Designing Command and Data Handling (C&DH) Subsystems from Software Architectural Design Patterns

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Outline

- **Motivation for this research**
- **Research approach**
- **Distributed, real-time and embedded (DRE) software design patterns**
- **Deriving DRE software design patterns for flight software**
- **Real world case study example**
- **Conclusions and future work**

Motivation for this research

- Software design patterns are best practice solutions to common software problems
  - *Avoid reinventing the wheel*
  - *Improvement in the -ilities*

- However, software design patterns can be difficult to apply in practice
  - *Abstract and generic descriptions*
  - *Can be applied at several different layers of abstraction*

- Taking advantage of design patterns is particularly import for the FSW domain
  - *Increased FSW responsibilities has led to additional complexity and a greater number of software related anomalies.*
    - "In the period from 1998 to 2000, nearly half of all observed spacecraft anomalies were related to software" [1]

  - *NASA's Study on Flight Software Complexity Report examined flight software complexity and provided a series of recommendations to better manage the associated challenge.*
    - This presentation aligns with their recommendation to perform early analysis and architecting [2]

Research Approach

- Select and categorize software design patterns for common DRE features
  - *A feature is a requirement or characteristic of the system that is provided by some DRE systems*
  - *Assuming DRE systems are built on top of RTOS therefore patterns for RTOS features are not included*
- Create executable UML design pattern templates for each pattern
  - *Validated for functional correctness using executable statecharts*
- Select and augment DRE design patterns for the FSW domain
- Customize the executable UML design pattern templates for FSW

Flight Software is a specialized type of DRE software therefore design patterns for flight software can be derived from DRE design patterns

DRE Common Features

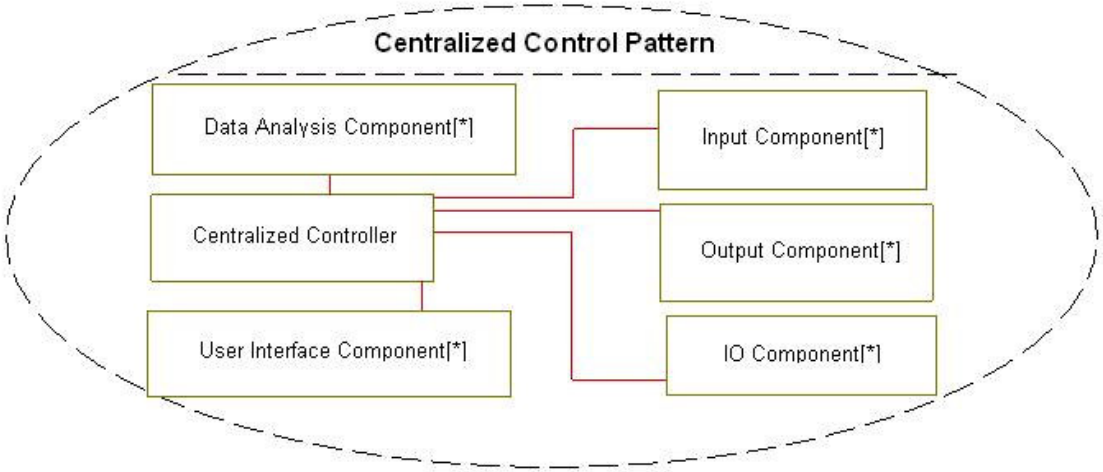
- **Architecture Structure**
  - *Decompose DRE software from a high-level perspective*
  - *Used early on in the architecting process since they provide the structural foundation of the software*
- **Control Feature**
  - *Controlling the system, subsystems, or external devices*
  - *Control can be handled and structured in variety of different ways depending on the requirements*
- **Data Processing Feature**
  - *Performing a single or series of transformational steps on a data*
  - *Examples include converting a set of data from one format to another and converting an analog signal into digital data*
- **Data Collection Feature**
  - *Gathering data from various sources*
  - *This includes pulling from the sources or pushing data to the receivers*
  - *Examples include monitoring system health and gathering data from input devices*
- **Data Sharing Feature**
  - *Strategies for ensuring data integrity when multiple concurrent components need to read and write data*
- **Fault Detection Feature**
  - *Detecting when a fault has occurred*
  - *Particularly important for DRE systems with autonomy because it needs be able to determine that a fault has occurred before it can execute the proper response*
- **Fault Response Feature**
  - *Ability to respond to a fault*
  - *Particularly important for DRE systems with autonomy because it needs to know how to respond to a fault when a human is not in the loop*
- **Communication Feature**
  - *Specifics of how components exchange information with each other*
  - *Cross cut the other features and therefore these patterns are intended to be used combination with the other feature groups*

Design Patterns for DRE Common Features

- **Architecture Structure**
  - *Layers*
  - *5 Layer Architecture*
  - *Whole-Part*
- **Control Feature**
  - *Centralized Control*
  - *Hierarchical Control*
  - *Distributed Control*
  - *State*
  - *Command Processor*
  - *Command Dispatcher*
- **Data Processing Feature**
  - *Pipes and Filters*
  - *Master Slave*
  - *Strategy*
- **Data Collection Feature**
  - *Pulling Data from the Source*
    - *Client Server*
    - *Multiple Client Multiple Server*
    - *Multitier Client Server*
  - *Pushing Data to the Receiver*
    - *Publish Subscribe*
    - *Broadcast*
    - *Multicast*
- **Data Sharing Feature**
  - *Two Phase Commit*
  - *Compound Commit*
  - *Long-Living Transaction*
- **Fault Detection Feature**
  - *Watchdog*
  - *Single Protected Channel*
  - *Homogeneous Redundancy*
  - *Heterogeneous Redundancy*
  - *Triple Modular Redundancy*
  - *Monitor Actuator*
  - *Sanity Check*
- **Fault Response Feature**
  - *Safety Executive*
- **Communication Feature**
  - *Asynchronous*
  - *Bidirectional Asynchronous*
  - *Asynchronous with Callback*
  - *Synchronous with Reply*
  - *Synchronous without Reply*
  - *Broker Forwarding*
  - *Broker Handle*
  - *Discovery*
  - *Publish Subscribe*
  - *Broadcast*
  - *Multicast*

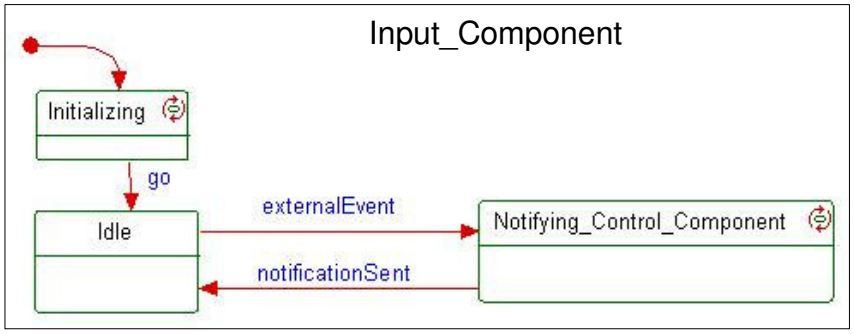
Executable UML Design Pattern Template Example

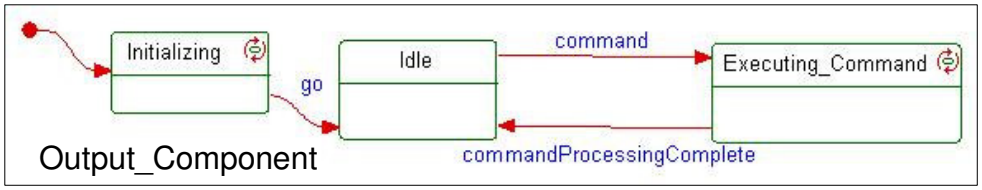
- Centralized Control Pattern
  - *One control component that provides overall control by conceptually executing a state machine*
- How it can be used to achieve Control feature
  - *It provides a control structure*
  - *All control logic is captured in a single component, which makes it easy to understand and maintain*
  - *Suitable for small applications because the centralized control can become a bottleneck*
- Collaboration Diagram
  - *Shows the components roles involved in the design pattern and their high-level interactions*

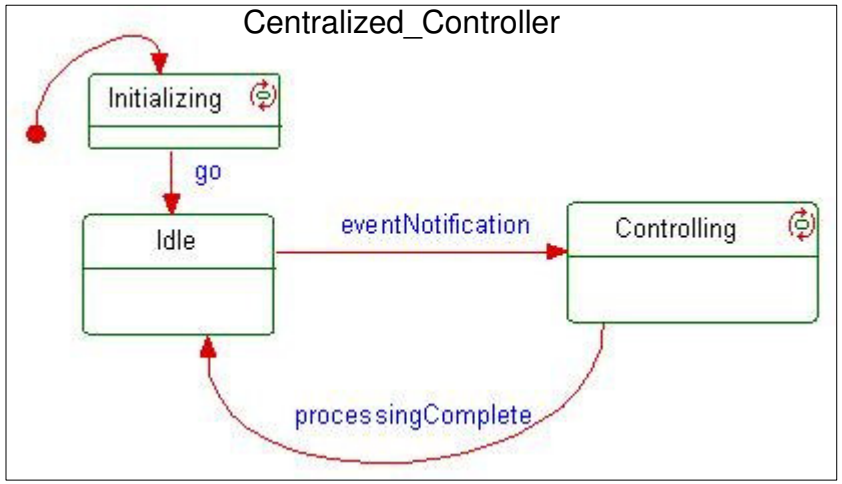


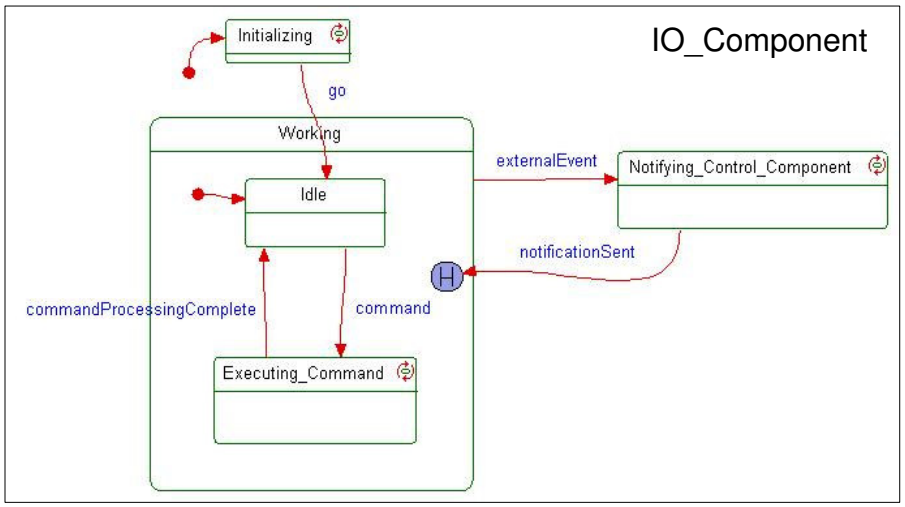
Executable UML Design Pattern Template Example (cont.)

- State machines
  - *Captures the internal behavior of a component*
    - State machine for each active component
  - *Used to validate a design pattern template by simulating the flow of events and messages through the design pattern*









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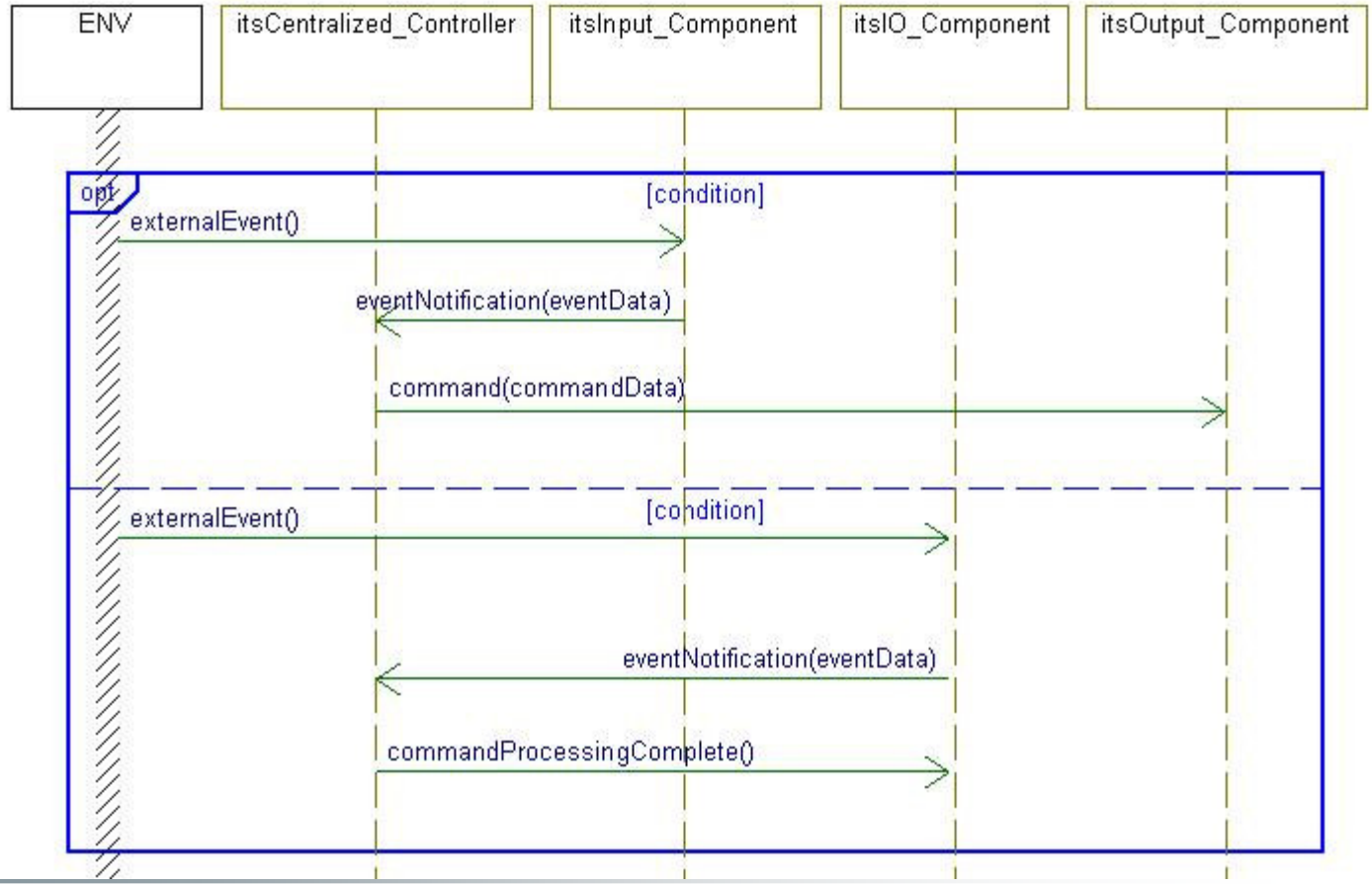
Executable UML Design Pattern Template Example (cont.)

- Sequence Diagram
  - *Illustrates interactions between the components*
  - *Sequence diagram covers a sample set of component interactions*



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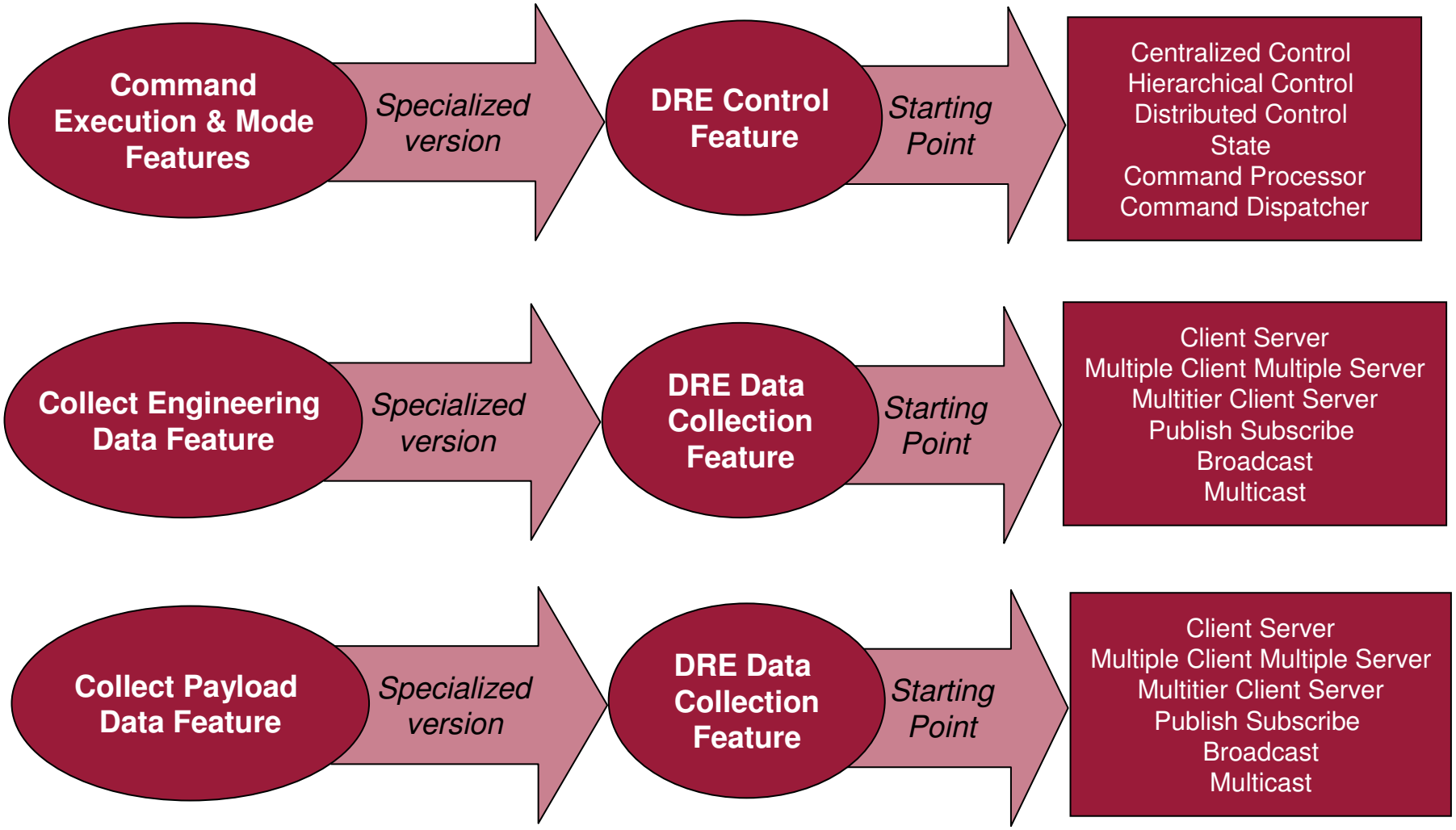
C&DH Common Features

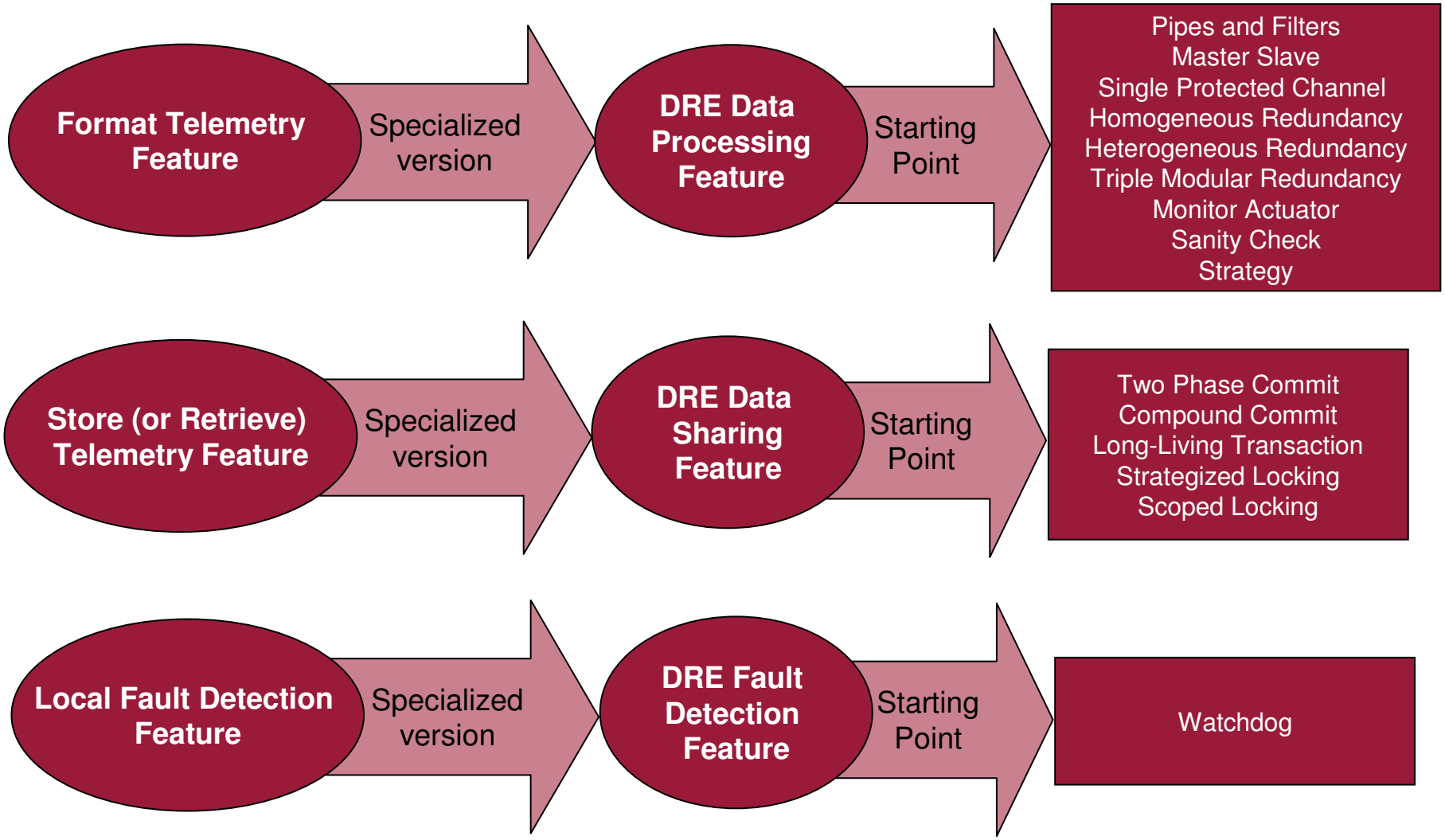
C&DH Common Features are features that are seen on a wide variety of spacecraft

- **Command execution feature**
  - *Executing the command or distributing the command to the appropriate subsystem for execution*
- **Mode management feature**
  - *Maintaining and changing the current mode of the spacecraft (e.g. Normal Mode, Safe Mode)*
- **Collect engineering data feature**
  - *Receiving health and monitor data from other subsystems*
- **Collect payload data feature**
  - *Receiving payload data from the payload hardware*
- **Format telemetry feature**
  - *Formatting the engineering or payload data into a telemetry format*
- **Store telemetry feature**
  - *Storing the telemetry in memory*
- **Retrieve telemetry feature**
  - *Retrieving telemetry from memory*
- **Local fault detection feature**
  - *Performing various checks on local operations and devices to ensure they are functioning correctly*

Deriving C&DH Patterns from DRE Patterns



Deriving C&DH Patterns from DRE Patterns (cont.)



Augment C&DH Design Patterns with C&DH specific patterns and customizations

- **Command execution and mode management features**
  - *Centralized Control*
  - *Hierarchical Control*
  - *Distributed Control*
  - *State*
  - ~~*Command Processor*~~
  - *Command Dispatcher*
- **Collect engineering data feature**
  - *Client Server*
  - *Multiple Client Multiple Server*
  - *Multitier Client Server*
  - *Publish Subscribe*
  - *Broadcast*
  - *Multicast*
- **Collect payload data feature**
  - *Client Server*
  - *Multiple Client Multiple Server*
  - *Multitier Client Server*
  - *Publish Subscribe*
  - *Broadcast*
  - *Multicast*
- **Format telemetry feature**
  - *Pipes and Filters*
  - *Master Slave*
  - *Strategy*
  - ***Abstract Factory with Facade***
- **Store telemetry feature**
  - *Two Phase Commit*
  - *Compound Commit*
  - ~~*Long Living Transaction*~~
- **Retrieve telemetry feature**
  - *Two Phase Commit*
  - *Compound Commit*
  - ~~*Long Living Transaction*~~
  - *Strategized Locking*
  - *Scoped Locking*
- **Architecture Structure**
  - *Layers*
  - ***4 Layer Architecture***
  - *Whole-Part*
- **Local fault detection feature**
  - *Watchdog*
  - ***Processor Restart Watchdog***
  - *Single Protected Channel*
  - *Homogeneous Redundancy*
  - *Heterogeneous Redundancy*
  - *Triple Modular Redundancy*
  - *Monitor Actuator*
  - *Sanity Check*
- **Communication**
  - *Asynchronous*
  - *Bidirectional Asynchronous*
  - *Asynchronous with Callback*
  - *Synchronous with Reply*
  - *Synchronous without Reply*
  - *Broker Forwarding*
  - ~~*Broker Handle*~~
  - ~~*Discovery*~~
  - ~~*Publish Subscribe*~~
  - *Broadcast*
  - *Multicast*

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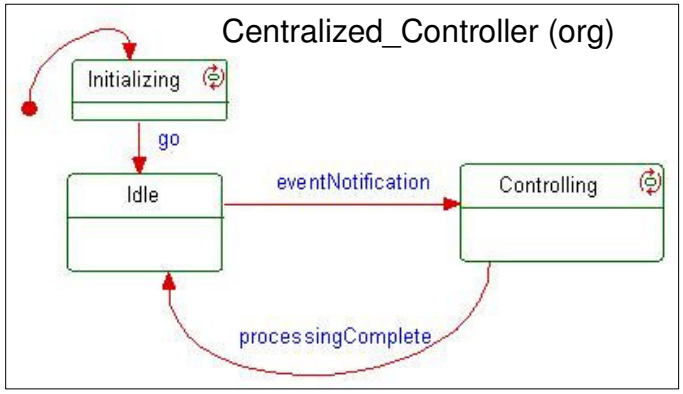
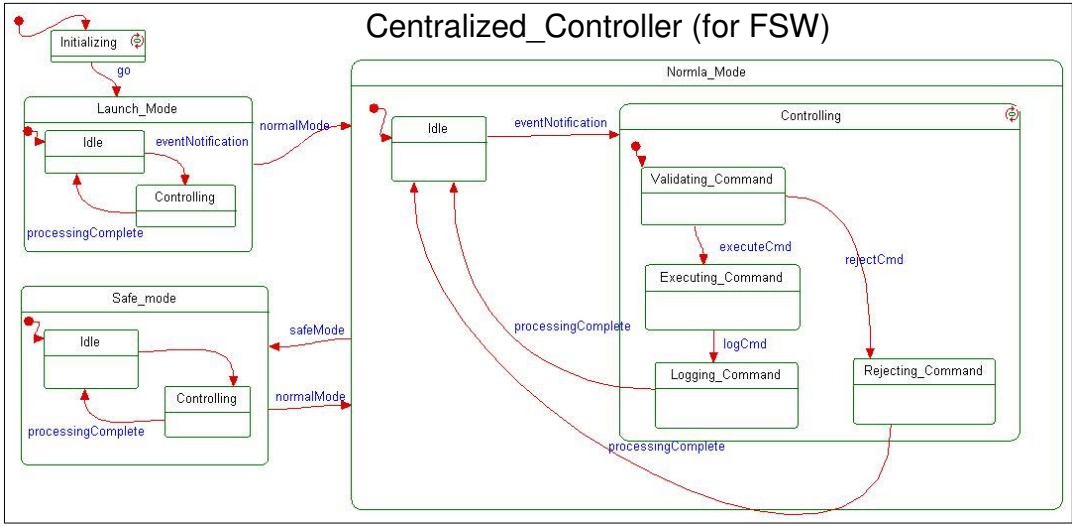
Customizing Executable UML Template Example

- Centralized Control Pattern
  - *One control component that provides overall control by conceptually executing a state machine*
- Customizations
  - *Add C&DH generalized logic to Centralized_Controller statechart*
  - *Add Ground Commands since the controller must balance when to execute ground commands & when to respond to onboard events*
  - *Update sequence diagram options to include Ground_Command scenario*





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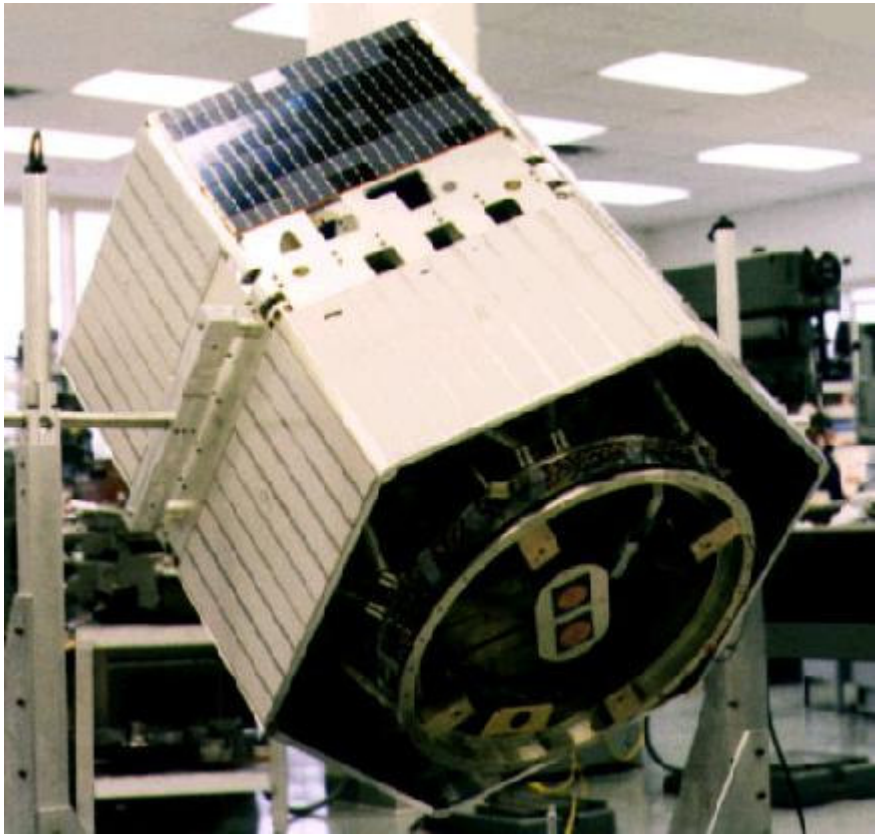
SNOE Case Study

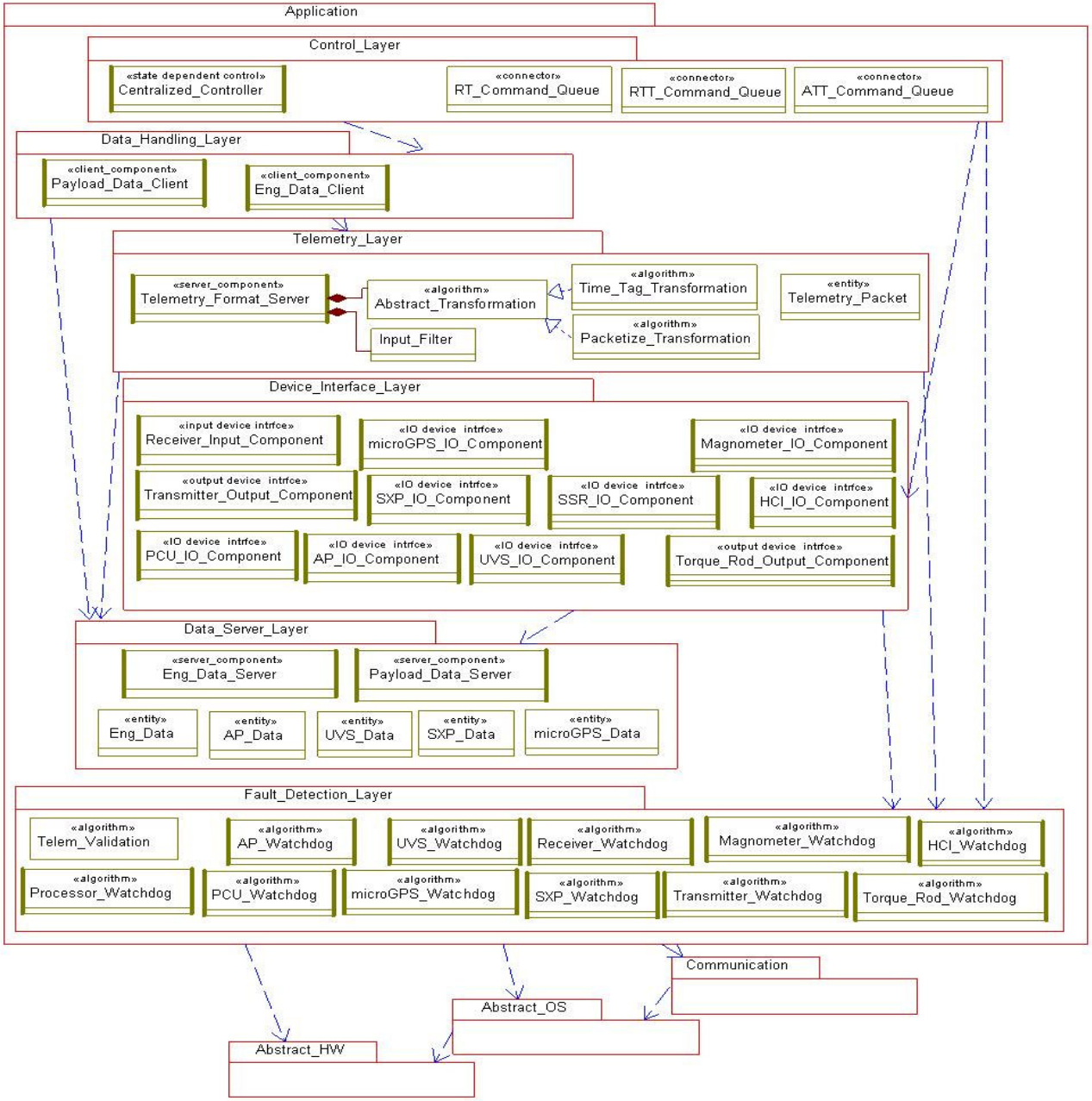
- **Student Nitric Oxide Explorer (SNOE)**
  - *Real world, small satellite program from NASA*
  - *Mission involves using a spin stabilized spacecraft in a low earth orbit to measure thermospheric nitric oxide and its variability*
  - *The spacecraft instruments*
    - ultraviolet spectrometer (UVS)
    - auroral photometer (AP)
    - solar soft X-ray photometer (SXP)
    - mircoGPS Bit-Grabber Space Receiver
  - *All the science and engineering data collected is downlinked to the ground for processing*
  - *The ground station is responsible for attitude determination and monitoring long term health and safety for the spacecraft and instruments*
  - *All data and commands are formatted using Consultative Committee for Space Data Systems (CCSDS) standards*
  - *Thermal control is passive and is handled solely by the hardware*
  - *Limited hardware redundancy*
  - *One SC4A Single Board Spaceflight Computer*
    - Five I/O blocks on two daughter boards that handle interfacing to all subsystems



SNOE C&DH Pattern Selection

- **Command execution and mode management features**
  - *Centralized Control*
  - *Hierarchical Control*
  - *Distributed Control*
  - *Command Dispatcher*
- **Collect engineering data feature**
  - *Client Server*
  - *Multiple Client Multiple Server*
  - *Multitier Client Server*
  - *Publish Subscribe*
  - *Broadcast*
  - *Multicast*
- **Collect payload data feature**
  - *Client Server*
  - *Multiple Client Multiple Server*
  - *Multitier Client Server*
  - *Publish Subscribe*
  - *Broadcast*
  - *Multicast*
- **Format telemetry feature**
  - *Pipes and Filters*
  - *Master Slave*
  - *Strategy*
  - *Abstract Factory with Facade*
- **Store telemetry feature**
  - *Two Phase Commit*
  - *Compound Commit*
- **Retrieve telemetry feature**
  - *Two Phase Commit*
  - *Compound Commit*
- **Architecture Structure**
  - *Layers*
  - *4 Layer Architecture*
  - *Whole-Part*
- **Local fault detection feature**
  - *Watchdog*
  - *Processor Restart Watchdog*
  - *Single Protected Channel*
  - *Homogeneous Redundancy*
  - *Heterogeneous Redundancy*
  - *Triple Modular Redundancy*
  - *Monitor Actuator*
  - *Sanity Check*
- **Communication**
  - *Asynchronous*
  - *Bidirectional Asynchronous*
  - *Asynchronous with Callback*
  - *Synchronous with Reply*
  - *Synchronous without Reply*
  - *Publish Subscribe*
  - *Broadcast*
  - *Multicast*

SNOE C&DH Software Architecture – Static View



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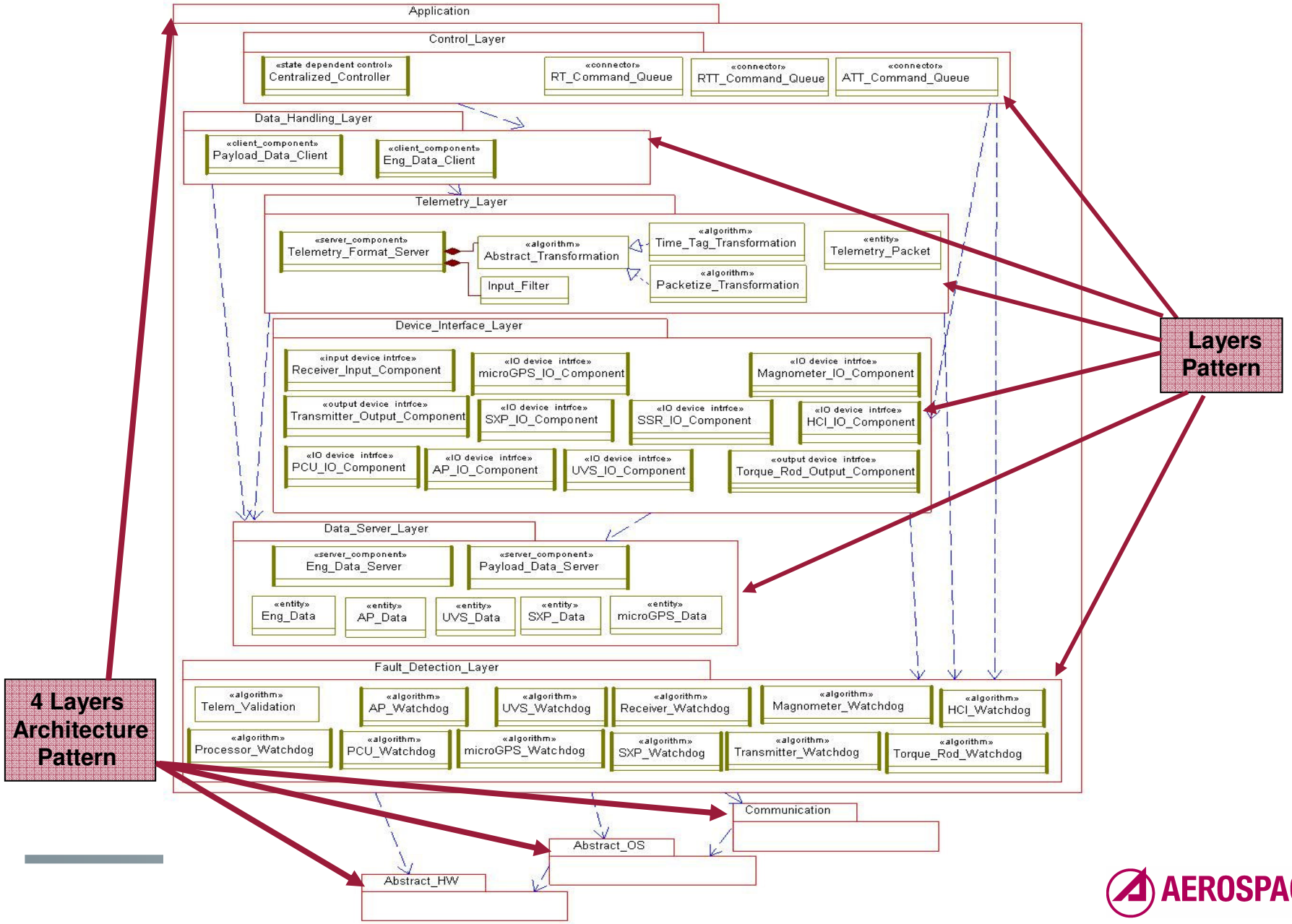
SNOE C&DH Software Architecture – Static View



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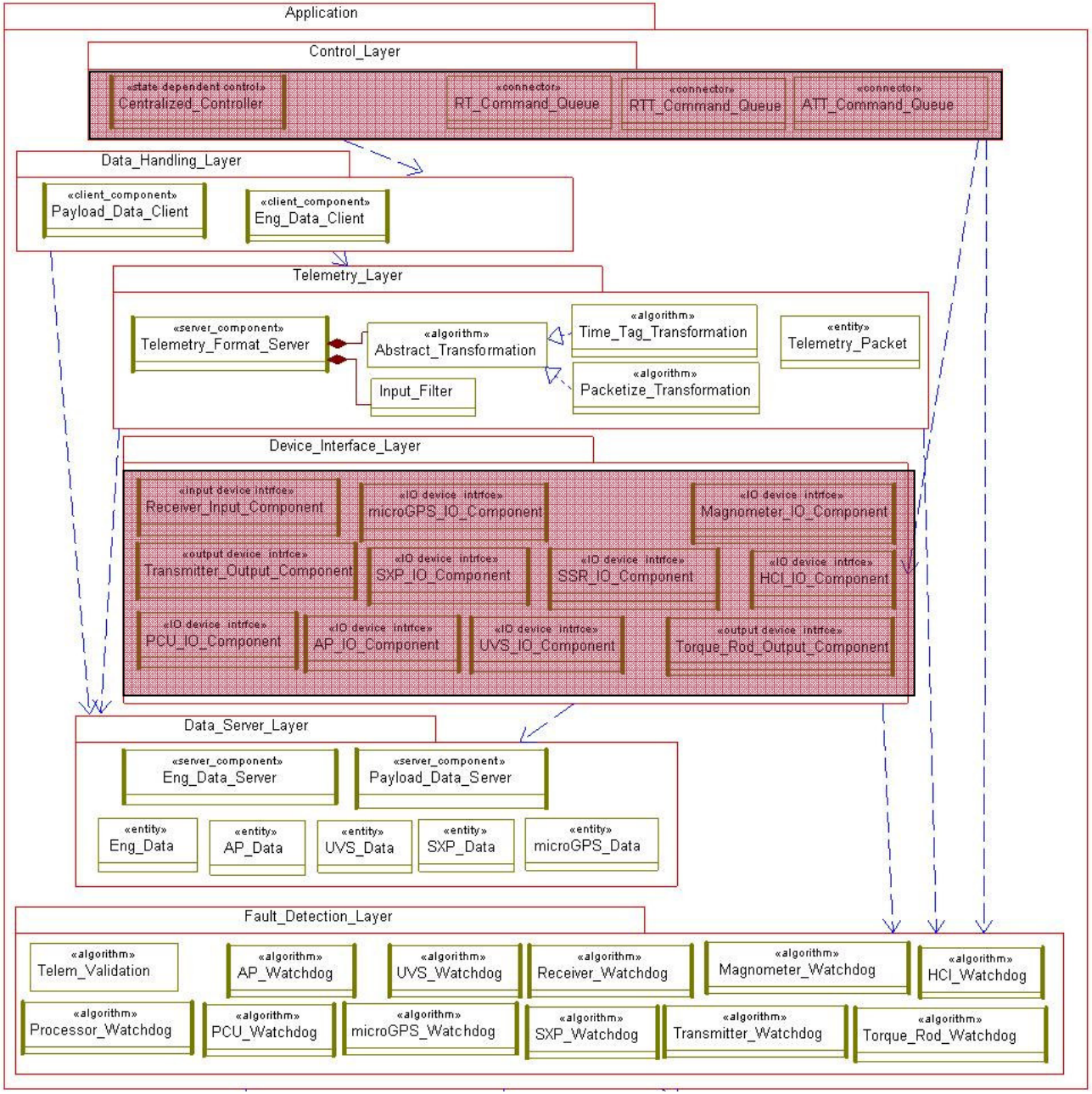
SNOE C&DH Software Architecture – Static View

Centralized Control Pattern



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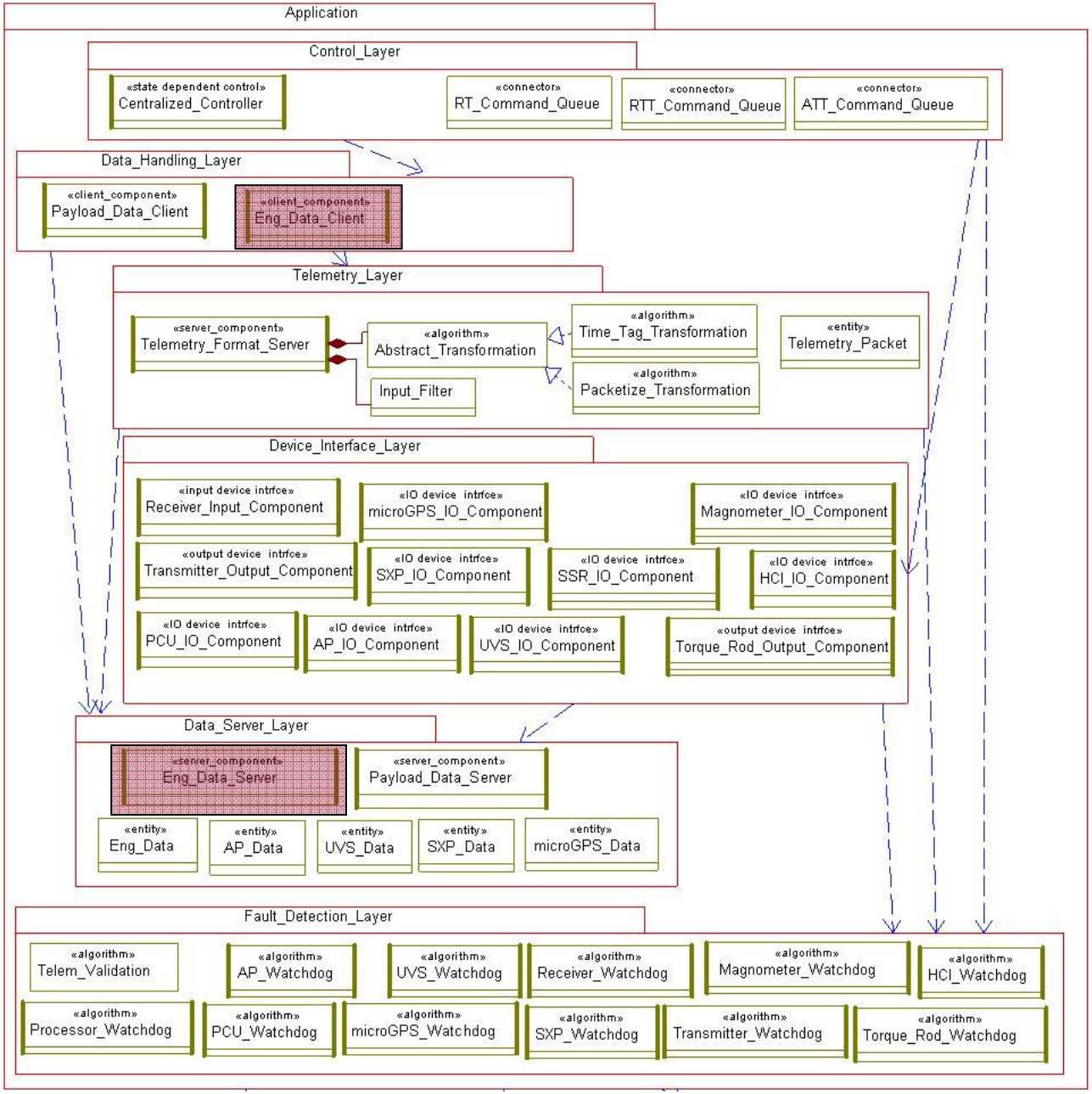
SNOE C&DH Software Architecture – Static View

Client Server Pattern (collect eng data)



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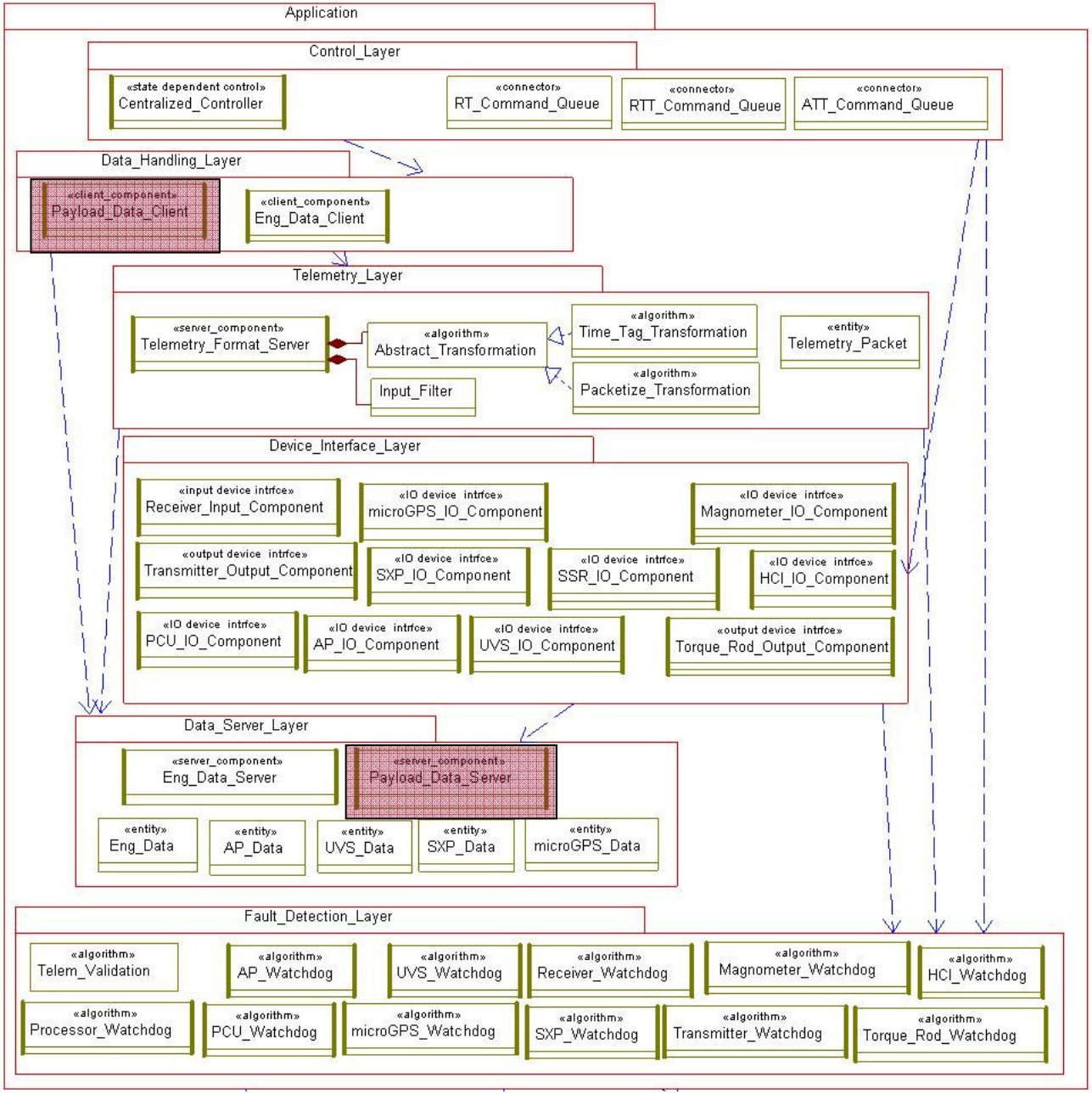
SNOE C&DH Software Architecture – Static View

Client Server Pattern (collect payload data)



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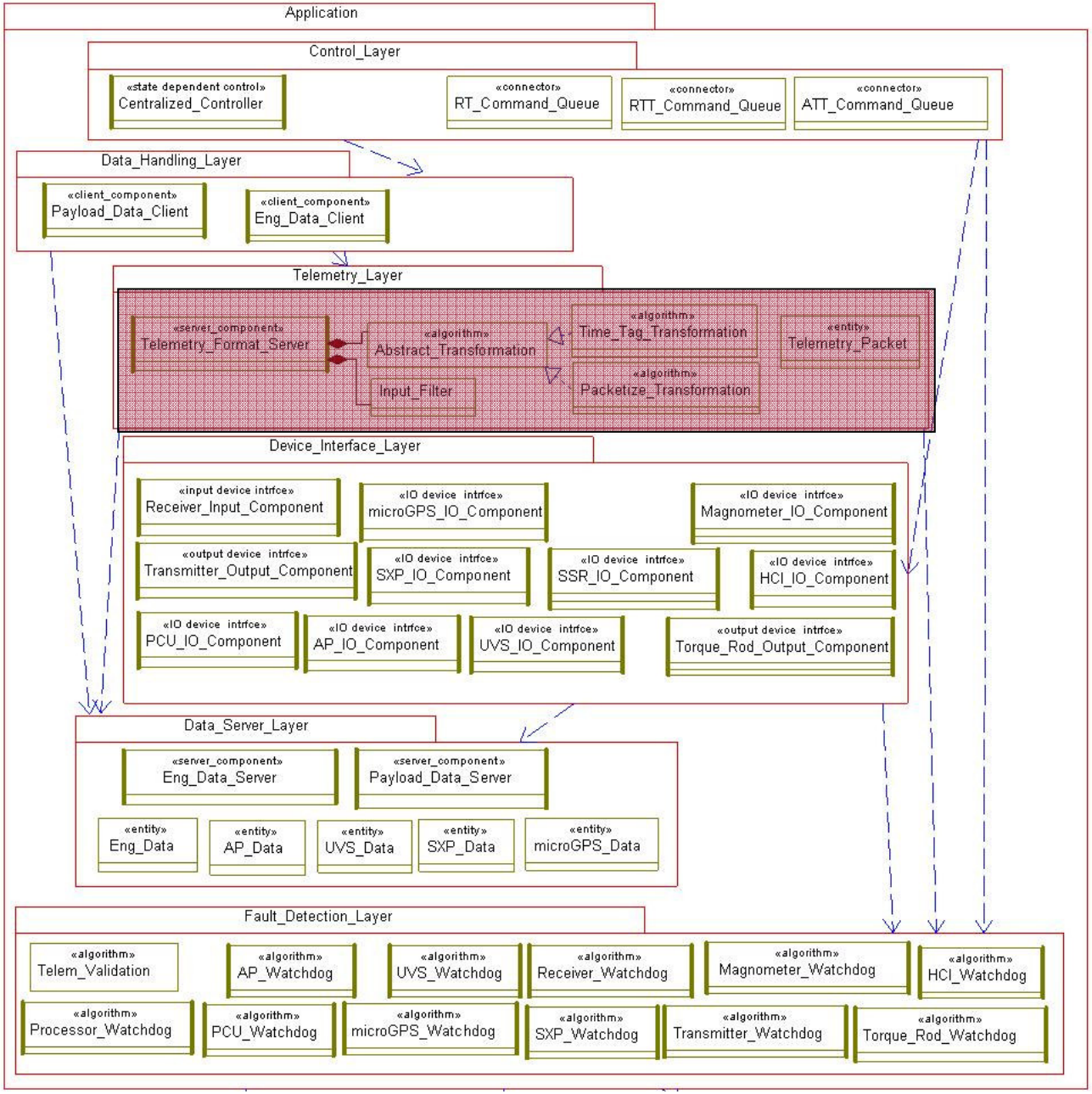
SNOE C&DH Software Architecture – Static View

Pipes & Filters Pattern



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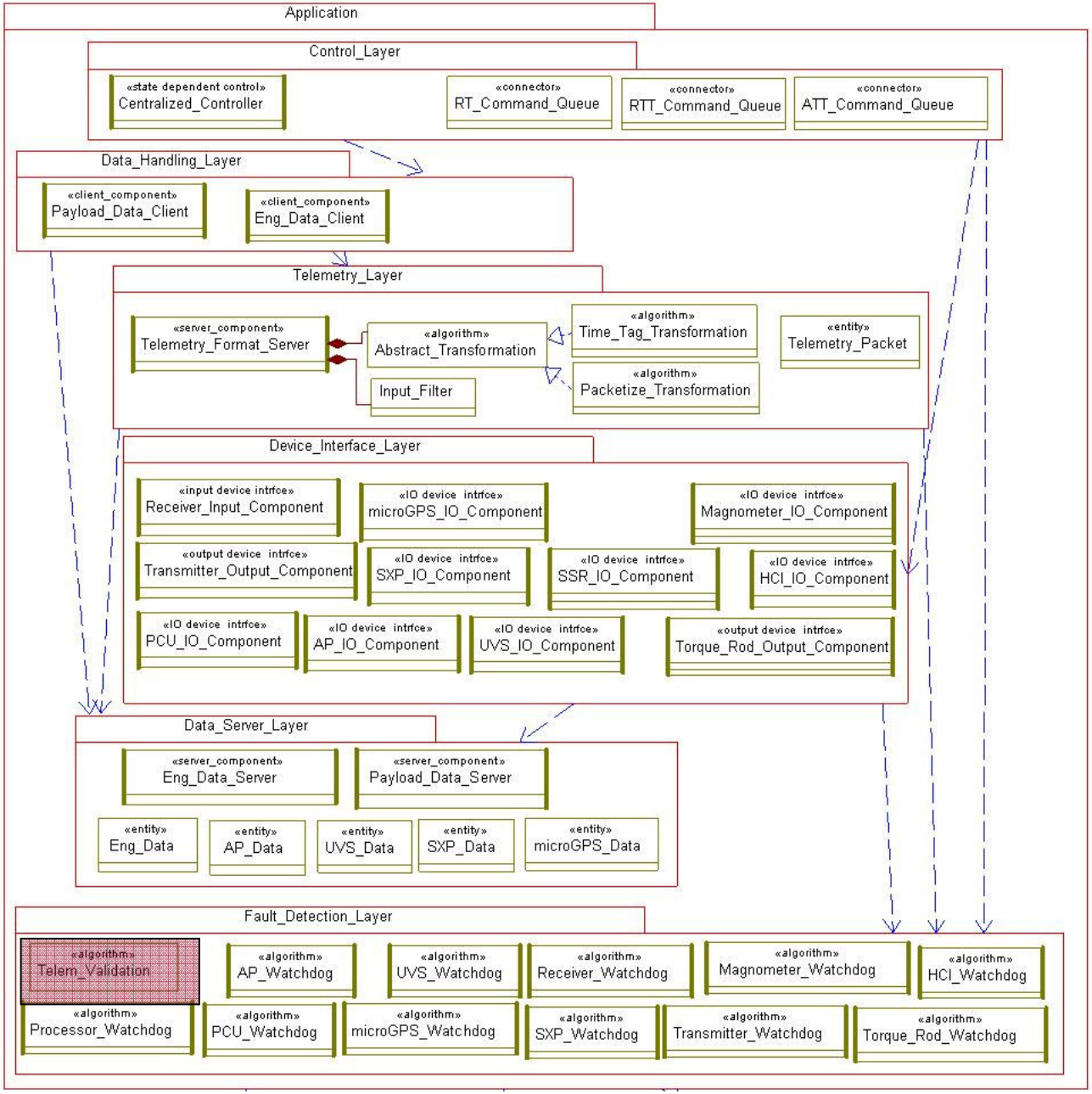
SNOE C&DH Software Architecture – Static View

Single Protected Channel Pattern



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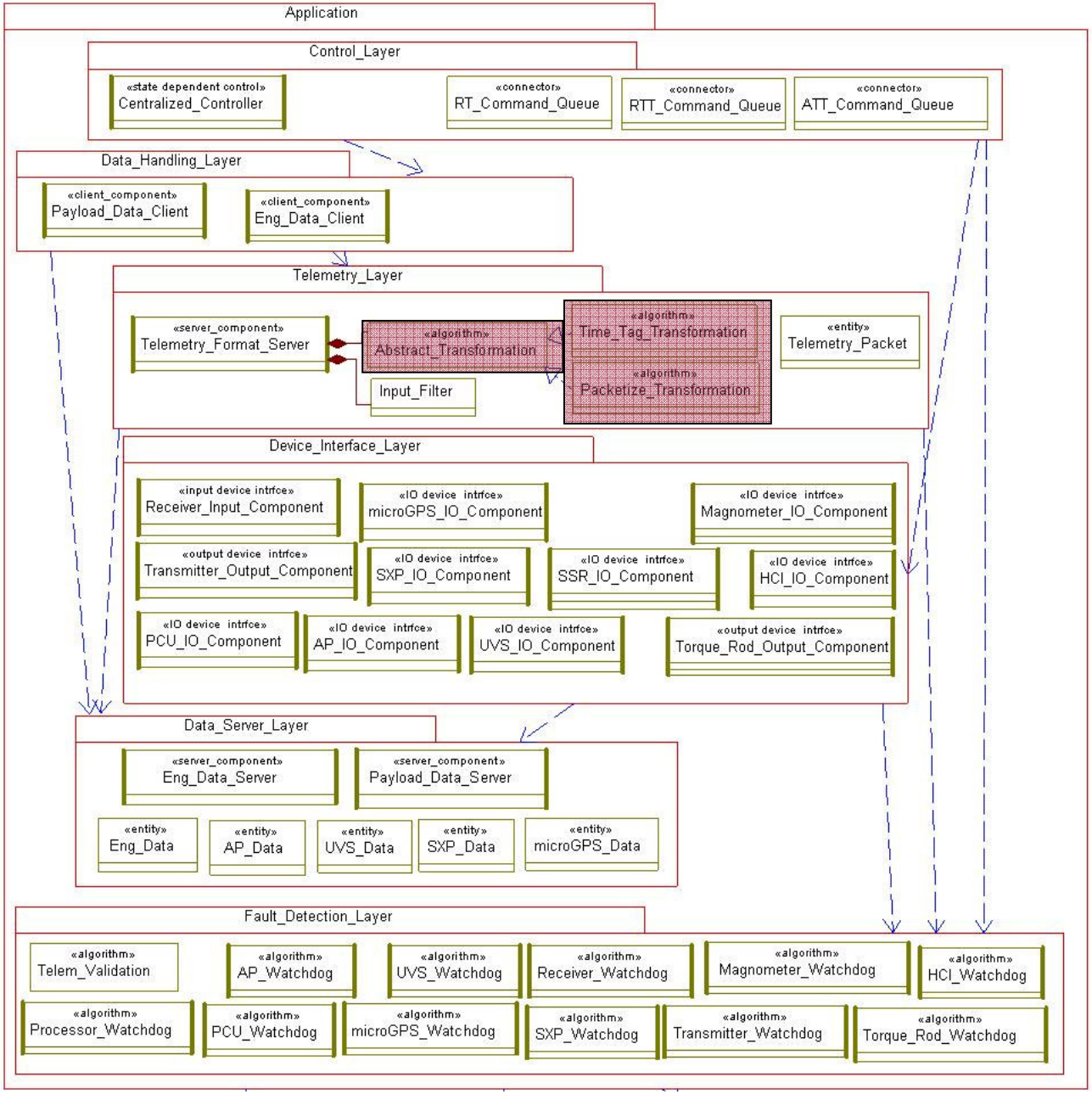
SNOE C&DH Software Architecture – Static View

Strategy Pattern



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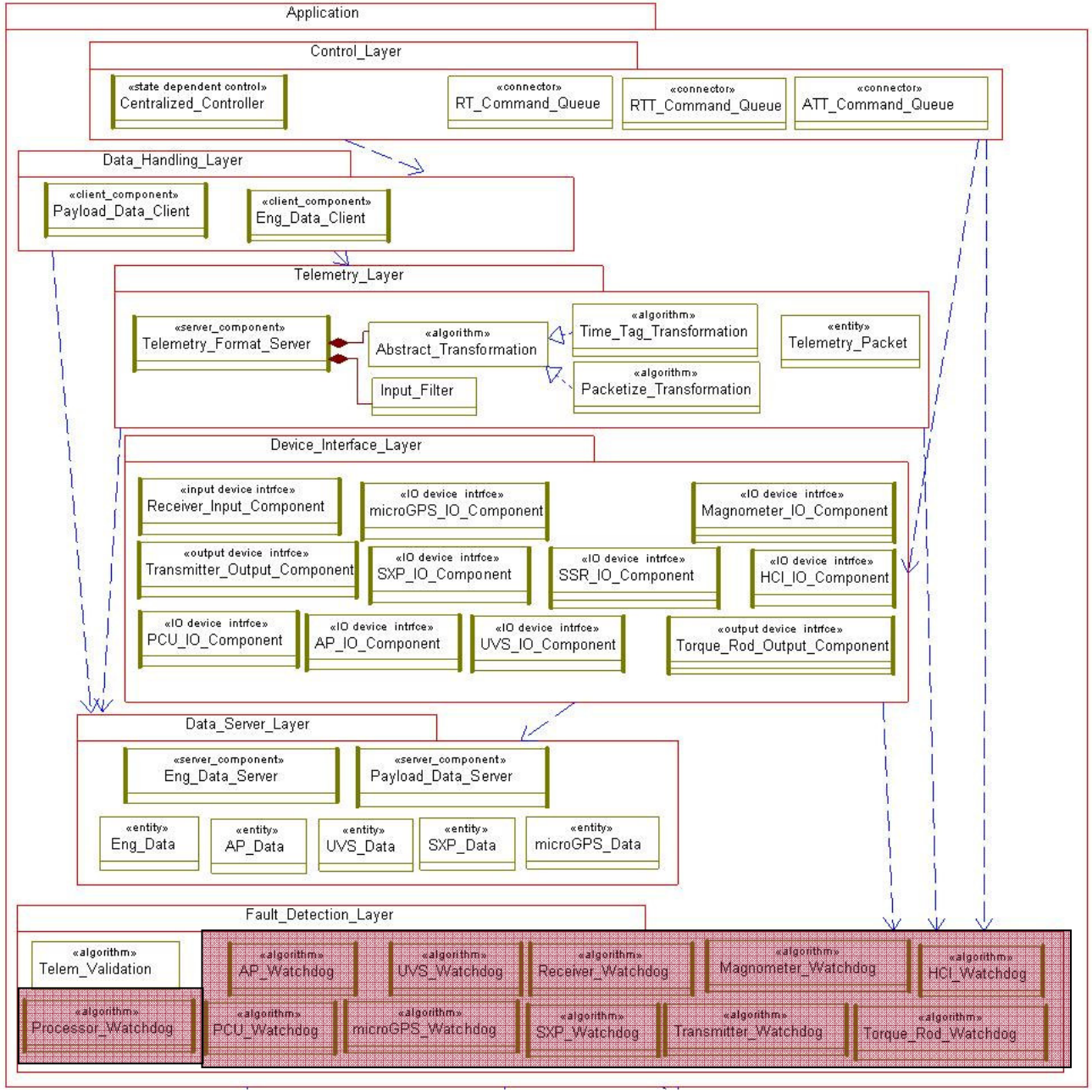
SNOE C&DH Software Architecture – Static View

Watchdog Pattern



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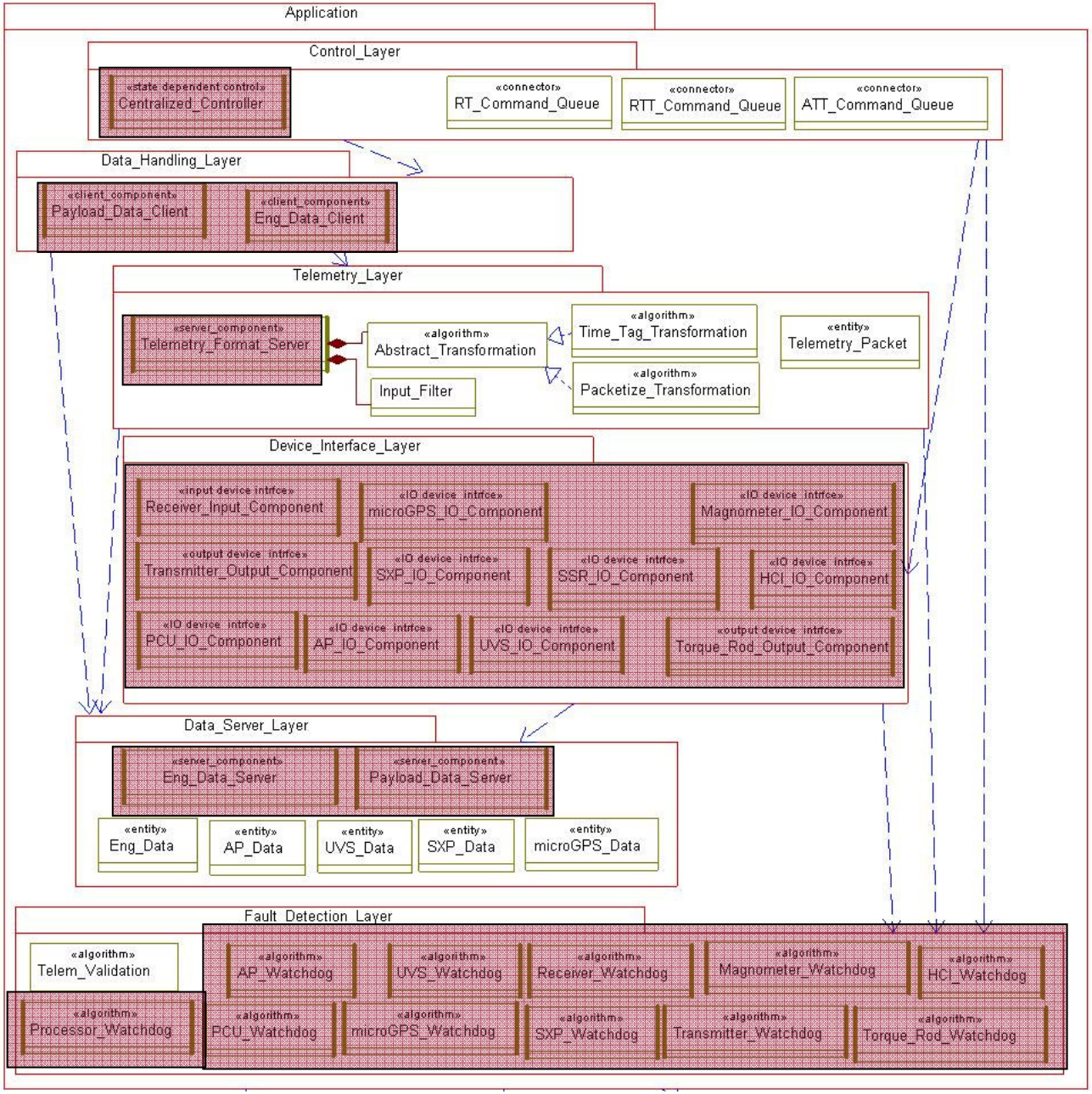
SNOE C&DH Software Architecture – Static View

Asynchronous Comm. Pattern



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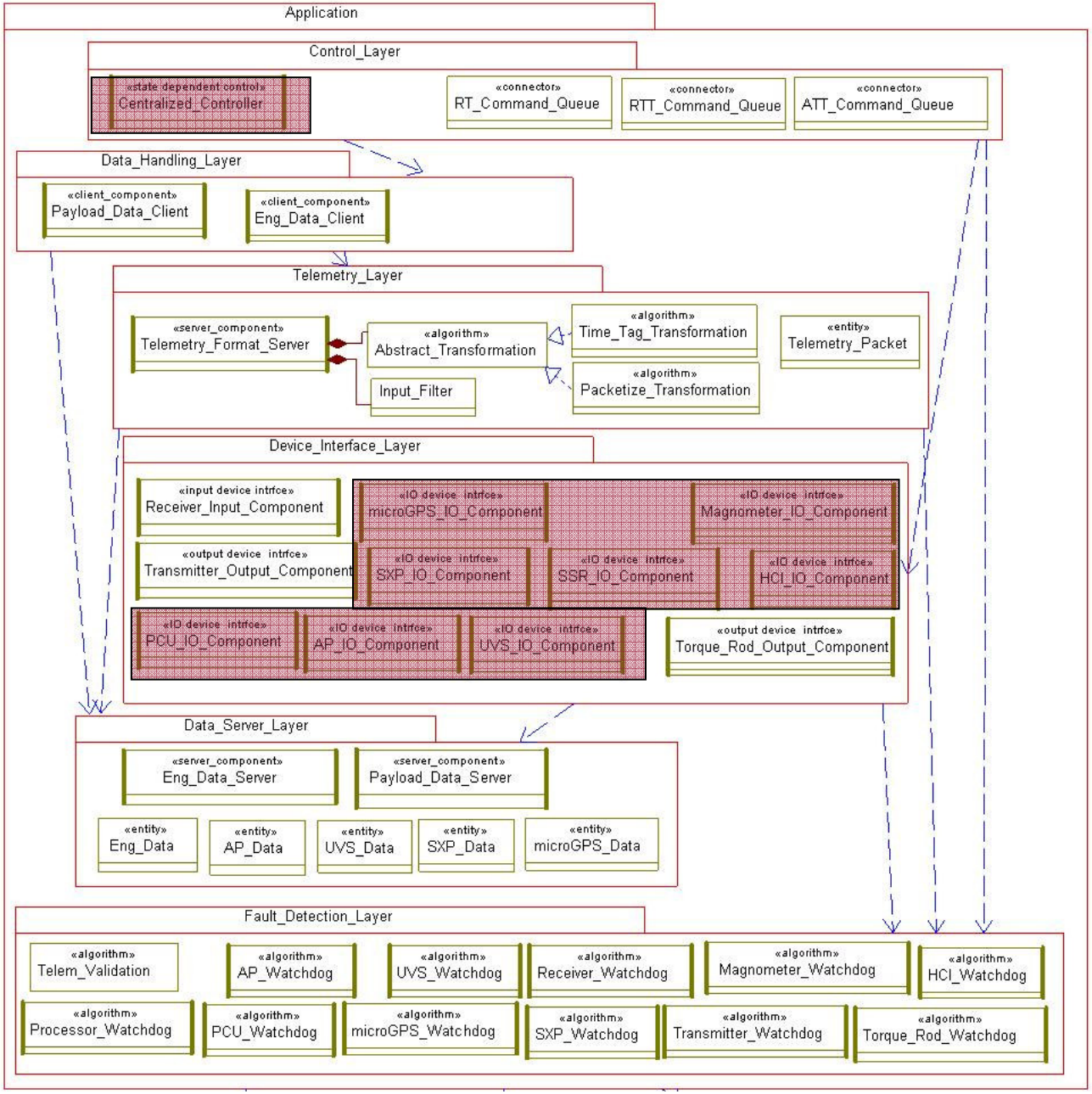
SNOE C&DH Software Architecture – Static View

Bidirectional Asynchronous Comm. Pattern



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SNOE C&DH Software Architecture (cont.)

- Design patterns after instantiation provide the foundation for the C&DH software architecture

- To have a complete C&DH software architecture the design patterns need to be:
  - *Interconnected with the rest of the software architecture*
  - *Customized to meet the application specific requirements*
    - Adding application specific processing logic
    - Adding application specific control logic to state machines
    - Updating sequence diagrams to reflect the application specific interactions

Conclusions and Future Work

- Conclusions
  - *Presented an approach to building C&DH subsystem from software architectural design patterns*
    - Based on DRE software architecture patterns
    - Leverages the UML software modeling language
  - *Using this approach C&DH software will lead to*
    - Better quality C&DH software architectures
    - Reduced number of onboard anomalies related to software
- Future Work
  - *Apply patterns to additional case studies*
  - *Expand research to include other FSW subsystems (e.g. Fault Management Subsystem, Attitude Control Subsystem)*
  - *Augment executable design pattern templates with software performance characteristics to facilitate software performance validation*
  - *Look for areas to automated the application of the executable design pattern templates*
  - *Expand research to other DRE domains*

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