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A Representative Application of a Layered Interface Modeling Pattern

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Introduction

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- Interfaces define
  - How a system interacts with its environment
  - How the components of a system interact
- Interfaces are specified in many domains
  - Electrical, mechanical, thermal, fluid, human, data
- System engineers must specify, analyze and verify this range of interfaces
- In addition, individual interfaces can be very complex
  - Specification for USB 2 is 650 pages
- Model Based Systems Engineering offers a method to support accurate interface specification, and allow common representation across disciplines

Layered Interface Modeling Approach

- Leverage layered interface concepts used to define communication interfaces (e.g., OSI stack)
  - This layered ISO interface model has functioned well as the basis for the Internet for decades
- Specify the interface in terms of what is exchanged
- Realize the interface by transforming the exchange from application layer to physical layers
- Define interactions between peer layers of the interacting components, and between vertical layers of each component.

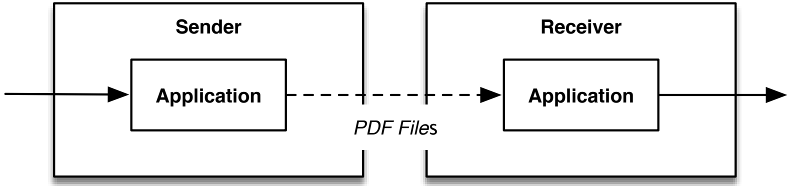
Why Layered Interfaces

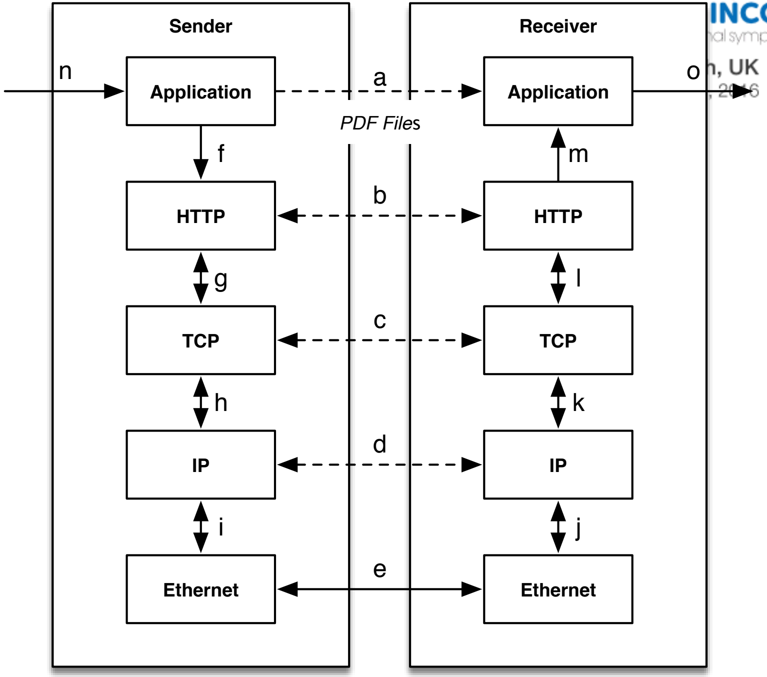
- Separation of concerns
- Each layer of the interface describes it's own functionality and addresses its own set of concerns
- Each layer may be considered separately, or in combination with others
- Layers are independent of each other, and can be combined in permissible ways
- All layers must function correctly for the interface to work as a whole.

Why Layered Interfaces (cont.)

- A rich and flexible representation in the model allows construction of many different views
  - Different interface abstractions are provided, from logical flows to complete protocol stacks
  - End-to-end data flows, connectivity, and data transformations
  - Physical connections
  - Protocol specifications
  - Message definitions
  - Complete interface specifications that span discipline concerns
- The generation of these views from a single model ensures their consistency.

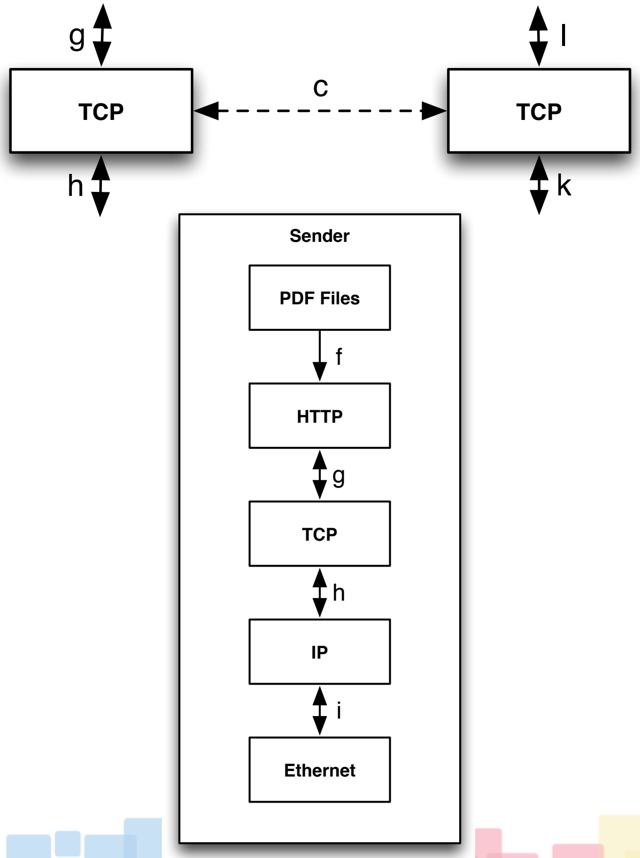
A Simple Example





- The simple view is "boxes and lines"
  - What are the interfaces?
  - What are the protocols?
- End-to-End simple view
  - Send a PDF file from A to B.
  - This is the requirement, what the user sees.
- Interface Specification
  - Implemented with HTTP, TCP, IP and Ethernet.
  - The protocol stacks in each component are connected both horizontally and vertically.
- Simple lists of interface protocols are just not sufficient to understand the architecture.

Selection of Focus



- We can focus on just the TCP layer.
  - How it is connected (horizontally).
  - How it behaves (horizontally).
- We can focus on just the stack.
  - How it is connected (vertically).
  - How it behaves (vertically).
- Data logically flows across the horizontal layers, the TCP spec describes the behavior of the peer protocol entities.
- Data actually flows "down the stack" through each successive layer until it gets to the physical layer where the "real" connections occurs.
- "On the wire" the whole stack is visible.

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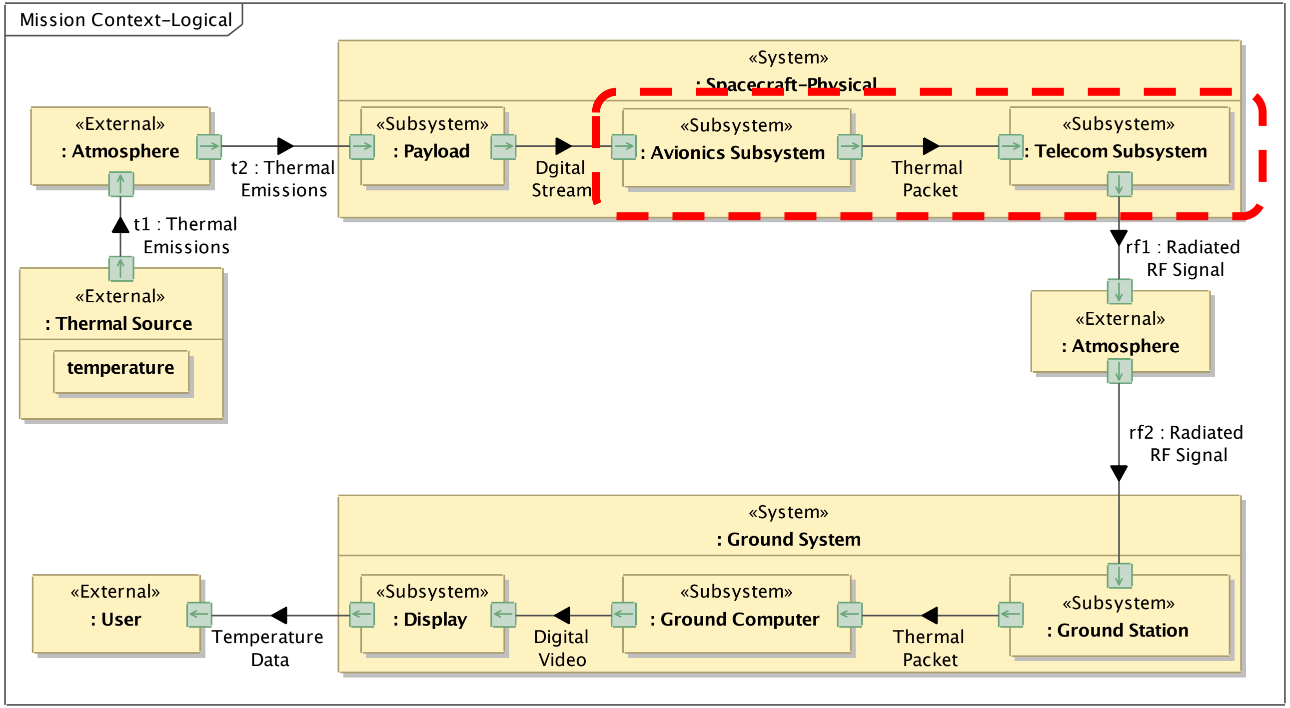
Space Data System Example

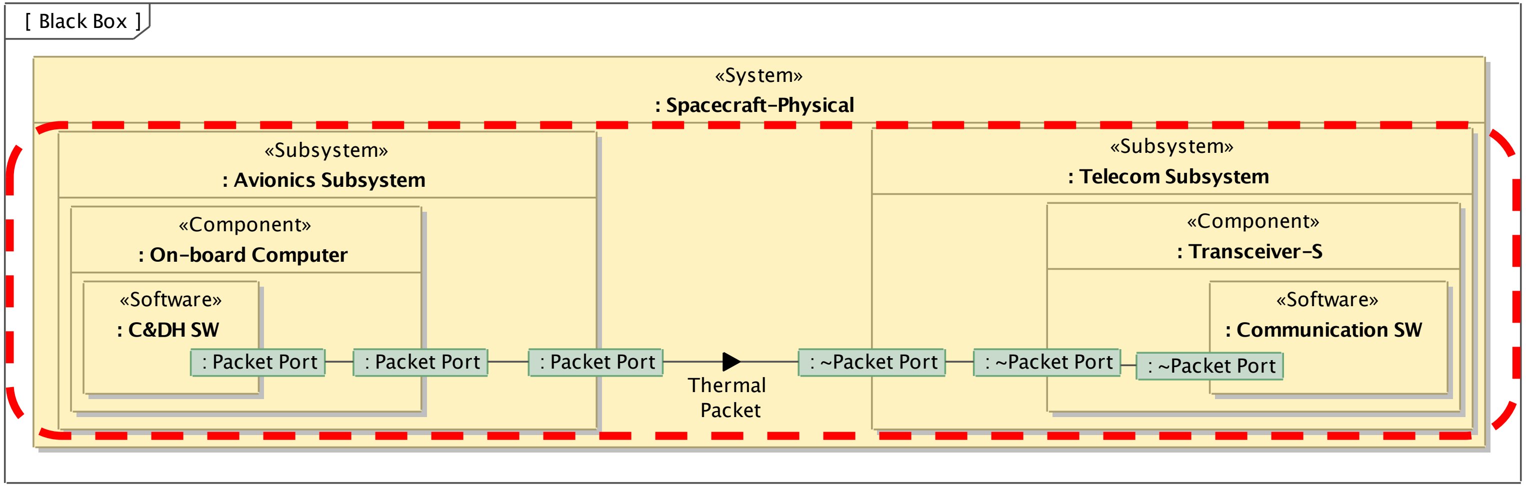
- Space data systems are composed of a flight segment and a ground segment.
- End-to-End Information Systems track data within each segment, and between the segments as an integrated flow.
- Systems include both mission-specific and shared multi-mission resources.
- So, how to accurately describe, model and characterize these system and their interfaces?

End to End Information Flow



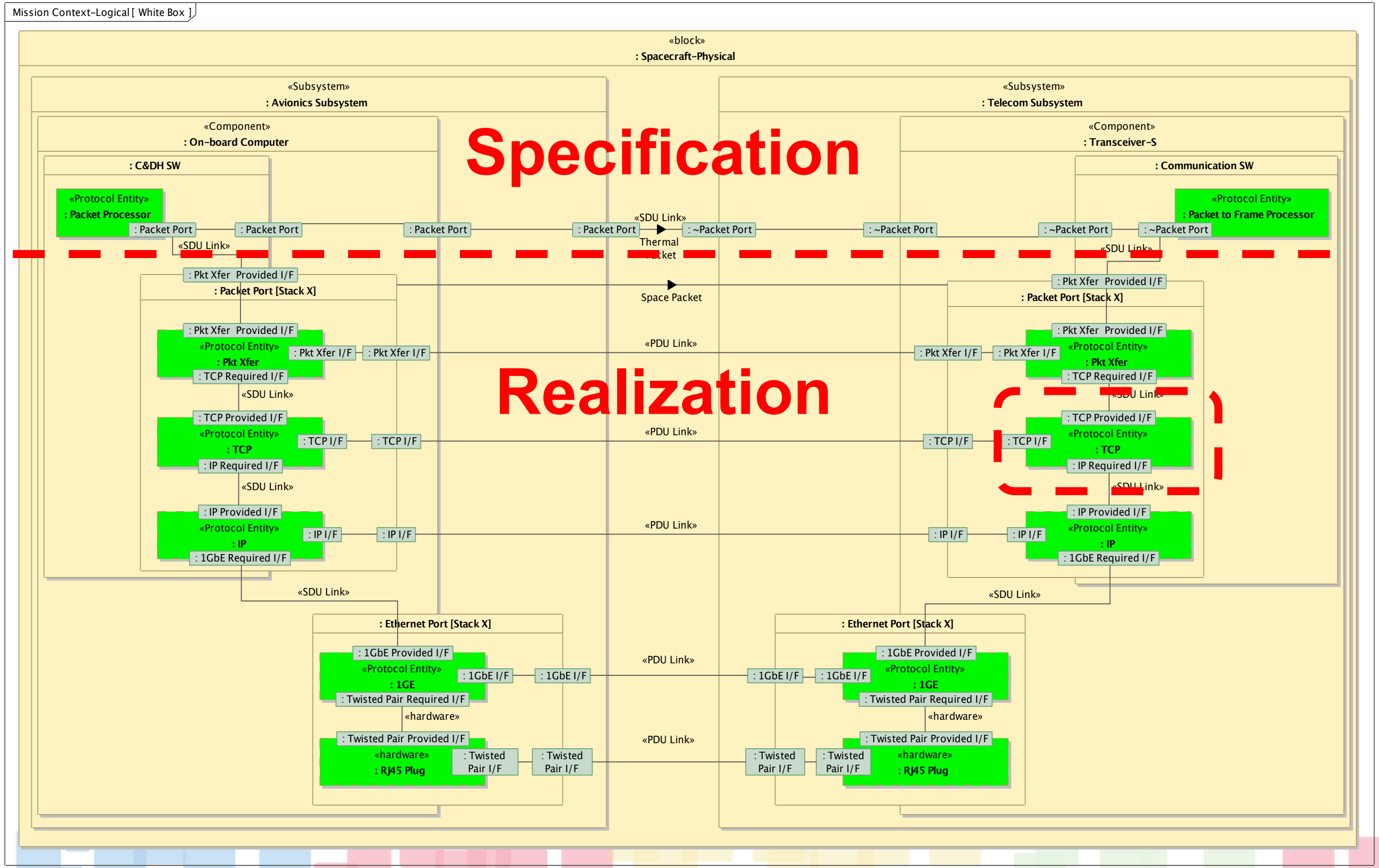
- End to End view of whole context
- Major physical element
- Coarse-grained decomposition
- Elides organizations, ownership and operational details
- Does not show interface or protocol details yet…

Subsystem Interface Specification



- Shows Avionics and Telecom subsystems from End-to-End view
  - Shows decomposition, component and hardware-software relationships
- Does not show interface details or protocol stacks

Subsystem Interface Realization



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- Details of protocol stack
- Ownership split among components between IP and Ethernet layers
- Interface Binding Signature

Typical Communication Interface Layers

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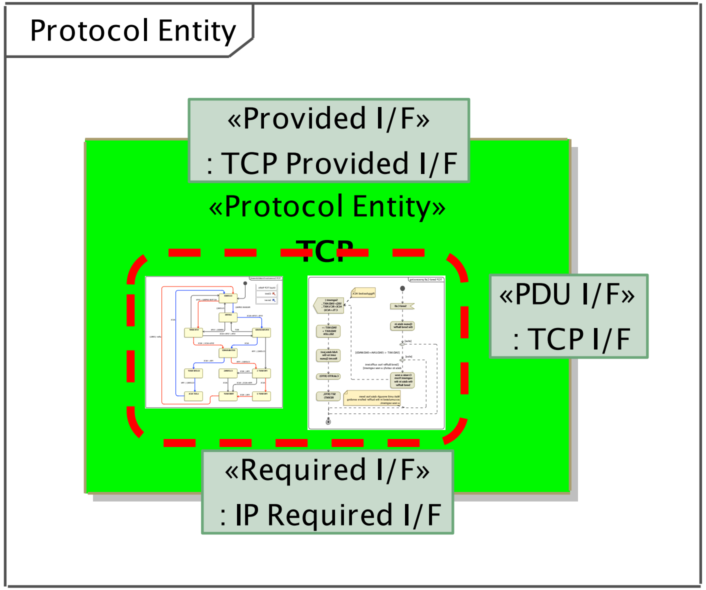
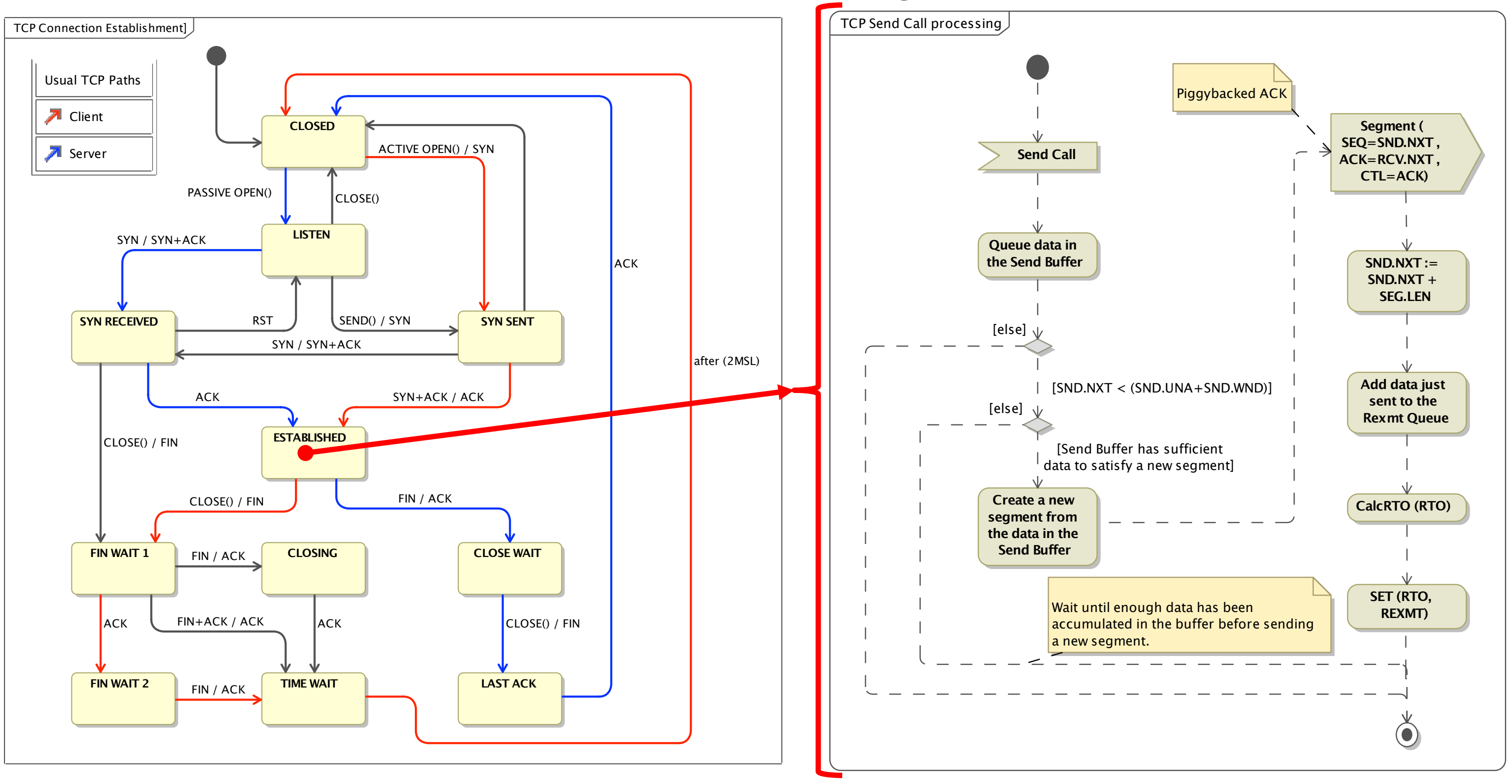
- **Application layer:** packet transfer protocol, manages exchange of packet data between applications.
- **Transport layer:** Transmission Control Protocol (TCP), provides end-to-end, once only, in order, complete delivery of data.
- **Network layer:** Internet Protocol (IP), provides network layer routing over any number of intermediate network nodes.
- **Data link layer:** 1 Gb Ethernet, provides data link layer services that may involve a fabric of switches and hubs.
- **Physical layer:** twisted pair cable (Cat-5) and RJ-45 plug terminations.

Protocol Entity

- Every protocol entity at layer (N) has three ports:
  - the interface that provides services to the upper (N+1) layer
  - the interface that requires services of the lower (N-1) layer
  - the interface with the peer protocol entity at the same layer
- There may also be a management interface, which can be in-line or separate



Protocol Entity Behavior



- Activity on right is one of many contained in the states on the left

Protocol Entity Behavior (cont.)

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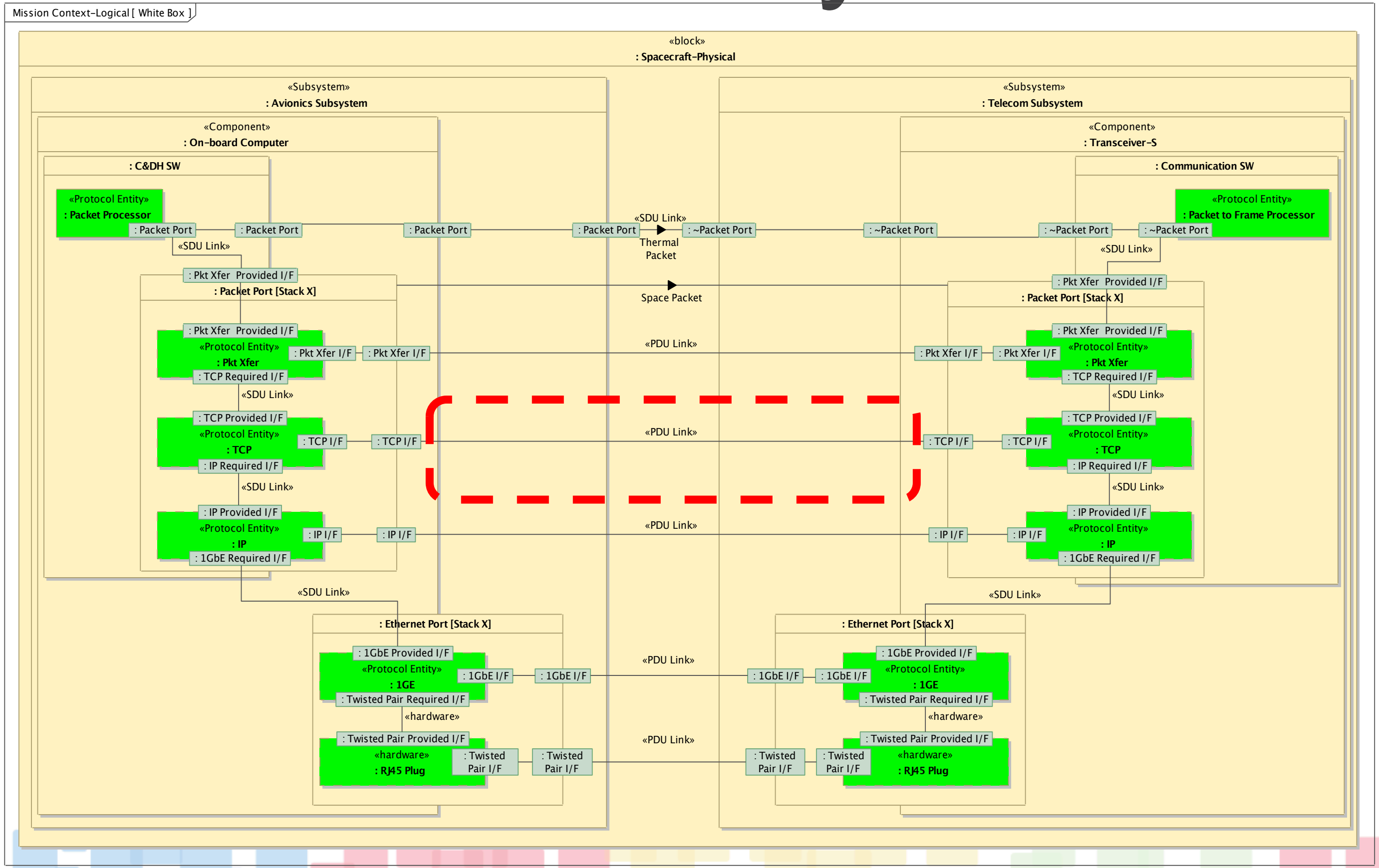
- Describes how a protocol entity behaves when receiving a Protocol Data Unit (PDU) from a peer entity
- Describes the exchange(s) of PDUs between peers
- May describe the behavior at the required and provided interfaces, such as start-up, connection establishment, and Service Data Unit (SDU) transformation into PDUs
- Typically involves describing the dynamics of PDU exchanges, including nominal and error conditions

Protocol Entity Interaction



- Constrains the behavior of peer protocol entities

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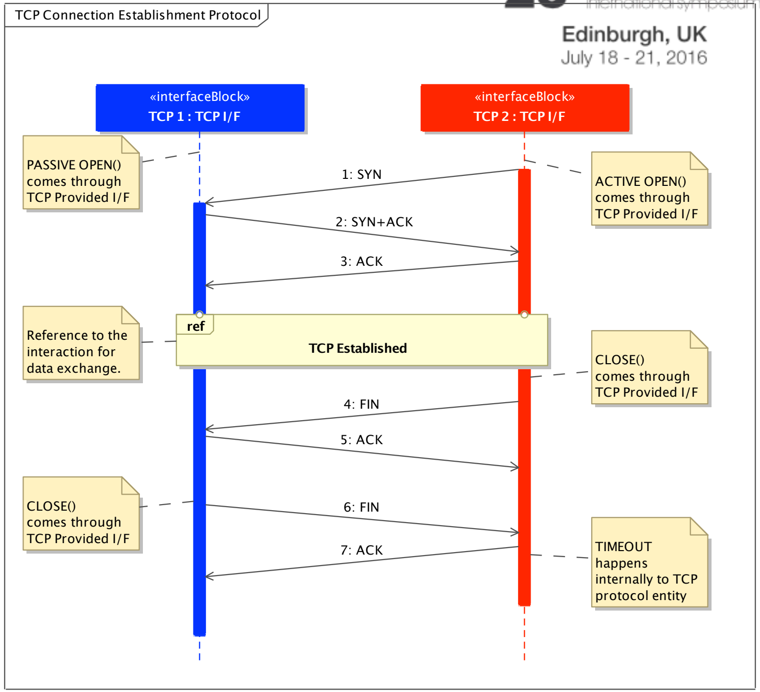
Protocol Entity Interaction (cont.)

- Specifies allowable interactions between peer protocol entities
- Keeps the peer state machines synchronized
- Describes the PDU exchanges you would see on the wire for a single layer



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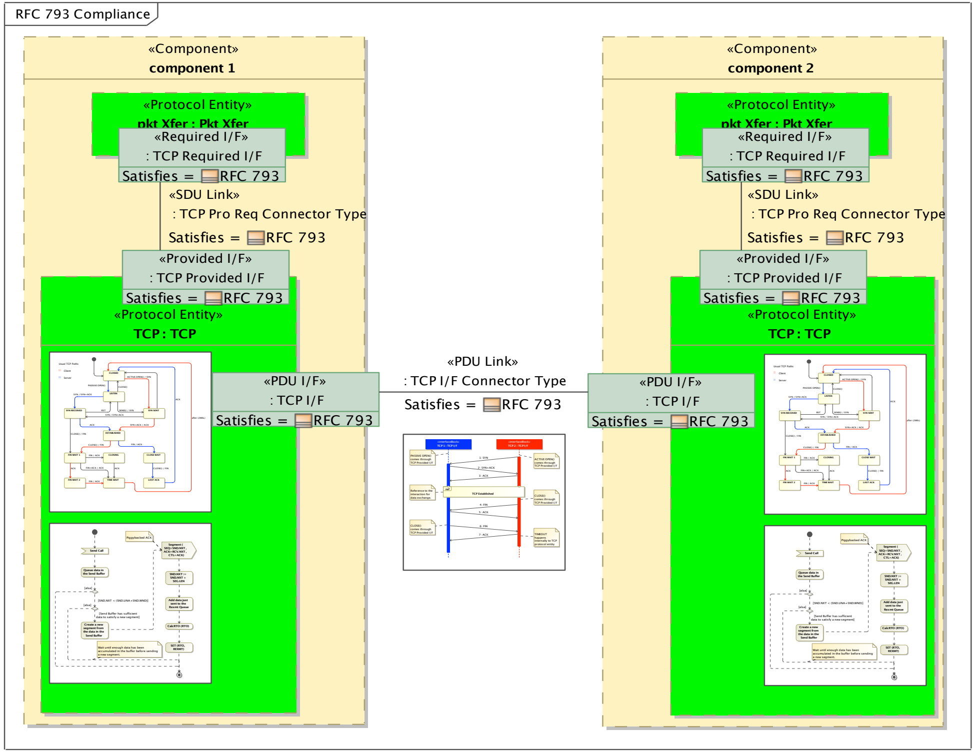
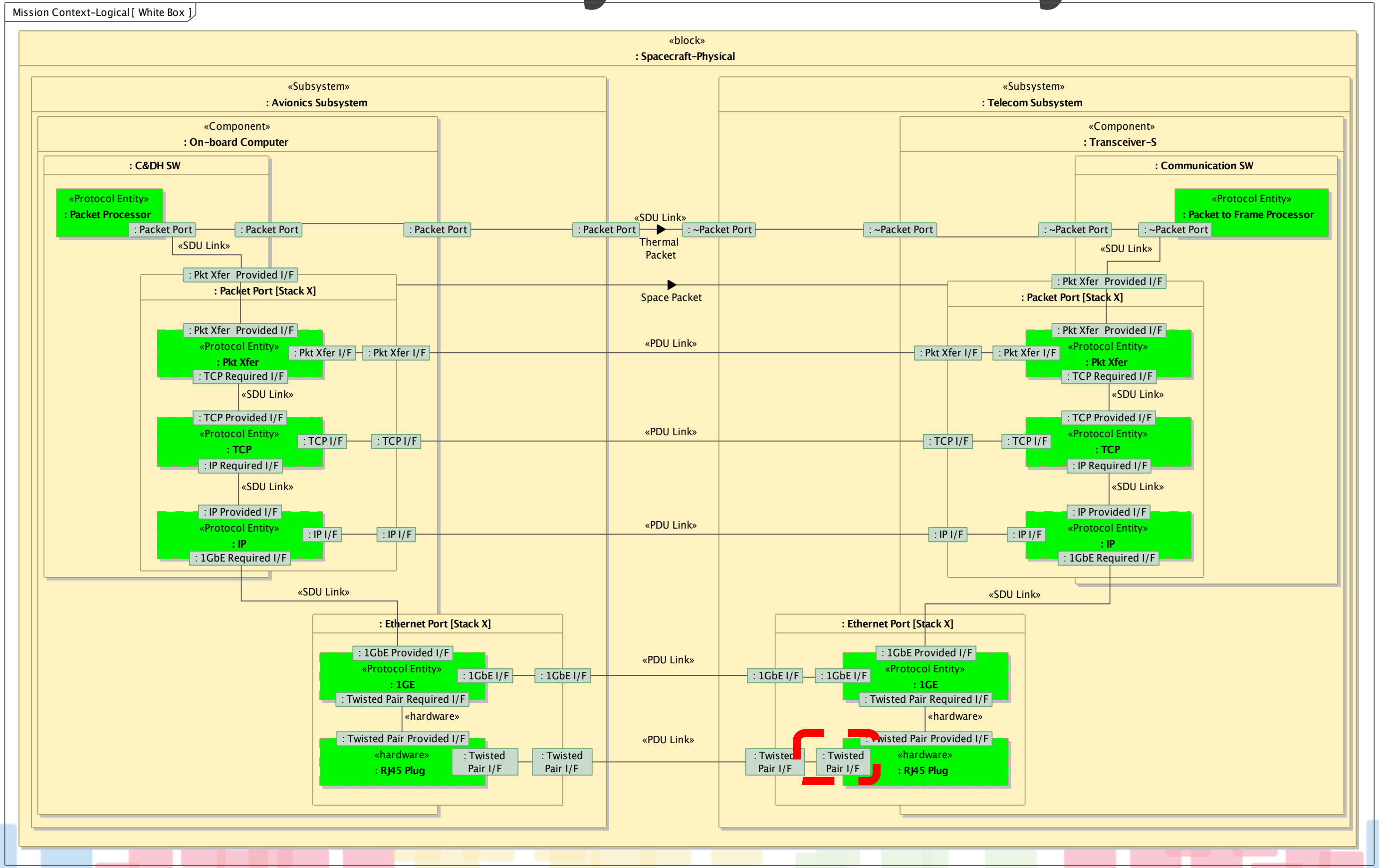
Behavior Context



- Shows all behaviors in context
- Shows compliance with RFC 793 spec
  - Note that Pkt Xfer entity also complies with RFC 793 spec at the Required Interface
  - Interface and behavior
- Behavior on vertical SDU links typically implementation specific, i.e. not specified in standards

Interface Physical Layer



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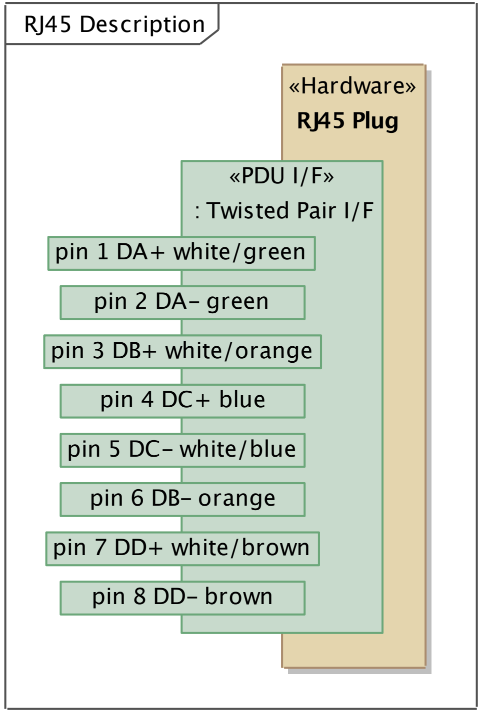
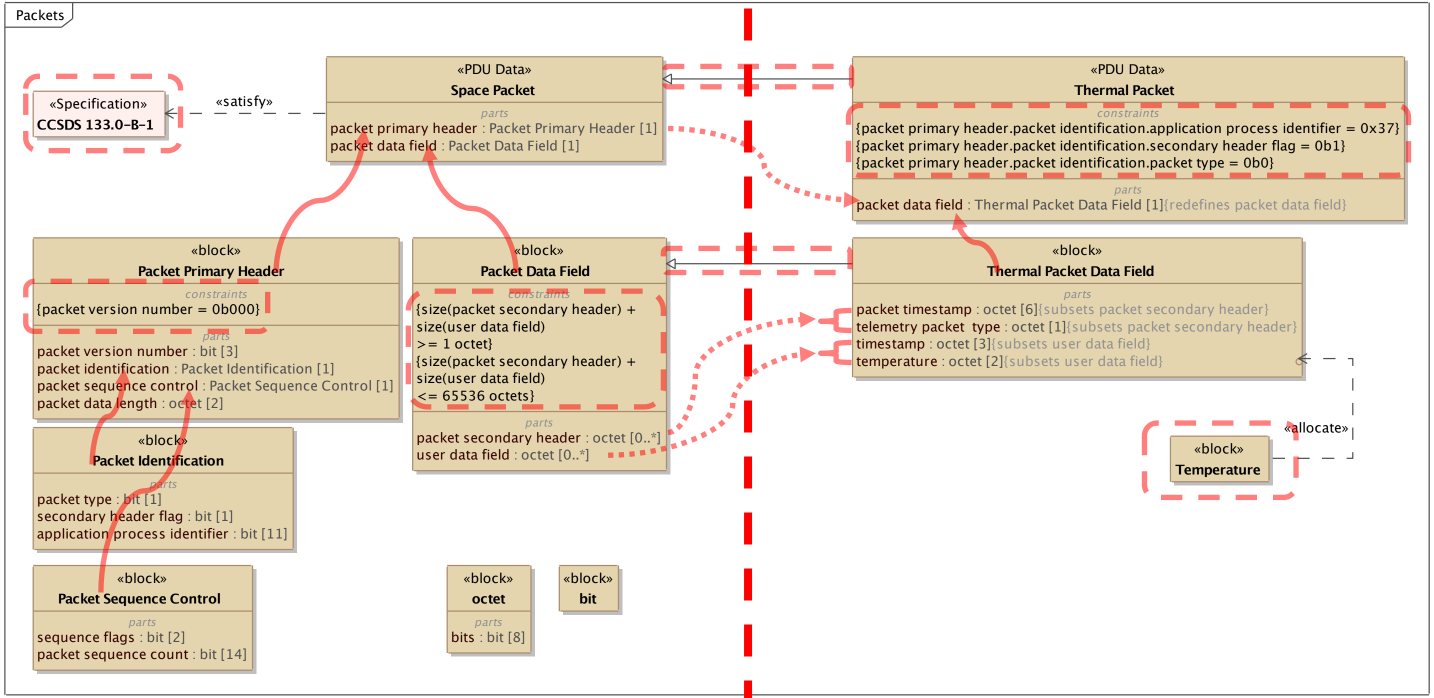
Electrical Connection



- Interfaces may be further decomposed
- Get as specific as your problem demands
- Physical layer interfaces may be governed by constraints based on physical laws
  - Ohm's law, Kirchhoff's law, laws of thermodynamics, etc.
  - Instead of activities and state machines

Data Packet Structure

Generic Space Packet | Specific Thermal Packet



- Shows how packets conform to standard
- Left side is generic space packet
  - Arrows show typing
  - Boxes show constraints
- Right side is specific thermal packet
  - Show adaptations (redefinition, subsetting and new constraints)

Methodology Summary

- Nested ports to capture interface details that a component presents
- Specification of stacks allows components to be explicit about what combinations of protocols, and in what order, they support
- Reference properties for protocol entities in ports allow separation of protocol implementation from all the contexts in which it’s used
- Power of the method depends on rigor of model content, rather than visual presentation on SysML diagrams

Summary

- Layered Interface Modeling Approach provides a means to model complex interfaces
- May be elaborated to include additional details as needed
- Ties to standards, and subsections of standards
- Compliance of data structures, behavior and physical laws
- Layered Approach
  - Specification vs Realization
  - Layers defined by protocol entities that have peer layer interactions and layer to next layer interactions.

Summary (cont.)

- Allows construction of full set of consistent views at desired level of detail
- Development of library components allows re-use of common protocols and standards
- Only model what is needed at any given point

Acknowledgements

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