Modeling Systems-of-Systems Interfaces with SysML

Peter Shames, Marc Sarrel,
Jet Propulsion Laboratory, California Institute of Technology
Sandy Friedenthal, SAF Consulting
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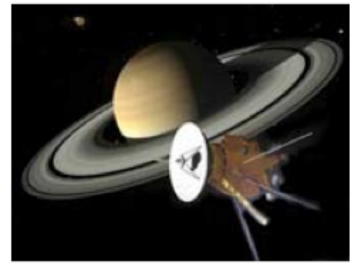
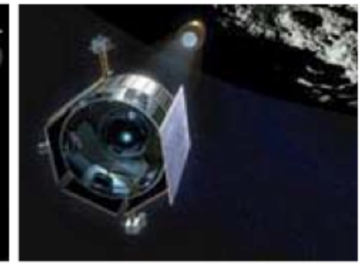
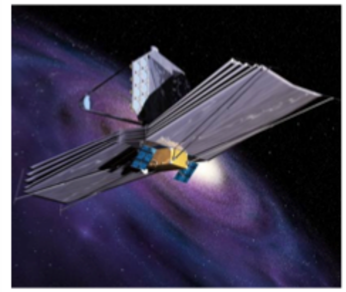
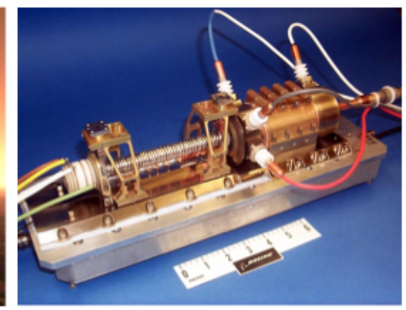
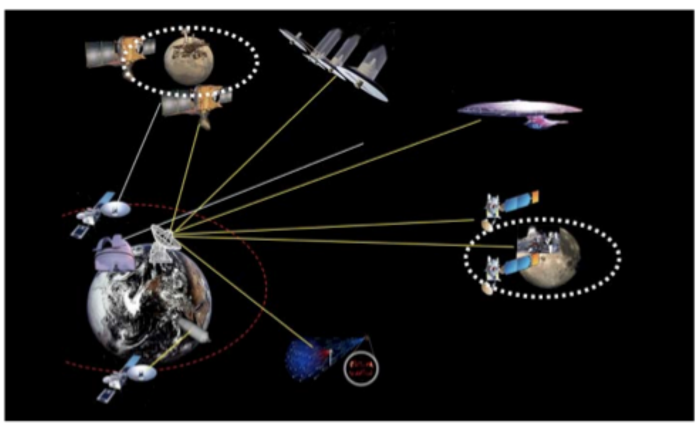
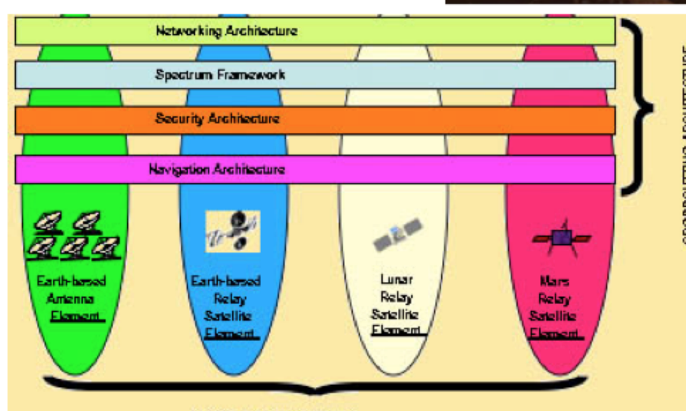




Introduction – End-To-End Space Data Systems

- **End-to-End space data systems are inherently systems of systems**

- **Typically composed of spacecraft and mission operations systems (MOS) that belong to one (or more) organizations, and multi-mission communication assets that belong to another organization.**

"The greatest leverage in system architecting is at the interfaces. The greatest dangers are also at the interfaces." Maier, 1998

- **So … how to accurately describe, model, and characterize these systems and their interfaces?**

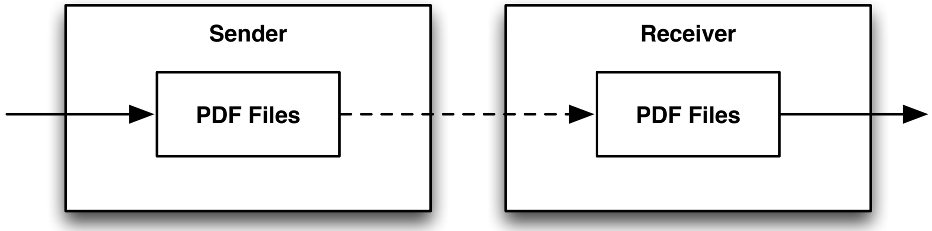
System-of-Systems Interfaces Considerations

- Each major system has interfaces
- The elements within each system have interfaces
- Interfaces include the connection points on the interacting elements, the items that are exchanged, the constraints and/or rules that govern the exchange, and the medium for the exchange (i.e. link)
- Multi-layered communications interfaces include application layer to physical layer
  - For some interfaces the link aspects can drive performance (e.g. atmospheric affects of various signals)
  - For other interfaces protocol behavior and data transformations can drive performance (e.g. end-to-end throughput)

System-of-Systems Interfaces Considerations, contd

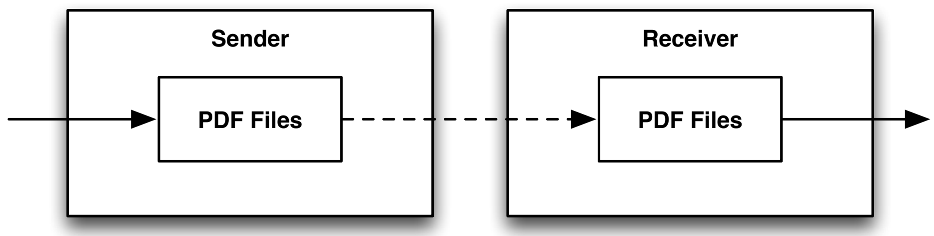
- **Different views may be used to address different concerns**
  - Different interface abstractions from logical flows to complete protocol stacks
  - End-to-end data flows, connectivity, and data transformations
  - Physical connections
  - Protocol specifications
  - Message definitions
  - Complete interface specifications that span discipline concerns
- **The type and detail of interface information for each view must be consistent**

A Simple Example of Interface Stack Specification



- 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

A Simple Example of Interface Stack Specification - Details



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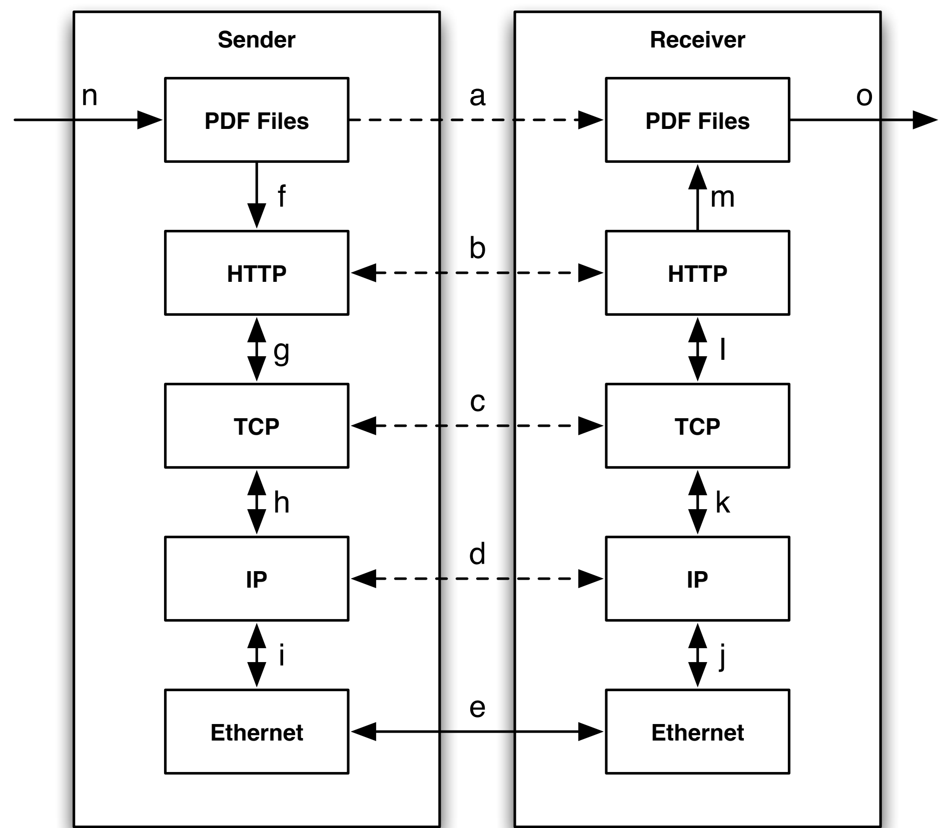
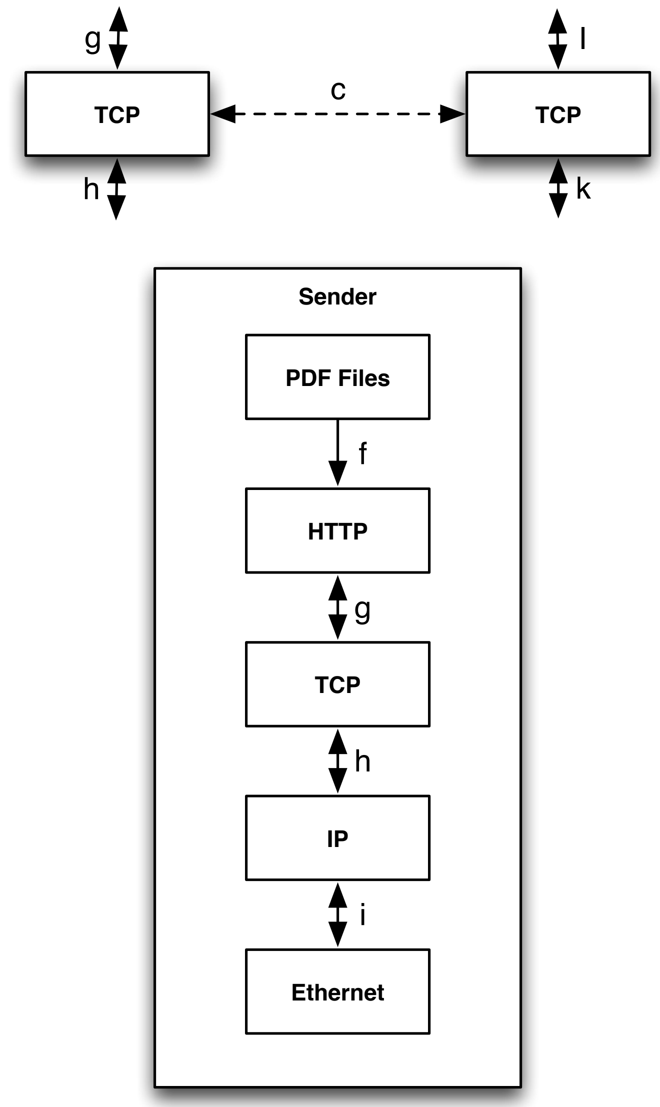
- Interface Specification
  - Implemented with HTTP, TCP, IP and Ethernet.
  - The protocol stacks in each component are connected both horizontally and vertically..
- Simple lists of interface protocols are just not sufficient to understand the architecture



Focus May be on the Protocol at a Layer or on the Interface Stack

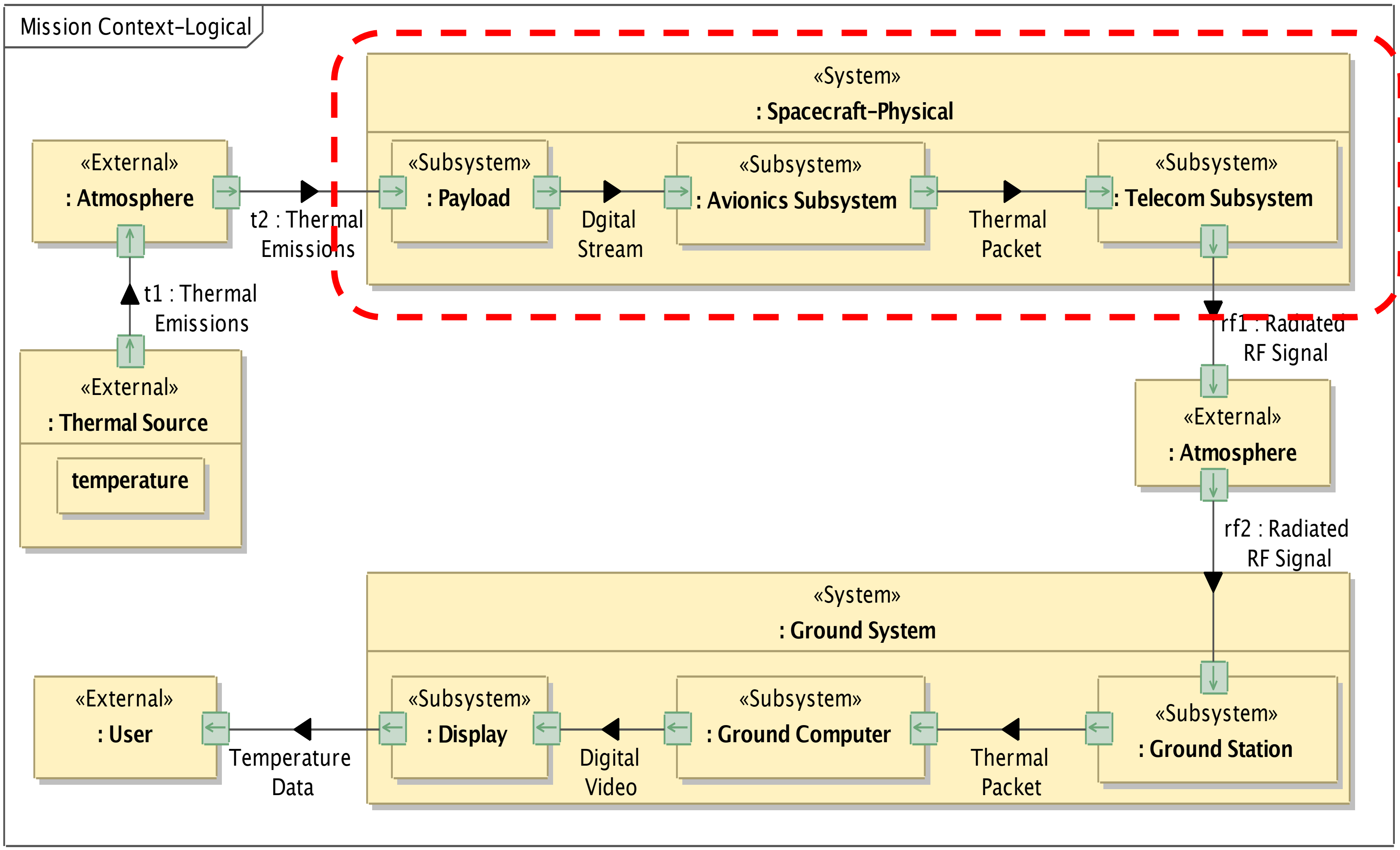


- Different views enforce separation of concerns.
- We can focus on just the TCP layer.
  - How it is connected (horizontally).
  - How it behaves (horizontally).
- We can focus on just the stack.
  - How it is connected (vertically).
  - How it behaves (vertically).
- Data logically flows across the 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.

Notes on the System Interface Modeling Method

- The method is intended to allow complete modeling of systems components, their interfaces, protocols, and protocol behaviors.
  - Supports evolution of detail as design progresses
- Several different views of these interfaces are presented.
- *Only selected views need to be used to address specific concerns (e.g., logical data flow, protocol stacks and behavior, message definition, physical interconnection).*
- Appropriate use of the method, starting with the basic views, allows other views and details to be added when and where they are required.

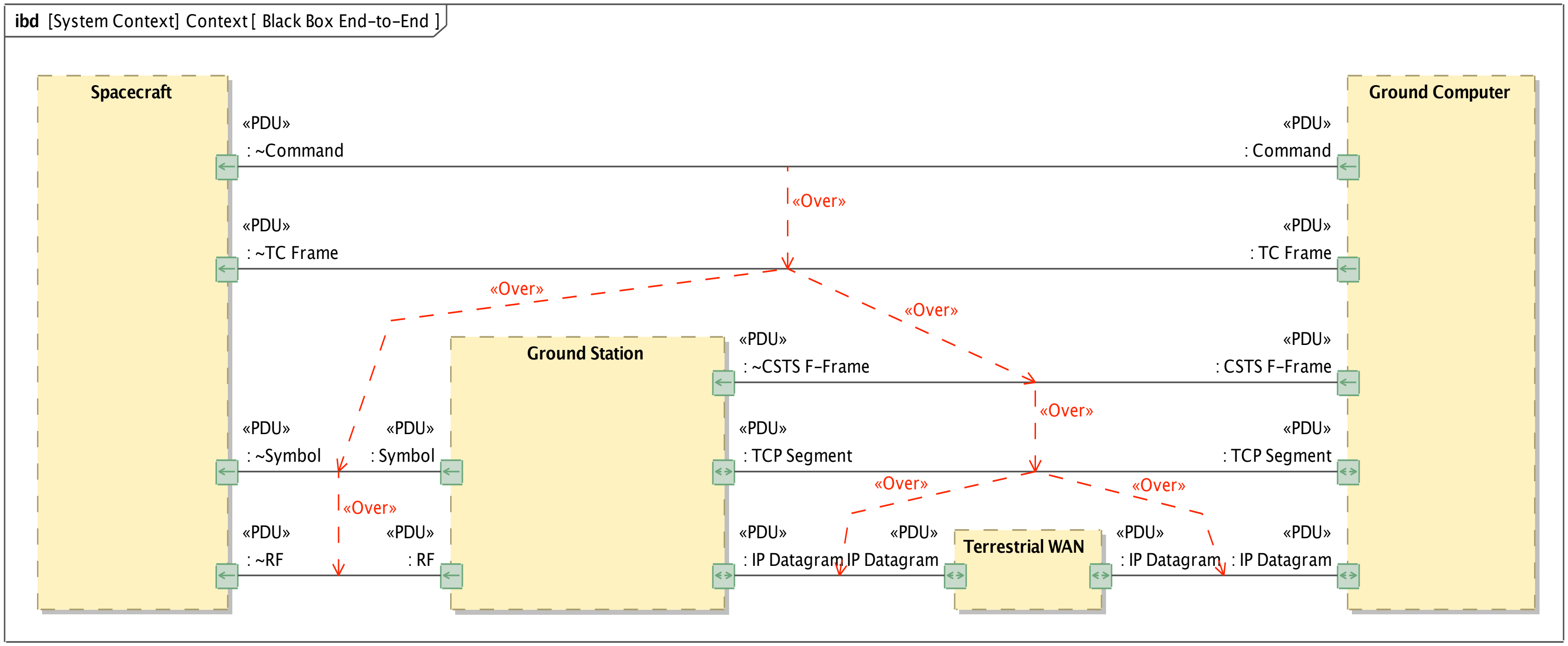
End-to-End Space Data System Example



Overall Mission Model Context

- Provides an End-to-End view of the whole context
- Shows the major physical elements that are being modeled
- Shows a coarse grained decomposition of the major system elements
- Shows the nature of the connections and the high level data flows
- Does not show organizations, ownership, or operational details, but views based on this could be developed to address these concerns
- Does not show interface or protocol details (yet…)

End-to-End Protocol View

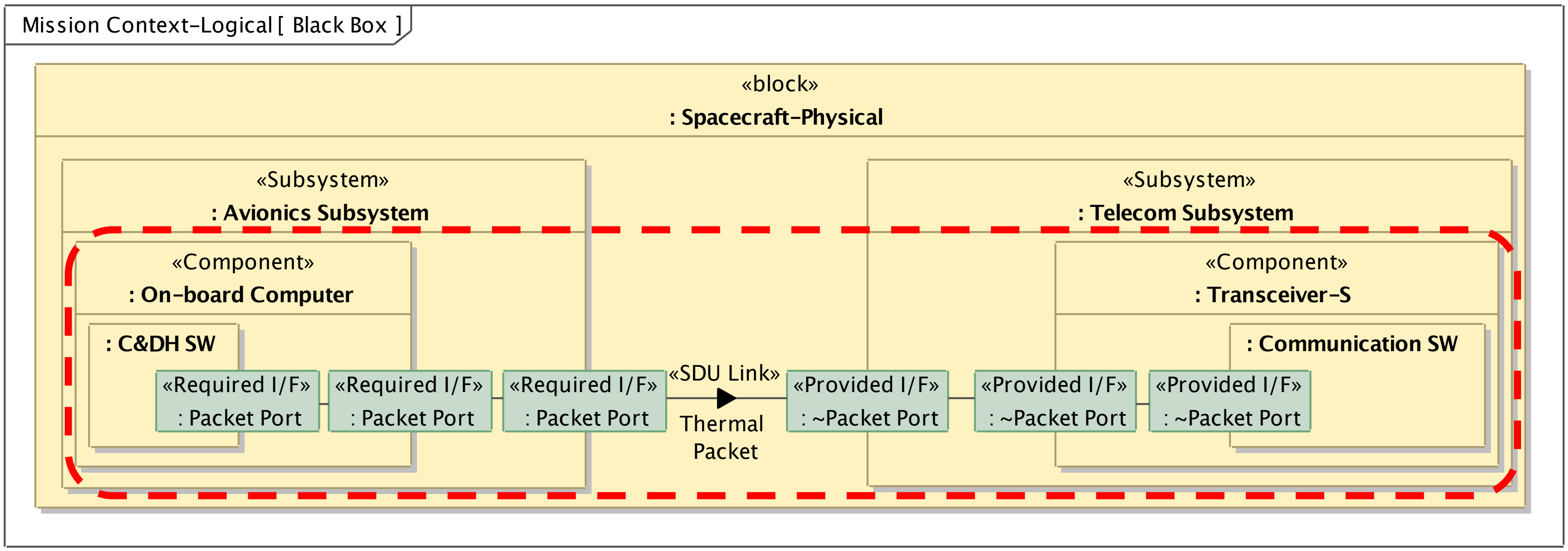


- Major communications systems from the End-to-End view
  - Shows End-to-End high level protocol flows
  - Shows typical CCSDS space communications standards in relationship to major system elements
- Interface Specification
  - Shows only the top level ports, protocol types, and data flows
  - Does not show interface nor protocol stack details

End-to-end Space Data System Flows and Connectivity

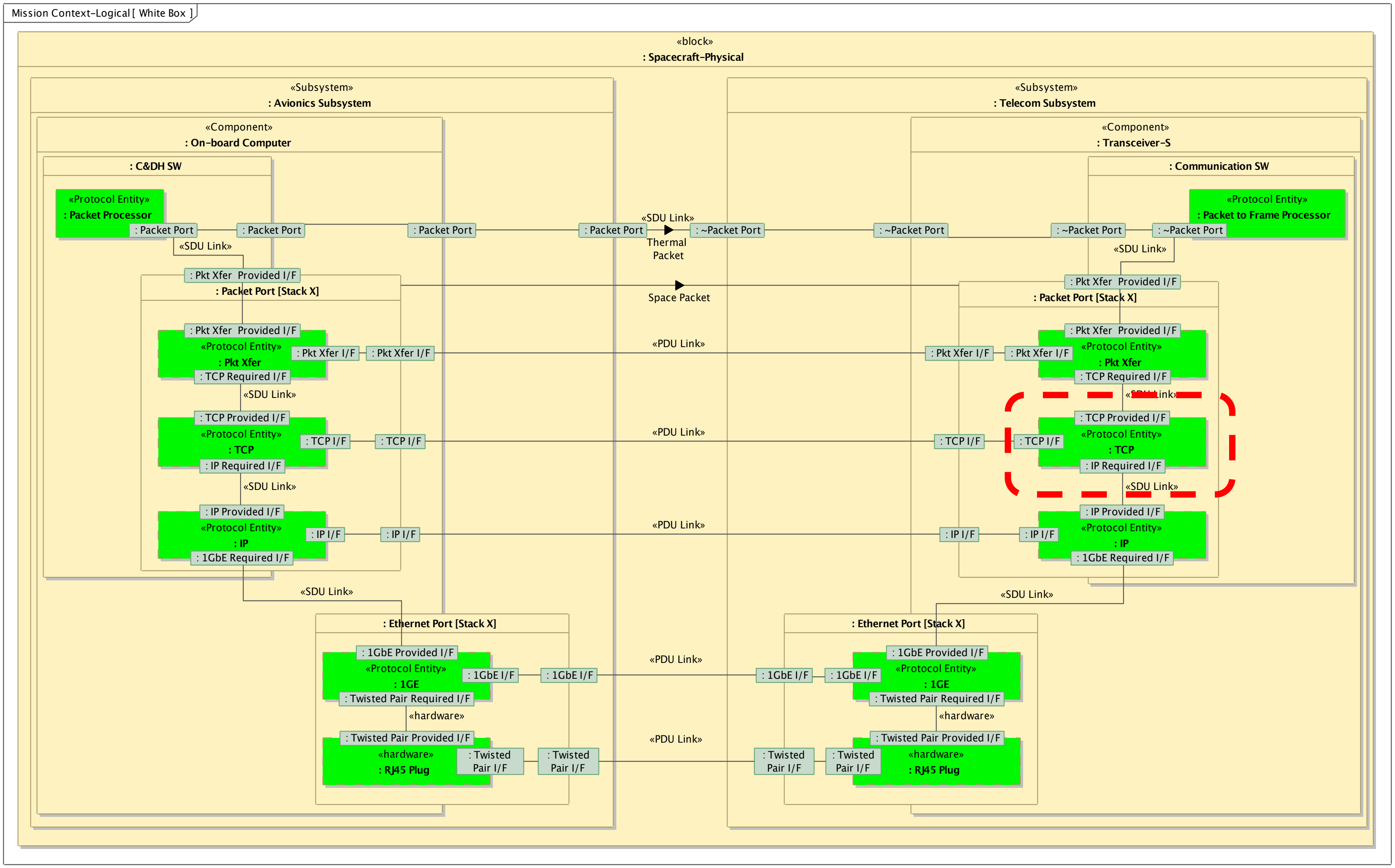
- **Unlike terrestrial systems, space data systems use a variety of different protocols in order to communicate end-to-end.**
- **Often these are asymmetric, with different protocols used for forward and return data paths.**
- **These protocols may be locally developed and used within a single organization, or standard, interoperable, ones like CCSDS.**
- **Terrestrial space communication assets are usually multi-mission and typically offer standard cross support interfaces like SLE or CSTS.**

Modeling the Spacecraft System Decomposition – "Black Box" View



- **Shows one of the systems from the End-to-End view**
  - **Shows a partial decomposition and component relationships**
  - **Shows hardware and software relationships**
- **Interface Specification**
  - **Shows only the top level ports and data flows and type of data**
  - **Does not show interface details nor protocol stacks**

Modeling the Interface – Protocol Stack Details ”White Box” View

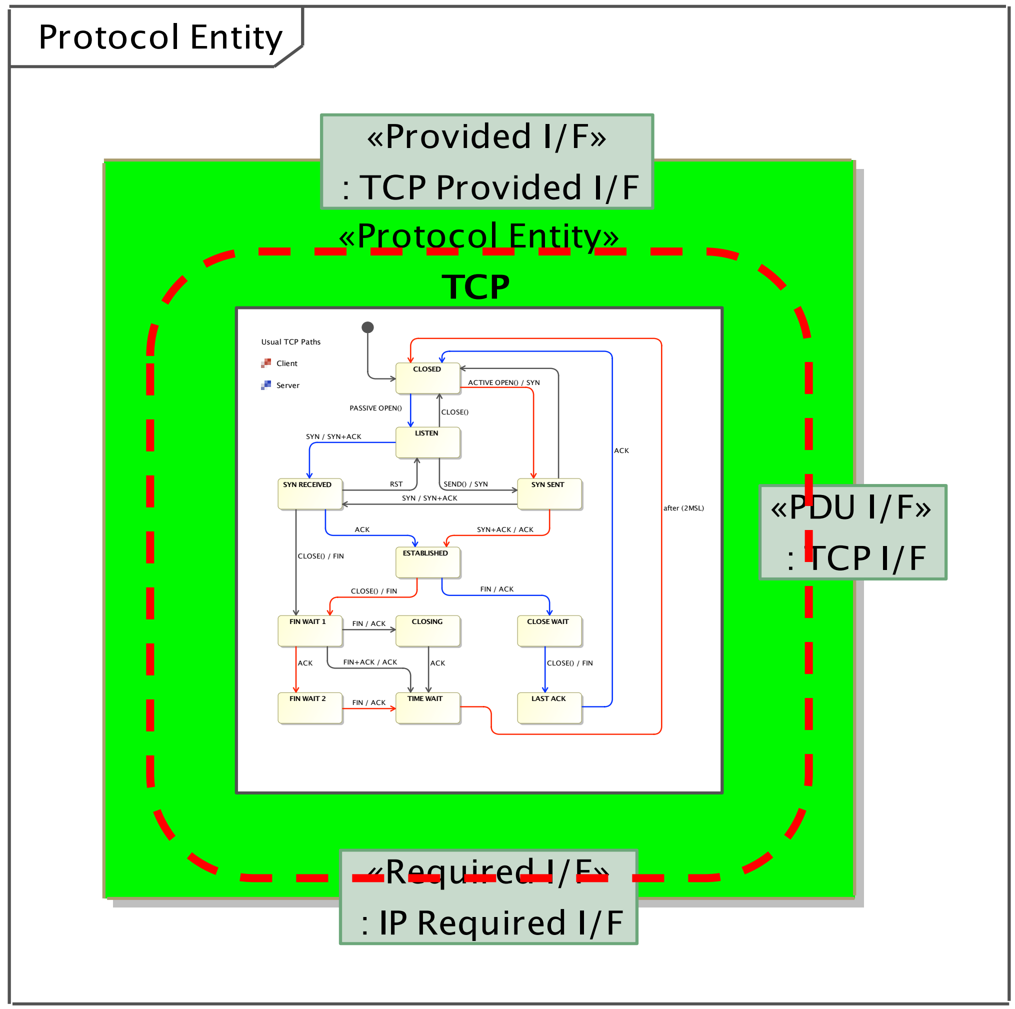


Interface Model – Protocol Stack Details

- Shows the details of the interface protocol stack
- Defines the Interface Binding Signature
  - 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.
- Distinguishes which components own the physical layers and which the data layers

Protocol Entity Interfaces

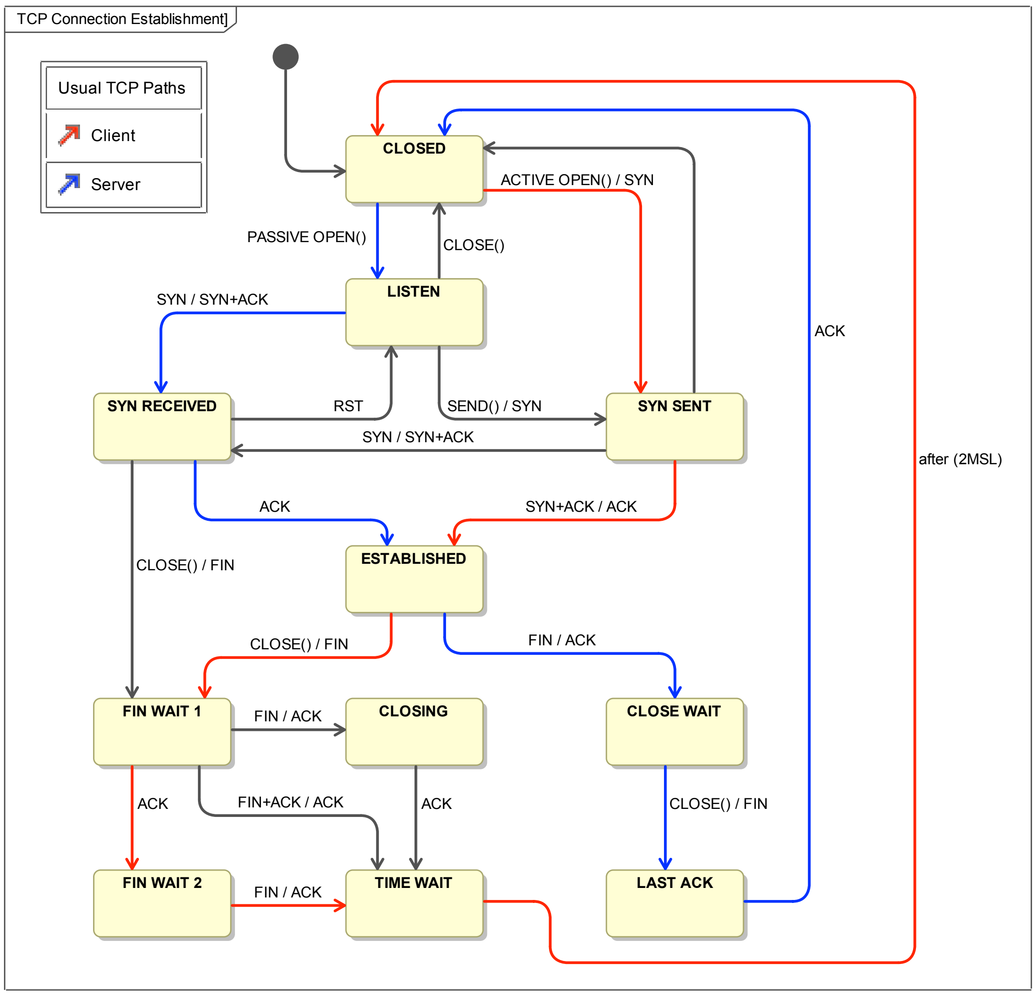
- **Every protocol entity has three ports: the interface that provides services to the upper (N+1) layer; the interface that requires services of the lower (N-1) layer; and the interface with the peer protocol entity at the same layer**
- **There may also be a management interface, which can be in-line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



Protocol Entity Port Details

- Description of protocol entity ports:
  - Provided service port: the services offered to any upper layer (N+1) protocol, defined as an abstract service and using a layer N Service Data Unit (passes SDUs)
  - Required service port: the services required from any lower layer (N-1) protocol, defined as an abstract service and using a layer N-1 Service Data Unit (passes SDUs)
  - Peer protocol port: the port that enables the protocol entity to interact with its peer entity at the same layer, defined by the protocol specification and using the layer N Protocol Data Units (exchanges PDUs)
  - Protocol management may be in-line with the protocol, via a MIB, or a separate interface

Protocol Behavior Specification - TCP Protocol State Machine Example

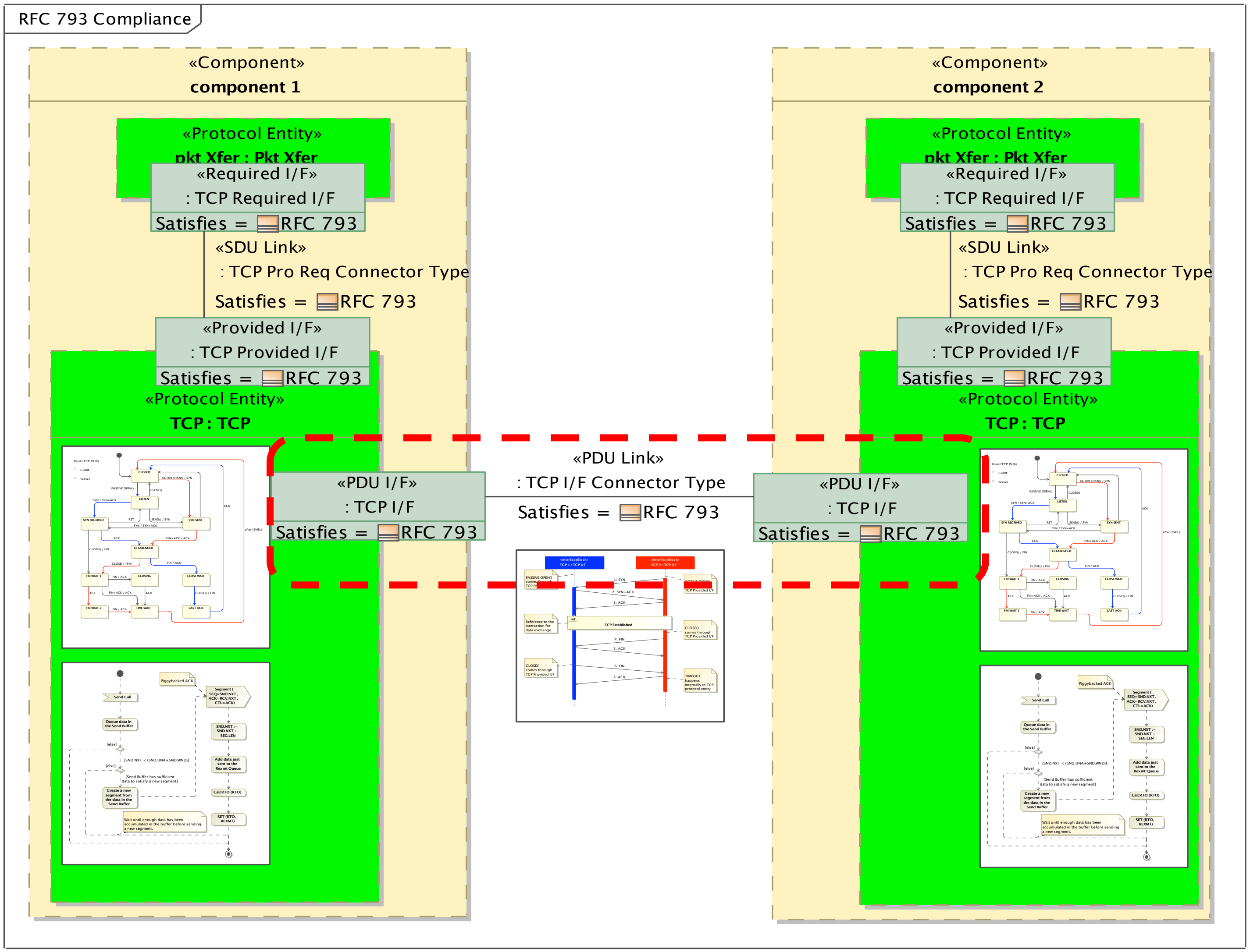


- Protocol behavior specification
- Might be described as:
  - State machine
  - or …
  - State tables
  - Sequence diagrams
  - Simple English text
- State machines are clear, formalized, and integrated with the rest of the model

Protocol Behavior Description

- 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 SDU transformation into PDUs
- Typically involves describing the dynamics of PDU exchanges, including nominal and error conditions

Interface Compliance Specification Example
TCP, RFC 793



Interface Compliance Specification Details

- Where necessary, interfaces may be defined by a full stack specification and by tying the details of each layer not just to a whole standard, but to specific sub-sections of a standard
- Compliance includes interface data, PDU structures, and behavior as illustrated by a state machine or by activity, and sequence diagrams.
- Compliance is captured explicitly in the model by the "Satisfies" notation shown on the diagram.
- If the protocol at any given layer is fully specified in a published standard, just using "Satisfies" for these layers may be adequate

Modeling Flexibility – Re-use of Components and Views

- Models may contain multiple views, from top level context, to composition and components, and down to low level interface and protocol details
- Appropriate use of carefully chosen stereotypes and views allows different levels of abstraction to be expressed clearly
- Development of libraries of components and of protocol entities allows them to be re-used and combined as needed in different views
- Different views allow the systems, and systems-of-systems, to be understood from different perspectives and at different levels of detail, as needed

Systems-of-Systems Interface Modeling Benefits

- The method permits space data systems, and systems-of-systems, their structure and interfaces, to be modeled with a high degree of fidelity
- *Not all systems require all of these layers of details*
- Adopting a principled approach to component and interface modeling allows successive levels of detail to be added as and when needed
- A well constructed partial model can document systems, interfaces, and behavior at a much deeper level of specificity than is typical in an ICD “protocol list” or “boxes and lines” diagrams
- Inclusion of clear descriptions of connectivity and composition, and mapping to specifications and behaviors, supports analysis of flow and continuity, and design of interfaces
- Further parametrization of the interfaces can be used to support analysis of end-to-end behavior and performance

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

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