A Service-based Architecture for Automated Guidance, Navigation, & Control Flight Software

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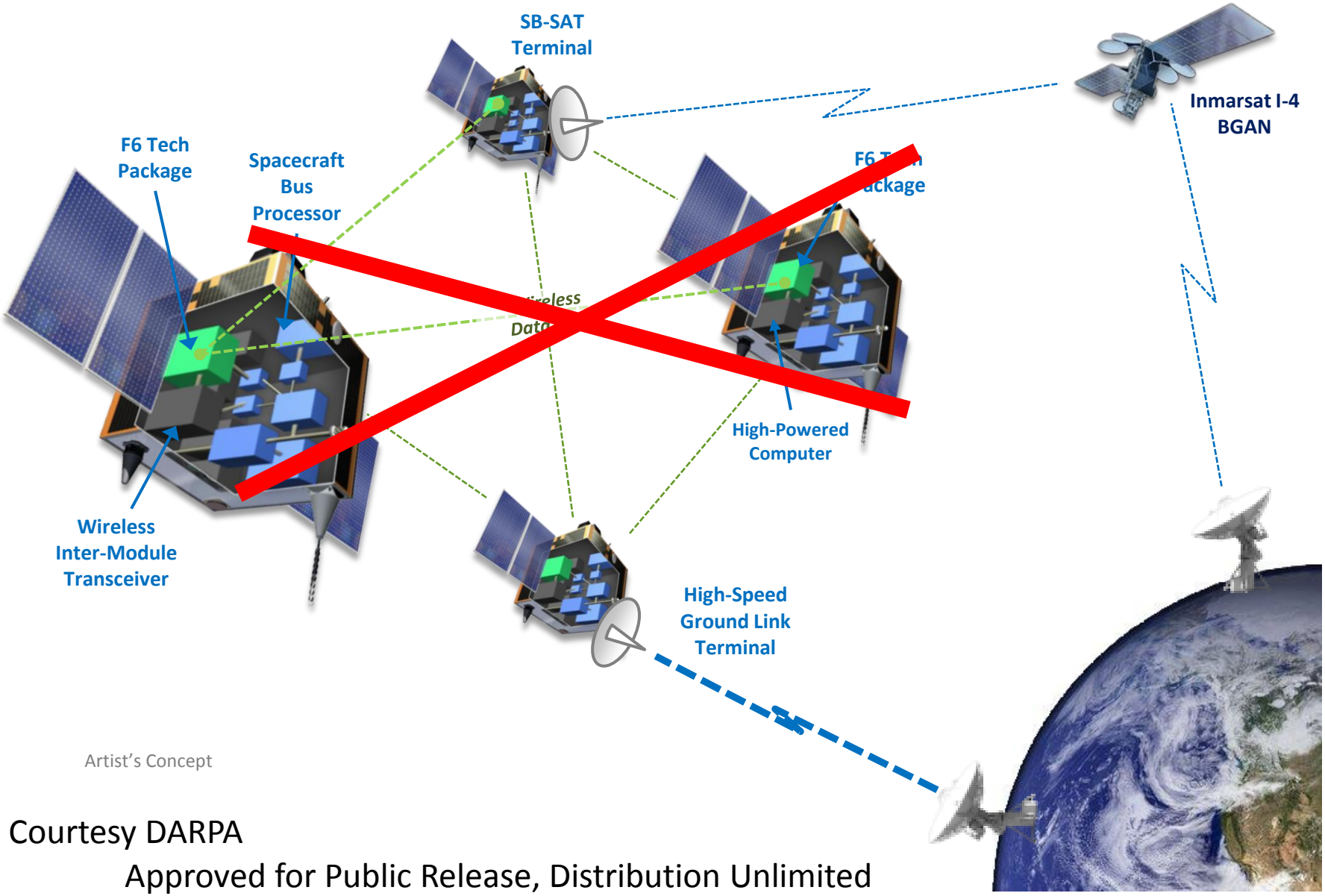
Notional System F6 On-Orbit Demo



Courtesy DARPA

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Key Program Artifacts

- ~~**On-Orbit Demo**—demonstrate universal attributes of fractionated architectures~~
  - ~~Launch in 2015, 6-month duration, low-earth orbit (LEO)~~
  - ~~Mission agnostic beyond demonstration of key fractionation capabilities~~
  - ~~F6 payloads, spacecraft bus are being procured separately from other mission elements~~

- **F6 Developer's Kit (FDK)**—everything needed for an independent 3rd party to develop a module that can fully participate in a fractionated cluster
  - Interface standards, network protocols, software, behaviors/rules
  - Freely distributed under an open source license, freely exportable
  - Solicited previously under FDK BAA (DARPA BAA-11-01)

- **F6 Technology Package (F6TP)**—low cost, commercialized physical instantiation of the FDK that enables a spacecraft bus to become a fractionated cluster module
  - Executes protocol stack, middleware, cluster flight software
  - Interfaces to wireless inter-module transceiver, F6 payloads, and spacecraft bus
  - Multiple sources, capable of supporting multiple spacecraft bus types
  - Goal is for a fully productized commercial off-the-shelf item

Courtesy DARPA

Cluster Flight Application (CFA)

Flight Software to Provide Autonomous Satellite Cluster Services

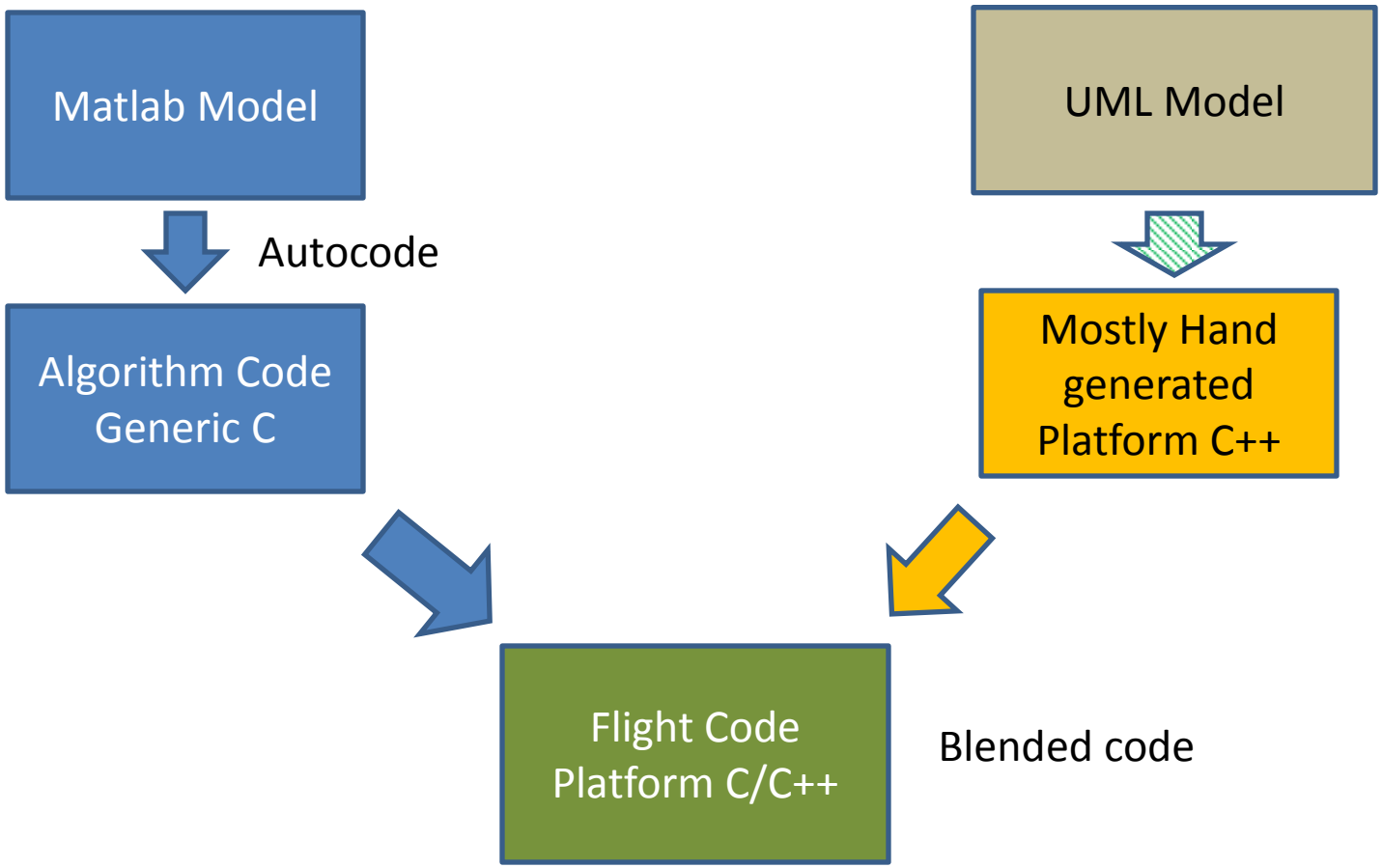
- Services
  - Autonomy
  - FDIR
  - Enhanced Navigation
  - Coordinated, optimized maneuver planning
  - Mission Management

- Development
  - Developed under a DARPA prime contract
  - Development cycle 30 month period ending 6/14
  - Primarily Use Case Driven
  - CMMI Level 3 Compliant
  - Scrum-based, agile software development process using small, distributed teams
  - Tested using NASA's Trick Simulation environment

Architectural Characteristics

- Built to flight software standards
- Multiple Target Hardware Platforms
- Service-based, but message bus agnostic (Pub/Sub is the default assumption)
- “Reusable” components (Focused purpose, well documented, high-quality)
- Non-real-time
- Built around ARINC 653 partitions
- Models are the primary source artifacts for the algorithms
  - No modifications are made to the generated code

Code Development Flow



Emergent's Holistic Cluster Flight Solution

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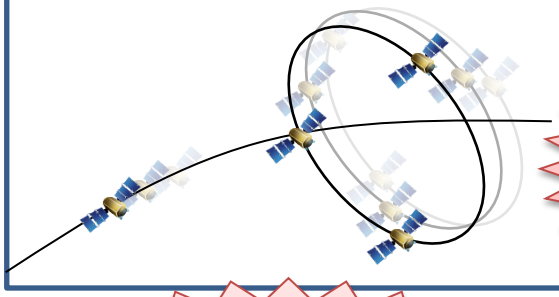
Station Keeping



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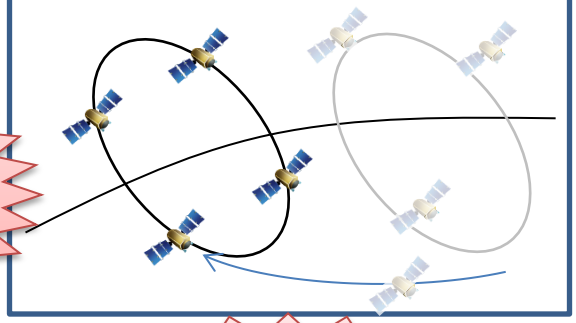
Service-Based Architecture

- Provides cluster flight algorithms as services
- Reside on any node including the ground

Ingress/Egress/Reconfiguration



Universal Maneuver Planning

- Single maneuver planner for all scenarios
- Finds near optimal solution
- Capable of pre-calculating maneuvers for rapid response

Cluster Flight System

Cluster Flight Manager

Fault Detection Isolation Recovery

Orbit Maintenance

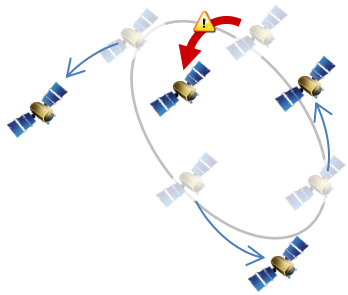
Maneuver Planning

Navigation

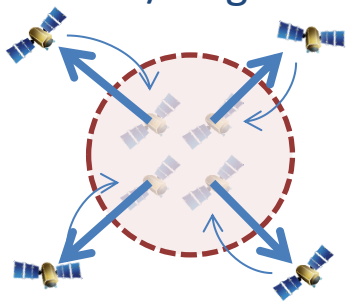
Flexible Navigation

- Modules sharing sensor data
- Processes any measurements that are range, range rate, or angles
- Dynamically reallocate filters based on computational resources

Collision Avoidance



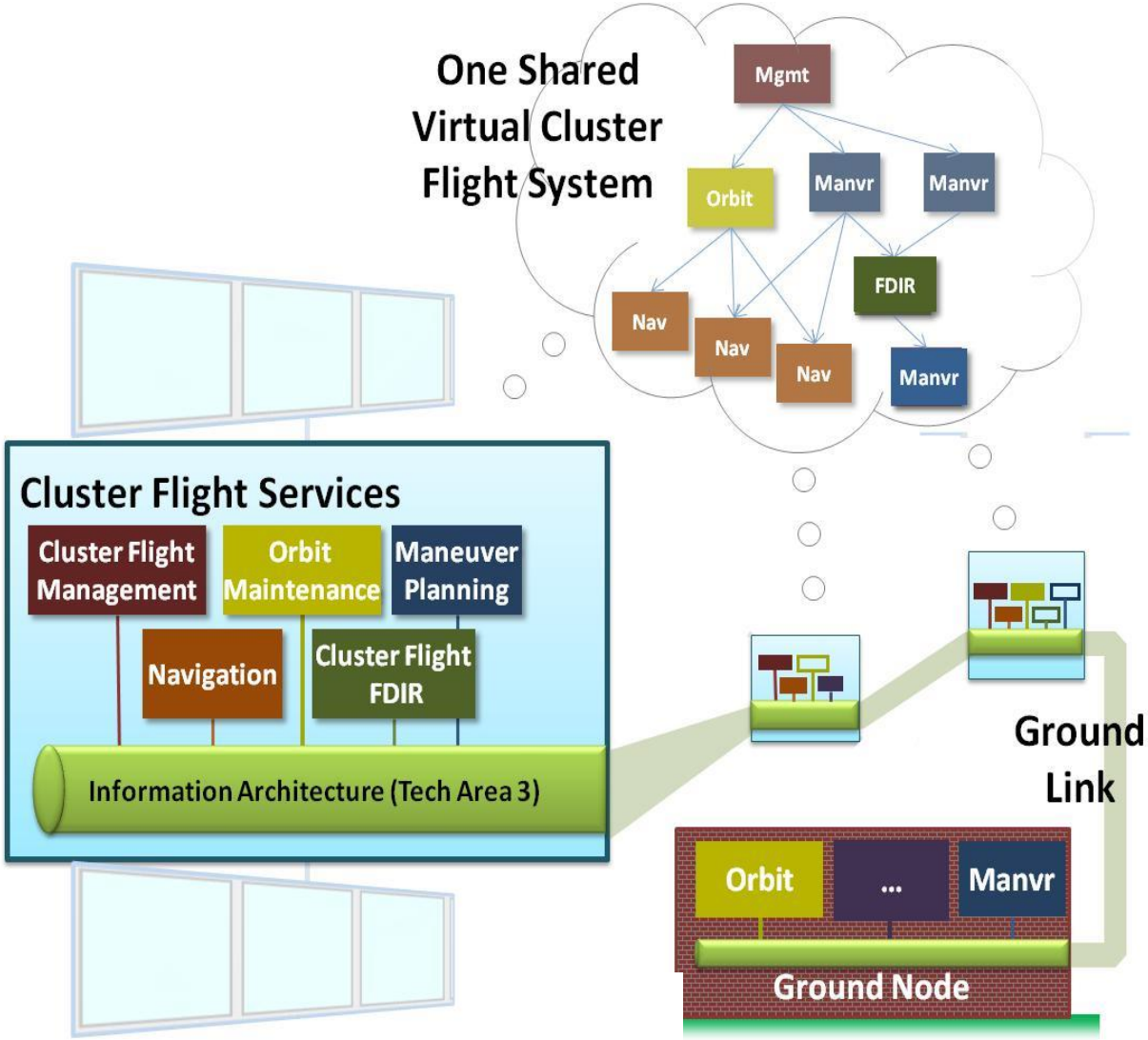
Scatter / Regather

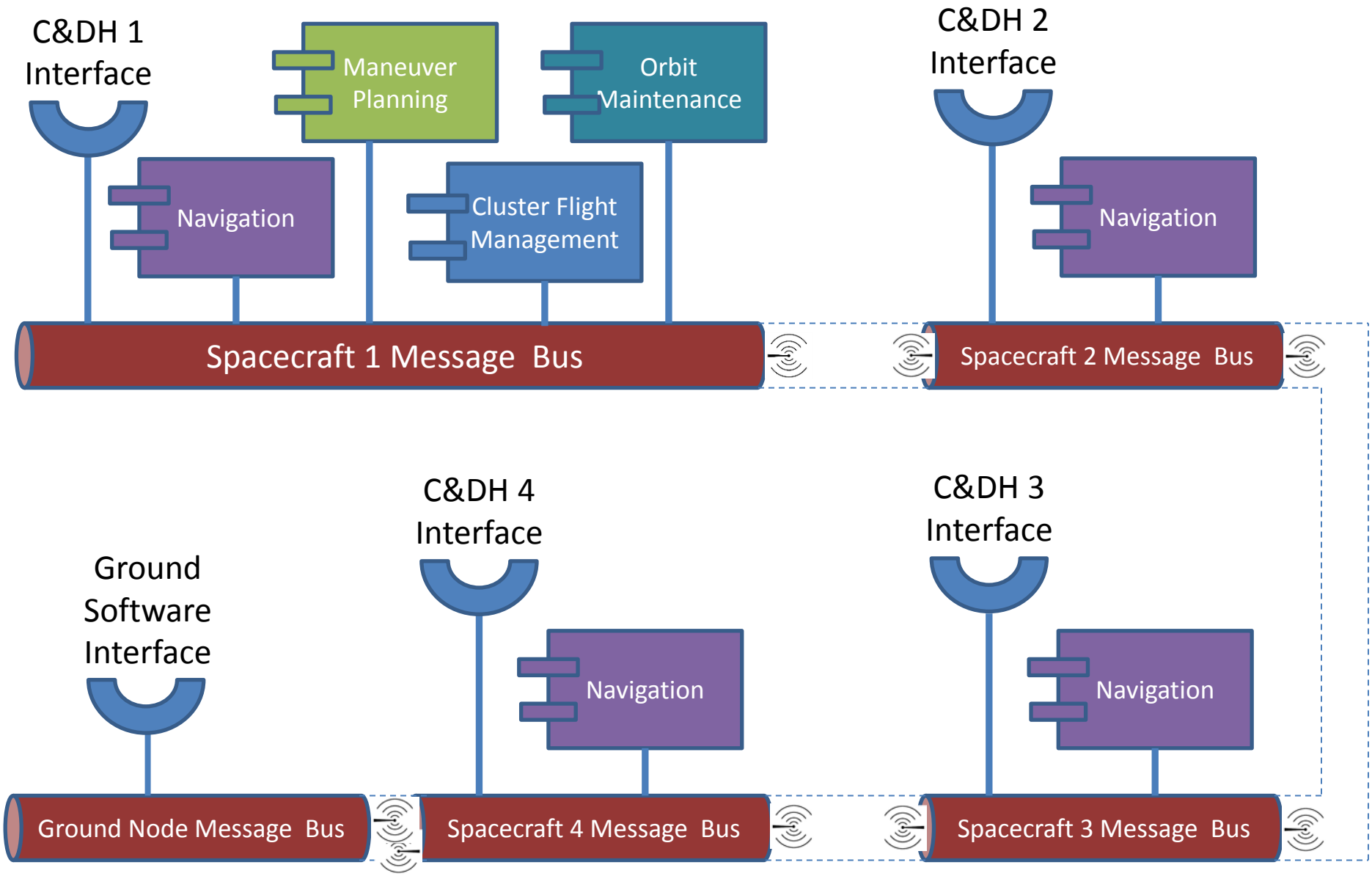


FDK

Service-Based CFS Architecture Takes Advantage of Middleware-Based IA

- **Pros**
  - Evolvable – New services, clients, transactions can be added
  - Adaptable – Services can be moved from node to node, even to the ground
  - Robust – Can survive network disruptions and node failures
- **Cons**
  - Higher resource overhead related to messaging





Cluster Flight Manager (CFM)

Cluster Flight Management

- Software Agent orchestrating activities of the CFA
- Initiates periodic Cluster activities – Reconfiguring, Station-Keeping, Probability of Collision Monitoring
- Manages the Cluster Inventory
- Manages Maneuver Plans – Saves, distributes, and expires them updates Maneuver states as they are executed
- Synchronizes Cluster Environment Data (EOD Data) with NAV

Orbital Monitoring Service (OMS)

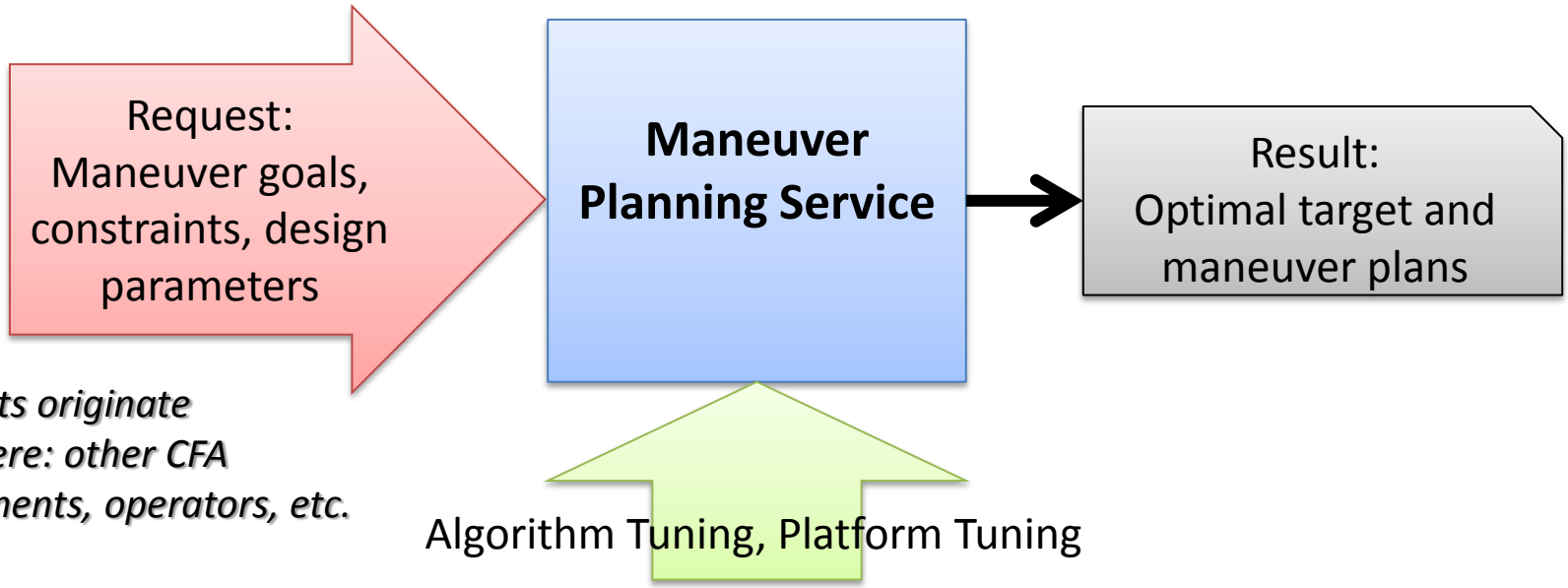
Orbit Maintenance

- Performs closed-loop cluster activities – Reconfiguring, Station-Keeping, Probability of Collision Monitoring
- Determines whether predicted trajectories violate key target orbit constraints
- Requests new maneuver plans (Δ**V** commands) from Maneuver Planning Service (MPS) as necessary
- Validates candidate maneuver plans from MPS before distributing to CFM
- Performs probability of collision determination upon request from CFM and during maneuver plan validation

Maneuver Planning Service (MPS)

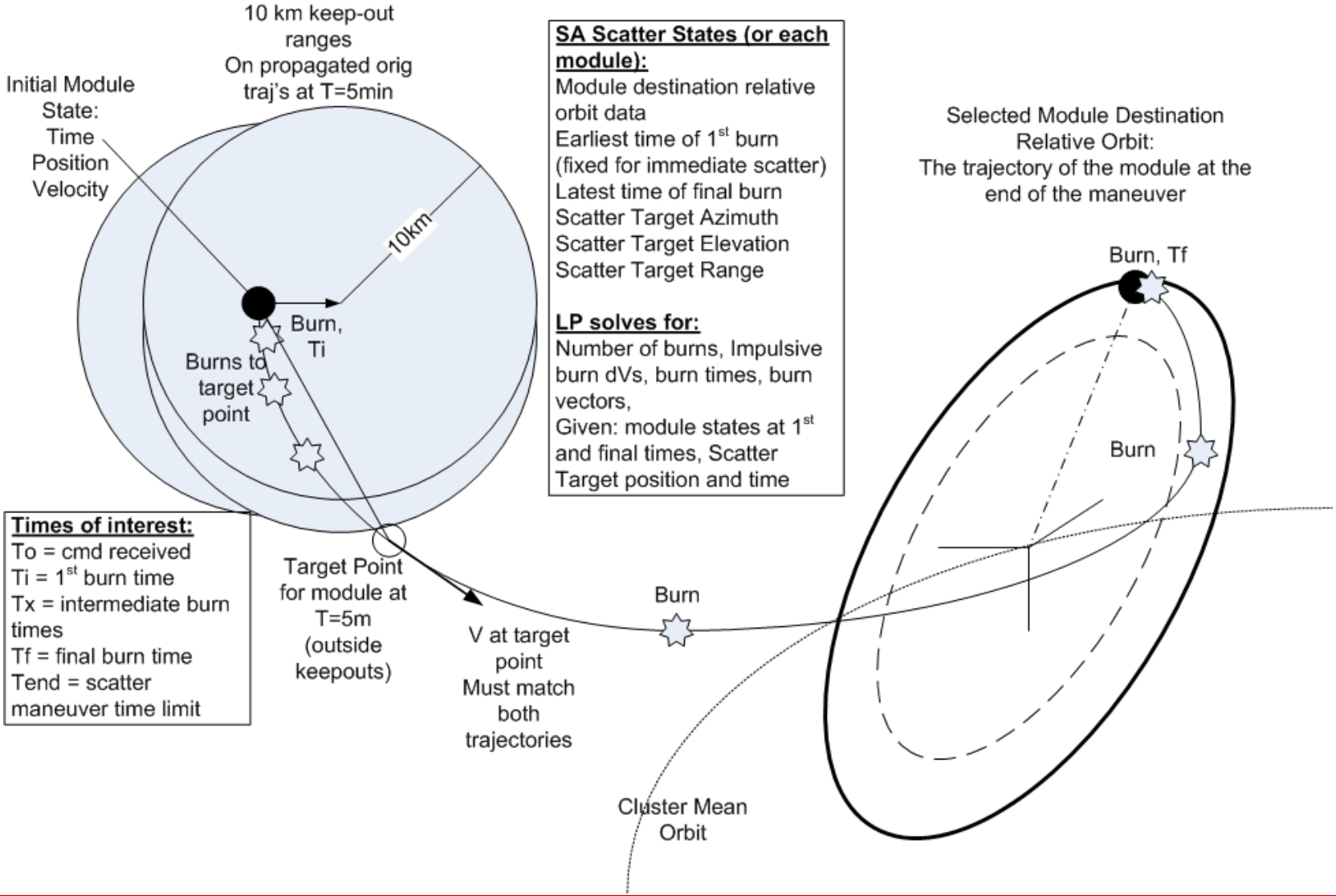
Maneuver Planning

- Designed to be deployed as a "job processing" **S**ervice
  - Message-based (service based architecture)
    - Clients submit maneuver requests on an as-needed basis
    - Application must remain responsive while computing
  - Maneuver planning returns, but does not store, results ("stateless")
- A "standardized" interface
  - Supports all maneuver types (Ingress, SK, etc.)
  - With constraints, objectives, etc.
  - Single request = single result



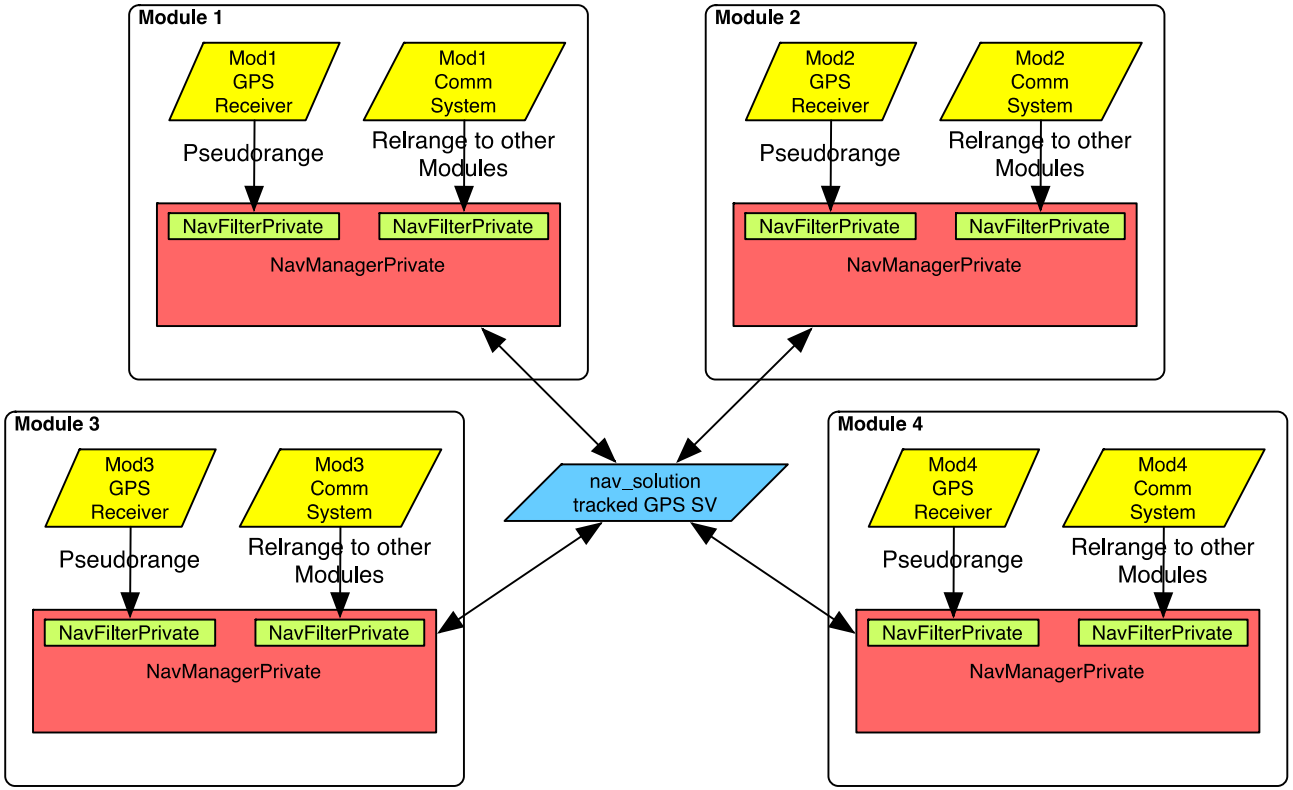
Requests originate anywhere: other CFA components, operators, etc.

Simulated Annealing Search State Description & Burn Solver Relationships

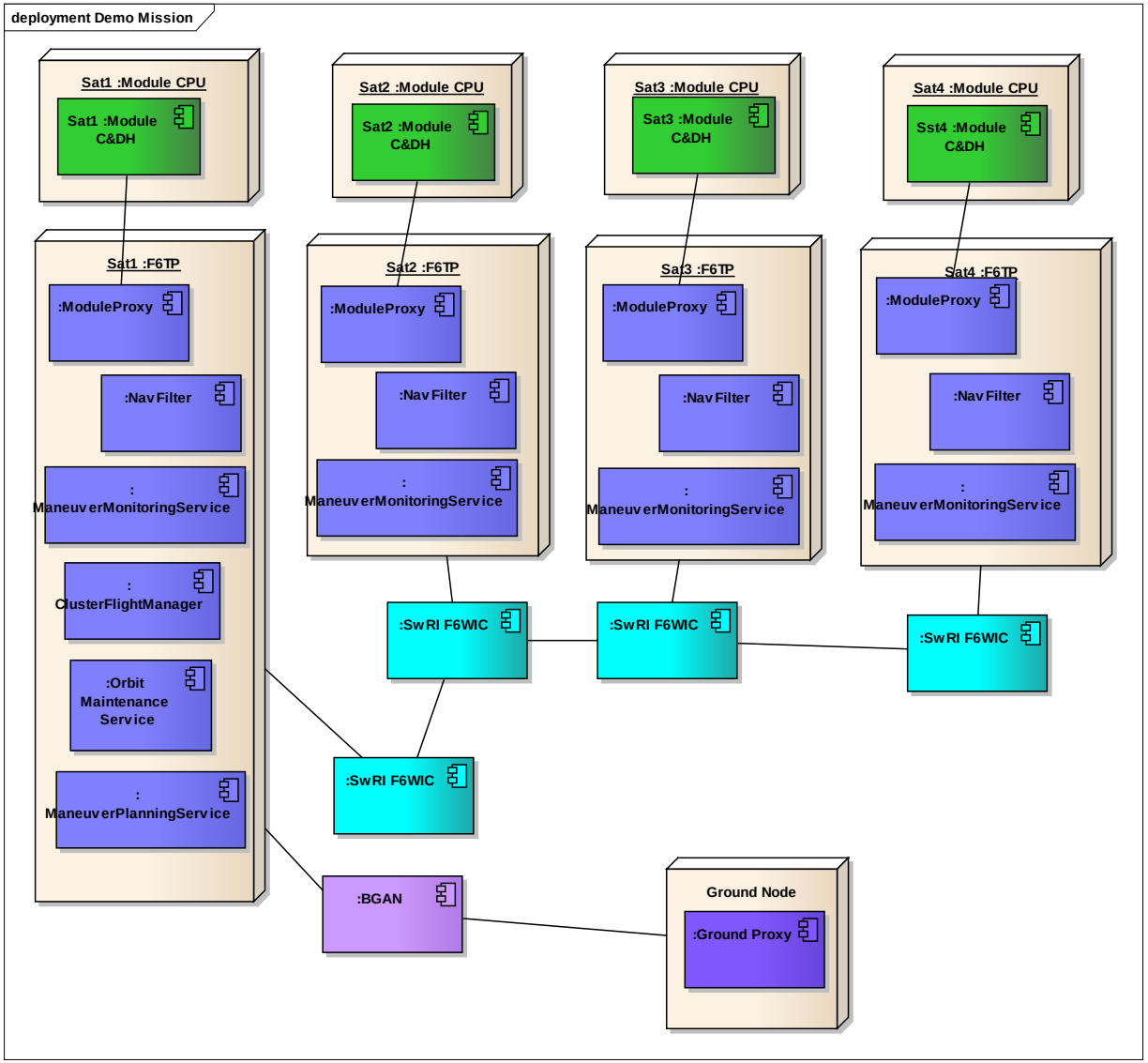


Navigation Service (NAV)

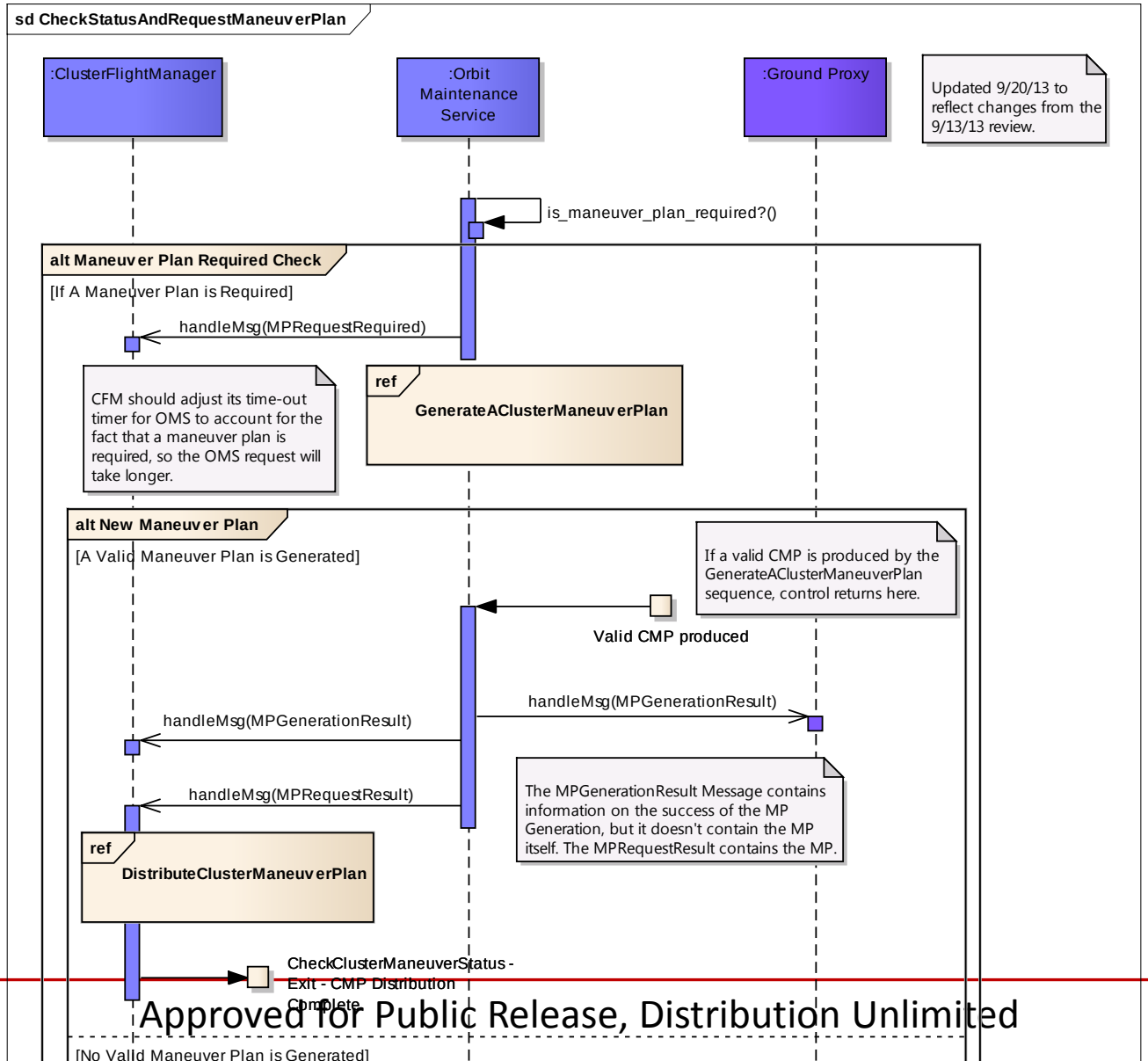
- Identical Navigation Flight Software (FSW) Components are located on each module in the cluster
- Each component runs a GPS pseudorange filter and a relative range filter in parallel and exchange navigation solutions and lists of tracked GPS satellites with other modules in the cluster.



Deployment View



Requesting a Maneuver Plan

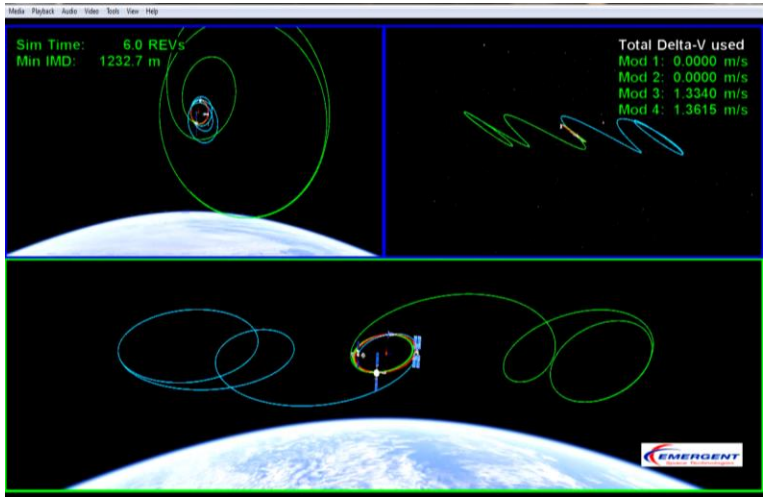


Architectural Factors that Make a Good Flight Software Services

- Relatively few “state” parameters
- Process atomic transactions
- Focused purpose
- Self-contained requests in a relatively narrow range
- Continue to provide services, if at all possible
- Be mission, platform, and message bus agnostic
- Service must be testable on its own

CFA Forward Plans

- Port to the cFE/CFS
- Make it open source
- Add Monte Carlo Capability
  - Python based Monte Carlo driver for managing cloud-distributed jobs
- GPS Model Upgrades
  - Conversion of high-fidelity GPS constellation model to C++ classes
  - Validation with Google unit tests
- HWIL interfaces for testing with GPS signal simulator
- Flight platform benchmark testing
- CFA mission testing and performance characterization



Emergent Space Technologies

- **Small Business**
  - Founded August, 2001
  - Solid growth each year since
- **Headquartered in Greenbelt, MD**
  - Houston, Austin, Denver, Colorado Springs, Albuquerque
- **Reliable Flight Software Development**
  - Proven CMMI Level 3 Certified Agile Software Development
- **Experienced in Multi-Satellite System Development and Operations**
  - Orion, Orbital Express, F6, ANGELS**,** MMS, Globalstar, Iridium, HST SM4

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