to advance scalable autonomy capabilities, command/control methodologies
- Includes two segments, a flight launch and a scalability study tested on ground hardware with up to 100 spacecraft

### Autonomy Demo



1/30/2021



National Aeronautics and Space Administration

# Background

1/30/2021

#### **Human-Swarm Interaction (HSI)**

- Deals with interface between a human and a swarm of robots within a mission
- Part of the Ground Data Systems sub-team within DSA

#### Challenges

- Informational complexity
- Reducing information overload
- Large swarm dynamics



Micro-satellite deployment mission- a constellation of three 1U CubeSats developed by Japan, Nepal and Sri Lanka

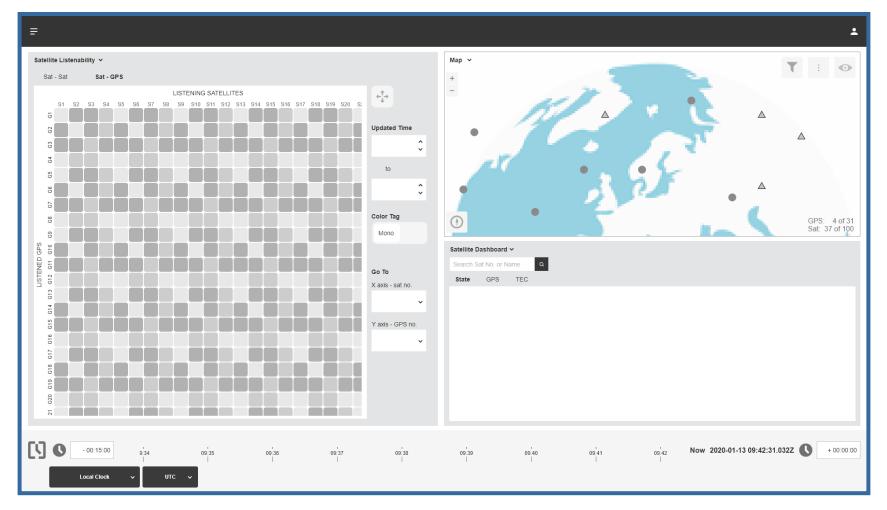
Need to understand the state of the swarm, with the ability to quickly find information of a particular satellite.

#### **Our Approach**

- Divide HSI User Interface into several components
  - Satellite Listenability Matrix
  - Timeline
  - Мар
  - Dashboard
  - Command Builder
- Determine roles associated with each component

#### Interface Design

#### Design created by Yunkyung Kim





National Aeronautics and Space Administration

# Component Roles

#### (Supervisor, Teammate, Operator)

1/30/2021

#### Roles

|               | Supervisor                            | Teammate   | Operator  |
|---------------|---------------------------------------|--|---|
| Interested In | Viewing collective satellite behavior | Details of satellite<br>behavior                         | Controlling satellite behavior                          |
| Mission Goals | Meet overall goals                    | Accomplish mission<br>goals, but does not<br>change them | Complete low-level<br>tasks related to<br>mission goals |
| Examples      | Project Manager                       | Tech Lead  | Operations Team   |

### Supervisor

Assesses system performance against mission objectives and sets command objectives that change the collective satellite behavior to meet the overall mission goals

| atellite Dashboa<br>Sat004 | ard ∽   |          |                          |      |                          |
|----------------------------|---------|----------|--------------------------|------|--------------------------|
| State GPS                  | TEC For | mation   |                          |      |                          |
| Sat No.                    | Azimuth | Altitude | Updated Time 🛛 🔻         | $^+$ | View Direction of Travel |
| > Sat037                   | 12      | 10000    | 2020-01-01 03:20:42.000Z |      | Form                     |
| > Sat076                   | 36      | 5000     | 2020-01-01 03:20:21.000Z |      |                          |
| > Sat040                   | 158     | 20000    | 2020-01-01 03:20:19.000Z |      | Sat076                   |
|                            |         |          |                          |      | Sat037 Sat004<br>Sat040  |

#### Teammate

# Works with satellites in order to accomplish mission goals without explicitly altering those goals

|  |  |  |  | Updated Time                |
|--|--|--|--|-----------------------------|
| TIME   | SAT 1  | SAT 2  | SAT 4  | ÷                           |
| 6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01                    | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, exploi<br>explore: -3.081239, exploi<br>explore: -3.081239, exploi<br>explore: -3.081239, exploi<br>explore: -3.081239, exploi | to                          |
| 6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01  | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550   | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550   | explore: -3.081239, exploit<br>explore: -3.081239, exploit<br>explore: -3.081239, exploit  |                             |
| 6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01                    | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, explor<br>explore: -3.081239, explor<br>explore: -3.081239, explor<br>explore: -3.081239, explor<br>explore: -3.081239, explor | Satellite 1                 |
| 6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01                    | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550   | explore: -3.081239, exploit: 19.165550<br>explore: -3.156822, explort: 25.000022<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, exploi<br>explore: -3.156822, exploi<br>explore: -3.081239, exploi<br>explore: -3.081239, exploi<br>explore: -3.081239, exploi | + Satellite 3               |
| 6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01<br>6/24/20 2:15:01 | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550<br>explore: -3.081239, exploit: 19.165550 | explore: -3.081239, explor<br>explore: -3.081239, explor<br>explore: -3.081239, explor<br>explore: -3.081239, explor<br>explore: -3.081239, explor | Satellite 4     Satellite 5 |
| _  |  |  |  | Color Tag                   |
| WARN   | INGS   |  |  | Mono                        |
| S1 and   | S2 have different values for 06  | 5/24/2020 06:00:20   |  | Comparison Mode             |
| S1 and   | S3 have different values for 06  | 5/24/2020 06:00:20   |  | Data                        |
| S2 and   | S4 have different values for 06  | 5/24/2020 06:00:20   |  |                             |
| S2 and   | S5 have different values for 06  | 6/24/2020 06:00:20   |  |                             |
| S3 and   | S4 have different values for 06  | 5/24/2020 06:00:20   |  |                             |

#### Operator

# Must actively control low-level tasks on the action level (e.g. teleoperation – controlling remotely)

|  | ΤΕΠΙΟΙΕΙΥ   |                                   |  |  |  |
|--|---|-----------------------------------|--|--|--|
| ATS/RTS BUILDER ±  |   |                                   |  |  |  |
| COMMANDS   |   | Filename: commands.rts            |  |  |  |
| DSA_AUTO START<br>DSA_AUTO STOP<br>DSA_AUTO NOOP<br>DSA_AUTO SEND_HK<br>DSA_AUTO RESET_COUNTERS<br>DSA_AUTO SET_MODE<br>DSA_AUTO SET_HETEROGENIETY<br>DSA_AUTO SET_LOG<br>DSA_AUTO SET_LOG<br>DSA_AUTO RECONFIG<br>DSA_COMM STOP<br>DSA_COMM HARD_RESET<br>DSA_COMM NOOP | 1. WAIT(20)<br>2. DSA_COMM START<br>3. DSA_TEC START<br>4. WAIT(5)<br>5. DSA_AUTO START(2000)<br>6. WAIT(1800)<br>7. DSA_AUTO STOP<br>8. WAIT(1800) | • ABS TIME           • WAIT (SEC) |  |  |  |
| DSA_COMM CONFIG_LOGGING  |   | IMPORT                            |  |  |  |
| DSA_COMM CONFIG_REPLAYING DSA_COMM START_LOGGING   |   | СНЕСК                             |  |  |  |
| DSA_COMM START_LOGGING   |   |                                   |  |  |  |
| DSA_COMM DELETE_LOGGER   | < modified>   | DOWNLOAD                          |  |  |  |

1/30/2021



National Aeronautics and Space Administration

#### Use Case

1/30/2021

#### How do we...

Interact with the spacecraft as a collective? Display swarm autonomy? Decrease external dependencies without reinventing the wheel?

1/31/2021

© 2021 by NASA Published by The Aerospace Corporation with permission

#### **Analyzing Stakeholder Requirements**

- Stakeholders each hold a different role when assessing interface
- Need to be able to view swarm status as a whole and single satellite data as needed
- Ease of access for different view modes

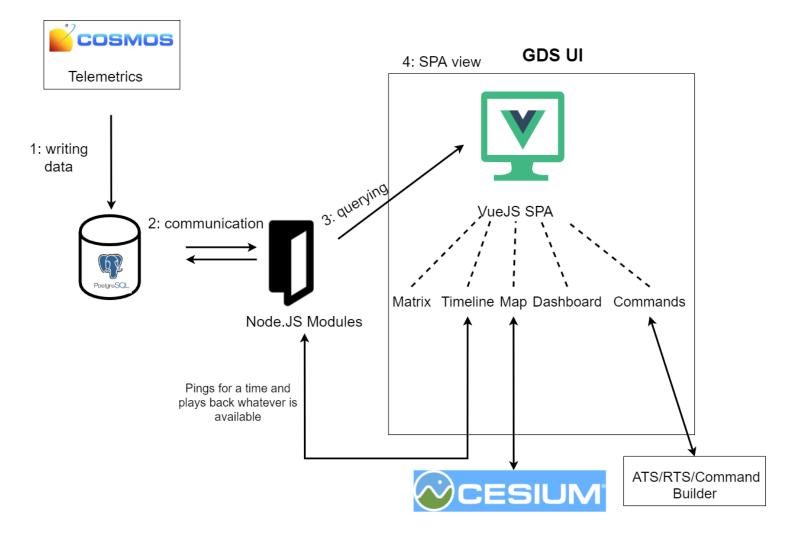


National Aeronautics and Space Administration

#### Development

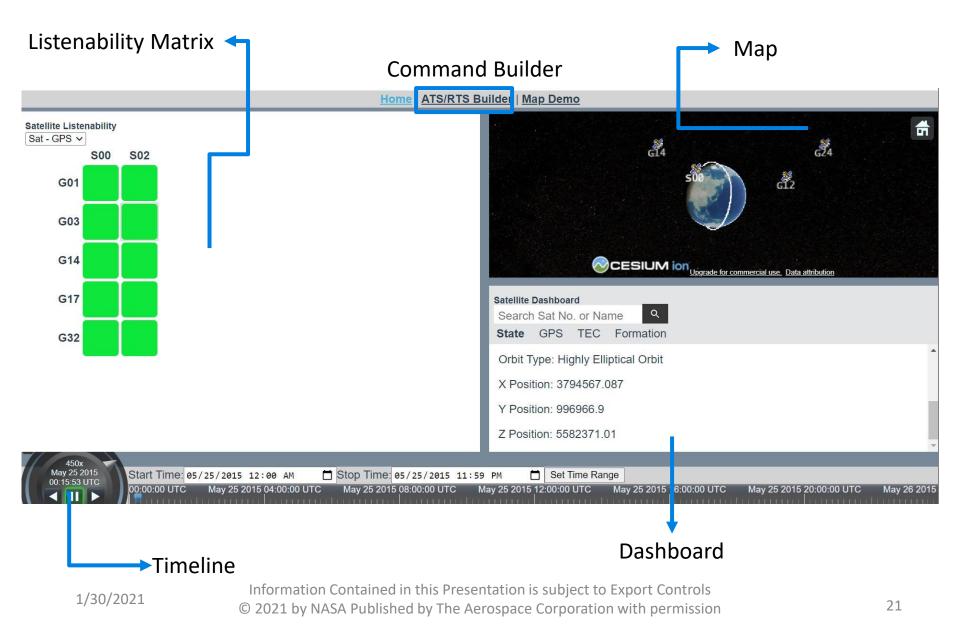
1/30/2021

# Technology Stack



1/30/2021

# User Interface (UI)

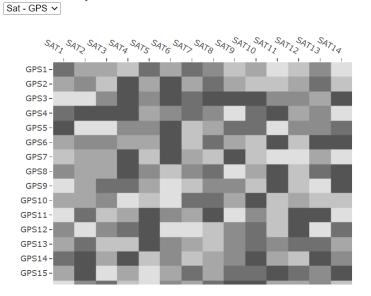


# Timeline



- Built using existing Cesium tools
- Controls information outputted in rest of components

### Listenability Matrix

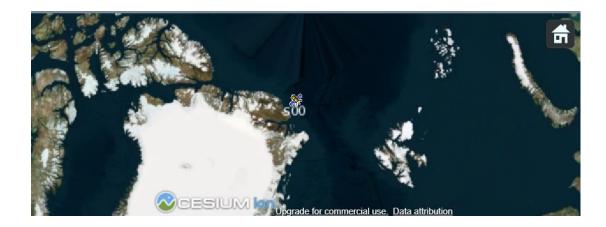




#### Shows connectivity between satellites

Satellite Listenability









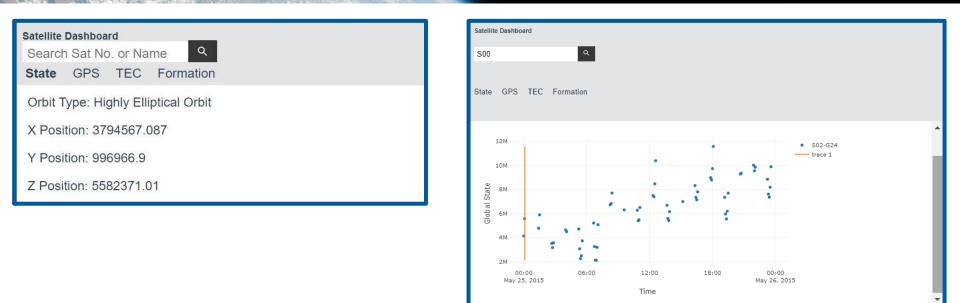
1/30/2021





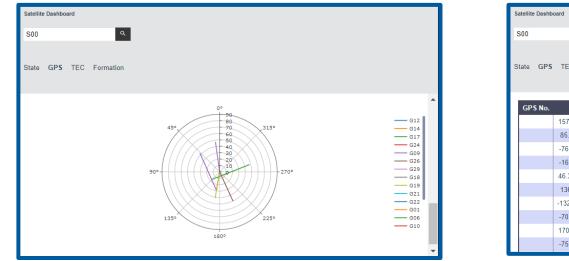
- See overall swarm positioning in reference to the Earth
- Orbit path of the satellite

# Dashboard



- Multiple tabs for different views
- More detailed data

### Dashboard

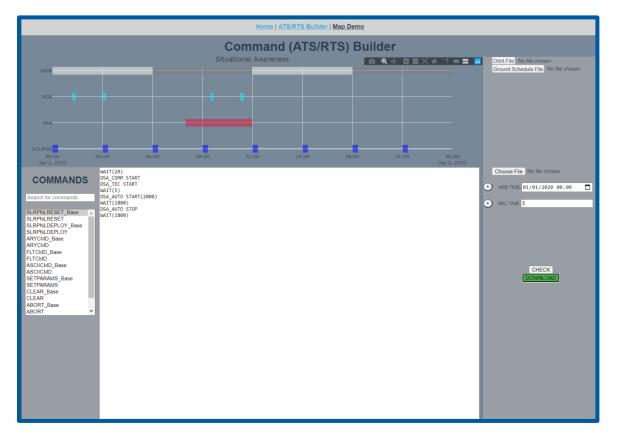


| Satellite Dashbu<br>S00<br>State GPS | ٩                   |                    |   |
|--------------------------------------|---------------------|--------------------|---|
| GPS No.                              | Azimuth             | Elevation          | Updated Time  |
|                                      | 157.40685596260275  | 29.02331249774685  | Mon May 25 2015 00:00:00 GMT-0700 (Pacific Daylight Time) |
|                                      | 85.17031776636871   | 43.28471079423851  | Mon May 25 2015 00:00:00 GMT-0700 (Pacific Daylight Time) |
|                                      | -76.25719977675833  | 47.9548444732008   | Mon May 25 2015 00:00:00 GMT-0700 (Pacific Daylight Time) |
|                                      | -169.9615519509003  | 42.63987190941006  | Mon May 25 2015 00:00:00 GMT-0700 (Pacific Daylight Time) |
|                                      | 46.312776623067464  | 42.48760005599196  | Mon May 25 2015 04:50:00 GMT-0700 (Pacific Daylight Time) |
|                                      | 136.4717870255091   | 42.11598999226501  | Mon May 25 2015 04:50:00 GMT-0700 (Pacific Daylight Time) |
|                                      | -132.06321625777412 | 43.71504806975825  | Mon May 25 2015 04:50:00 GMT-0700 (Pacific Daylight Time) |
|                                      | -70.10577280043621  | 48.96951924383195  | Mon May 25 2015 09:40:00 GMT-0700 (Pacific Daylight Time) |
|                                      | 170.25025354129804  | 41.73720294040512  | Mon May 25 2015 09:40:00 GMT-0700 (Pacific Daylight Time) |
|                                      | -75.49343136003891  | -3.107128846864079 | Mon May 25 2015 09:40:00 GMT-0700 (Pacific Daylight Time) |

- Multiple tabs for different views
- More detailed data

# **Command Builder**

- Build ATS/RTS commands
- Check for flight rules



# References

- A. Kolling, P. Walker, N. Chakraborty, K. Sycara, and M. Lewis. Human interaction with robot swarms: A survey. IEEE Transactions on Human-Machine Systems, 46(1):9–26, Feb 2016.
- Hussein, A.; Abbass, H. Mixed initiative systems for human-swarm interaction: Opportunities and challenges. In Proceedings of the 2018 2nd Annual Systems Modelling Conference (SMC), Canberra, Australia, 4 October 2018; pp. 1–8. [Google Scholar]
- 3. NASA Images www.nasa.gov