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Satellite Fleet Operations Using a Global Ground Station Network

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ABSTRACT

Satellite operation policy and ground system architecture are changing due to the emergence of satellite constellations. Until recently, most Low Earth Orbit (LEO) satellite developers/operators have been operating 1 to 5 satellites for research or business. However, new players who operate large satellite constellations have appeared in the past few years, for instance Planet Labs or Spire Global. We can expect more players like these to enter the industry because of trends such as the emergence of low cost satellite and growing market needs for real-time satellite imagery. Within this new paradigm, satellite operators will be operating tens to hundreds of satellites using tens of ground stations. It is not realistic for the satellite operator to manually operate all of these satellites. Receiving telemetry and transmitting pre-planned commands will be automated. On the ground station side, there is another problem. In many cases, it is extremely difficult for a single ground station operator to own and maintain tens of ground stations because of the cost. Ground station operators need to collaborate with each other to develop an integrated ground station network.

1 INTRODUCTION

With the emergence of small satellites and satellite constellations, there have been drastic changes in the overall methodology of satellite operation. Previously, satellite operators tended to operate 1 to 5 satellites using 1 to 3 ground stations. In this newly emerging paradigm, satellite operators will be operating tens to hundreds of satellites using tens of ground stations. Because manual operation of all these satellites is not realistic, receiving telemetry and transmitting pre-planned commands will need to be automated. There is another problem on the ground station side. In many cases, it is very difficult for a single ground station operator to own and maintain tens of ground stations due to the costs involved. In order to solve this, ground station operators must collaborate with one another to develop an integrated ground station network.

To realize a democratization of space and business success for upcoming space companies, two things need to happen:

- Constellation operation technology must be made available
- Ground station networks must be made available

2 CONSTELLATION OPERATION TECHNOLOGY

How can we get full performance out of a satellite constellation? Many constellation business providers are currently focusing on this challenge. Existing satellite operation methods were developed for one to a few satellites. If these are applied to constellation operation, operators will not be able to reap the full benefits of constellation operation.

In general, there are two main purposes of satellite operation:

- Execute a mission
- Conduct satellite maintenance (= Maintain on-board components)

In constellation operation, multiple satellites carry out mission execution. Meanwhile, satellite maintenance (satellite housekeeping) should be carried out automatically. Human operators monitoring hundreds of satellites is inefficient. In order to discuss constellation operation, this paper will first analyze existing satellite operation methods.

Key concepts of satellite operation

Existing satellite operation is static and essentially all pre-defined. There are three key modules that make up existing satellite operation: satellite mode, procedure, and operation phase.

Satellite mode

A satellite mode defines a configuration of satellite components. For example: mission execution mode, maneuver mode, battery recovery mode, etc. Each mode defines each of the following:

- On/off status of each component
- Mode of each component
    - Defines fixed power consumption
    - Defines fixed amount of housekeeping (HK) telemetry
- Total power consumption
    - Derived from power consumption of each component
- Communication speed
    - Derived from volume of HK telemetry and commands

Procedure

Procedure refers to a series of commands and telemetry to be checked. A procedure does the following:

- changes satellite modes
- executes actions (Eg. take an image, inject fuel, capture debris, etc.)

Procedure can optionally include sub-procedures. The satellite operator determines the depth of those sub-procedures. Each procedure has minimum execution time needed.

Operation phase

Each satellite operator has a different definition of the operation phase. However, the following phases are common among many operators:

- LEOP (Launch and Early Orbit Phase)
- Commissioning phase
- Operational phase
- Disposal phase

The procedures to be run during each operation are pre-defined.

Procedure-oriented planning

The procedures to be run are pre-defined, but there is still a planning process required due to limited communication windows. Communication windows are limited because of the limited number of ground stations, as well as because of the satellite's orbit. The basic task of planning is to allocate the procedures to carried out to different communication windows.

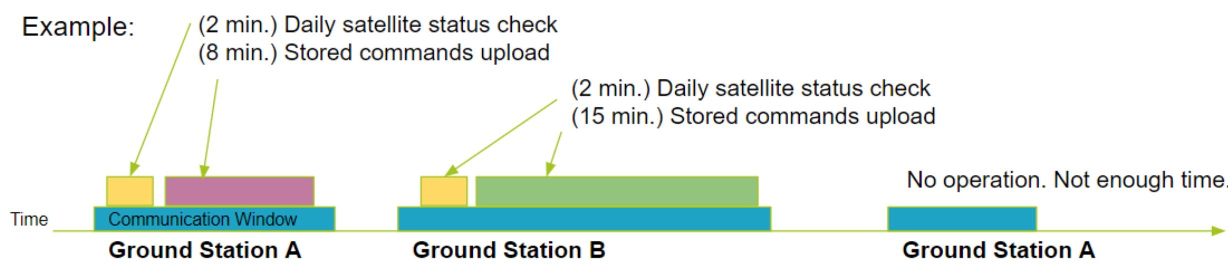

Figure 1: Example of satellite operation planning

Planning Process

There are three types of planning:

- Mission planning
    - For mission execution
- Housekeeping operation planning
    - For satellite maintenance
- Network planning (Ground station allocation)
    - For allocating procedures to different communication windows

Planning process is shown in following block diagram.

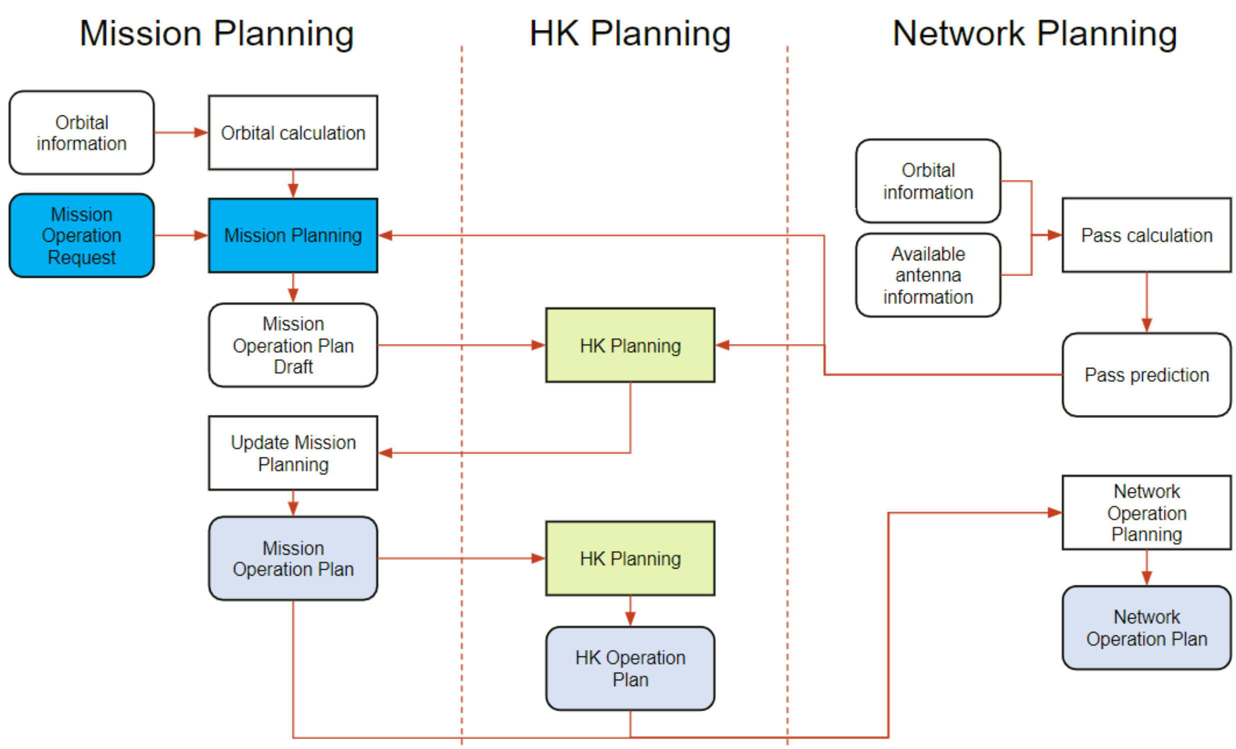

Figure 2: Planning process

For constellation operation, how to maximize mission execution and how to minimize housekeeping and human operation are key challenges. Therefore, the main discussion points in this conversation are 1) how to define mission operation requirements and 2) how to automate, i.e achieve autonomous housekeeping operation. Additionally, the number of available ground station creates a bottleneck in operation planning.

3 GROUND STATION NETWORK

The number of available ground station creates a bottleneck in operation planning. That said, how long is a ground station able to communicate with a satellite?

Pass duration

Satellite pass duration is dependent on orbital parameters and ground station location. This chapter discusses pass duration as a function of orbit inclination. Two orbits are assumed. Orbit A is 600 km altitude, circular, polar orbit. Here, it is defined as a simplified polar orbit. Orbit B is 400 km altitude, circular orbit. Here, it is defined as a simplified ISS orbit (Table 3).

Table 3: Orbit parameters.

Orbit Parameter	Orbit A (Simplified polar orbit)	Orbit B (Simplified ISS orbit)
Apogee Altitude	600 km	400 km
Perigee Altitude	600 km	400 km
Inclination	98 deg	51 deg
Argument of Perigee	0 deg	0 deg
RAAN	0 deg	0 deg

Ground station location is assumed as shown in Table 4.

Table 4: Ground station location.

	Ground Station Location
Ground Station A – I	Latitude: 0, 10, 20, 30, 40, 50, 60, 70, 80 deg Longitude: 0 deg Altitude Reference: WGS84

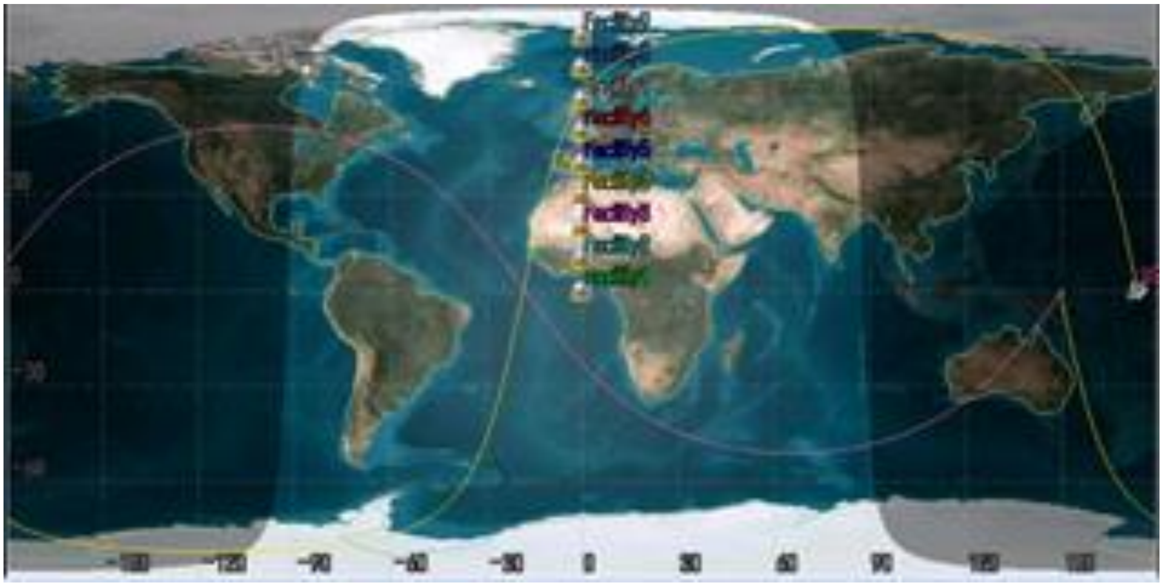

Figure 5: Ground station location.

For orbit A, average pass duration per day is less than an hour if the ground station is located below 50 deg latitude. If latitude is between 50~60 deg, average pass duration is 1~1.5 hours. If latitude is between 60~80 deg, average pass duration is 1.5~2.5 hours.

Table 6: Pass duration analysis for orbit A.

Latitude (deg)	Number of Pass/Week	Total Pass Duration/Week (min)	Average Pass Duration/Day (min)
80	90	1056	150
70	74	807	115
60	64	625	89
50	42	417	59
40	33	331	47
30	29	286	40
20	26	262	37
10	24	245	35
0	24	240	34

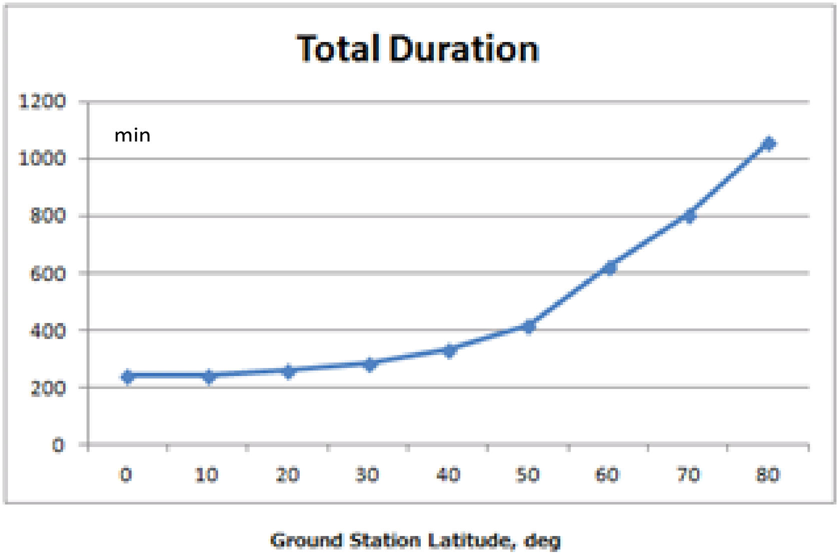

Figure 7: Average pass duration/day for orbit A.

For orbit B, the average pass duration per day is less than an hour. If the ground station is located above 70 deg latitude, it cannot see the satellite. Overall, the pass duration for the ISS orbit is less than the duration for the polar orbit.

Table 8: Pass duration analysis for orbit A.

Latitude (deg)	Number of Pass/Week	Total Pass Duration/Week (min)	Average Pass Duration/Day (min)
80	0	0	0
70	12	34	4
60	30	234	33
50	36	344	49
40	42	391	55
30	39	312	44
20	29	242	34
10	25	215	30
0	27	216	30

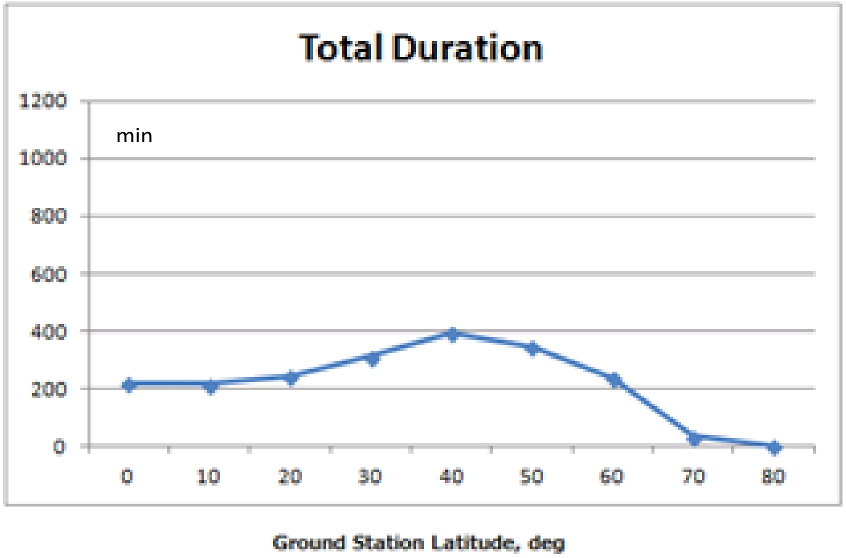

Figure 9: Average pass duration/day for orbit B.

6 SUMMARY

More research is required to discuss effective mission planning for constellations. More research is required to determine how many passes can realistically be used. However, there is significant potential in networking in order to connect and use discarded passes.

The required number of ground stations needed to operate a satellite constellation is large. It is difficult for a single ground station operator to own and maintain tens of ground stations because of the costs involved. Therefore, a new framework to develop an integrated ground station network is required.

"Sharing economy" is a term used to describe a service which allows individuals or groups to generate revenue from idle assets. For example, Airbnb is a sharing economy service that allows individuals to rent their unused rooms to individuals looking for affordable lodging. Uber is a sharing economy service that allows individuals to offer for-fee transportation as an affordable, flexible alternative to taxis or public transportation. The sharing economy can also be applied to the space industry. Ground facilities such as communication antennas or launch pads tend to have significant idle time. An antenna sharing service can be a solution for the coming satellite constellation operation era.

References

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