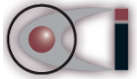

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DDS in Multi Level Security Environments for System F6

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Future Fast, Flexible, Fractionated, Free-Flying Spacecraft (F6)

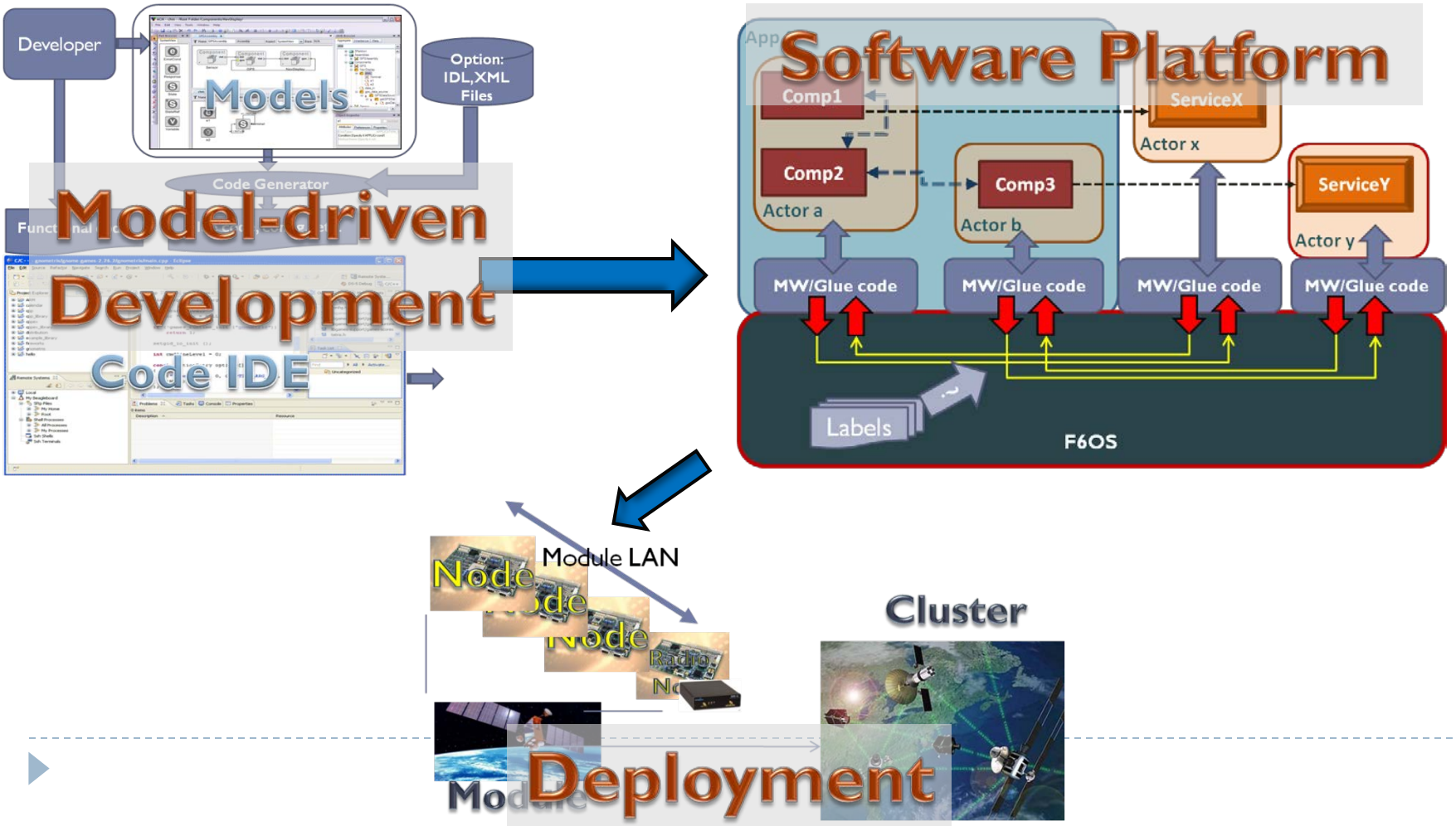
- Objective: Develop and demonstrate a satellite architecture where the functionality of a traditional monolithic spacecraft is replaced by a cluster of wirelessly connected modules
- Advantages:
  - Increased flexibility during design and acquisition
  - Reduced development and launch costs
  - Increased adaptability and survivability of space systems on-orbit
  - Potential to apply economies of scale to satellite design & manufacture
- Key program objective is the promulgation of open interface standards for hardware and software.

High Level System F6 Technical Goals

1. Distributed system with network addressability
   - Everything and anything (modulo security permissions) can be accessed and addressed
2. Cope with highly variable network quality & availability
   - Inter-satellite links are highly unreliable with unpredictable bandwidth; ground links are infrequent and flow
3. Dynamism
   - Dynamically deployed applications, security configurations, and cluster architectures
4. Resource sharing
   - Specific resources can be shared across applications: CPU, communication links, memory, services
5. Fault tolerance
   - Faults in components, services, communication links, computing nodes are detected, isolated, and their effects mitigated
6. Multi-level security
   - The architecture enforces mandatory access control based on MLS

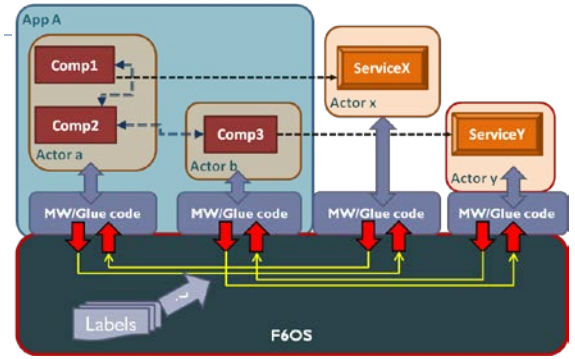
Solution:
F6MDA (Model-driven Architecture)

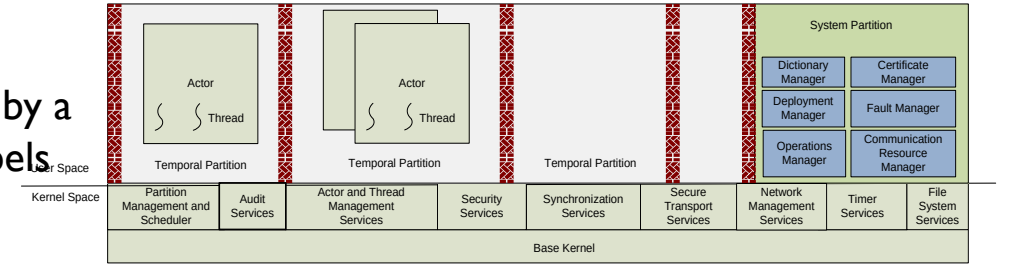
Layered architecture supported by a model-driven development toolchain

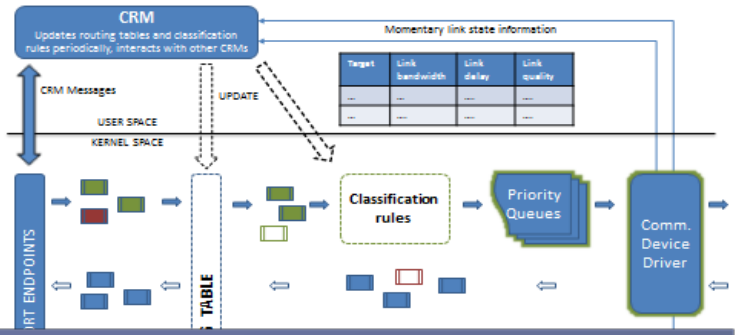


Solution: F6OS

- The 'Operating System' that provides
  - Restricted OS calls for application actors
  - Privileged calls for platform ('service') actors
  - All system calls are time-bounded
- Provides messaging services
  - All component interactions are via messages
  - No other interactions are possible
- All component interactions are facilitated by a 'secure transport' that verifies security labels on messages
- Resource management functions
  - CPU time: temporal partitioning for actors, utilization cap per actor within partition
  - Memory: space partitioning, limit caps
  - Network bandwidth: diffserv, bandwidth budget, differentiated routing
- F6OS is part of the TCB







F6OS enforces Mandatory Access Control (MAC) on all inter-actor interactions

F6OS Secure Transport (1/2)

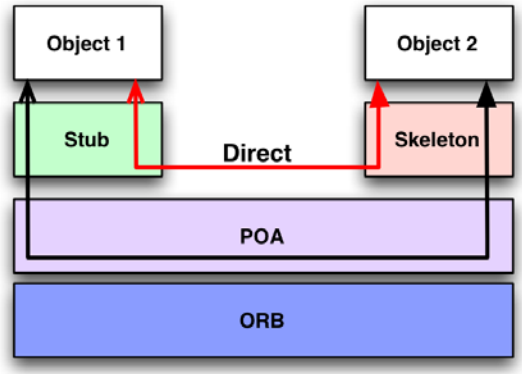
- Goals:
  - Secure information sharing (confidentiality, integrity, authenticity)
  - No unauthorized information flows
  - (Application) Actors do not have to be trusted
  - Support for real-time ('timely') communication and fault tolerance
  - Individual actors should be addressable
- Approach:
  - Communication connections are *explicitly* set up by a privileged and trusted actor
    - *Information flows must be set up by trusted entities*. Communication endpoints are addressed in a manner that is independent of the underlying node's identity.
    - *Allows the actors to be relocated at runtime without disrupting the application level logic.*
  - Actors are given the endpoints of connections at initialization time
    - *Actors cannot simply create endpoints, they must be given to them by a trusted entity*
  - Actors supply security labels when communicating
    - *Actors can handle multiple communications simultaneously on different labels, hence they must inform the kernel which one is needed*
  - F6OS verifies labels against labels independently supplied in actor's meta-data
    - *Trusted entity verifies label matching (or compatibility)*

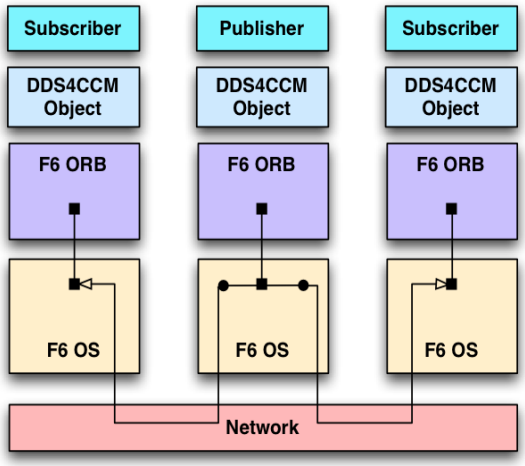
F6OS Secure Transport (2/2)

- All inter-actor communication happens via *endpoints* that are *logically connected* via flows.
  - Endpoints …
    - Are like sockets (connect an actor to another endpoint – of another actor)
    - But can be created by only privileged actor(s)
  - Flow….
    - Associations between one source and one or more destination endpoints
    - Special case: destination endpoint can be multicast group
    - Configured by only privileged actor(s)
  - Endpoint/flow configuration is part of the 'Deployment Plan'
- Labels
  - Generated and assigned by a trusted party (system integrator)
    - There has to be one authoritative source of labels
  - Both actors and endpoints have labels
    - Multi-label actors communicating on multi-label endpoints are possible
  - Write Equal/Read Equal and Write Equal/Read Down are supported

Solution: Middleware

- The 'middleware layer' that provides:
  - Synchronous and asynchronous point-to-point communication with call/response semantics (→ Subset of CORBA RMI)
    - Location transparency
    - Request (de)multiplexing
    - Message (de)marshalling
    - Error handling
    - Support for QoS (client timeouts, reliable one-ways)
  - Anonymous publish/subscribe communications with one/many-to-many data distribution patterns (→ Subset of DDS)
    - Datatype specification
    - Static discovery





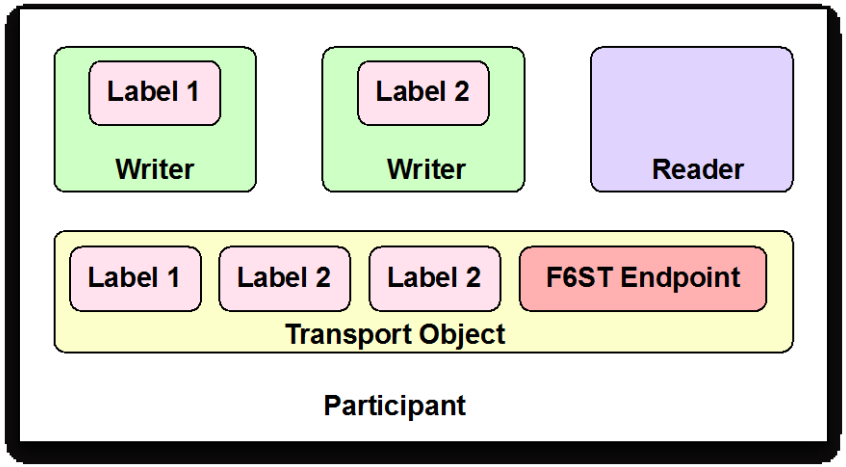
CORBA and DDS are complex standards; certification as part of the Trusted Computing Base (TCB) would be prohibitive

Implications for DDS

- DDS Implementation must be label aware
  - Must use secure transport APIs to transmit data samples
  - Must associate labels with DDS entities
- Restricts Quality of Service properties that may be supported
  - Low label actors can not be aware of high label actors
  - Any QoS that requires such knowledge can not be supported
- Complicates conventional DDS discovery process
  - Participants can not spontaneously connect to peers for discovery
  - Unrestricted discovery creates a significant covert channel

Security Label Associations (1/2)

- Transport Object
  - Interacts with a F6ST Endpoint
  - May have multiple labels; subset of endpoint labels
- Writer
  - Assigned a single label at creation
  - Label may not change, and it applied to all samples
- Reader
  - Unlabeled
  - Each sample's label is communicated via Sample Info mechanism

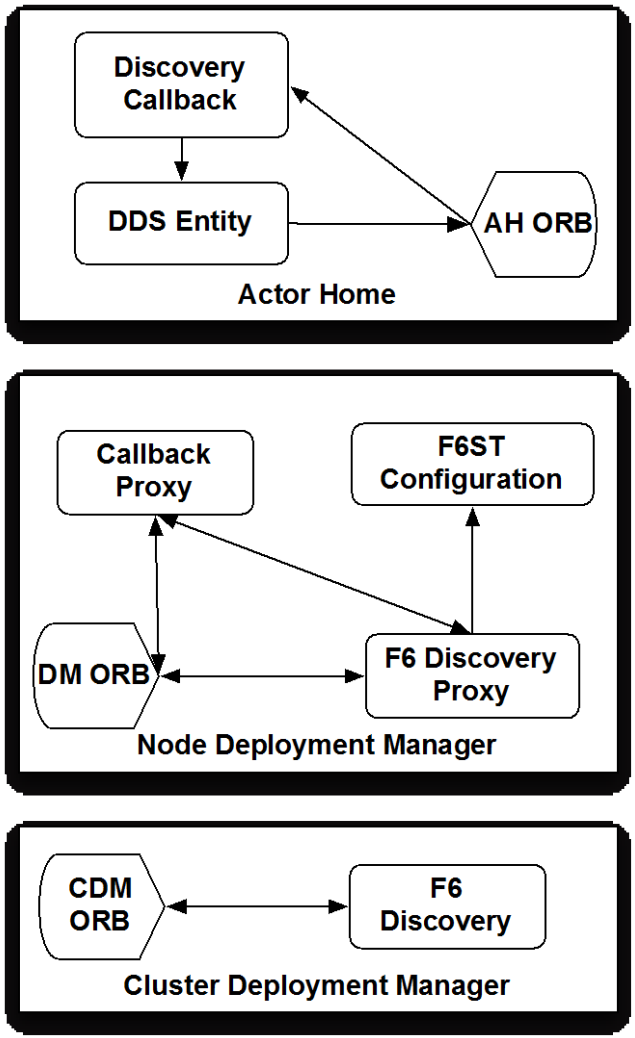


Security Label Associations (2/2)

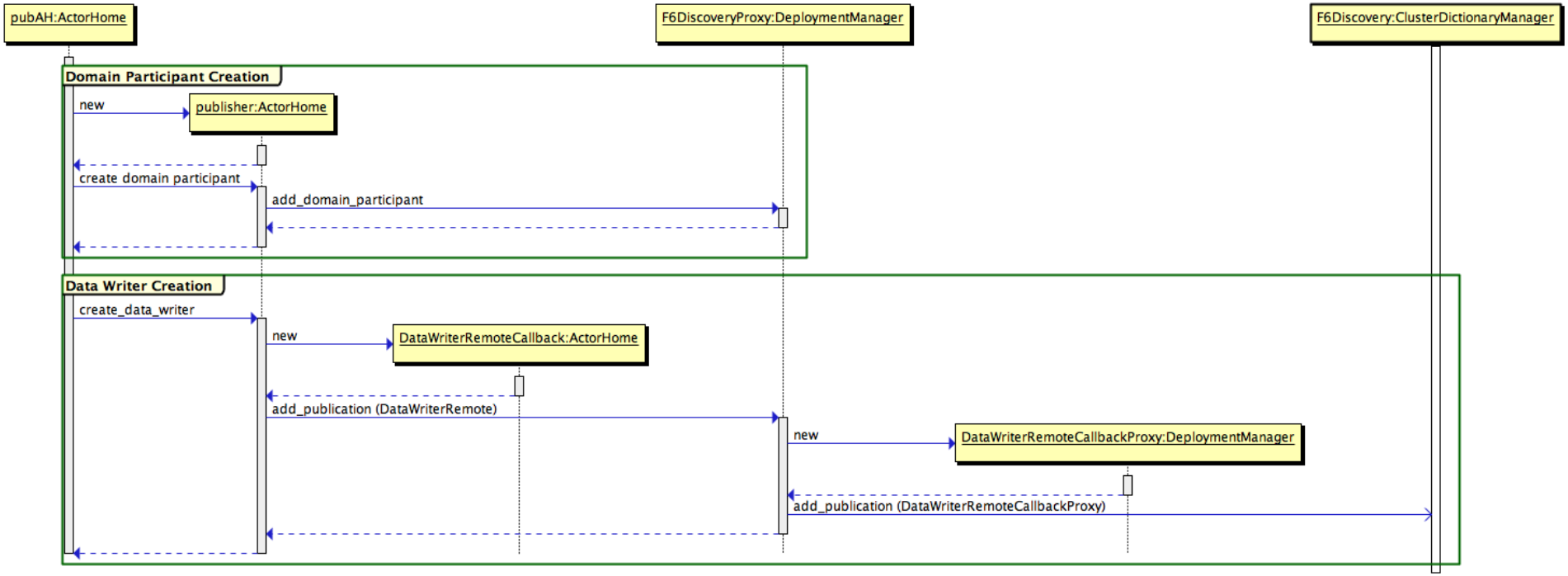
- Topics and domains may have multiple labels
- Write-Equal/Read-Equal
  - Publishers/Subscribers are the same label
  - Publishers and Subscribers may mutually "know" each other
  - Allows for both unicast and multicast communication
  - Nearly full range of DDS QoS supported
- Write-Equal/Read-Down
  - Publishers have a lower label than subscribers
  - Publishers **may not** have any knowledge of subscribers
  - Only allows multicast communication
  - QoS requiring such knowledge is forbidden
    - Reliability
    - Ownership

F6 Discovery Participants

- Actor Home
  - Generic process that hosts application business logic hosted in components
  - Hosts the DDS implementation
- Deployment Manager
  - Trusted deployment infrastructure local to the node on which an Actor runs
  - Responsible for configuring Secure Transport
  - Part of the TCB
- Cluster Dictionary Manager
  - Trusted cluster repository of DDS entities and topics
  - Responsible for matching publishers and subscribers
  - Part of the TCB

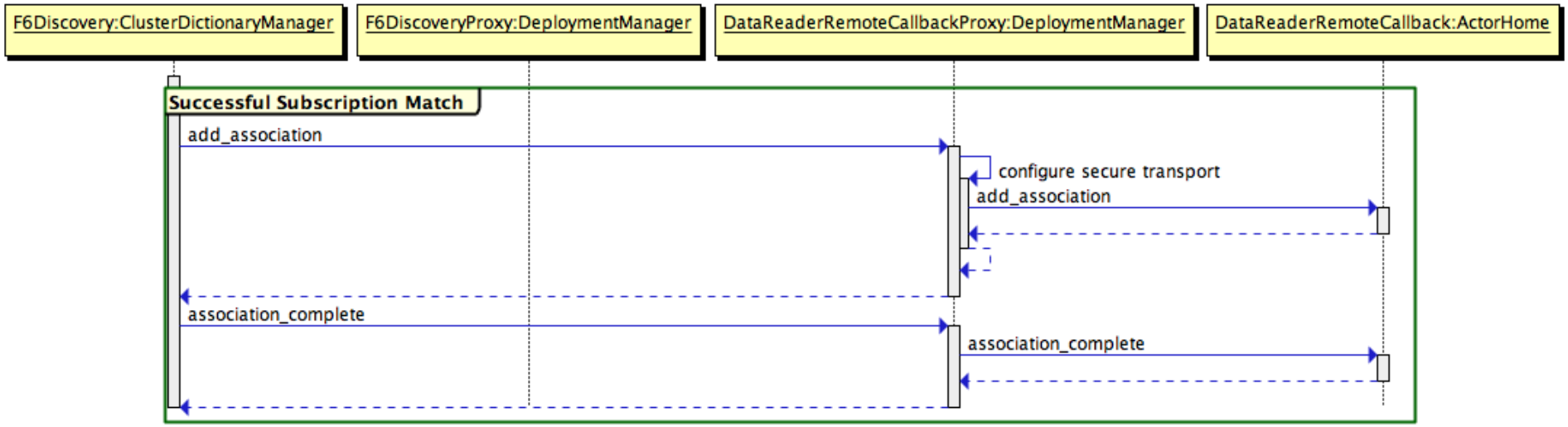


F6 Discovery: Entity Registration



- Process is similar for subscriber entity
- Proxy objects provide a trusted mediator between discovery service and untrusted actor

F6 Discovery: Subscription Match



- Discovery services is label aware
- Only matches entities of compatible labels
- Proxy objects intercept discovery events and configure Secure Transport before informing entity of matches
- F6 Discovery generates "fake" meta data (GUID, etc) when matching low writers to high readers

Lessons Learned

- DDS is a useful and popular platform for future space systems
  - Most submitted designs for the System F6 IAP featured DDS as a communication mechanism
  - Shown to be an effective tool to write distributed flight software for fractionated spacecraft
- Segregating Discovery substantially simplifies integrating DDS in MLS systems
  - DDS need not be part of the TCB, substantially simplifying analysis and design
  - Reduces possibility of covert channels between low and high actors
- Proprietary F6 discovery process could present a interoperability concern

More Information:
http://www.isis.vanderbilt.edu/projects/F6
http://www.darpa.mil/Our_Work/tto/Programs/System_F6.aspx