OMAR Mission Architectures

2021 Clean Space Industrial Days

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OMAR Mission Architecture Study - Objectives

Overall Objective	**to identify all viable mission architectures to have a fully operational On-Orbit Servicing Station (OSS) and the associated auxiliary vehicles, which is capable to provide on-orbit services.**
Task 1 Objective	to map and classify all possible mission scenarios and to perform a mission level functional analysis for each of the identified services. → down-selection to 5 scenarios for further investigation
Task 2 Objective	to establish the domains of application and driving criteria for different mission profiles, concept of operations and functional breakdown, by assessing each of the identified mission scenarios. → down-selection to 2 scenarios for further investigation
Task 3 Objective	to define a comprehensive mission architecture for selected mission profiles (i.e. the architecture, mission profile and concept of operations shall be detailed). Furthermore an initial assessment of commercial considerations shall be carried out.

Scenario Mapping - Overview

LEO Scenarios

- Refurbishment
  - Refurbishment Facility for Telecom Constellations
  - Refurbishment Facility for SSO Satellites
- Manufacturing and assembly
  - Manufacturing Facility for Telecom Constellations
  - Manufacturing Facility for SSO Satellites
- Upgrade
  - SSO satellites upgrade with De-orbit Kits at EOL

GEO Scenarios

- Refurbishment
  - Refurbishment Facility near GEO
- Manufacturing and assembly
  - Manufacturing Facility in / near GEO
- Recycling
  - Recycling Facility near GEO graveyard

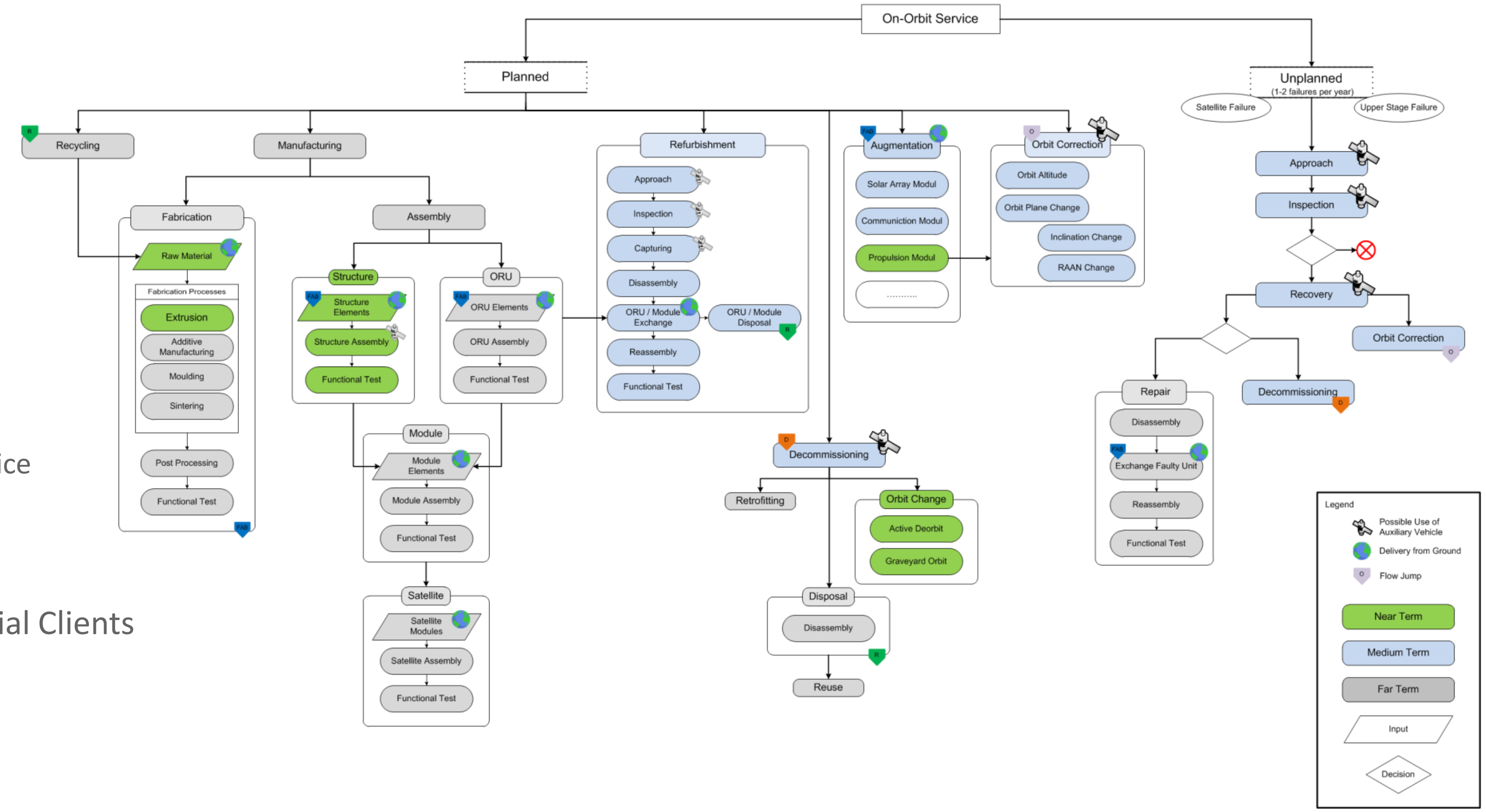
MEO Scenario

- Refurbishment / Upgrade
  - GNSS constellation refurbishment or upgrade

Scenario Selection - Overview

Selection Criteria

- Mission Representativeness and Commonalities
  - Orbit Regime / Orbit
  - Type of Service
  - Feasibility Timeframe
    - near-term = 2030+
    - mid-term = 2040+
    - far-term = 2060+
  - Level of Satellite Preparation and Cooperation
    - Designed / not designed for service
    - Cooperative / non-cooperative
- Economic Aspects
  - Client Base / Number of Potential Clients
  - Satellite Value / Revenue
  - Launch Cost
  - Standardization Aspects
  - Market Development Aspects



Scenario Selection - Overview

LEO Scenarios

- Refurbishment
  - Refurbishment Facility for Telecom Constellations
  - **Refurbishment Facility for SSO Satellites**
- Manufacturing and assembly
  - **Manufacturing Facility for Telecom Constellations**
  - Manufacturing Facility for SSO Satellites
- Upgrade
  - **SSO Satellite upgrade with De-orbit Kits at EOL**

GEO Scenarios

- Refurbishment
  - Refurbishment Facility near GEO
- Manufacturing and assembly
  - Manufacturing Facility in / near GEO
- Recycling
  - **Recycling Facility near GEO graveyard**

MEO Scenario

- Refurbishment / Upgrade
  - **GNSS constellation refurbishment or upgrade**

Scenario Selection - Overview

LEO Scenarios

- Refurbishment
  - Refurbishment Facility for Telecom Constellations
  - **Refurbishment Facility for SSO Satellites** ✓
- Manufacturing and assembly
  - **Manufacturing Facility for Telecom Constellations** ✓
  - Manufacturing Facility for SSO Satellites
- Upgrade
  - **SSO Satellite upgrade with De-orbit Kits at EOL**

GEO Scenarios

- Refurbishment
  - Refurbishment Facility near GEO
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- Recycling
  - **Recycling Facility near GEO graveyard**

MEO Scenario

- Refurbishment / Upgrade
  - **GNSS constellation refurbishment or upgrade** ✓

In-Orbit Manufacturing and Assembly Station for Medium-sized Telecom Constellation in LEO

General Assumptions

- In-Orbit Manufacturing of Satellite Structure
- Supply of ORUs from Ground
- Assembly on Orbit to Functional Telecom Satellite
- Build-up of Medium Sized Constellation
- Utilization of J2 effect (natural RAAN drift) to move station between constellation planes
- Average Production per Satellite 2.5 months based on current AM technology

- Constellation Size: 72 Satellites
- Orbit Planes: 6 (spaced 30° RAAN)
- Satellites per Orbit Plane: 12
- Reference Satellite: Iridium-Next

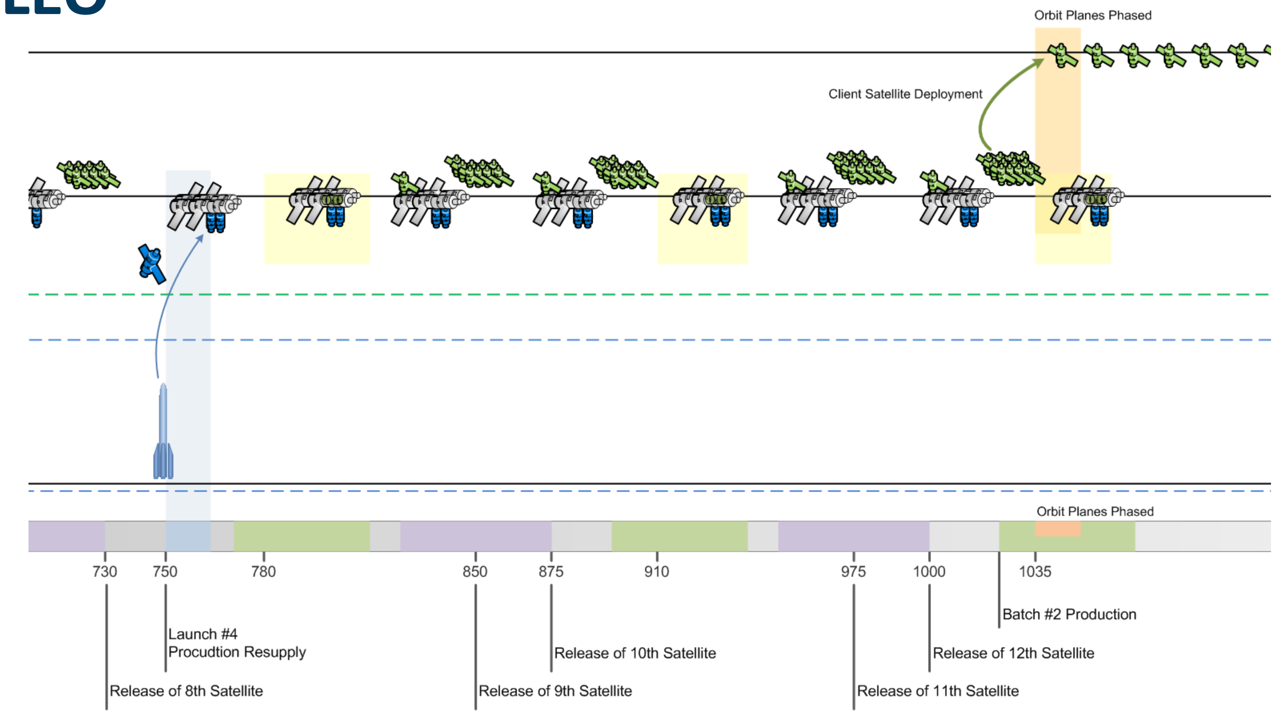
Constellation Orbit Study Cases	Case 1	Case 2	Case 3	Case 4
Orbit Type	near-polar		non-polar	
Reference Orbit	Irdium	OneWeb	Orbcomm	Globalstar
Constellation Orbit				
Altitude, km	800	1200	750	1400
Inclination, deg	86.4	87	45	52

Manufacturing Station - Operational Orbit				
Altitude, km	750	1100	760	1330
Inclination, deg	86,2	86,8	45	52

In-Orbit Manufacturing and Assembly Station for Medium-sized Telecom Constellation in LEO

Preliminary Mission Time Line – Operational Phase

- In-Orbit Manufacturing of Satellite Structure utilizing additive manufacturing methods
- In near-polar orbits scenarios - during long no eclipse periods the structure for 2 satellites is manufactured and stored until assembly
- IOAM Station drifts from plane to plane - during drift time a batch of 12 satellite is produced
- When the orbit planes of Station and Constellation phase, the Satellites travel to their target orbit



Commercial Assessment Results

- ✚ Ability to assemble satellites in space would open new types of applications by ending existing limitations due to available fairing volume
- ✚ Promote design modularity which would facilitate heritage and enable in-flight upgrades

– Relatively long build time is mainly driven by the additive manufacturing step, resulting in the:
  – need to improve existing additive manufacturing capabilities and to consider different type of structures and/or materials
  – Need to consider “assembly only” scenarios in near / medium term future

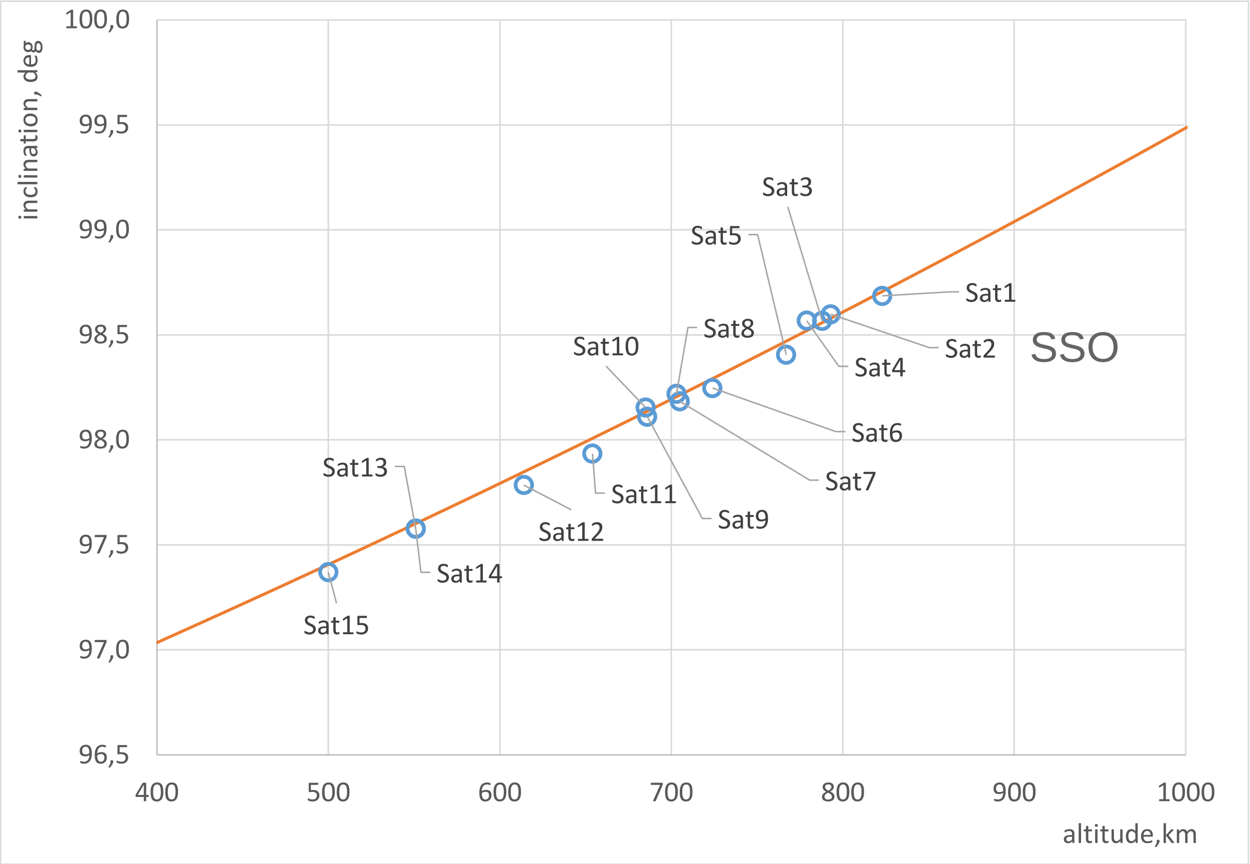
Refurbishment Facility in LEO – Sun-Synchronous Orbits

General Assumptions

- Several Clusters of Earth Observation Satellites in SSO
- Planned Refurbishment and Failure-Response Refurbishment
- ORUs supplied from Earth
- 10 to 15 Client Satellites per Cluster
- Utilization of J2 Effect and Minor Plane Change Maneuvers to move Station between Client Satellites

Study Case	Cluster X
Reference Orbit Planes	
Altitude Range, km	500 - 823
Inclination Range, deg	97,4 - 98,7
Relative RAAN Range, deg	4

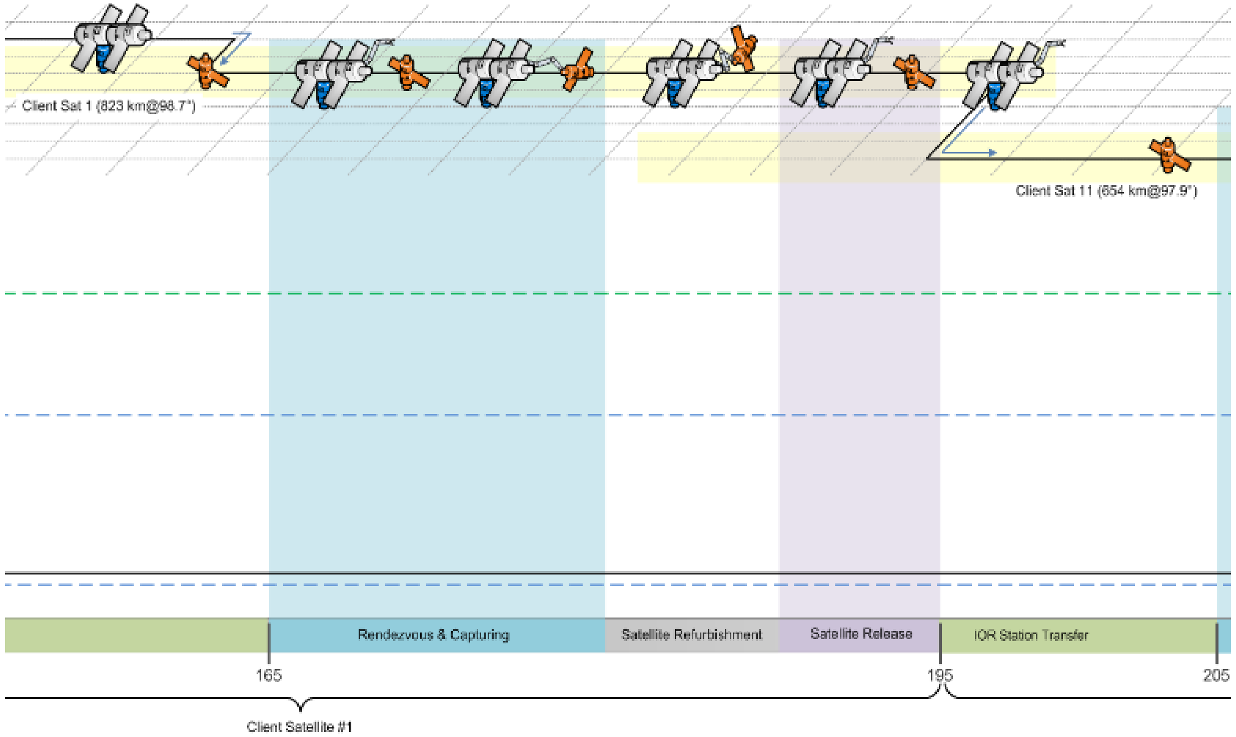
IOR Station Operational Orbit	
Altitude, km	500 - 823
Inclination, deg	97.4 - 98.7



Refurbishment Facility in LEO – Sun-Synchronous Orbits

Preliminary Mission Time Line – Operational Phase

- Refurbishment material resupply is delivered into initial IOR Station orbit at the end of the commissioning phase
- IOR Station drifts / moves to targeted Client Satellite using a combination of minor plane change maneuvers and drift orbits
- IOR Station captures the Client Satellite and performs the refurbishment operations, e.g. Exchange of ORUs and Refueling
- Client Satellite is released and Station prepares to move to the next Client Satellite



Commercial Assessment Results

- Mission Scenario is very Delta v / fuel intensive
- Commercial Competiveness mainly depends on cost of the IOR station compared to the value and number of Client Satellites
- Further IOR station specialization on specific Client Satellite types (e.g. radar and optical missions) may be beneficial

GNSS Constellation Refurbishment / Upgrade in MEO

General Assumptions

- One IOR Station per Orbital Plane
- Spare satellites temporarily replace satellite during refurbishment
- ORUs supplied from Earth
- Reference Constellation: Galileo
- Constellation Size: 30 Satellites
- Orbit Planes: 3 (spaced 120° RAAN)
- Satellites per Orbit Plane: 10
  - Active Satellites: 8
  - Spare Satellites: 2
- Refurbishment Duration: ~30 days

Refurbishment Rates and Intervals - Assumptions

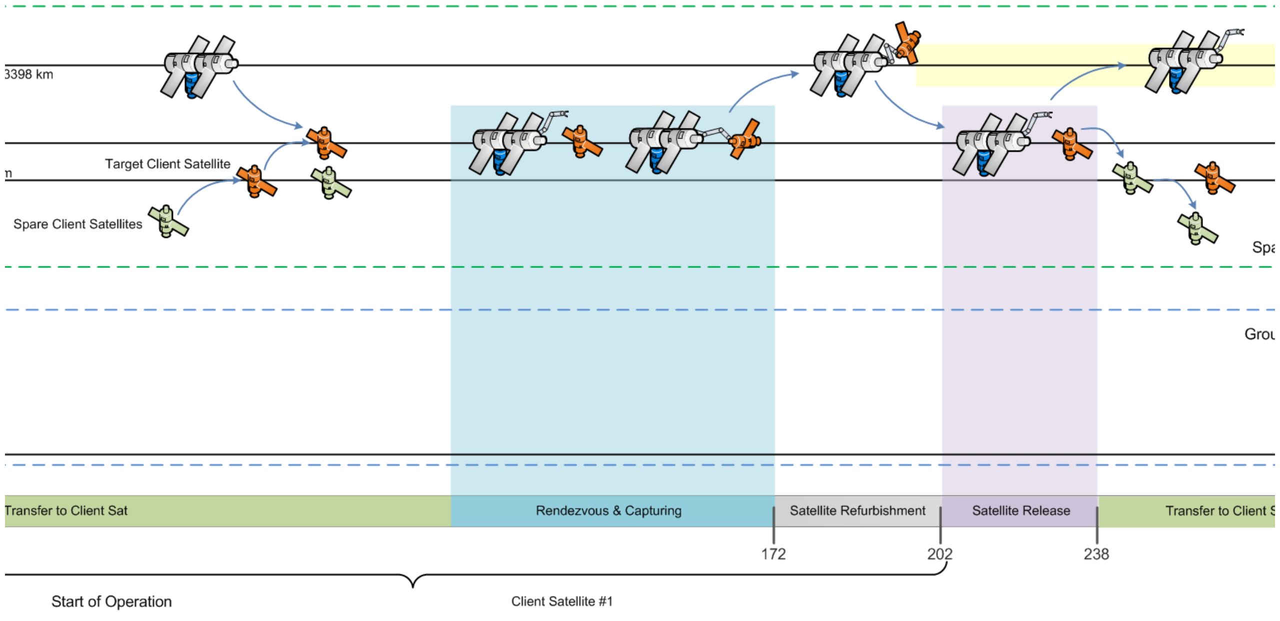
- Satellites serviced per year: 4
- Satellites angular distance: up to 90°
- Service Time per Satellite: 90 day (including transfer)
- Refurbishment Interval per Satellite: ~ 10 years

Galileo Satellite Orbit Slots

GNSS Constellation Refurbishment / Upgrade in MEO

Preliminary Mission Time Line – Operational Phase

- Refurbishment material resupply is delivered into initial IOR Station orbit at the end of the commissioning phase
- IOR Station drifts / moves to targeted Client Satellite via altitude change maneuvers
- Spare Satellite replaces targeted Client Satellite
- IOR Station captures the Client Satellite and moves to higher trailing orbit
- IOR Station performs refurbishment operations, e.g. Exchange of ORUs and Refueling
- IOR Station moves Client Satellite back to its orbital slot and prepare to move to the next Client Satellite
- As low Delta v alternative a barrel-roll approach is also considered



Commercial Assessment Results

- MEO missions are driven by limited launcher performance
- Commercial Competiveness mainly depends on cost of the IOR Station and number of ORU resupply missions required

OMAR Mission Architecture Study - Summary & Conclusions

- Mission scenarios in LEO, MEO and GEO were identified and investigated
- Most viable and versatile in terms of use cases were selected for detailed analysis in order to establish comprehensive mission architectures and assess the feasibility of technical and economic aspects
  - Medium-sized telecom constellation manufacturing and assembly
  - Refurbishment facility in SSO
  - GNSS Constellation Refurbishment / Upgrade
- Mission architectures established can also be applied with modifications in other scenarios, for example the refurbishment of GEO satellites
- The results also revealed major obstacles in regard to the economic competitiveness of in orbit manufacturing
  - To achieve the competitiveness of full satellite manufacturing in orbit the production times have to be significantly reduced, various technology gaps have to be overcome and alternative methods have to be taken into account
  - For the near and medium term future a more competitive strategy is to focus on utilization of volume saving structure launch kits that are manufactured on ground and assembled in orbit