Interoperable End-to-End Space Communications Architectures Using CCSDS Building Blocks

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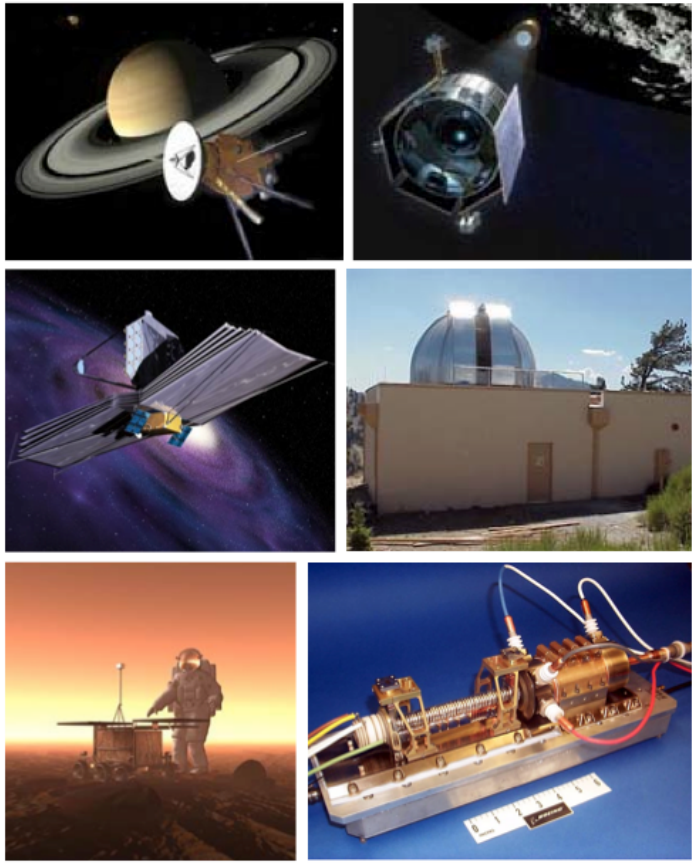
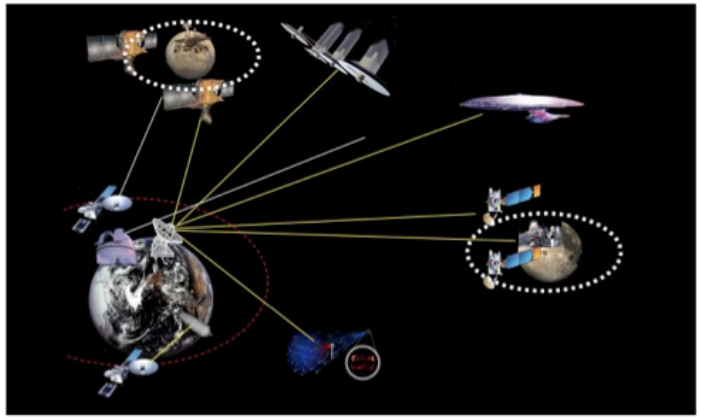
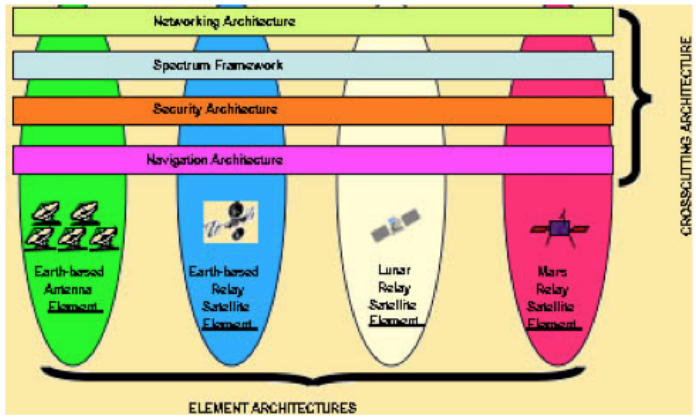






Introduction – Interoperable End-To-End Space Data Systems

- 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
  - Multi-mission communication assets that belong to another organization.

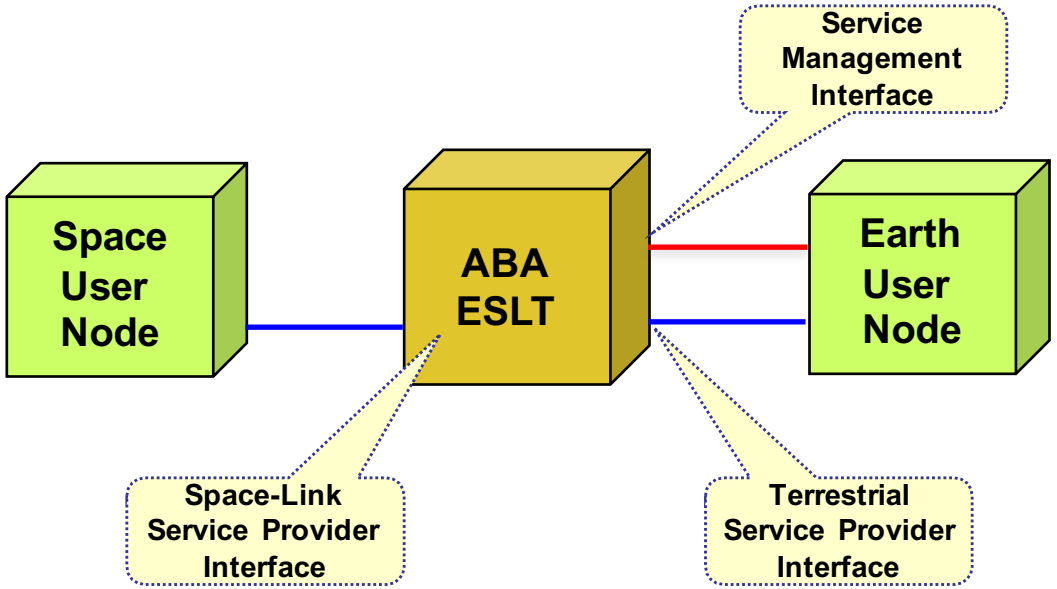
- Interoperability and cross support are essential to:
  - Take advantage of expensive, shared, multi-mission assets (DSN, ESTRACK, commercial, …)
  - Provide interoperability within and among spacecraft owned by different agencies (e.g. Mars and Lunar exploration)
  - Move toward Solar System Internetworking (SSI)

- What standard building blocks are available to build such systems?

Service and Interface Interoperability Considerations

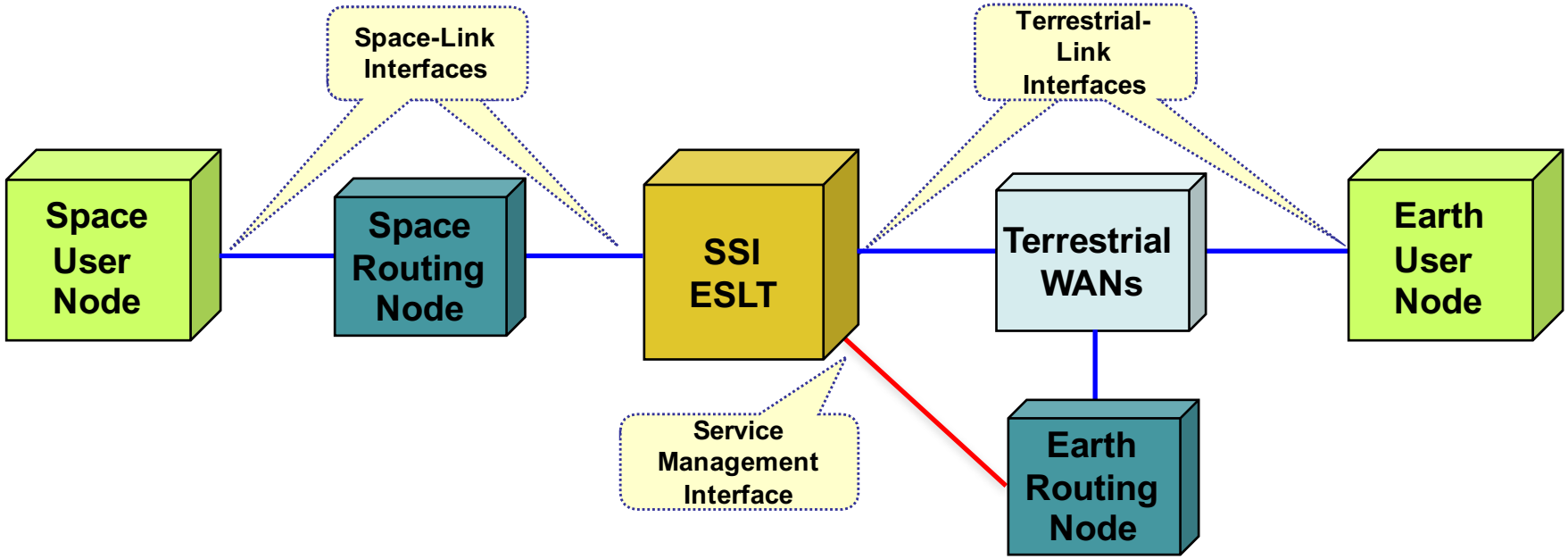
- CCSDS has developed a large suite of interoperable, and cross-supportable, protocols and other standards.
- Each of these defines a specific "layer" of functionality, such as: RF modulation, space link, error coding, cross support frame delivery, or network layer routing.
- What had not been provided was an end-to-end view of how all of these many parts fit together to provide a solution for different missions.
- Missions may be "traditional" single space link (called ABA) or may use a relay or network approach (SSI).
- The Space Communication Cross Support Architecture document (CCSDS 901.1-M-1) describes best practices for service, system, and protocol building blocks based on more than 80 CCSDS standards.

Generic End-to-End Space Data System (ABA)



- "ABA" configuration
  - Agency A develops the spacecraft (Space User Node) and the MOS (Earth User Node).
  - Agency B owns/operates the ground station (Earth Space Link Terminal).
- Interfaces
  - Service interfaces between EUN and ESLT.
  - Space Link interfaces between ESLT and SUN
- Each of these system building blocks has defined interfaces and component behaviors
- Each of these interfaces has an associated set of protocols and protocol behaviors

Generic End-to-End Space Internetworking Data System (SSI)



- "SSI" configuration
  - Agency A develops the spacecraft (Space User Node) and the MOS (Earth User Node).
  - Agency B owns/operates the Earth and Space Routing nodes.
  - Agency C owns/operates the SSI capable ground station (SSI Earth Space Link Terminal).
- Interfaces
  - Service interfaces between ERN and ESLT.
  - Space Link interfaces between ESLT to SRN and SRN to SUN.
  - Space internetworking (network layer) interfaces end-to-end,
- Each of these system building blocks has defined interfaces and component behaviors.
- Each of these interfaces has an associated set of protocols and protocol behaviors.

Overall Building Block Approach

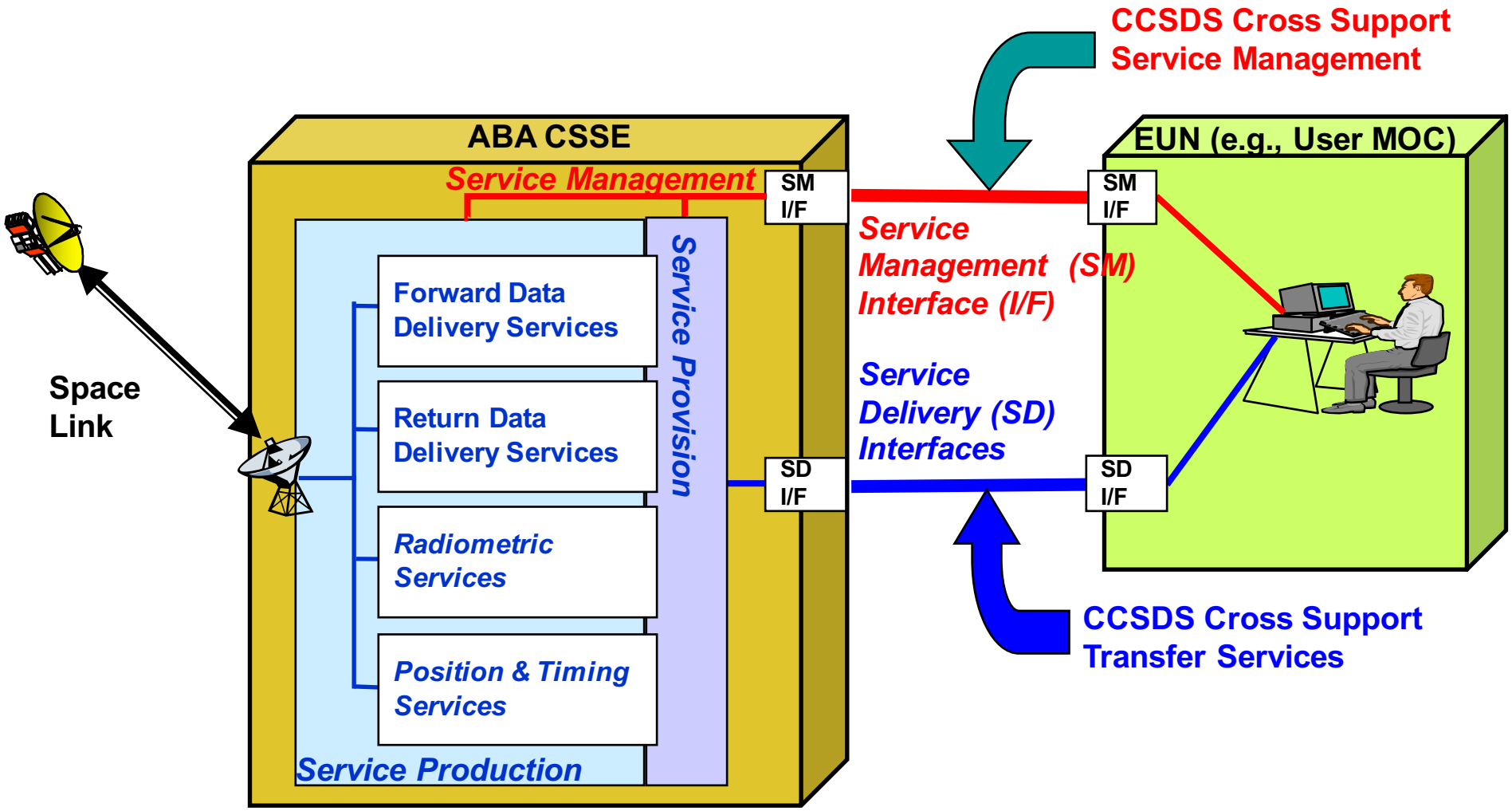
- **Service Interfaces**
  - Describes how missions may plan, schedule, configure, use, and monitor cross supported service interfaces
- **Component (Physical) Building Blocks**
  - Shows the major physical elements that are used to compose end-to-end systems
  - Describes their typical functions and interfaces
  - Supports development of a coarse grained composition of the major system elements
  - Shows the nature of the connections and the high level data flows
- **Protocol (Communications) Building Blocks**
  - Shows the primary protocol stack assemblies for ABA and SSI configurations
  - Shows the protocol configurations as they are intended to be used
  - Describes appropriate assemblies for different kinds of services: link layer, radiometric, network layer, application layer, and security
- **End-to-end Diagrams**
  - Use the component and protocol building blocks to demonstrate how to construct typical end-to-end ABA and SSI system deployments
- **The focus is on data transport and related communications services, all user applications, using whatever protocols, are constructed upon these services**

ABA Service Interface View

Space User Node

ABA ESLT
(CSSE Service Provider)

Earth User Node
(Service User)

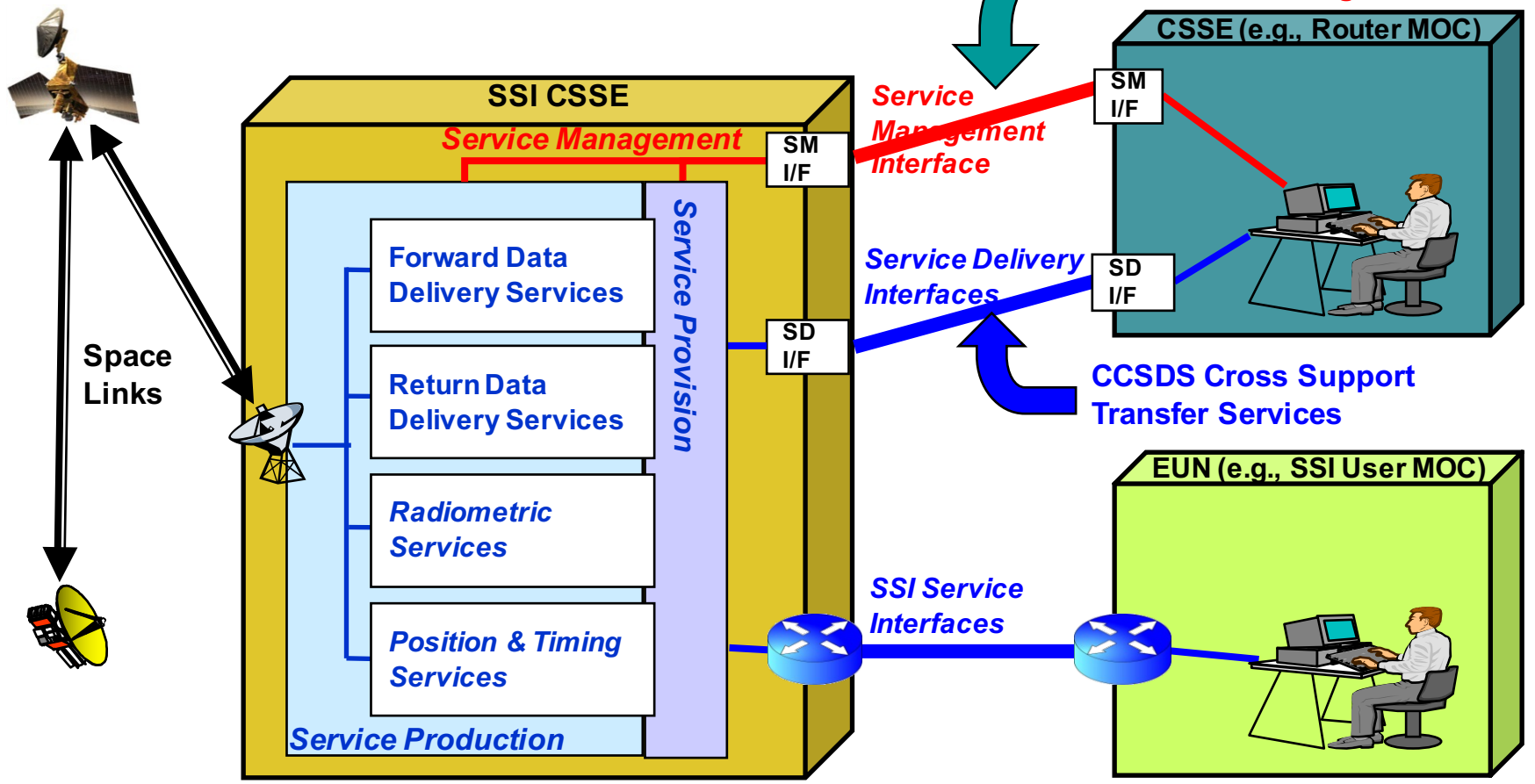


ABA Service Interface Types

- **Service Management Interfaces (SM)**
  - **Used by the EUN to plan, schedule, configure, use, and monitor cross supported service interfaces**
  - **Defined by a related set of interfaces for exchange of requests and responses between the EUN and the ESLT**

- **Service Delivery Interfaces (SLE & CSTS)**
  - **Two related sets of data delivery interfaces, SLE and CSTS**
  - **SLE includes: forward CLTU, return all frames, and return channel frames**
  - **CSTS includes: a framework and services for radiometric data, monitor data, service control of forward frames built on that framework**

SSI ERN & EUN Service Request and Delivery



SIS Service Interface Types

- **Service Management Interfaces (SM)**
  - **Used by the ERN to plan, schedule, configure, use, and monitor cross supported service interfaces**
  - **In the SSI the ERN "owns" the SM interfaces to the ESLT, and the space link interfaces from ESLT to SRN**

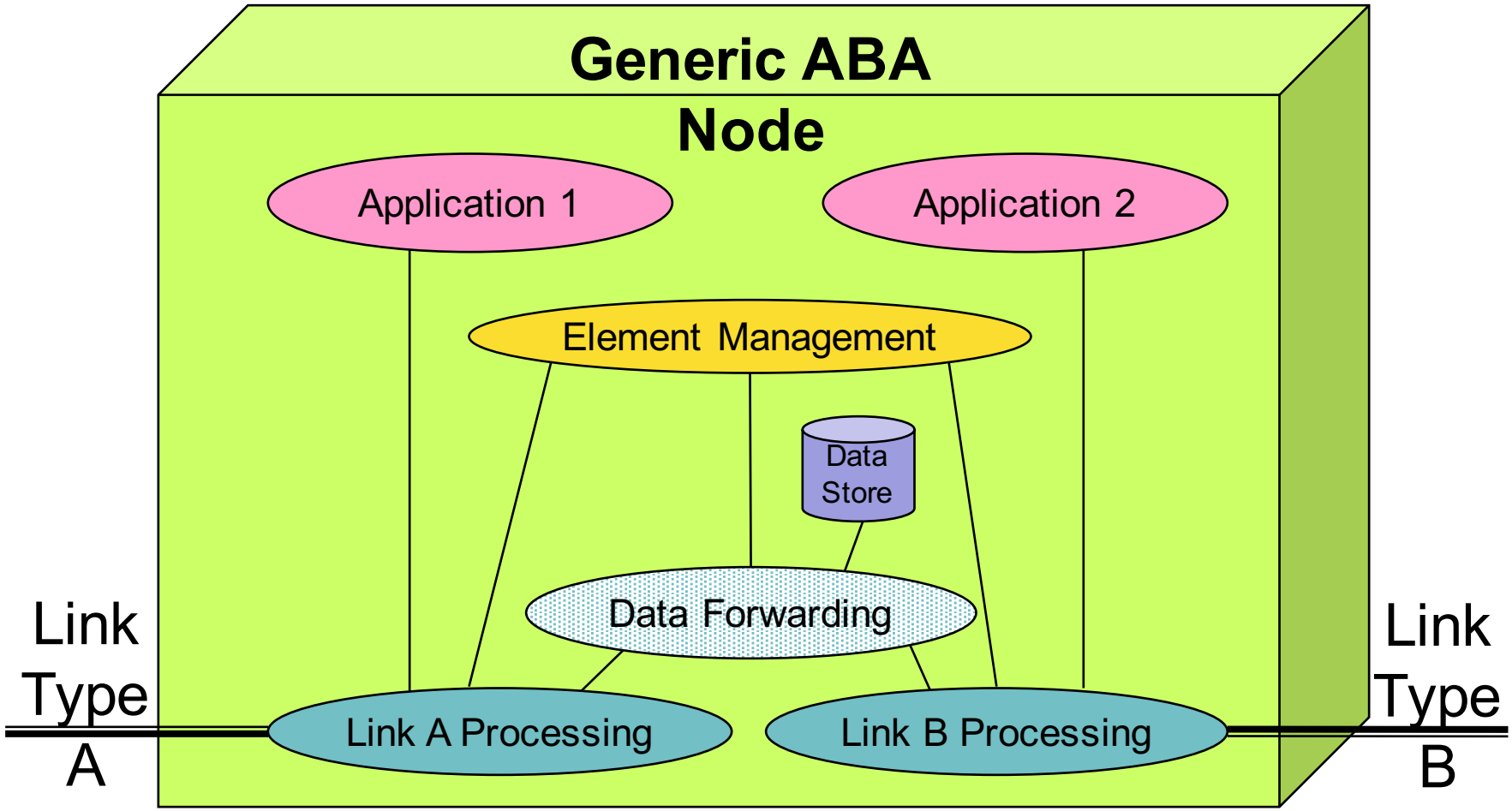
- **Service Delivery Interfaces (SLE, CSTS, and SSI)**
  - **The ERN uses the data delivery interfaces, SLE and CSTS when it requires link layer access to the SRN**
  - **At the link layer the ERN to SRN connections look like an ABA mission**
  - **At the network layer the EUN and ERN use SSI services end-to-end to route data through the SSI ESLT and SRN, all may operate as SSI nodes**

Component Building Blocks

- **ABA Component Building Blocks**
  - **ABA Earth Space Link terminal**
  - **ABA Earth User Node**
  - **ABA Space User Node**

- **SSI Component Building Blocks**
  - **SSI Earth Space Link terminal**
  - **SSI Earth Routing Node**
  - **SSI Earth User Node**
  - **SSI Space Routing Node**
  - **SSI Space User Node**
  - **Wide Area Network (WAN) Routing Node**
  - **Planet Space Link Terminal**
  - **Hybrid Science / Routing Node**

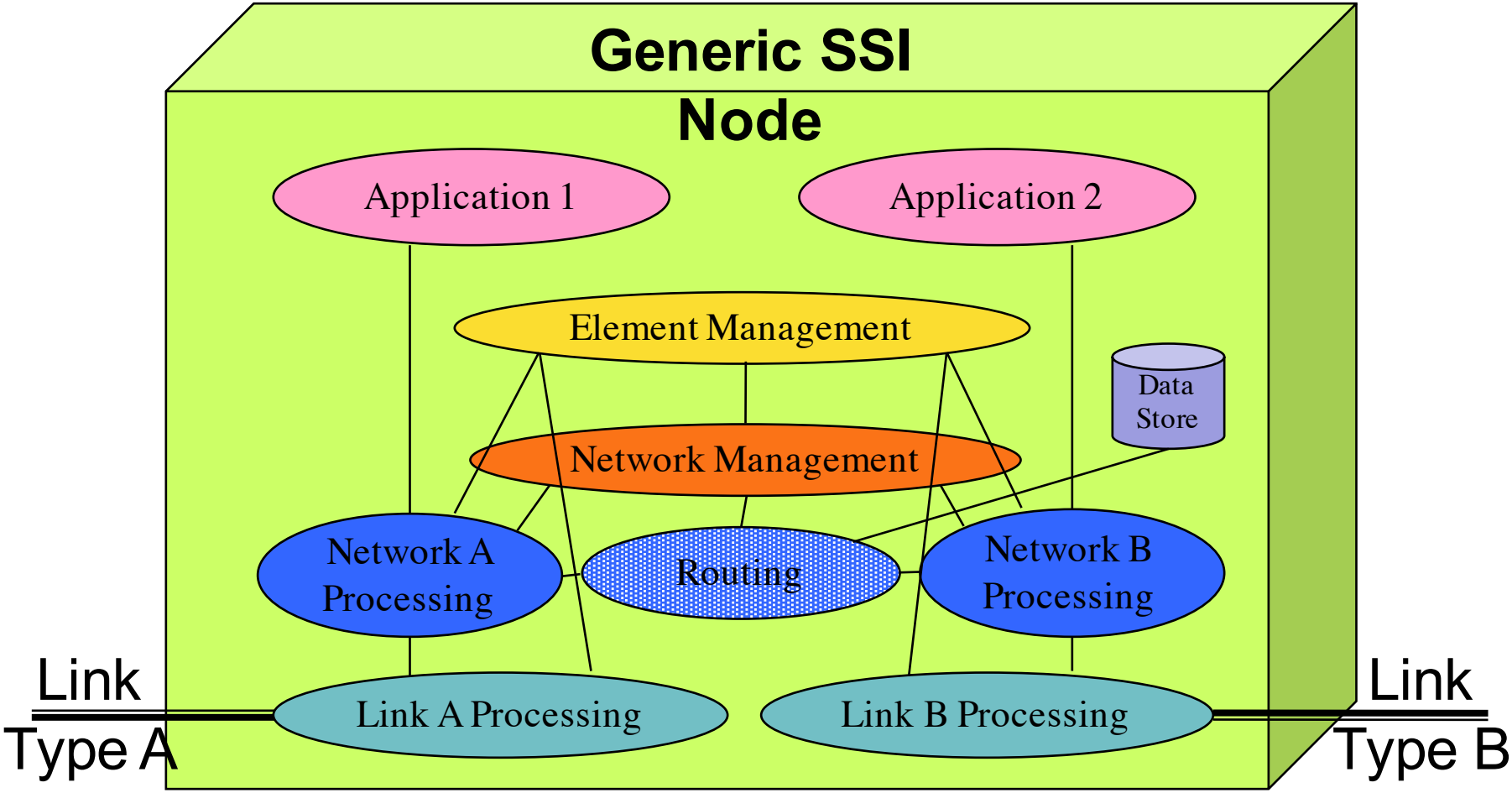
Generic ABA Building Block and Functions



Generic ABA Building Block Notes

- **Not all ABA building blocks will include all functions, user building blocks are often "one-sided"**
- **The functions for link layer processing are well specified in the relevant link layer and related standards**
- **The data forwarding and data storage functions are defined, but typically not in a fully specified form**
- **Some functions, like element management, will be present, but not specified and use interfaces that are not standardized**

Generic SSI Building Block and Functions



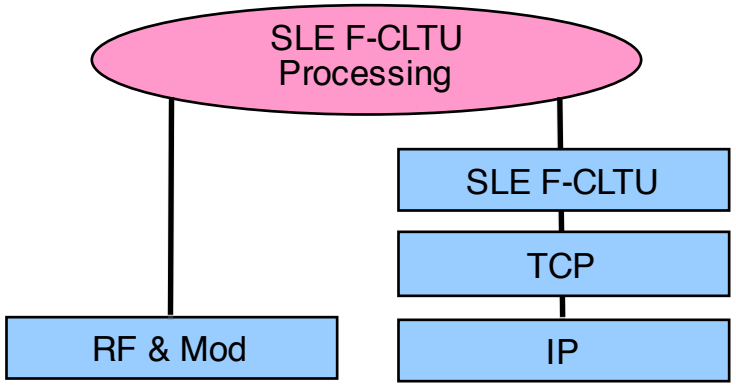
Generic SSI Building Block Notes

- Not all SSI building blocks will include all functions, user building blocks are often “one-sided”
- The link layer functions are essentially the same as for ABA configurations, with the exception of the ESLT frame creation, merging, and encoding functions
- The SSI networking and routing functions are specified in the relevant SSI standards, some of which are still in development (marked as [Future] in the SCCS-ARD)
- Network management functions are identified, but they are not yet in a fully specified form
- Some functions, like element management and cross-domain coordination, will be present, but are presently specified only in the SSI conceptual architecture

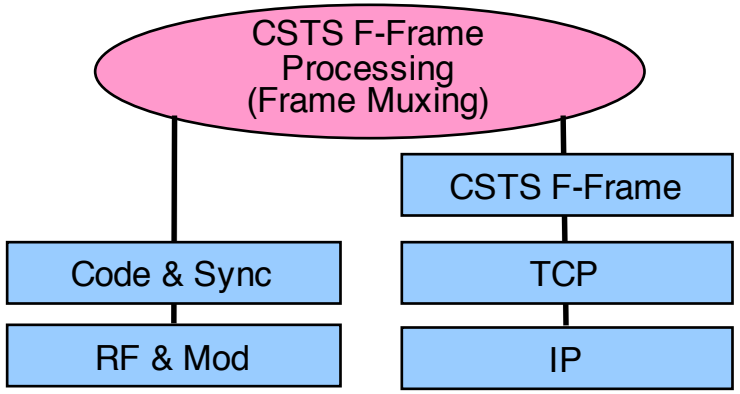
ABA Protocol Building Blocks

- Describe CCSDS ABA protocol configurations as they are intended to be used
- Describe appropriate assemblies for different kinds of services: physical, link layer, radiometric, application layer, and security
- Are designed to be used as the interface bindings for the different services and functions within components
- The following diagrams include:
  - ABA Earth user protocol stacks, forward and return (may be asymmetric)
  - ABA ESLT protocol stacks
  - ABA Space user protocol stacks
  - Specialized “round trip” protocol stacks such as radiometric processing
  - An example security protocol deployment
  - Many other examples, including security, are in the SCCS-ARD

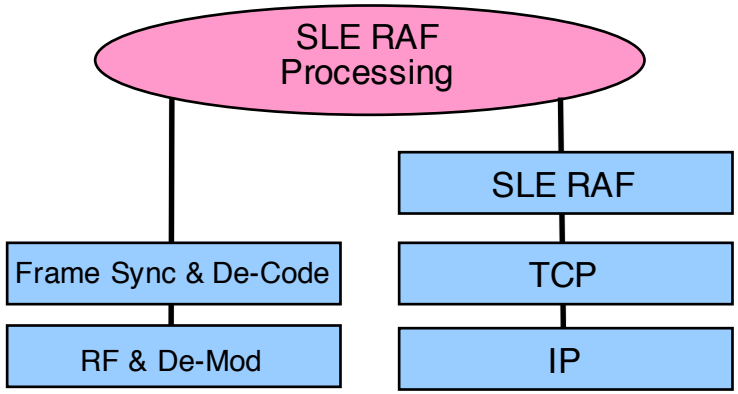
ESLT Fwd / Ret Service Provider Protocol Stack Building Blocks



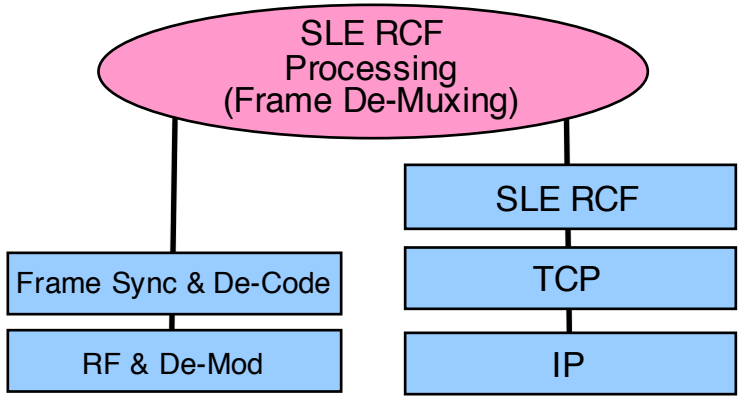
a) SLE F-CLTU



c) CSTS F-Frame (multiplex)

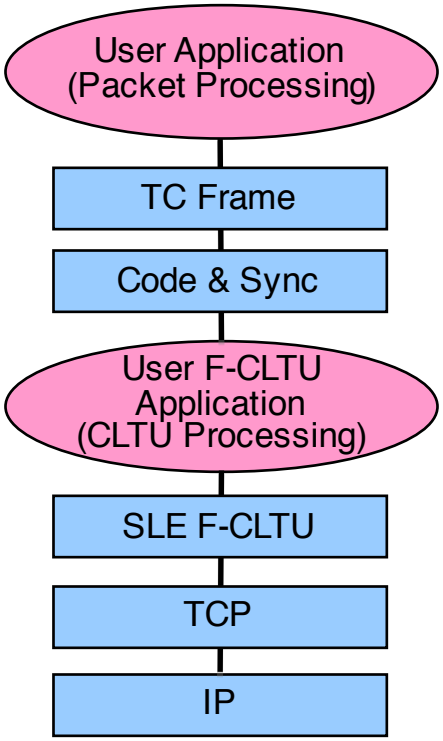


b) SLE RAFs

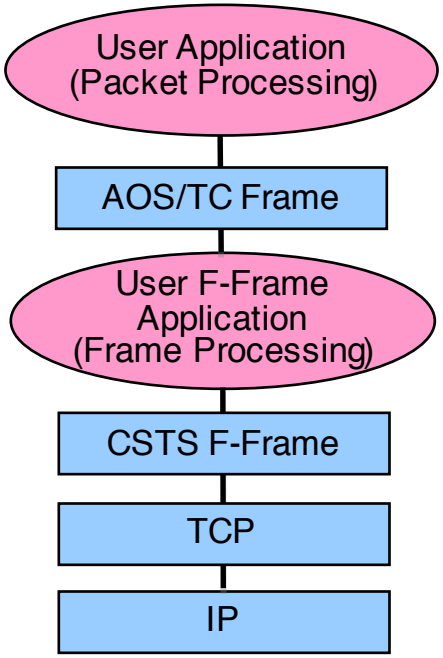


d) SLE RCFs (de-multiplex)

ABA Service-User CLTU & F-Frame Building Blocks

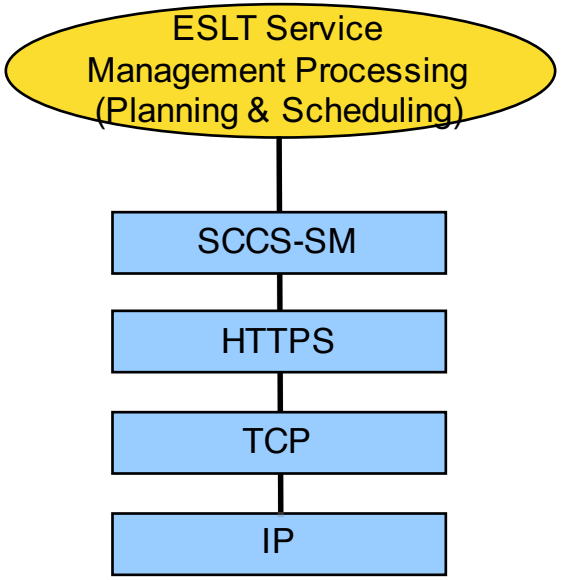


a) ABA User SLE F-CLTU

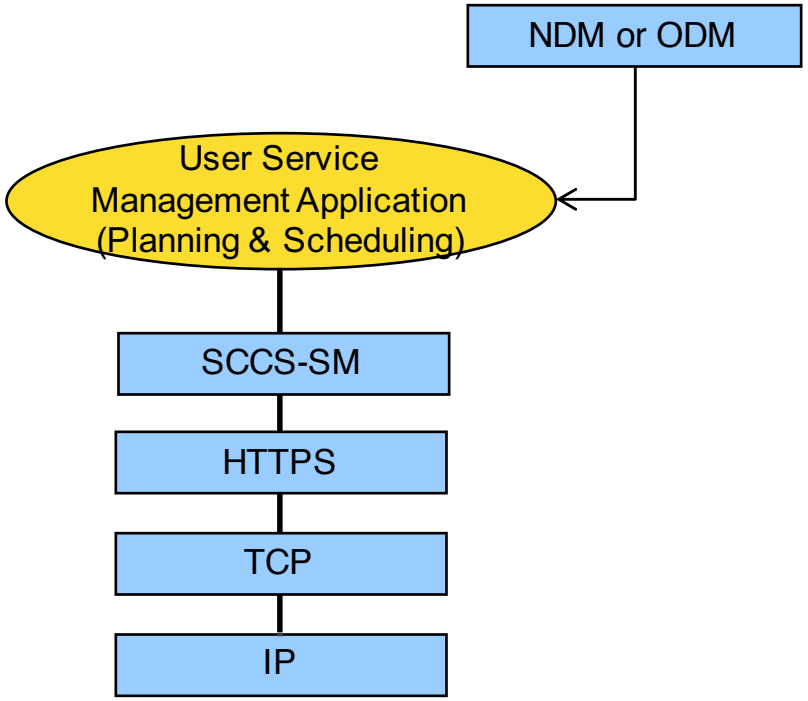


b) ABA User CSTS F-Frame

ABA Service-User Service Management Building Blocks

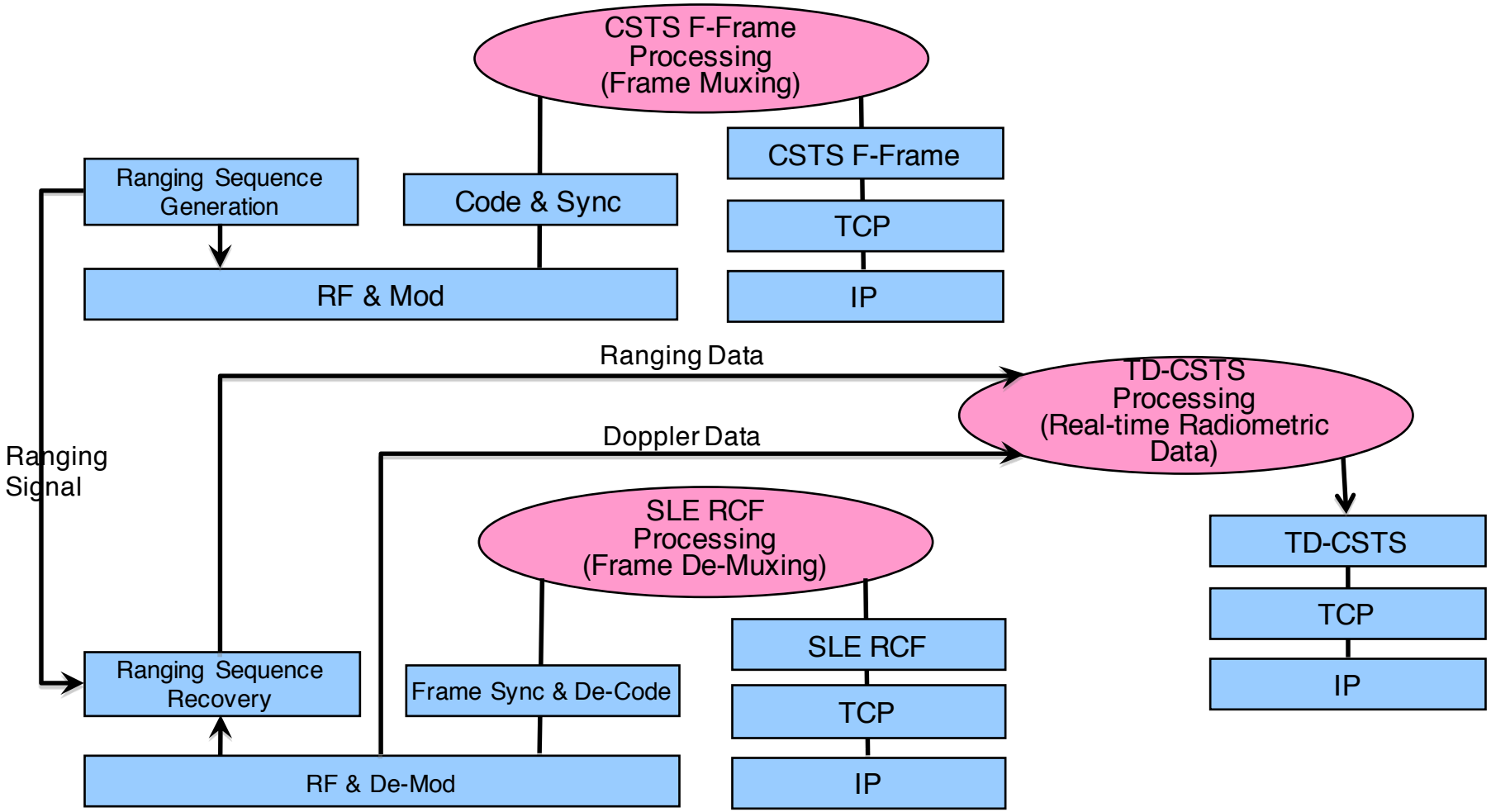


a) ABA ESLT Service Management



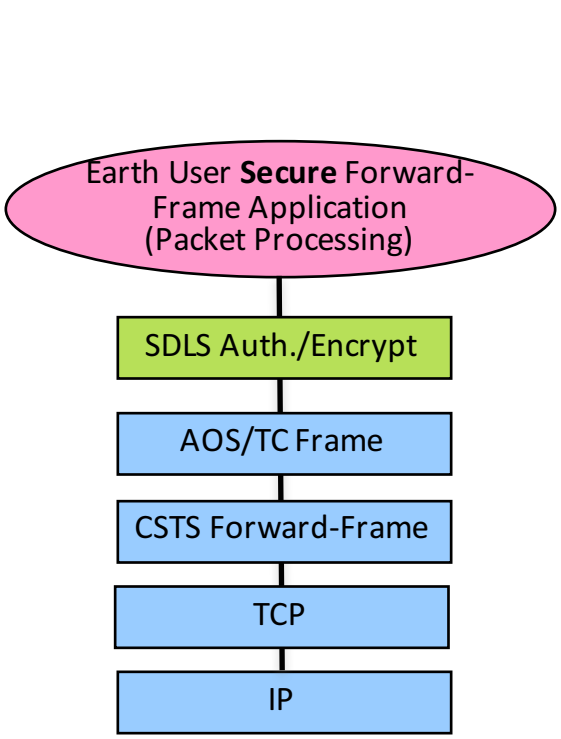
b) ABA User Service Management

ESLT Radiometric Service Provider Protocol Stack Building Blocks

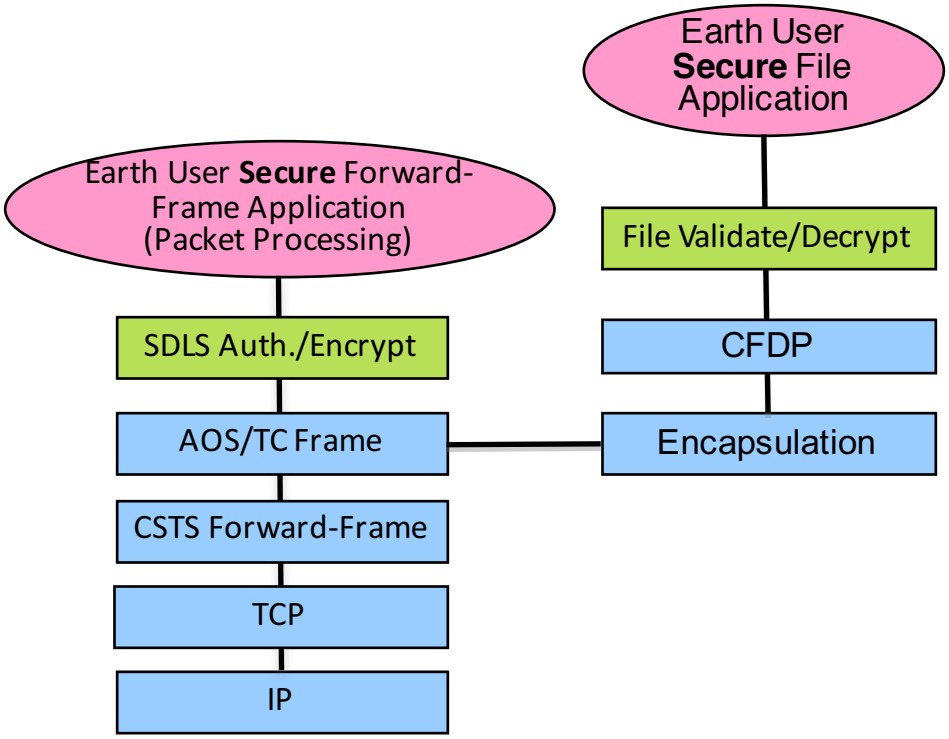


TD-CSTS Ranging & Radiometric Data

ABA Earth User Secure Forward-Frame / File Building Blocks



a) ABA Secure CSTS Forward-Frame User

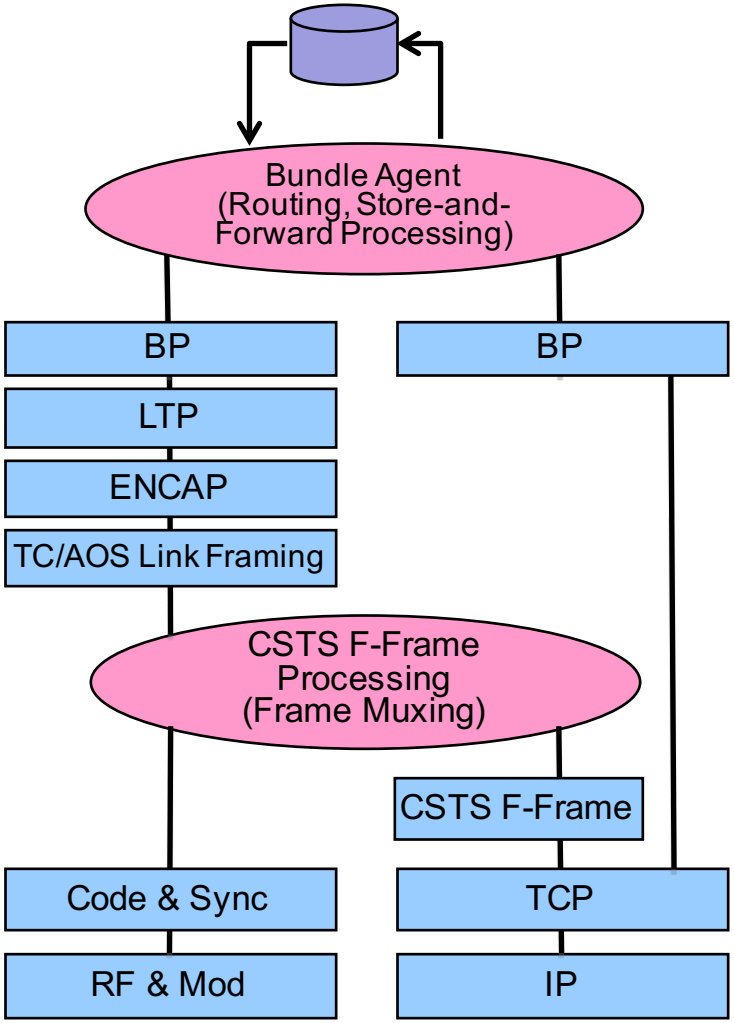


b) ABA Secure CDFP file & CSTS Forward-Frame User

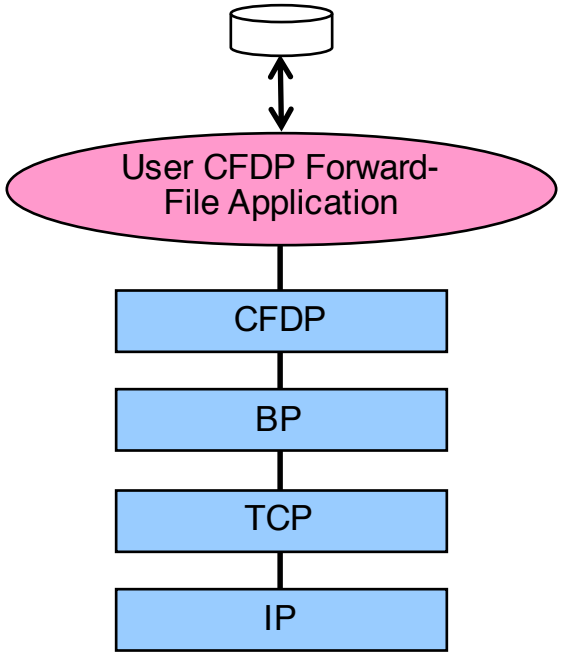
SSI Protocol Building Blocks

- Describe CCSDS SSI protocol configurations as they are intended to be used
- Describe appropriate assemblies for different kinds of services: network layer, application layer, using underlying link layer protocols
- Are designed to be used as the interface bindings for the different SSI services and functions within components
- The following diagrams include:
  - SSI Earth user and relay protocol stacks, forward and return
  - SSI ESLT protocol stacks
  - SSI Space user and relay protocol stacks
  - Many other examples, including security, are in the SCCS-ARD

SSI Earth Service User / Provider Building Blocks

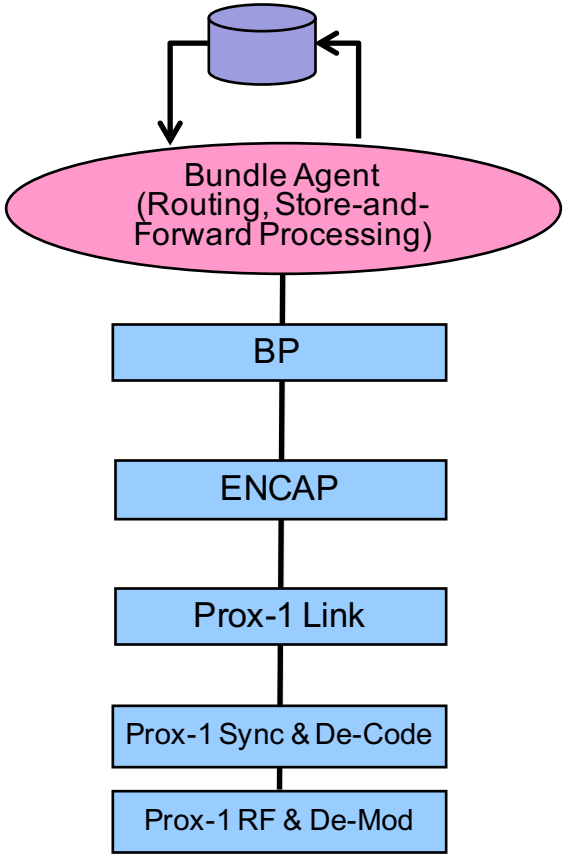


a) SSI Earth Bundle Routing with Frame Multiplexing

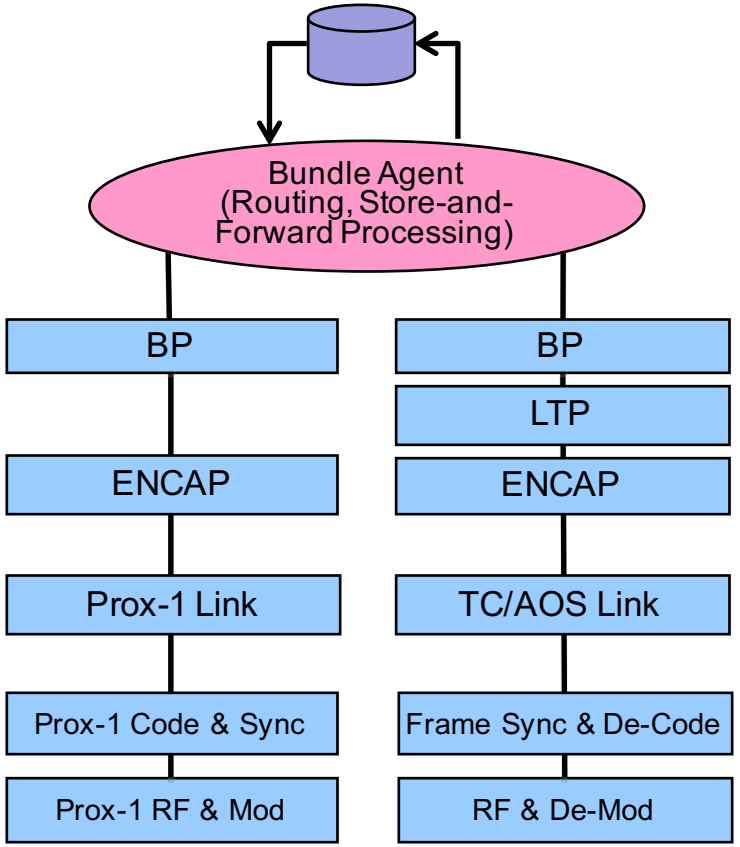


b) SSI User CFDP File Delivery Directly over BP

SSI Space User / Service Provider Building Blocks



a) SSI Space User Relay Link with Bundle Routing

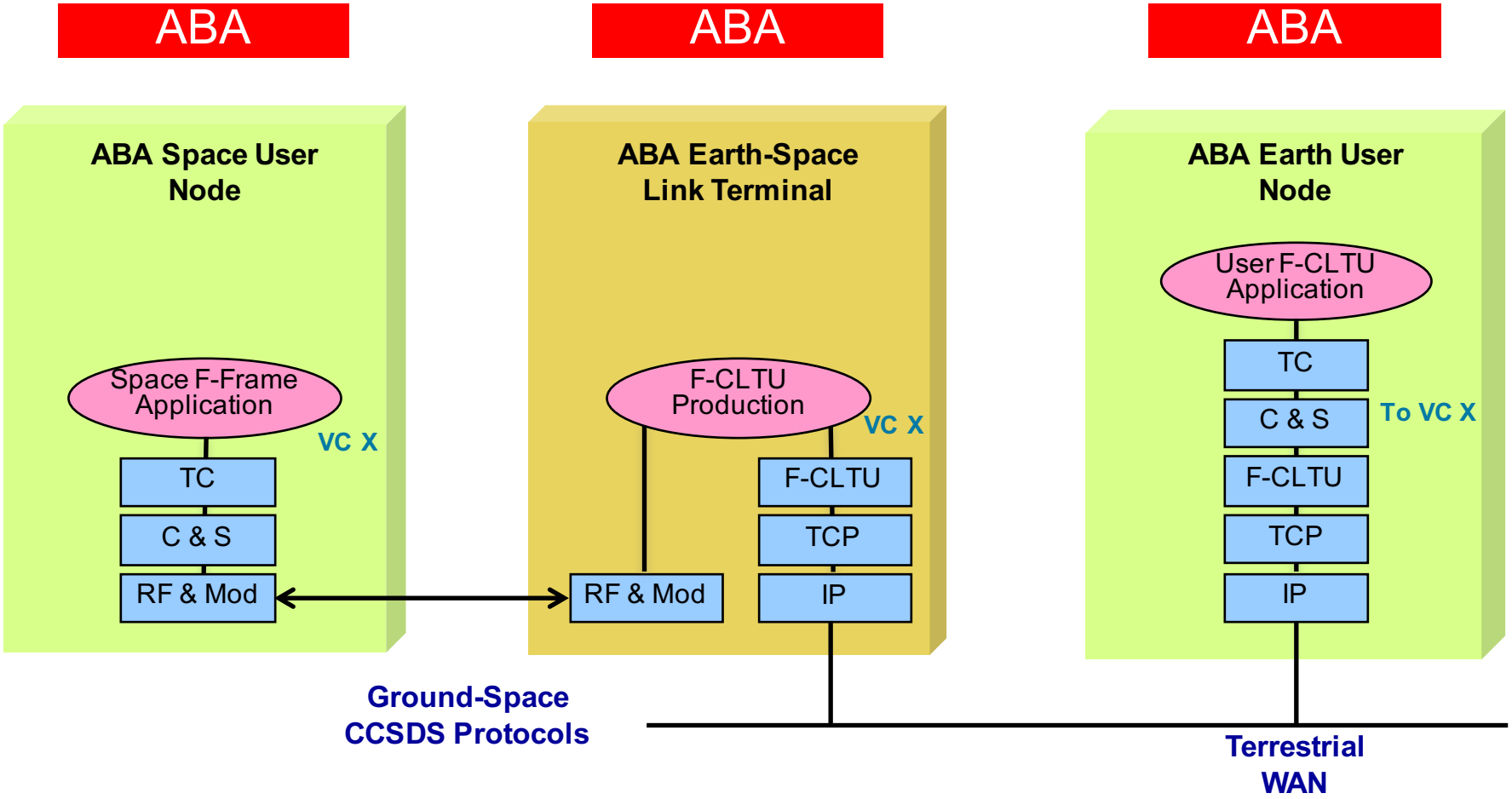


b) SSI Space Bundle Routing Long-Haul and Proximity Links

End-to-End Deployments

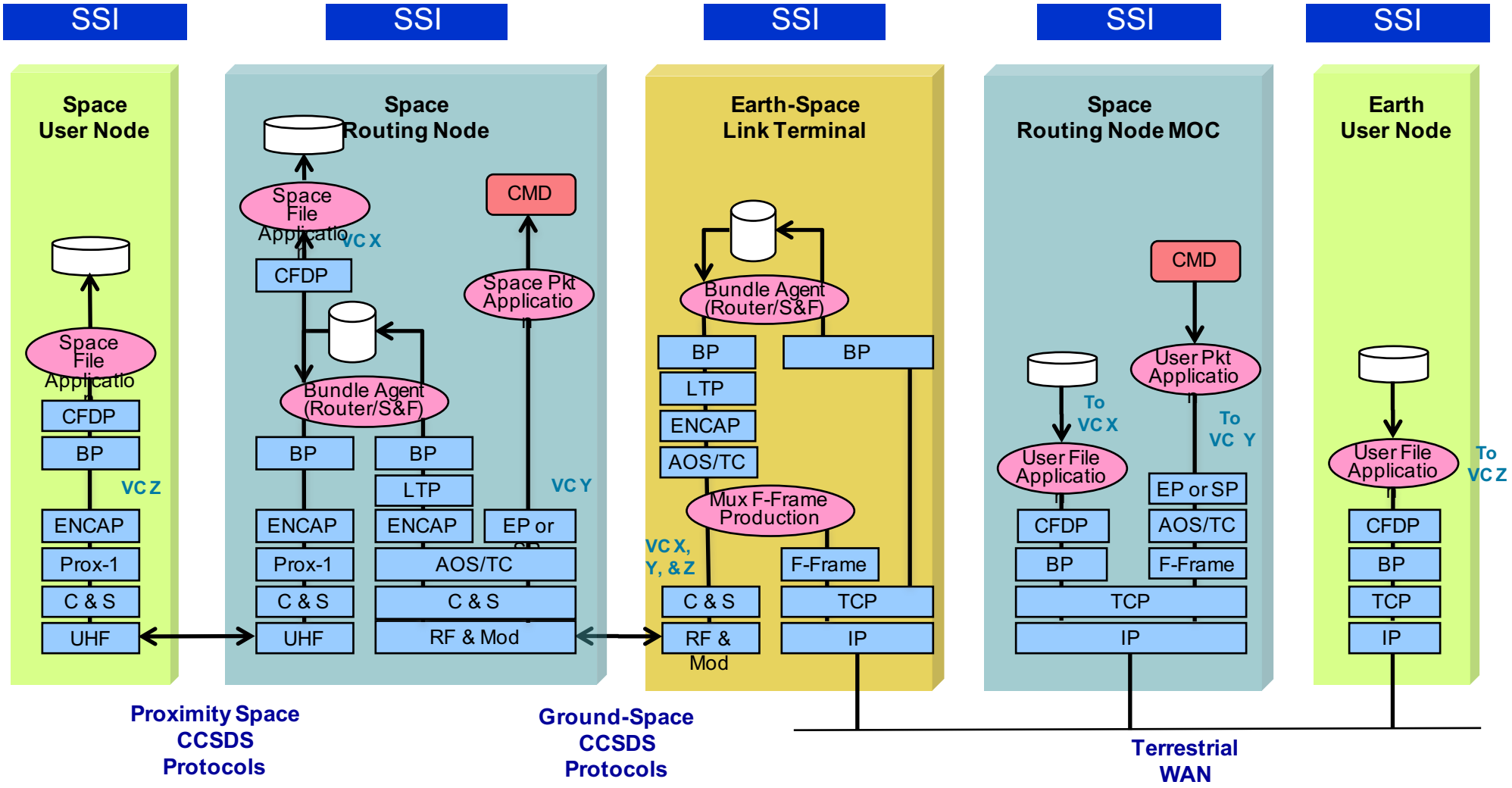
- Both ABA and SSI examples are provided in the SCCS-ARD and the companion SCCS Architecture Description Document (911.0-G-1)
- The following two examples show the Component building blocks and a typical protocol stack building block configuration
- The ABA example shows a very “traditional” forward TC deployment
  - Similar examples for return flows, radiometric processing, file delivery, and secured services are possible
- The SSI example shows both forward command and forward file using a SSI ESLT and Earth and Space Routing Nodes
  - Similar examples for return flows and secured services are possible

Basic ABA End-to-End Forward CLTU Protocols



C & S = Coding & Synchronization

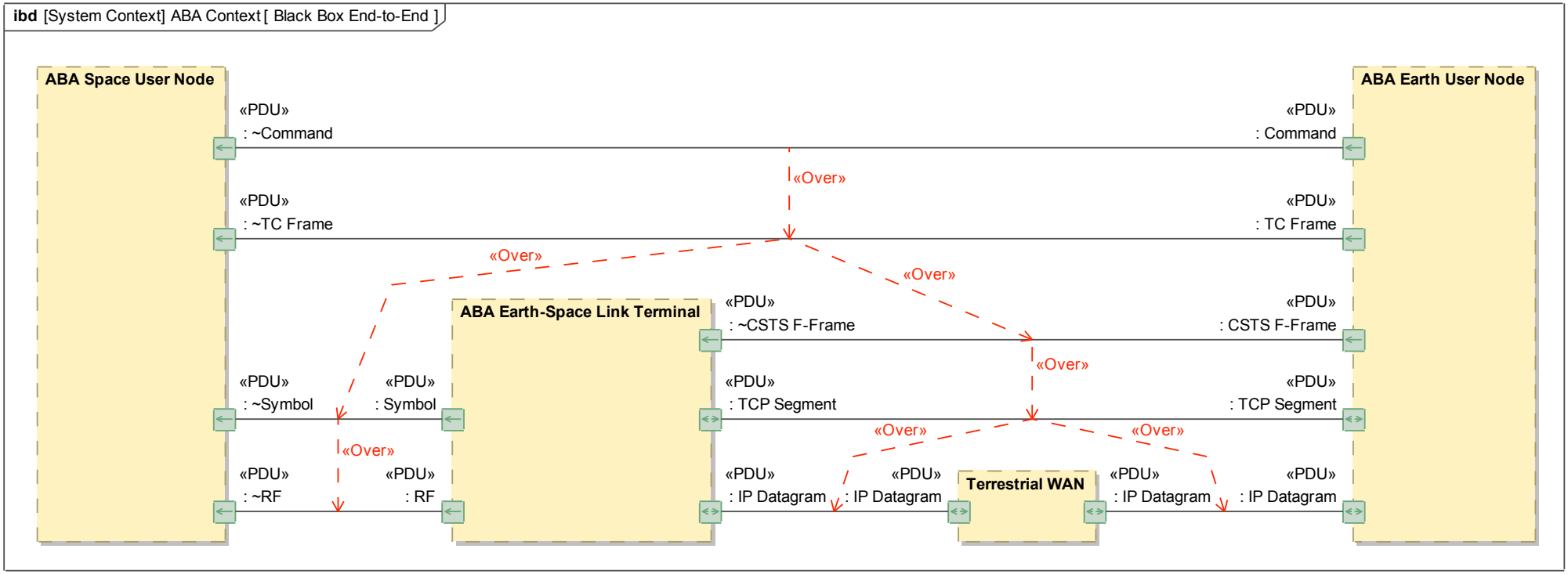
SSI End-to-End Forward: All DTN



A word about the figures

- All of the figures use the viewpoints and methods documented in the Reference Architecture for Space Data Systems (RASDS, CCSDS 311.0-M-1)
- These figures use simple Powerpoint drawings and agreed conventions for representing function, components, links, protocols, and other objects
- These same viewpoints and the fundamentals of the methods may also be represented using SysML or similar approaches
- See a related SpaceOps 2016 paper by Shames, Sarrel, and Friedenthal, 2307501, for a description of this modeling approach

End-to-End Protocol View using SysML



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

End-to-End Building Block Benefits

- The building-block approach presented here provides the means for specifying, analyzing, and designing interoperable, cross-supportable, end-to-end space communications systems.
- This approach enhances reuse, consistency, conformance to standards, and provides guidance for adopting CCSDS service, data link, and space internetworking interfaces.
- Adopting standard component interfaces and services, complying to CCSDS standards, will support high levels of interoperability and cross support
- Using these building blocks supports system connectivity and composition, and will enable re-use of expensive ground communications assets
- These building blocks, used appropriately, will support multi-mission and multi-agency space deployments and the development of a Solar System Internet (SSI)
- Not all systems deployments require all of these viewpoints

References

Space Communications Cross Support Architecture Requirements Document (SCCS-ARD, CCSDS 901.1-M-1)

Space Communications Cross Support Architecture Description Document (SCCS-ADD, CCSDS 901.0-G-1)

Reference Architecture for Space Data Systems (RASDS), CCSDS 311.0-M-1, Sept 2008

Shames, Peter M, Sarrel, Marc A, Freidenthal, Sanford A, A Representative Application of a Layered Interface Modeling Pattern, to be published 26th Annual INCOSE International Symposium (IS 2016), Edinburgh, Scotland, UK, July 18-21, 2016

Shames, Peter M, Sarrel, Marc A, A modeling pattern for layered system interfaces, 25th Annual INCOSE International Symposium (IS2015), Seattle, WA, July 13 – 16, 2015

Information technology - Open Systems, Basic Reference Model, ISO/IEC 7498-1, revised June, 1996

Systems and software engineering — Recommended practice for architectural description of software-intensive systems, ISO/IEC 42010, July 2007, revised 2011

And eighty other CCSDS standards as documented in Sec 1.7 References of CCSDS 901.1-M-1