Bringing the Vision of Plug-and-play to High-Performance Computing on Orbit

Presentation to HPEC 2009

22 Sept 2009

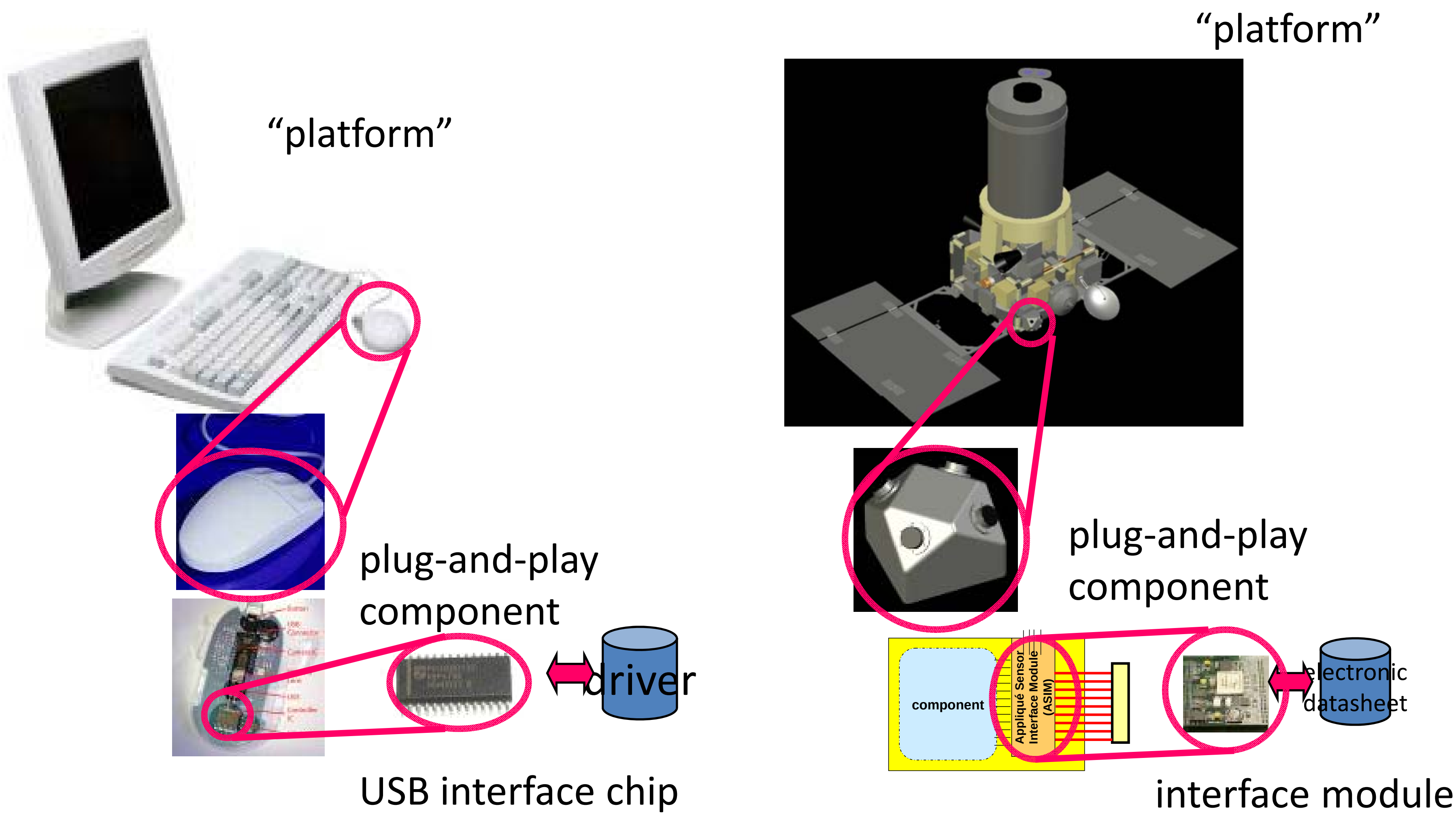
Outline

- Introduction
- Space Plug-and-Play Avionics (SPA)
- Extending SPA to HPEC
- Conclusions

Space PnP Avionics (SPA)

- Introduction
- Key Features
- Status

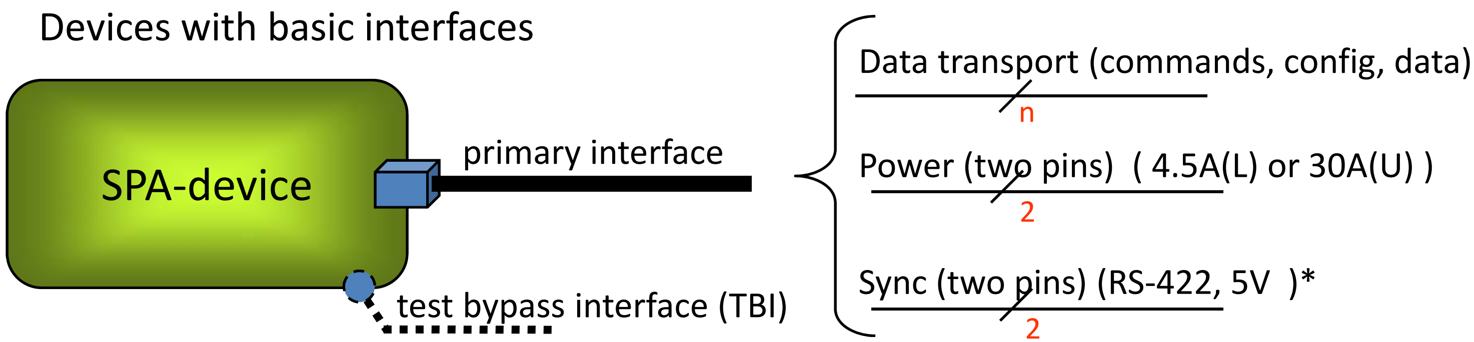
Analogy of Consumer PnP with SPA



Space Plug-and-play Avionics Key Features

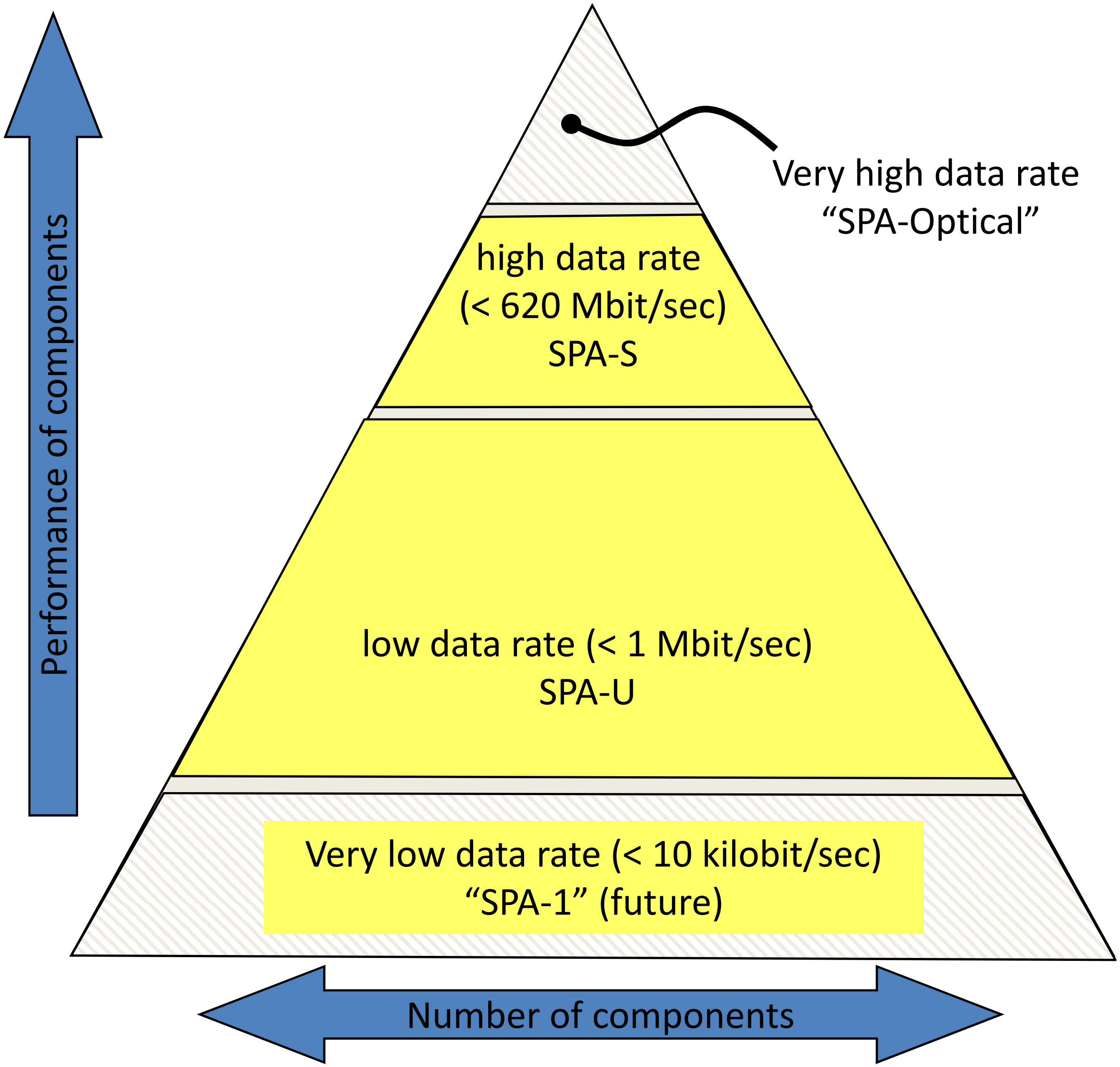
- Single-point interfaces (e.g. SPA-S) and protocols
- Appliqué Sensor Interface Module (ASIM)
- Electronic datasheets (XTEDS)
- Software -- Satellite data model (SDM)
- Test bypass
- Pushbutton toolflow

Interfaces

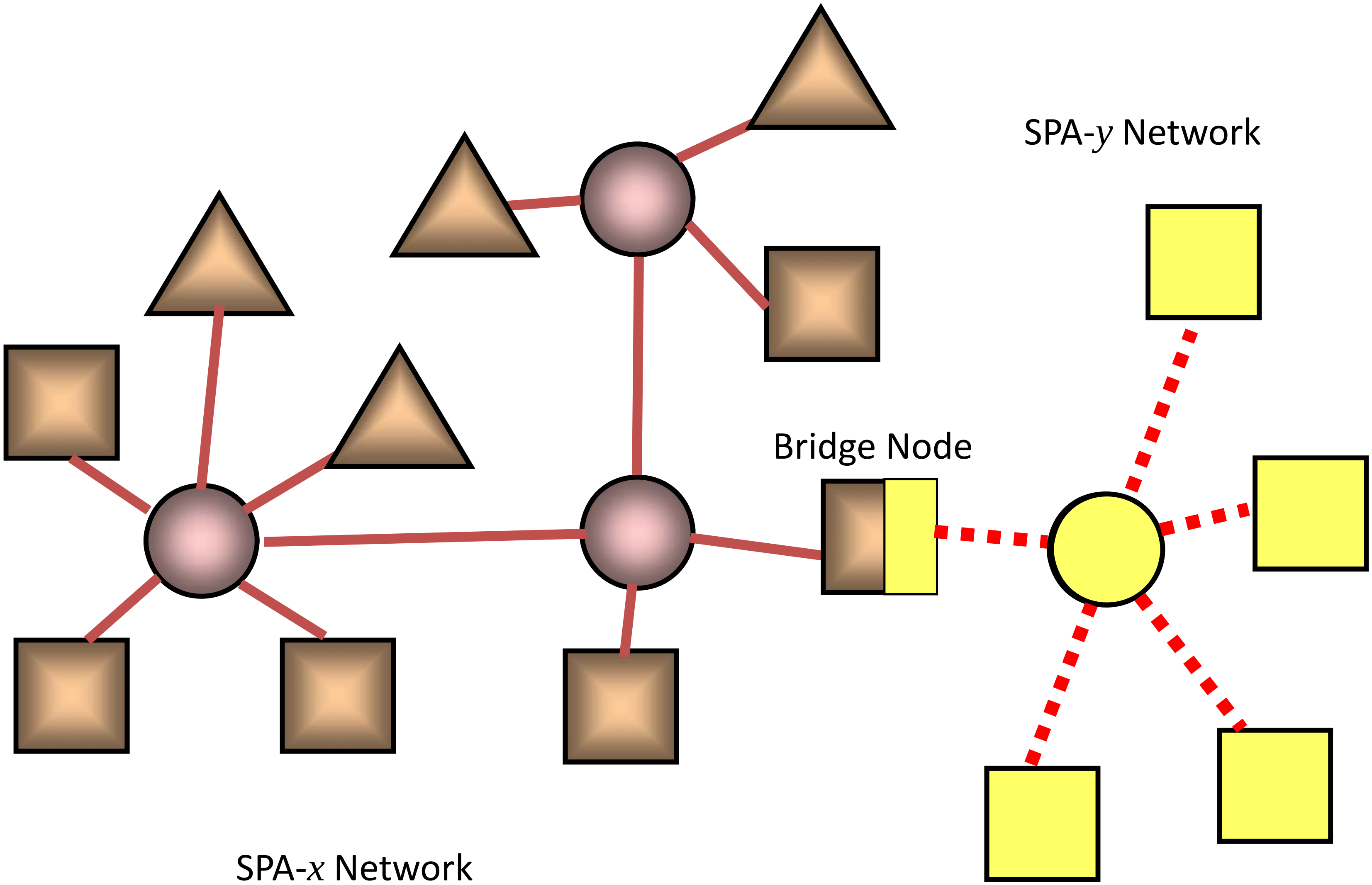


- SPA-U (Data transport = USB 1.1, limited to 12 Mbps for entire bus)
- SPA-S (Data transport = Spacewire, limited to 600 Mbps per direction per link)

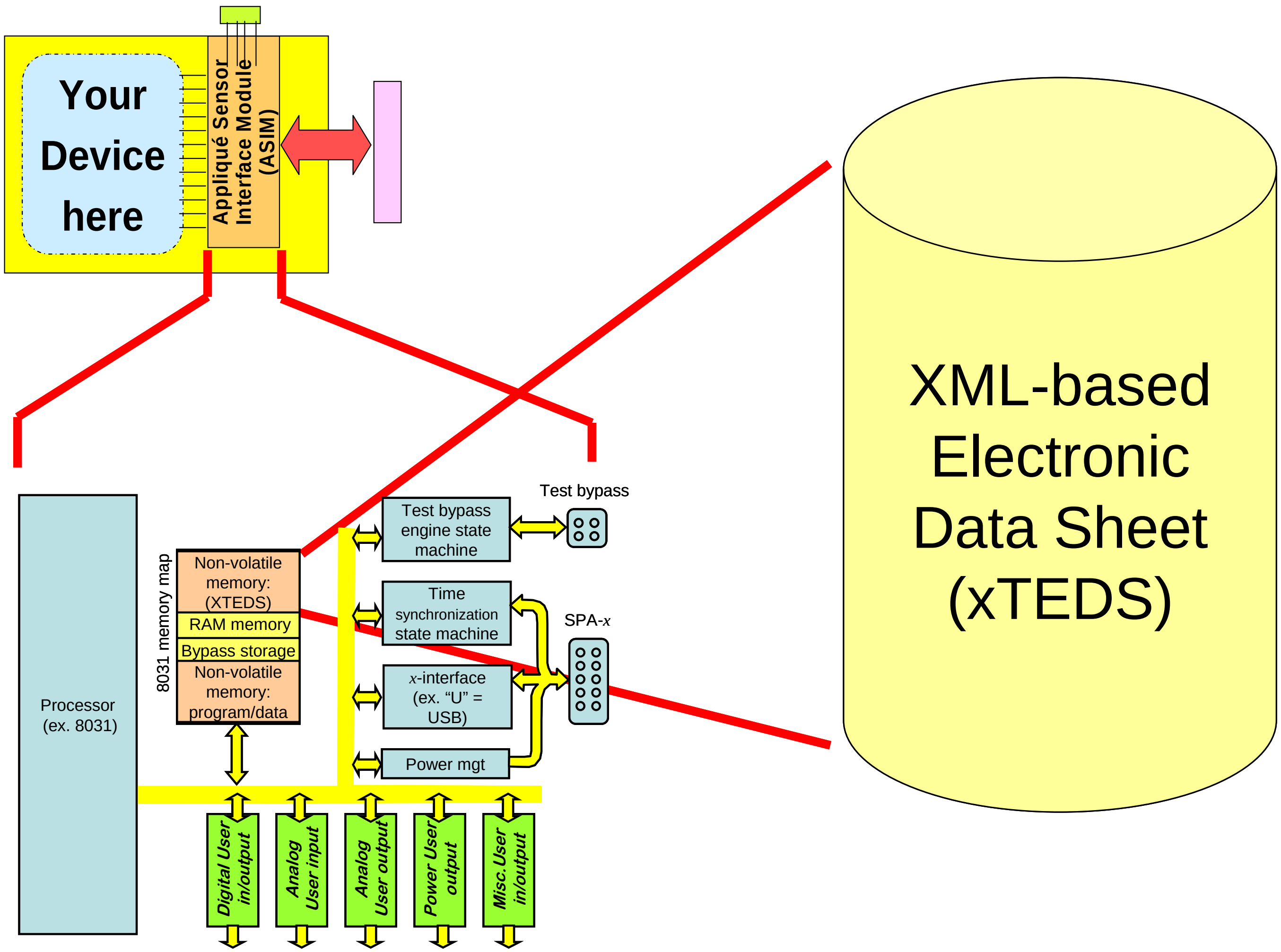
Distribution of bandwidth in systems



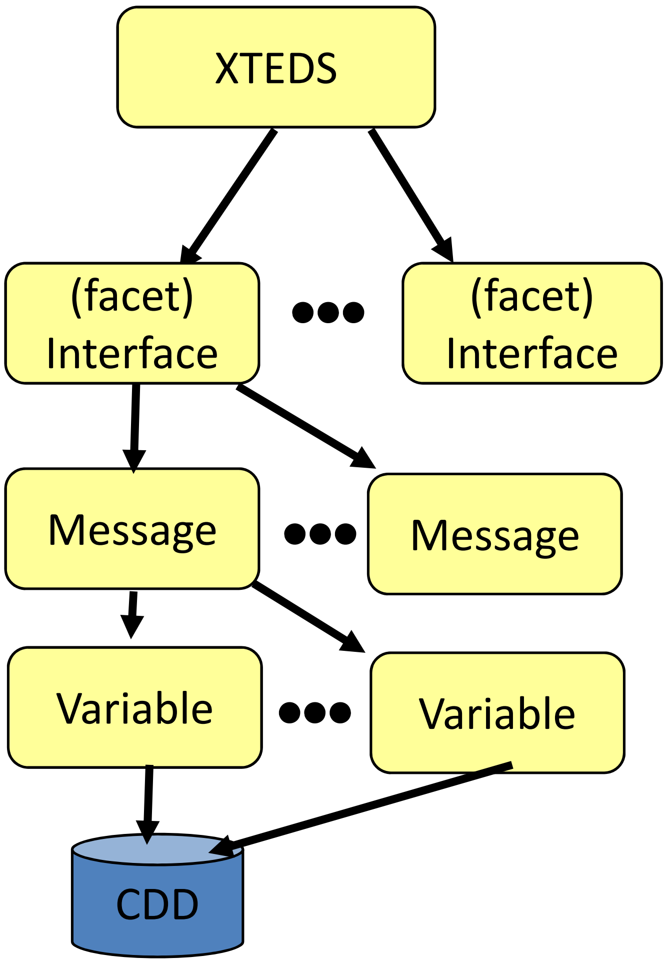
Heterogeneity – Mixture of SPA networks



Applique Sensor Interface Module (ASIM) – Simplifying SPA Engineering and SPA Compliance

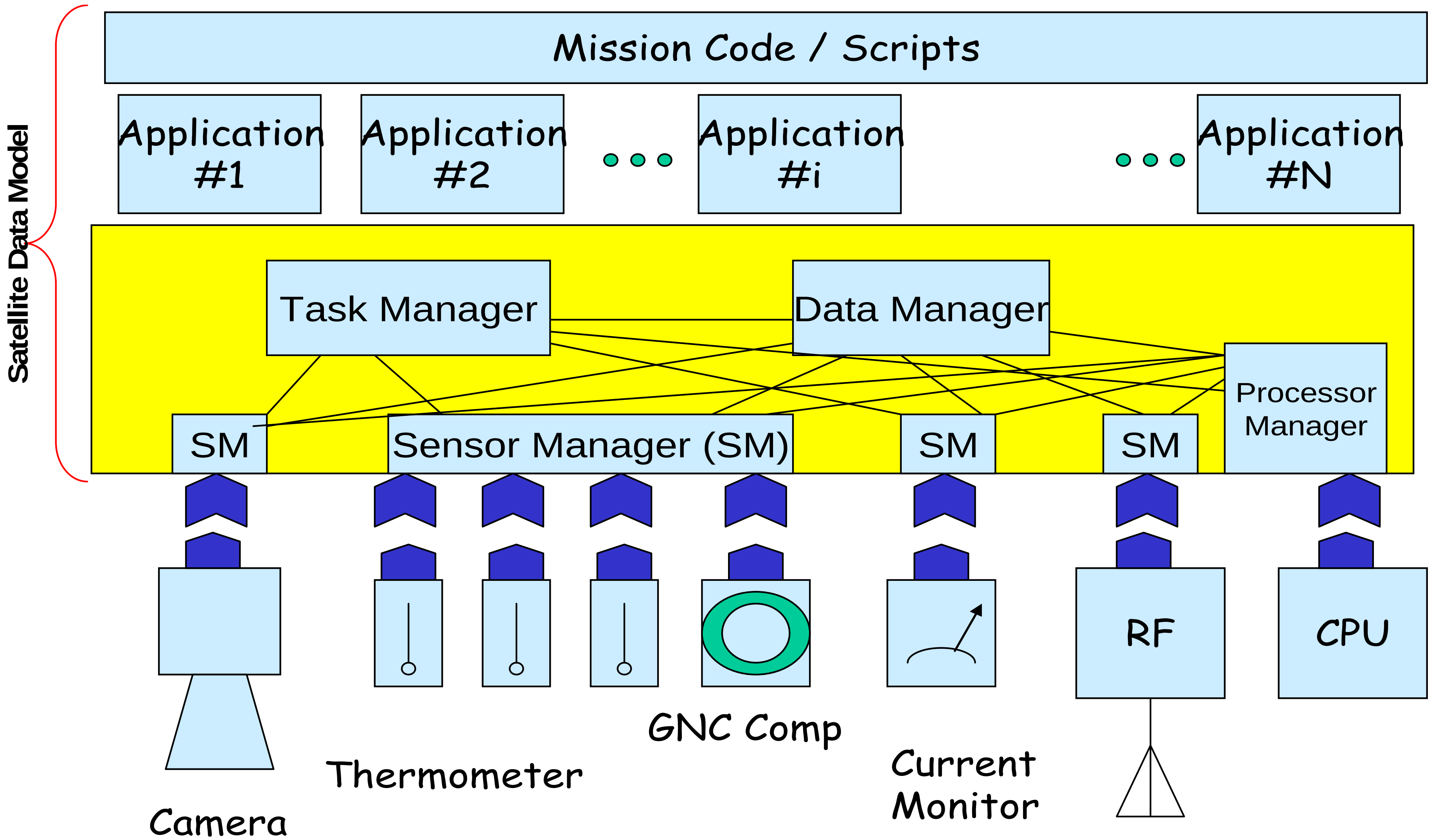


eXtended Transducer Electronic Datasheet (xTEDS)



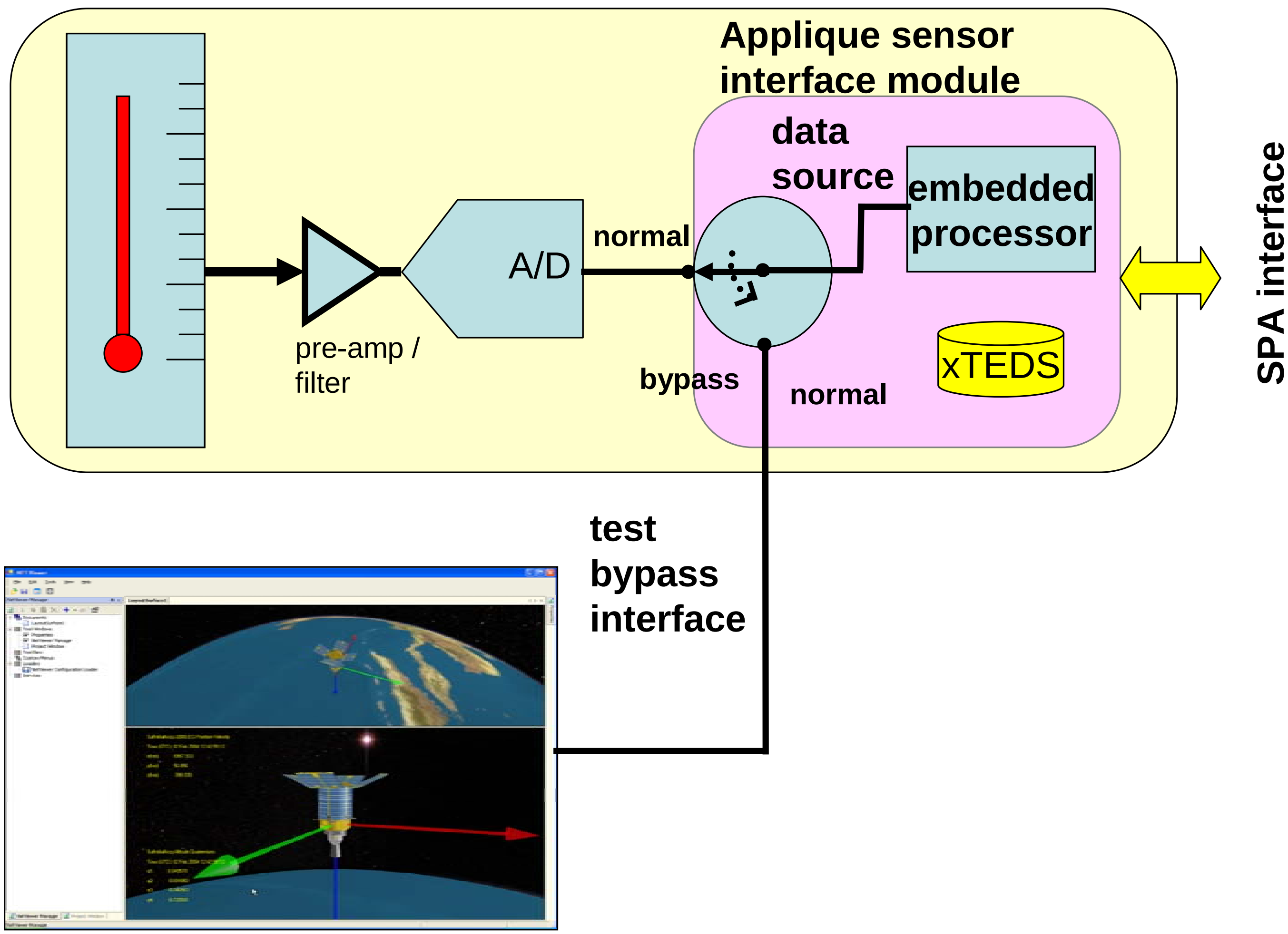
- Primary mechanism for self-description
  - Embedded in hardware and software applications
  - Describes "knobs" and "measurands"
- Conveys "semantic precision" through a common data dictionary (CDD)
- Enforces order in the "LEGO universe" of SPA (features only exist if known through XTEDS)
- Recently released to public domain
  - Studied as possible AIAA and ISO standard

The Satellite Data Model (SDM) – Building Awareness into Plug-and-play



Test Bypass – Automating Support for Hardware-in-the-Loop

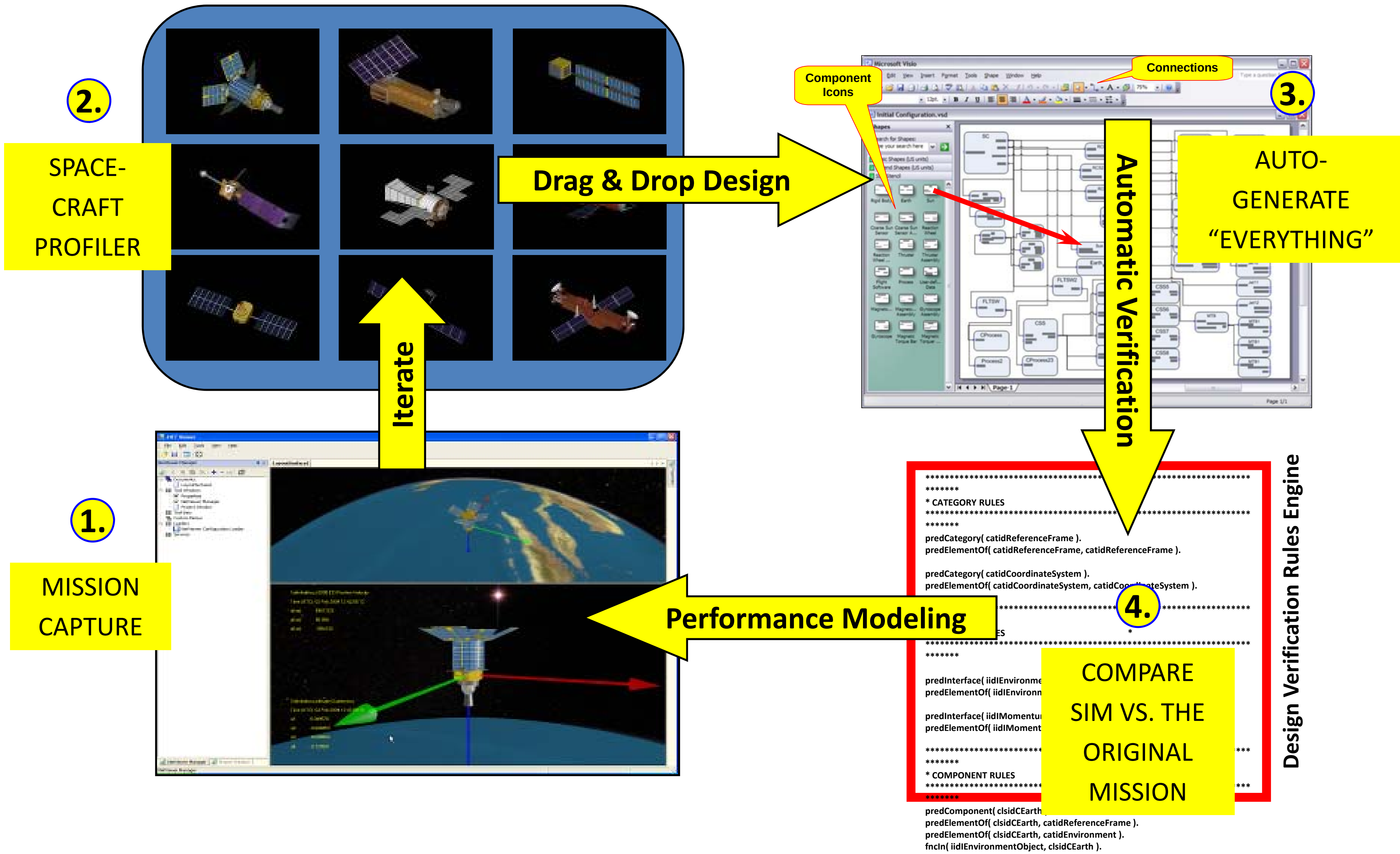
SPA (plug-and-play) thermometer



Push-button Tool Flow
(aka Satellite Design Automation)

Mission Goals and Requirements

Component Capabilities



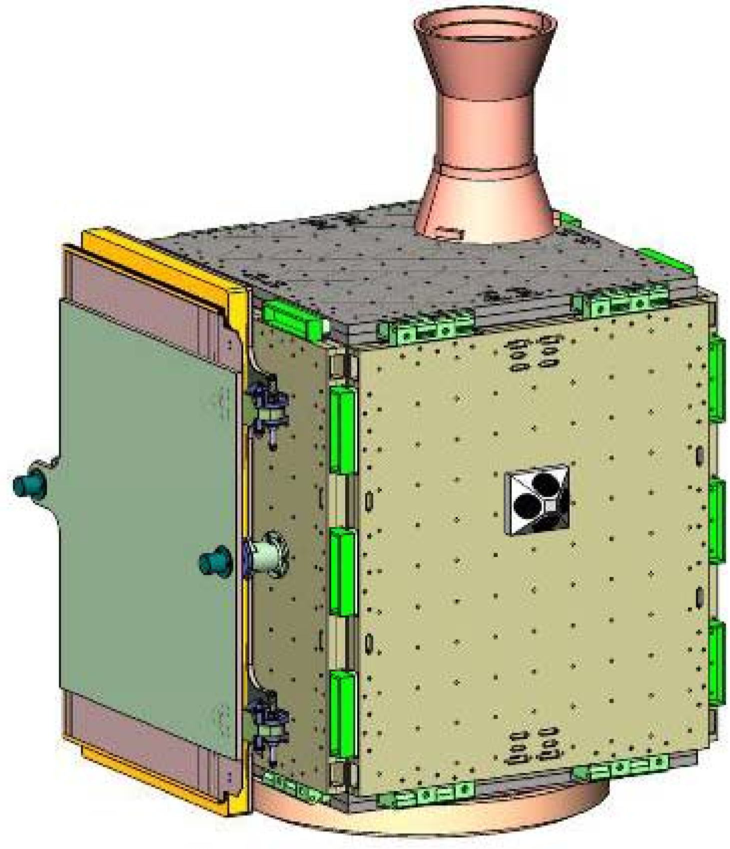
Other Tenets of SPA

- Seek OS independence
- Seek decentralization
- Seek to conceal (unnecessary) complexity through encapsulation

SPA Status

- SPA Workshops (eight from 2004-2006)
- Creation of Responsive Space Testbed (Kirtland AFB)
- Flight developments
  - RESE (SPA-U, 4-port) – Launched and operated September 2007
  - TacSat 3 (SPA-U, 4-port) – Integration into TacSat 3 (Launched in 2009)
- Adoption of SPA as central interface approach for TacSat 5
- Creation of outreach concepts for SPA-based CubeSats
- International agreement (with Sweden) and pursuit of national/international standards for SPA

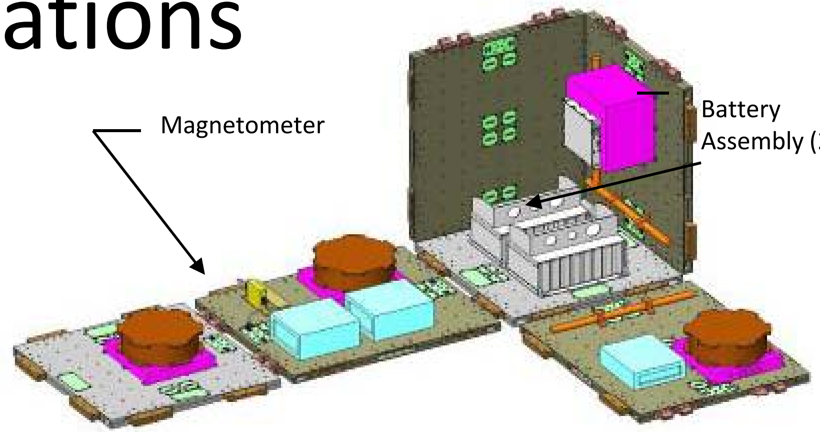
Plug-and-play Satellite (PnPSat)

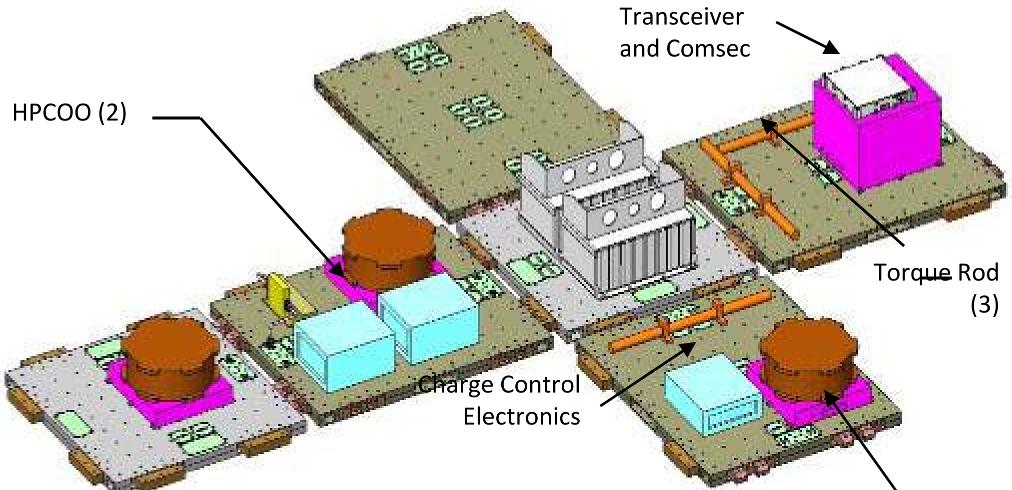


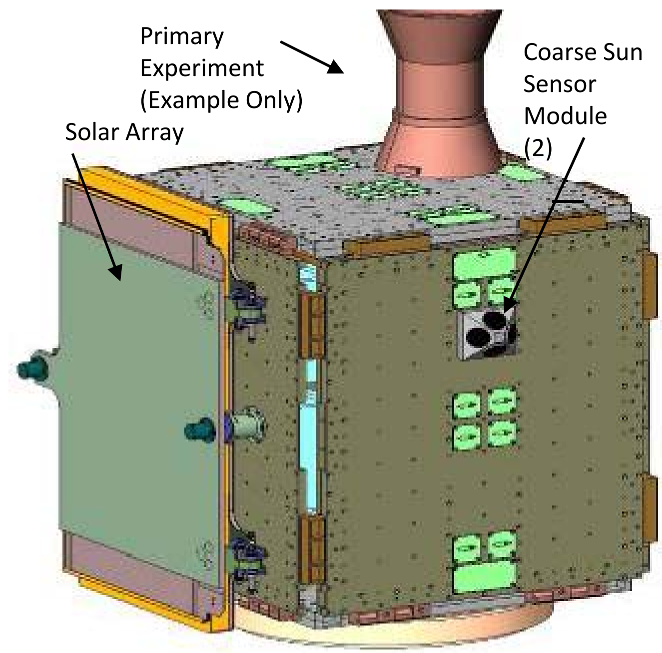
- First spacecraft ever built entirely on PnP principles
  - Decentralized, scalable computation
  - Use of satellite data model
  - All components (even panels) are SPA devices
  - up to 48 mounting sites
- Ambitious development schedule
  - Targeting flight in 2009

Component and Experiment Accommodations

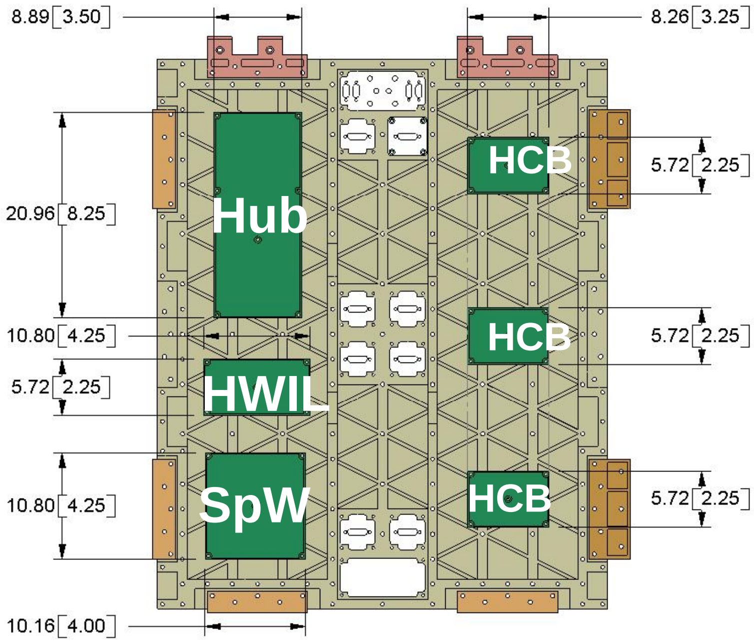
- A full complement of PnPSat components shown
  - By recessing electrical infrastructure and harnessing, we significantly increase flexibility for component and experiment mounting
  - Initial version of PnPSat may have fewer spacecraft components than the version shown







Encapsulation (complexity hiding)



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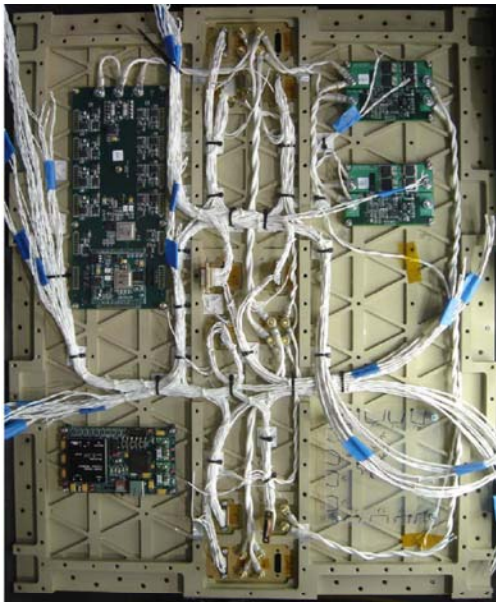
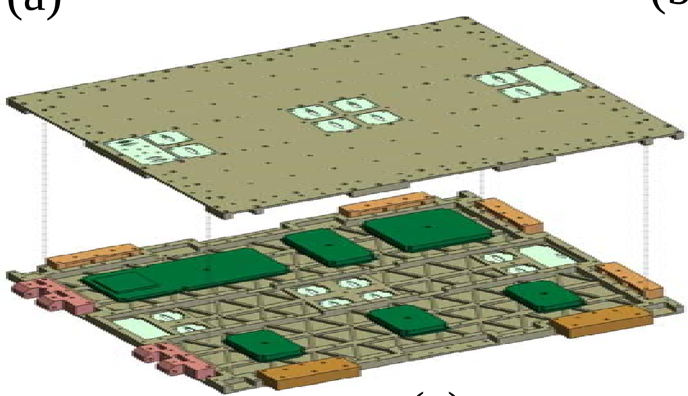
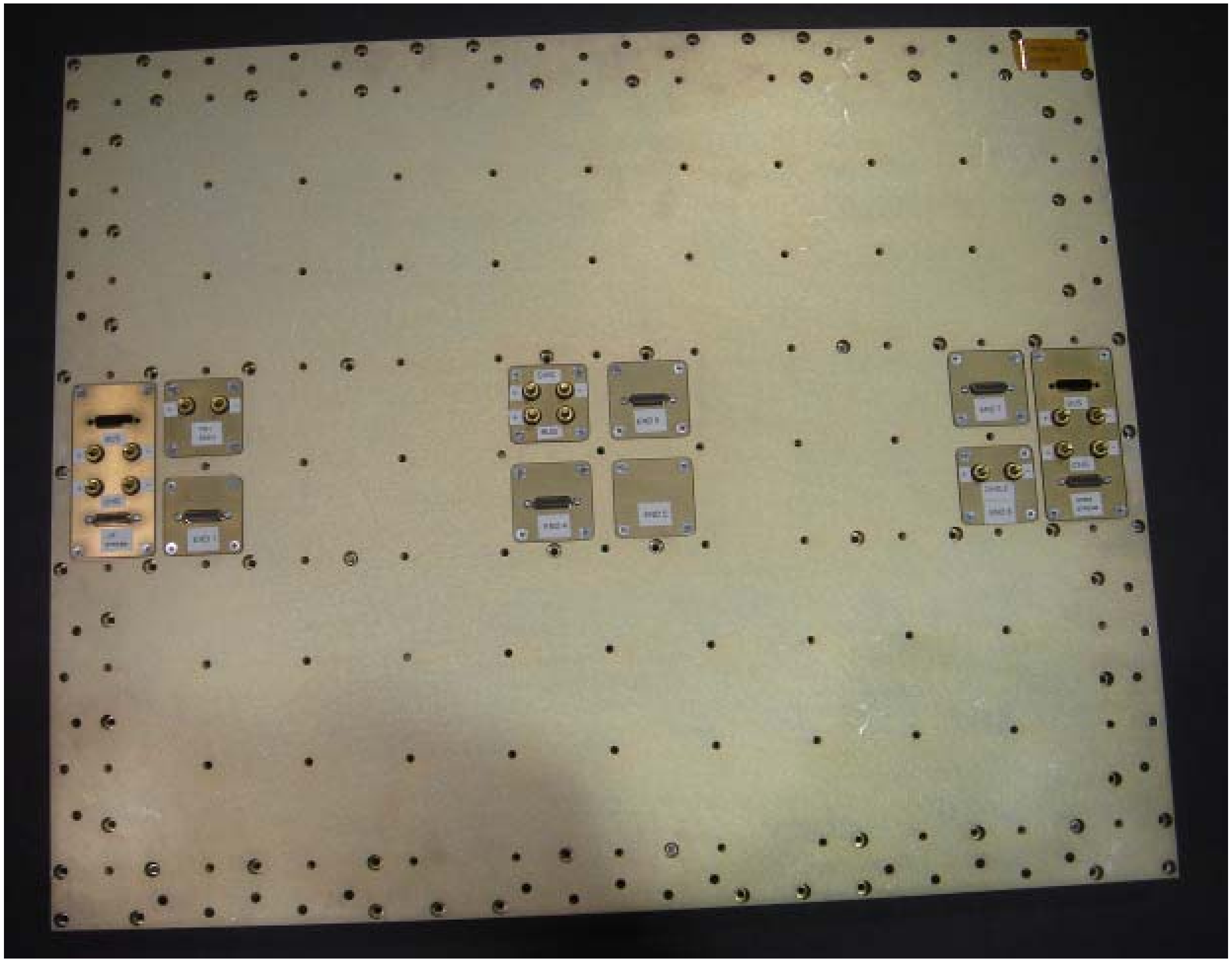


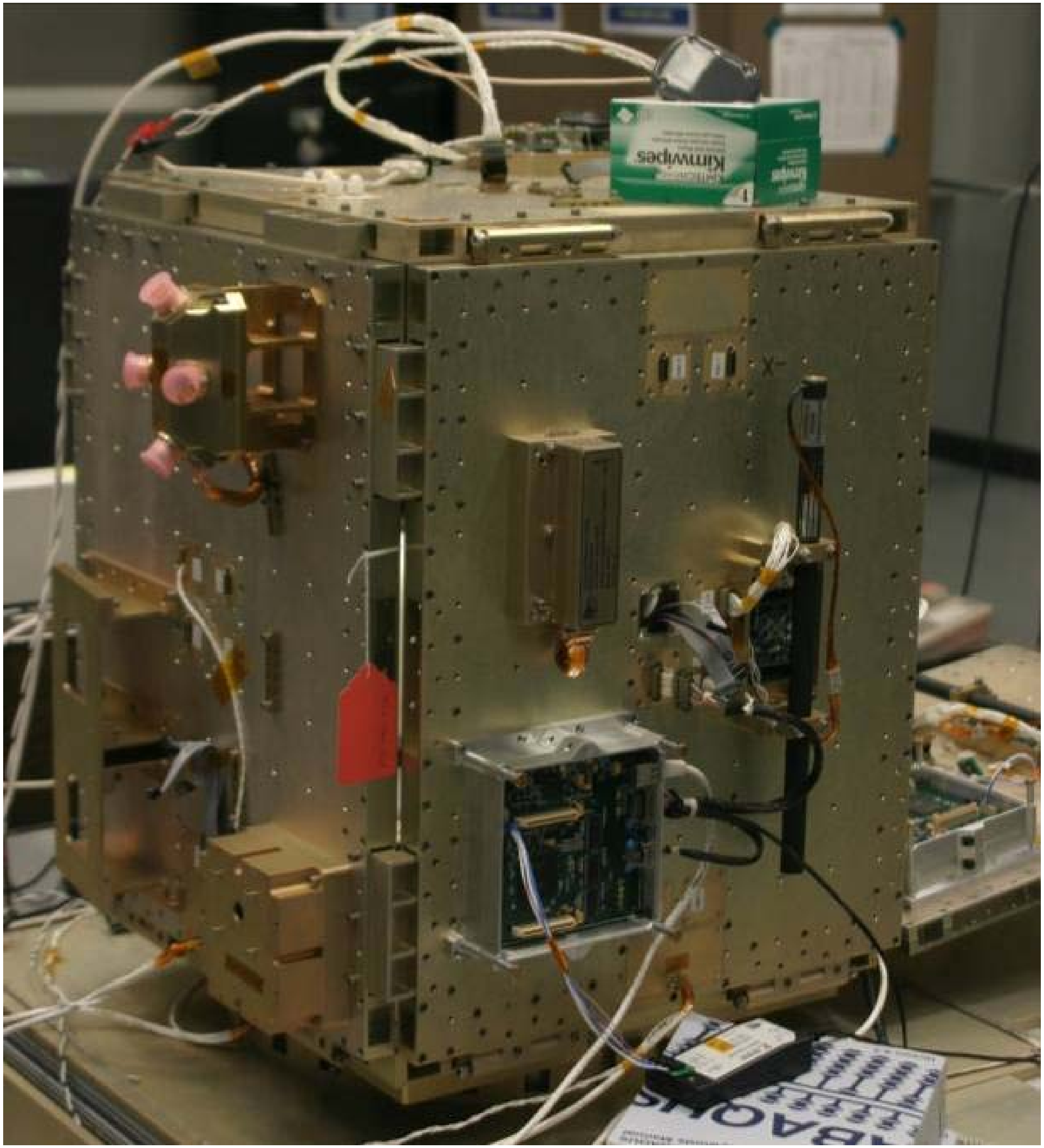
(b)



(c)

Encapsulation (complexity hiding)




Kimwipes

Miniaturization
CubeFlow = SPA+CubeSat

- Targeting PnP platforms as small as cubesats (100mm)
- Supports increased payload mass fraction and creation of PnP nanosatellites
- Compact nanosat modular form factor (NMF)standard (70mm x 70mmx12.5mm)

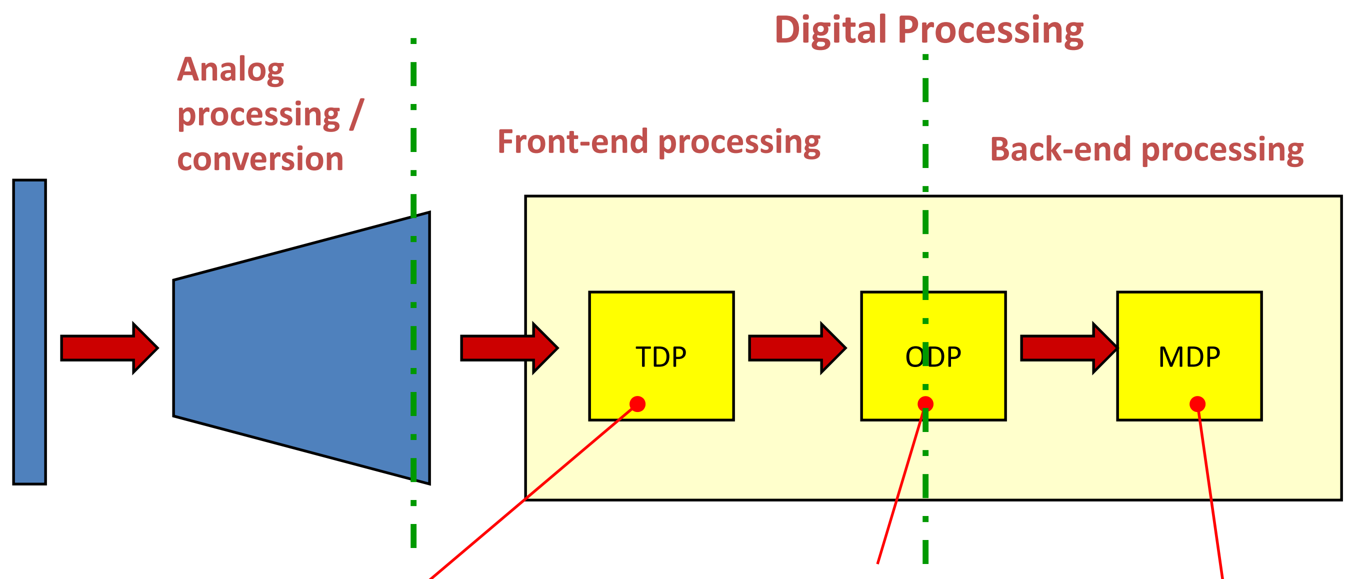
CubeFlow Training

- "Eli Whitney meets spacecraft"
- Short course based on the principles of SPA embedded in take-apart Cubesats
  - Entire system (with laptop console) fits in briefcase
  - Fifteen+ kits distributed so far (May 2009 course)
  - More CubeFlow courses planned

SPA for high-performance embedded systems?

- Scaling of SPA interfaces currently limited
- Complex processing architectures far from plug-and-play

Example Processing Chain Framework for high-performance (surveillance) sensor



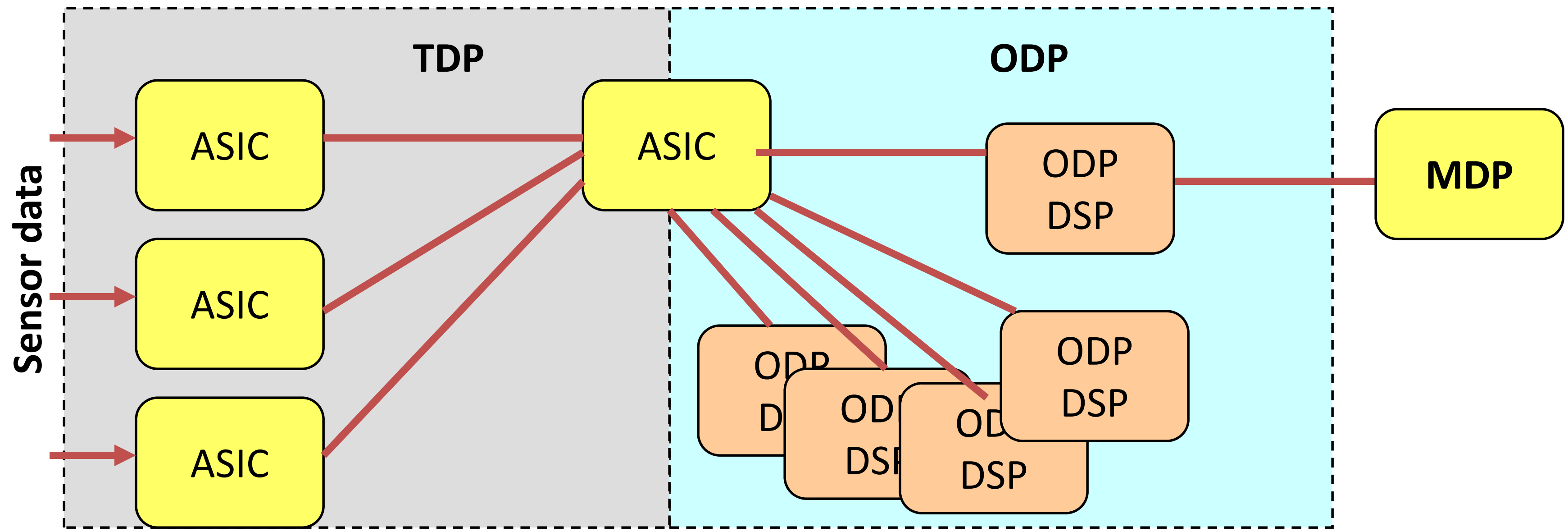
Sensor – Pixels, # rows, # cols, # frames/sec, modes (windowing)

Processes that are done on every single pixel, intensive processing, but usually relatively simple. generates objects

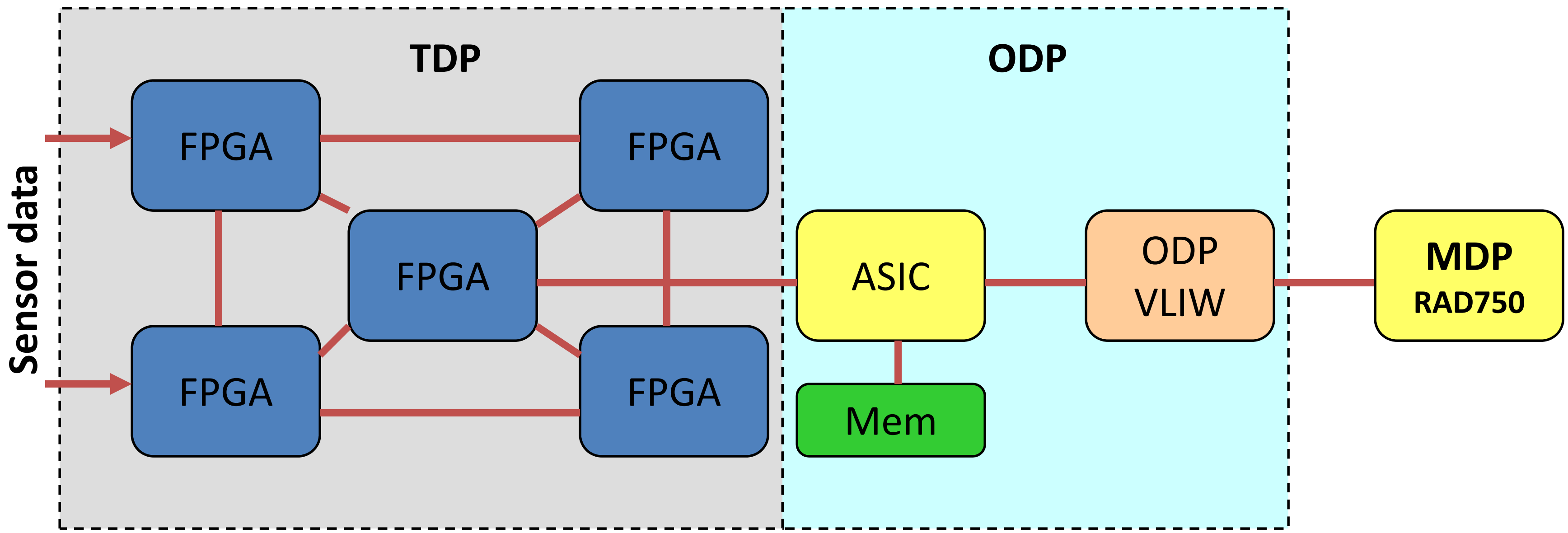
Processes that are done on every single object. Much reduced data rate compared to raw data. Generates enhance objects

Processes that are done on enhanced objects. Much reduced data rates, but much greater # ops / enh.object

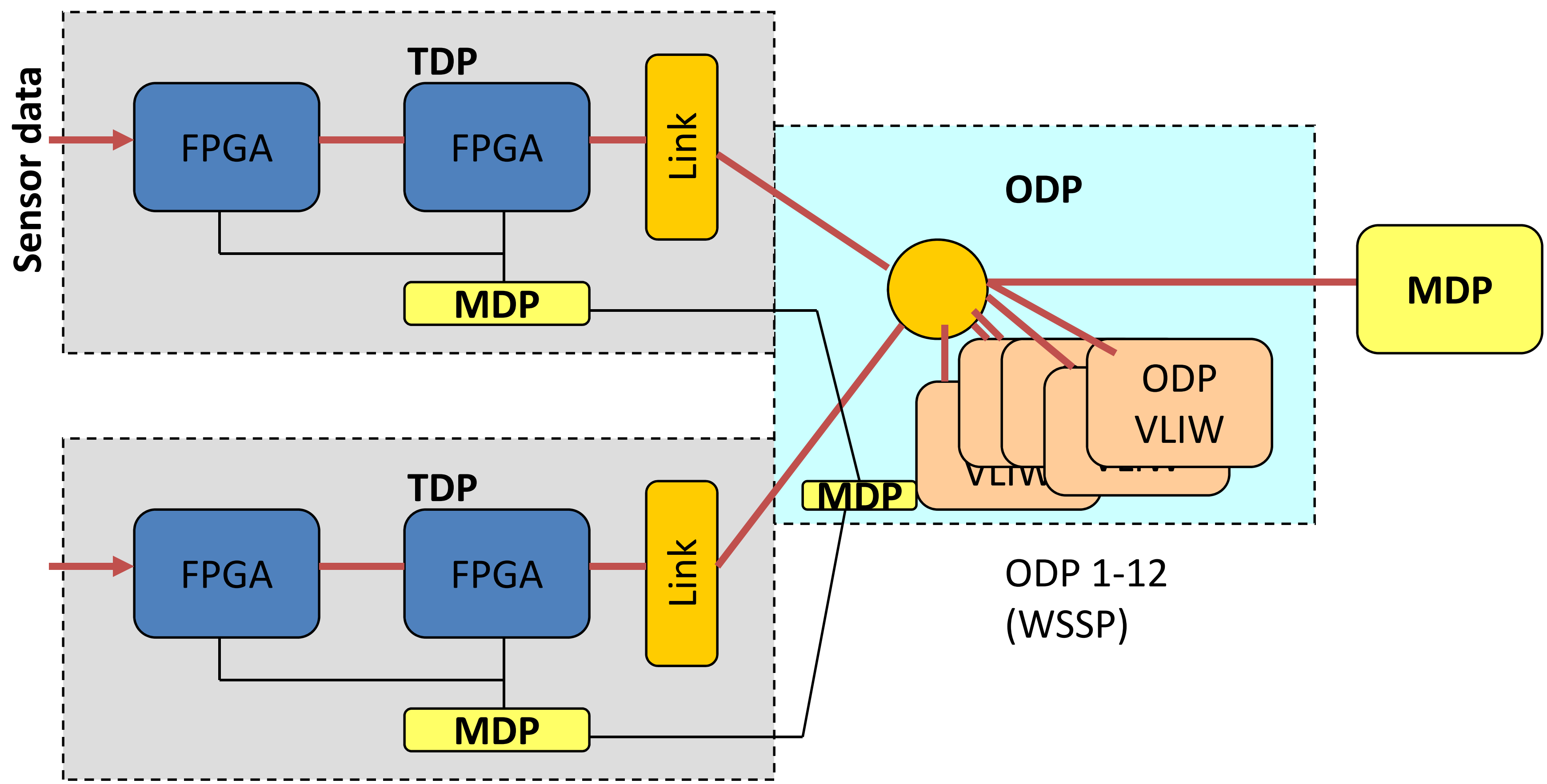
Generic Processing System



Example 1: TacSat 2 Processing System



Example 2: Sensor And Fusion Engine (SAFE) Processing System



Problems With Ad Hoc HPEC Frameworks

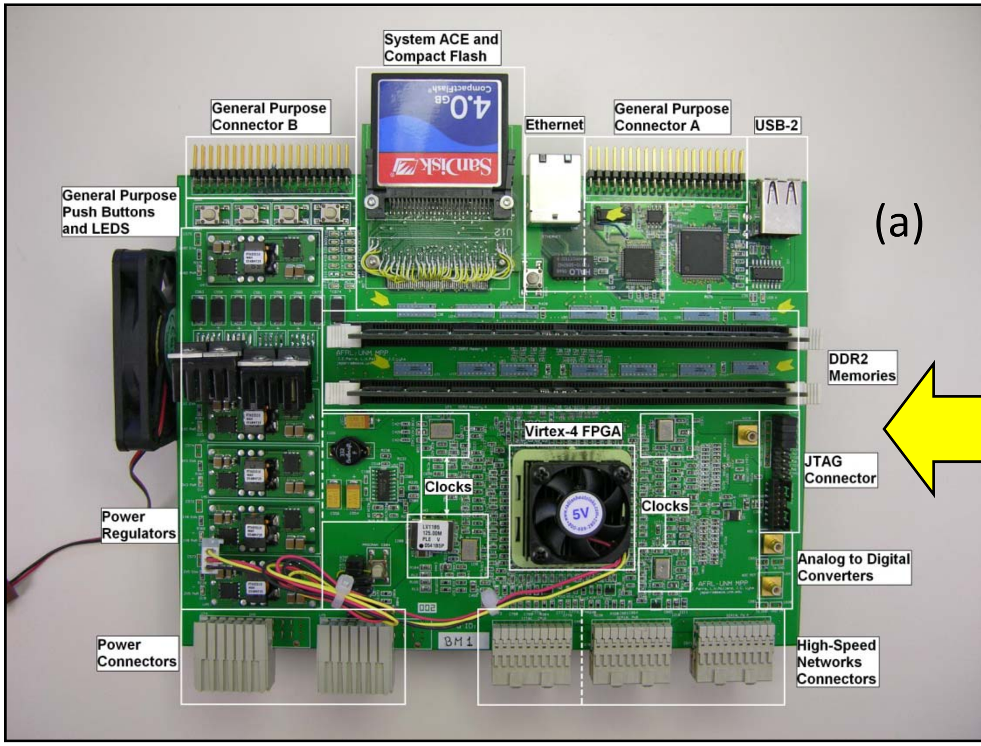
- Constant reinvention of reconfigurable computation architectures
- Fragile, proprietary link structures
- Difficult migration across heterogenous partitions

How could SPA concepts be applied?

Avoiding the "yet another reconfigurable computer" syndrome

- Nodes based on single computation device
- Ok to have heterogeneous node composition
- Regular socket and messaging infrastructure
- Not ok to have disparate socket/interface/messaging infrastructure
- Pray for the existence of adequate tools to handle amortizing code (circuitize-able) into the fabric of distributed nodes
- Use SPA-like ideas to manage the whole thing

MPP Platform to study high-bisection bandwidth reconfigurable computing architectures



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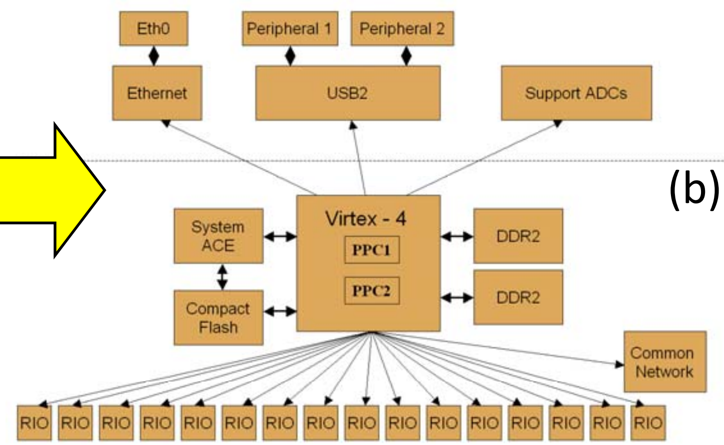

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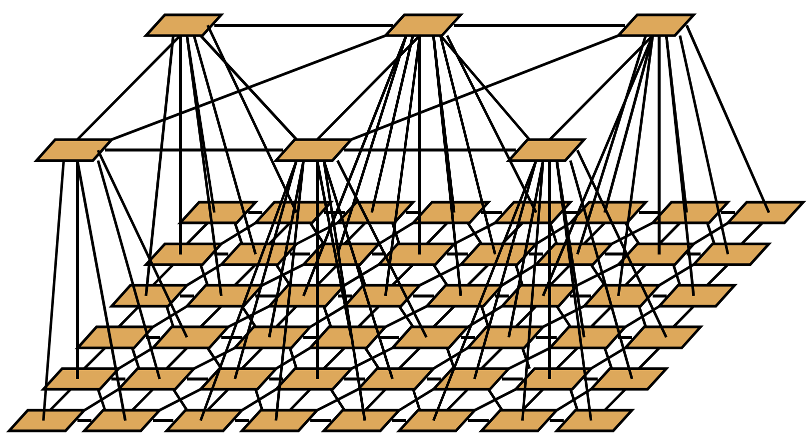
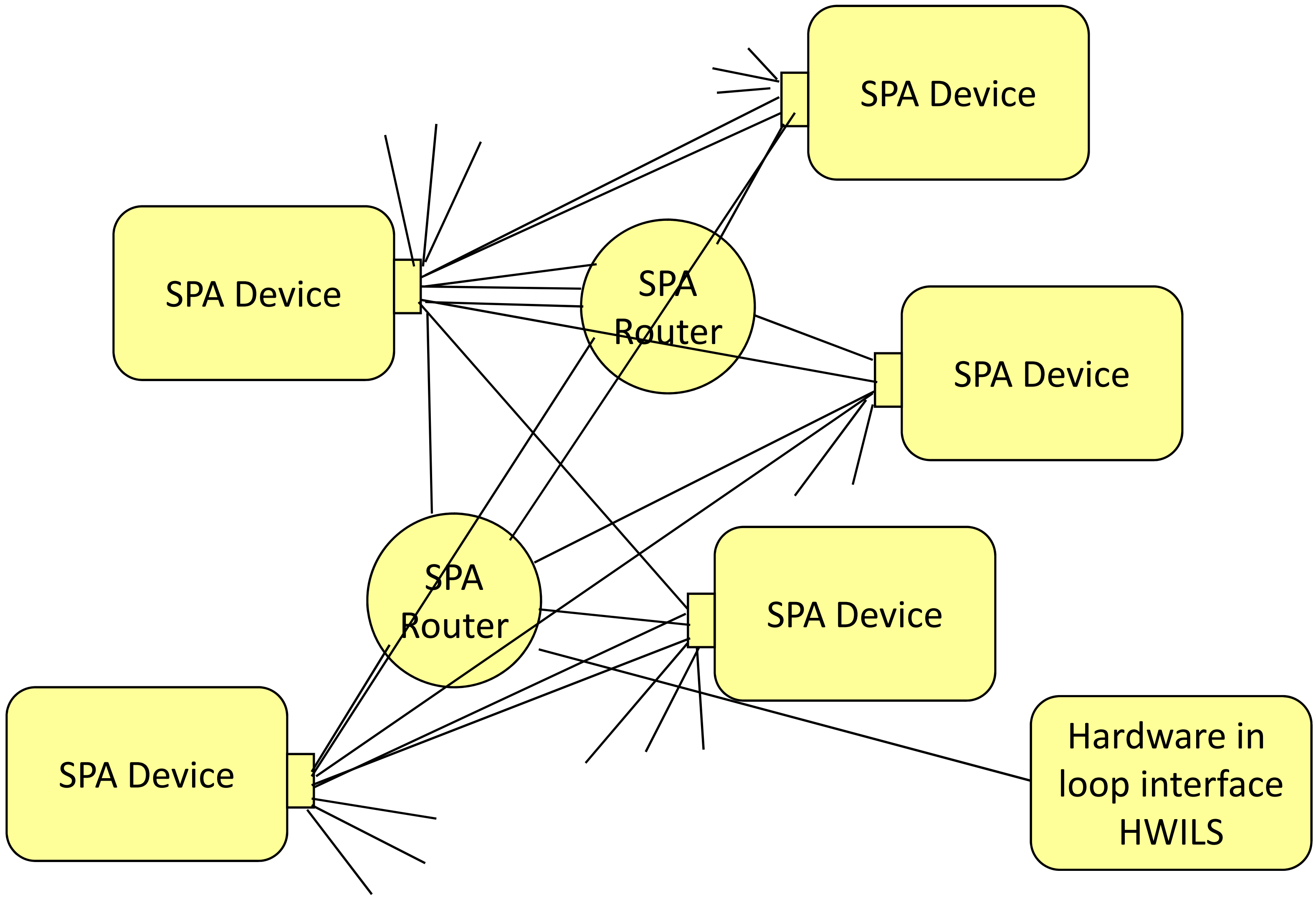
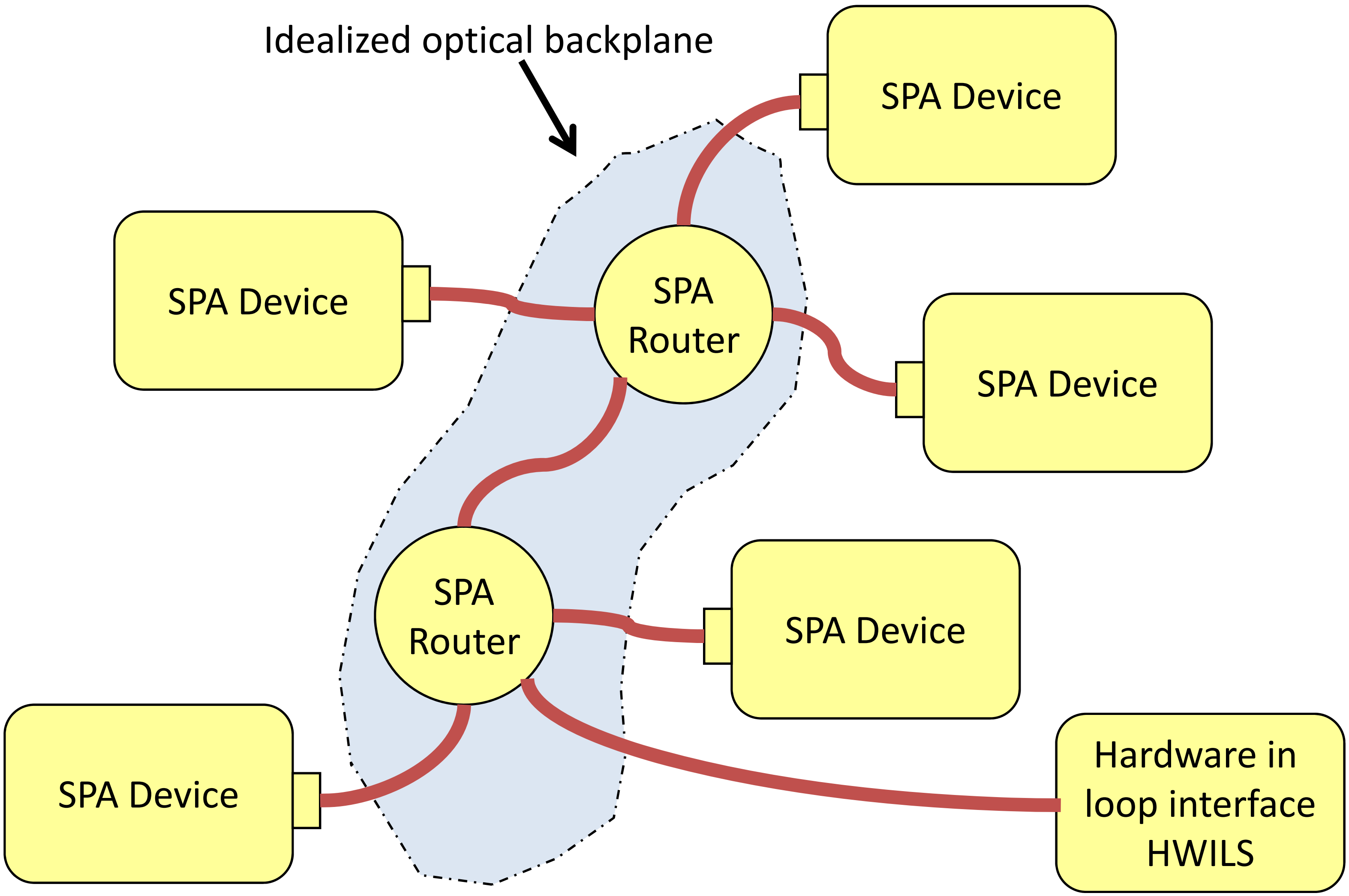


(c)

Conceptual "HPEC SPA" network without optical (multiple ports/device)



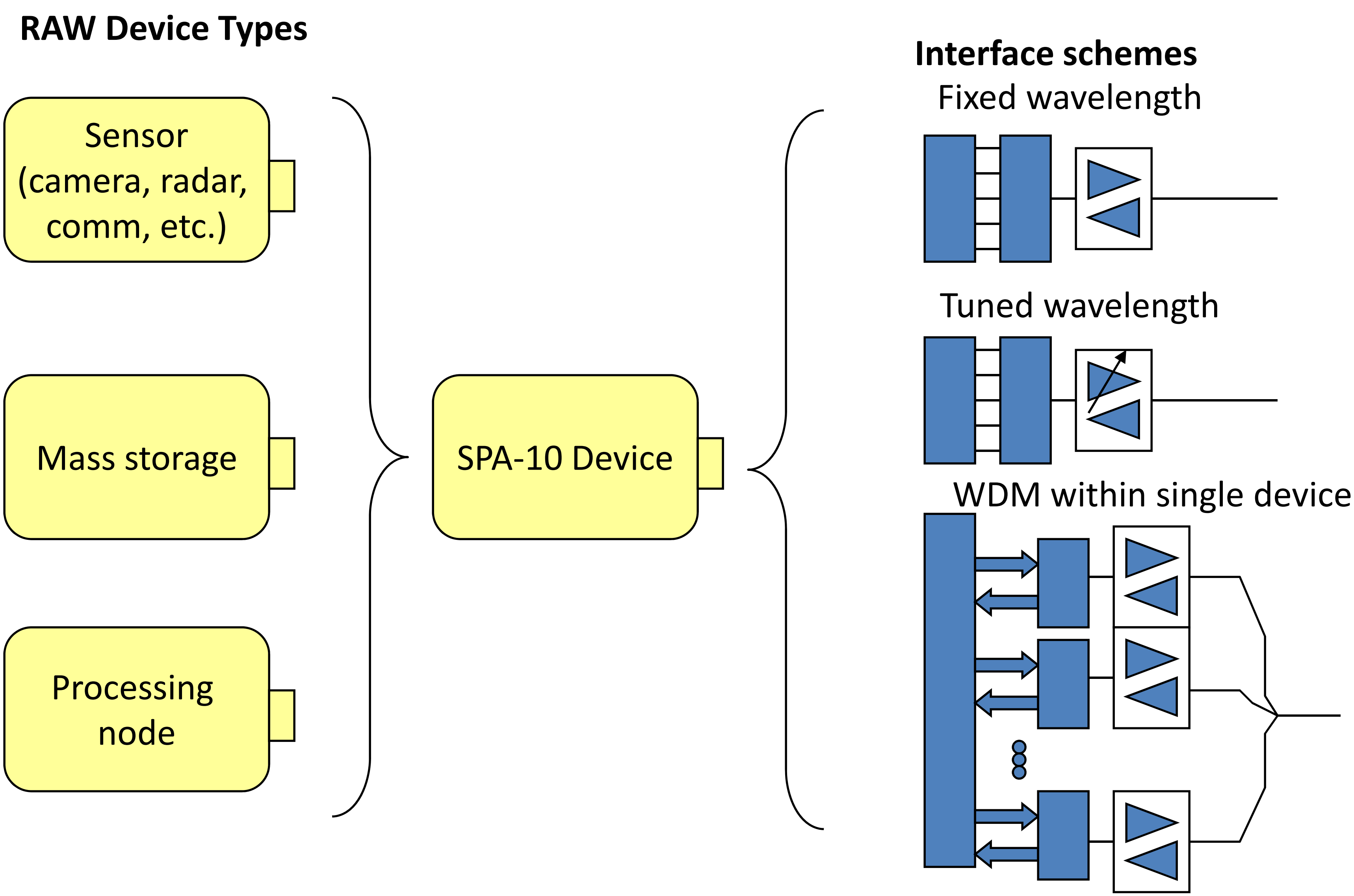
Conceptual HPEC-SPA network based on optical transport



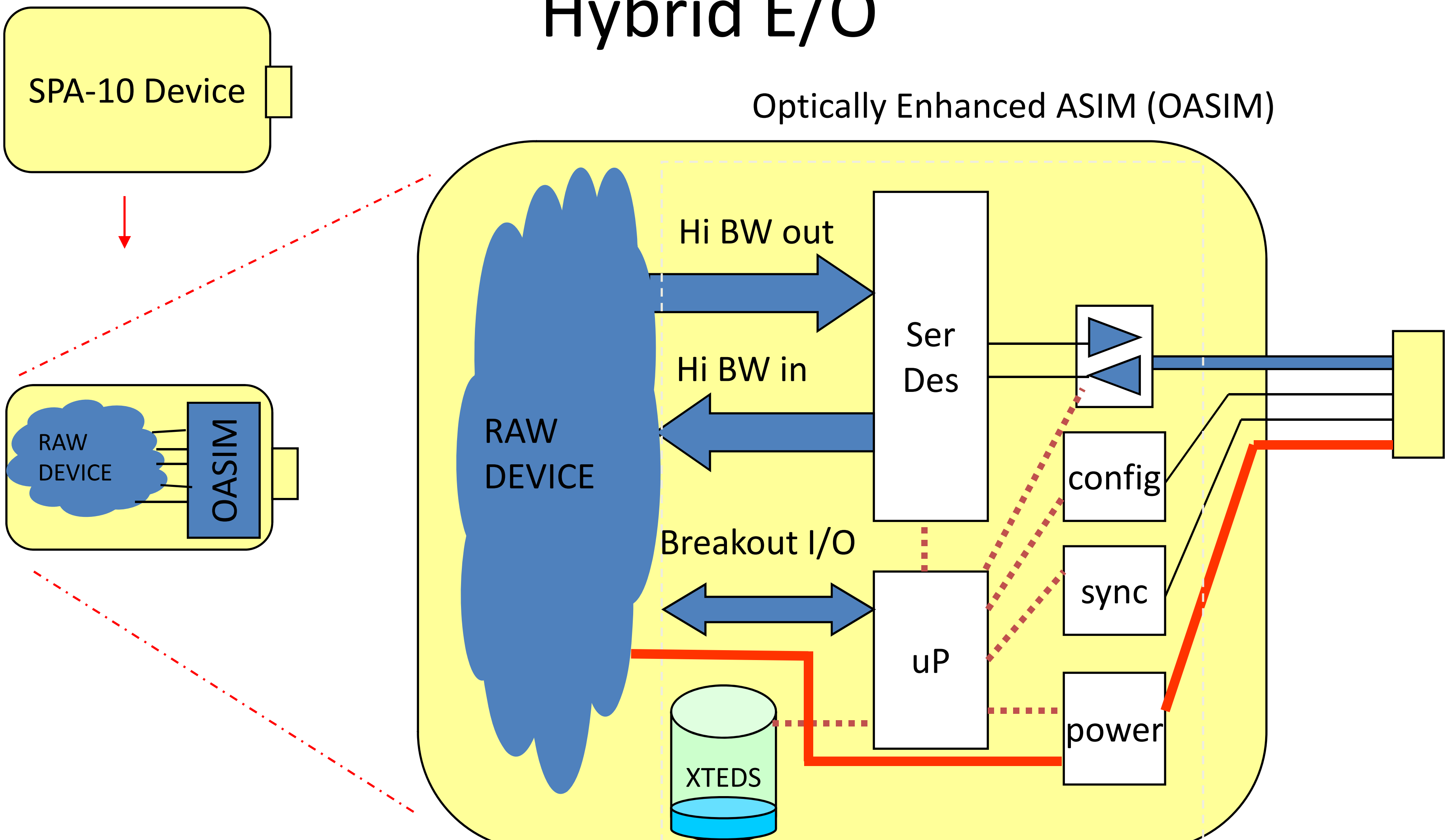
SPA-Optical “exec summary”

- Also referred to as SPA-10 (original Gbps target, just a label now)
- Expect to have properties similar to (nonscalable) SPA-S, but higher link speed
  - Use of embedded clock recovery
- Desire to support optical physical layer for data, command, synchronization
  - Allows >Tbps scaling through WDM
  - Allows flexibility in “provisioning” (i.e. assigning particular wavelengths, protocols, to particular SPA-10 ports)
  - Allows greater flexibility in managing topology, routing policies, faults

SPA-10 Device concepts



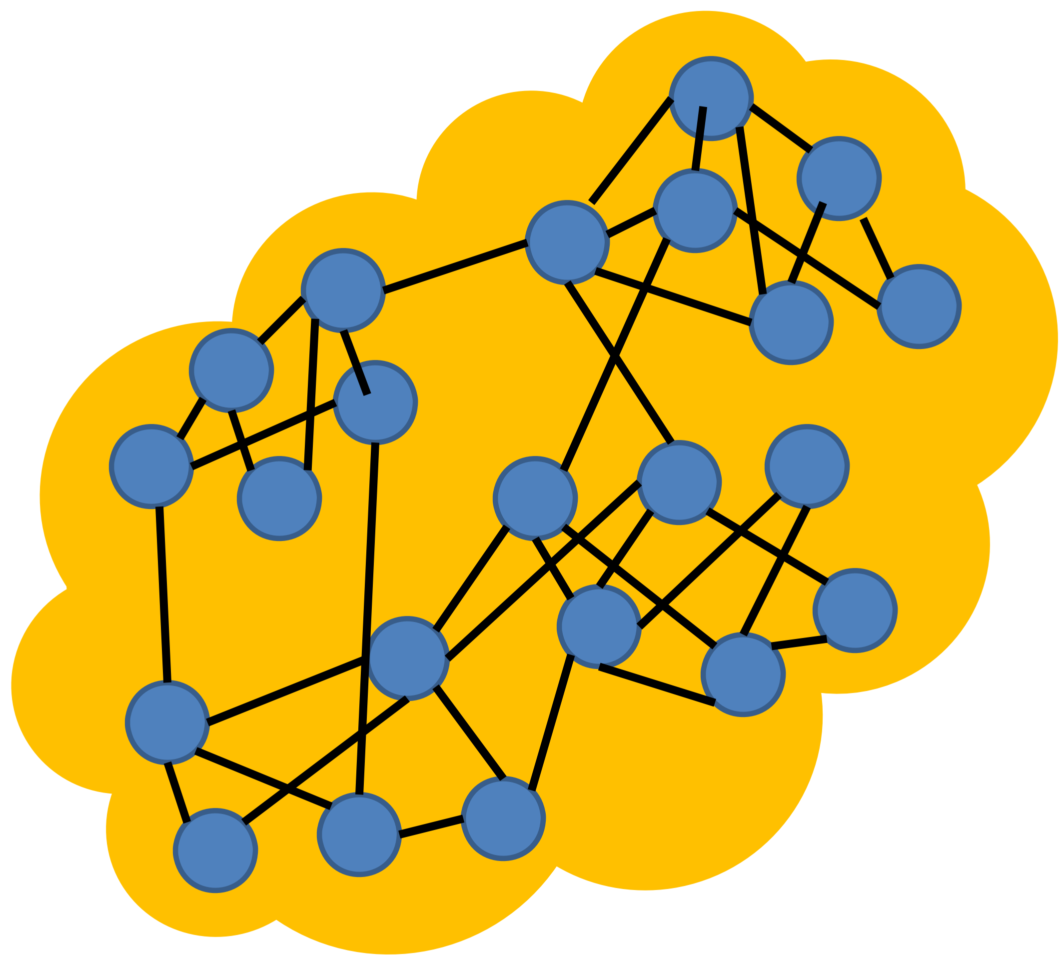
SPA-10 Possible Interface Details
Hybrid E/O



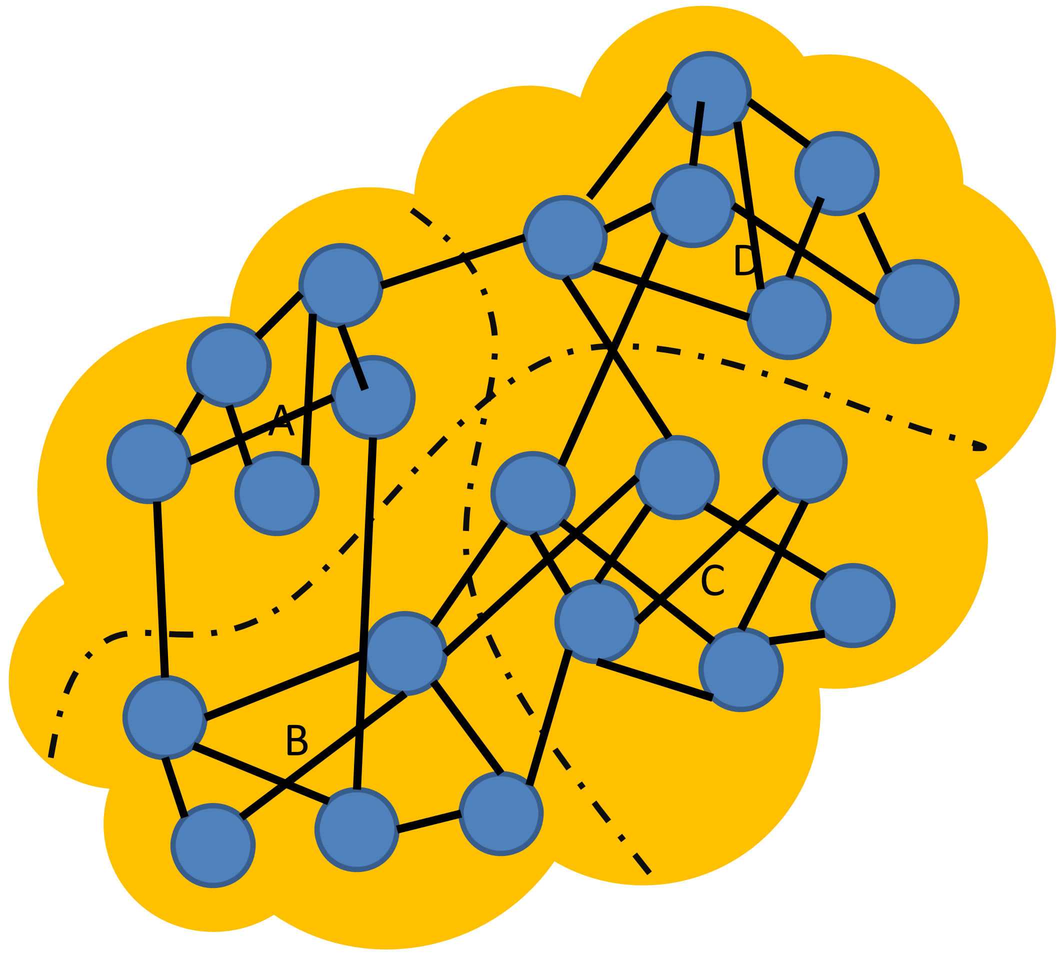
SPA Computation

- Addressing interconnection bottleneck leaves the problem of efficiently mapping computation problems to resources

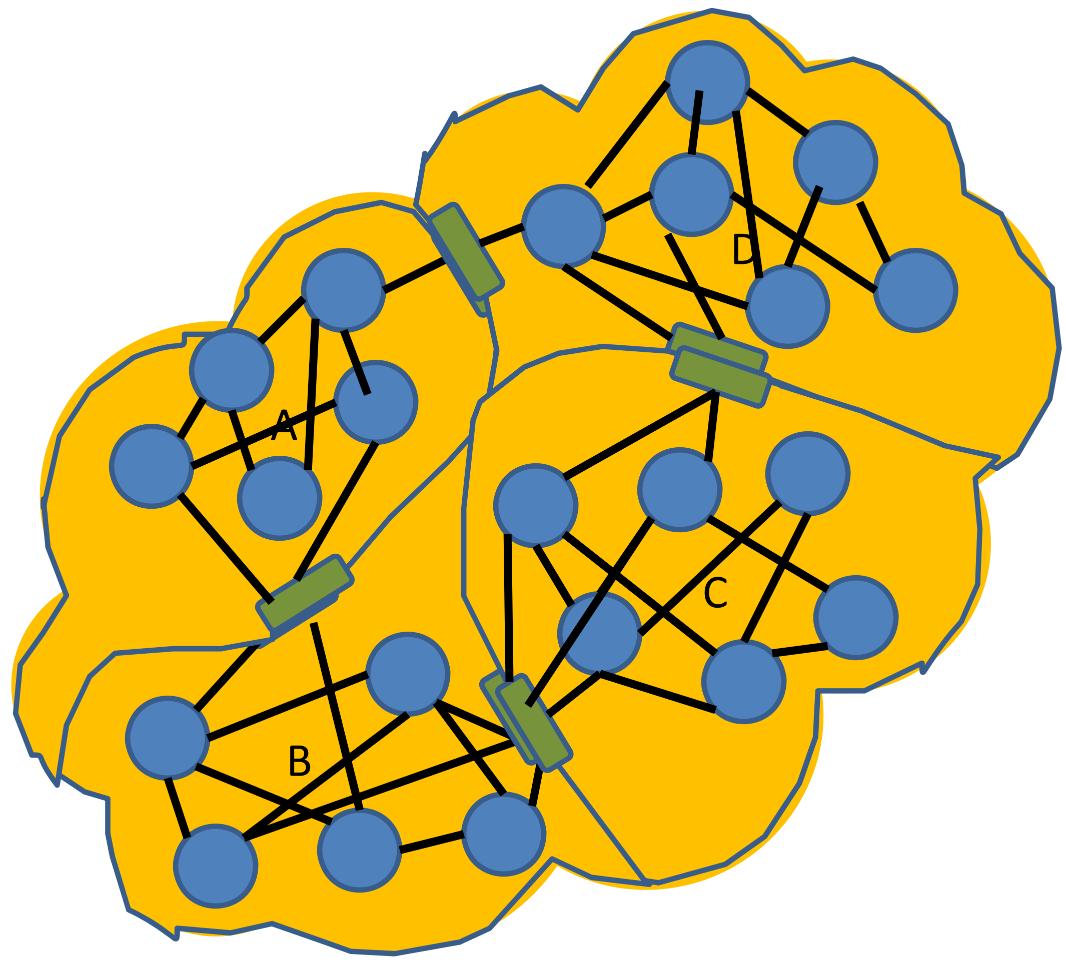
Complex (multi-FPGA board) Circuit Representation



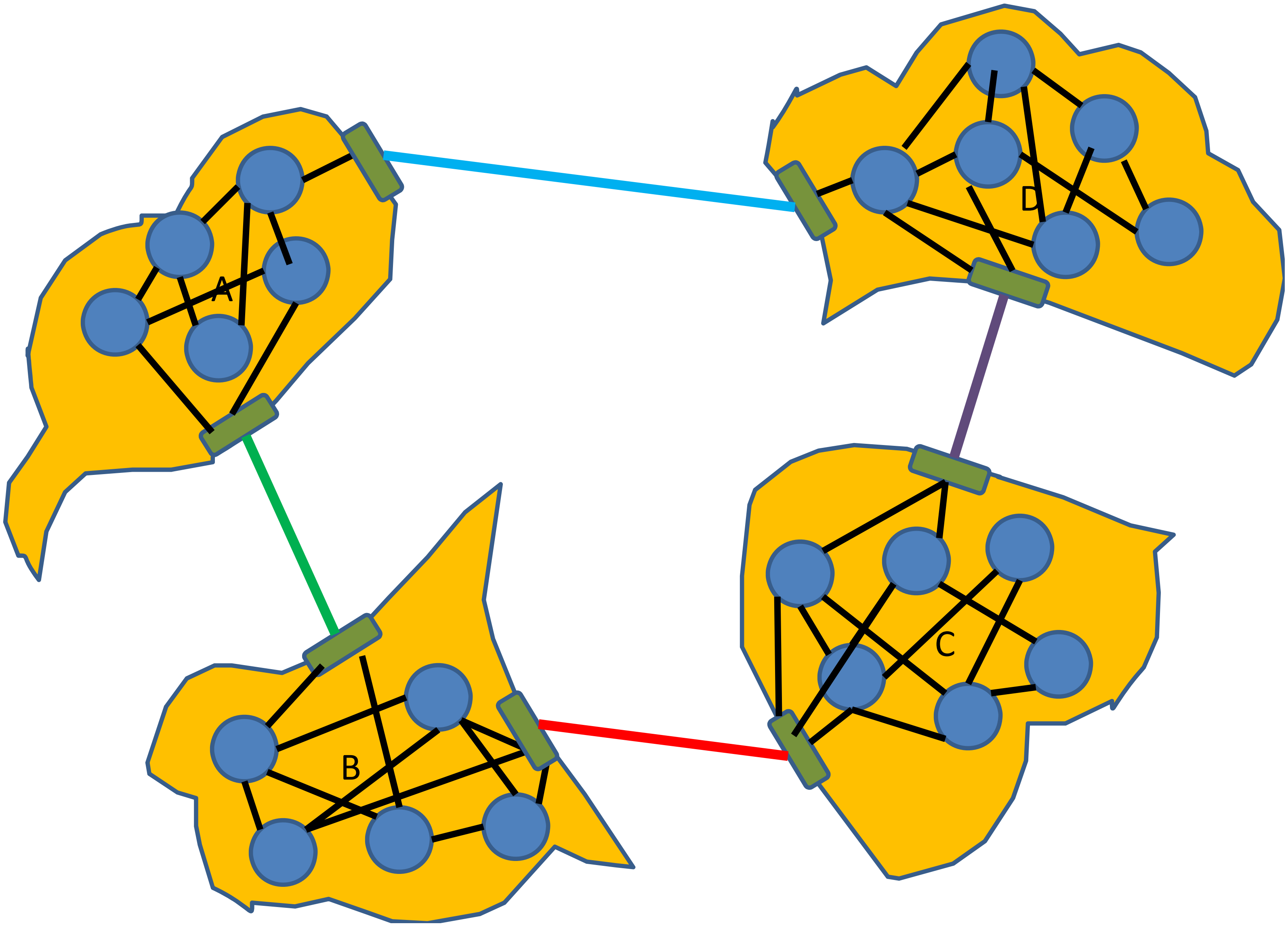
Partition into Unit-sized Portions



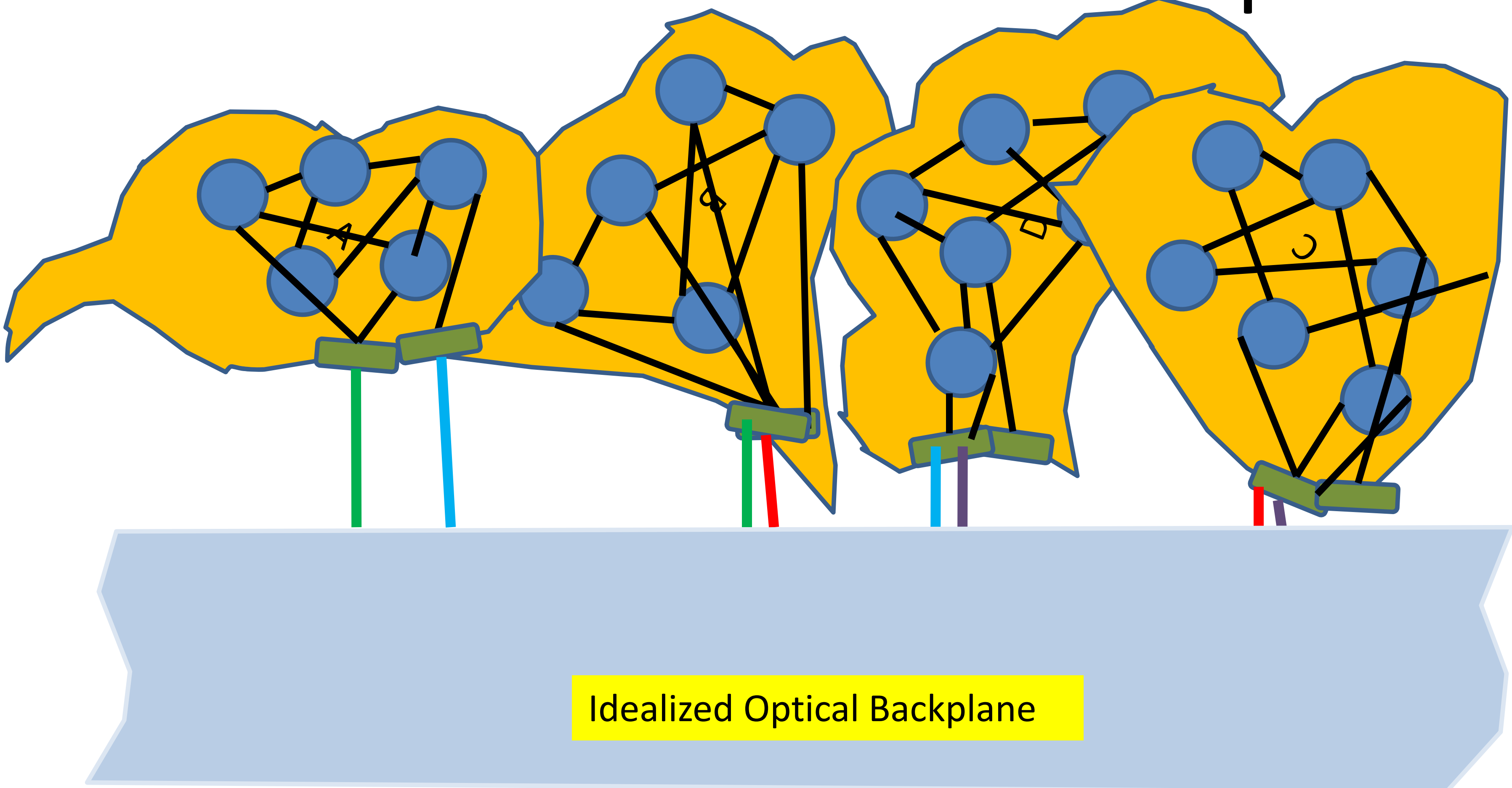
Insertion of Socketing Infrastructure



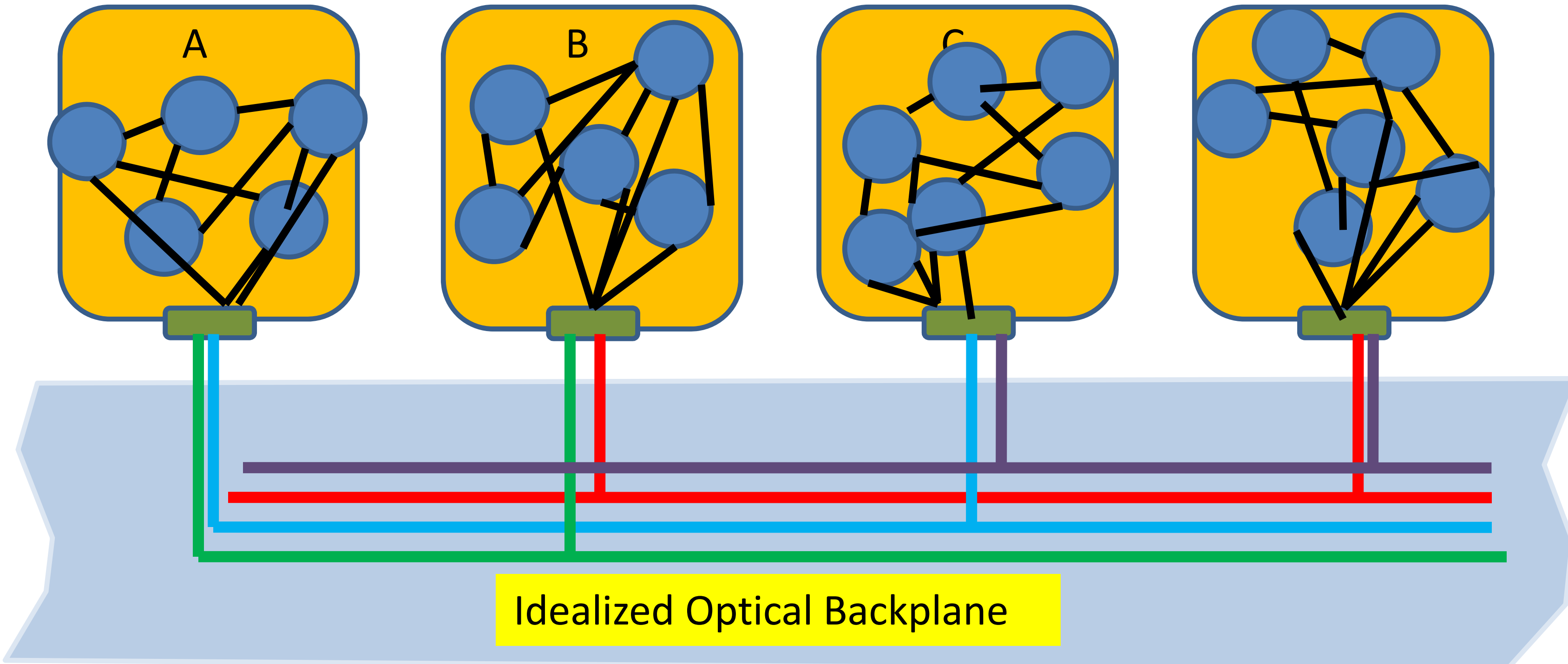
Wavelength Assignments to Sockets



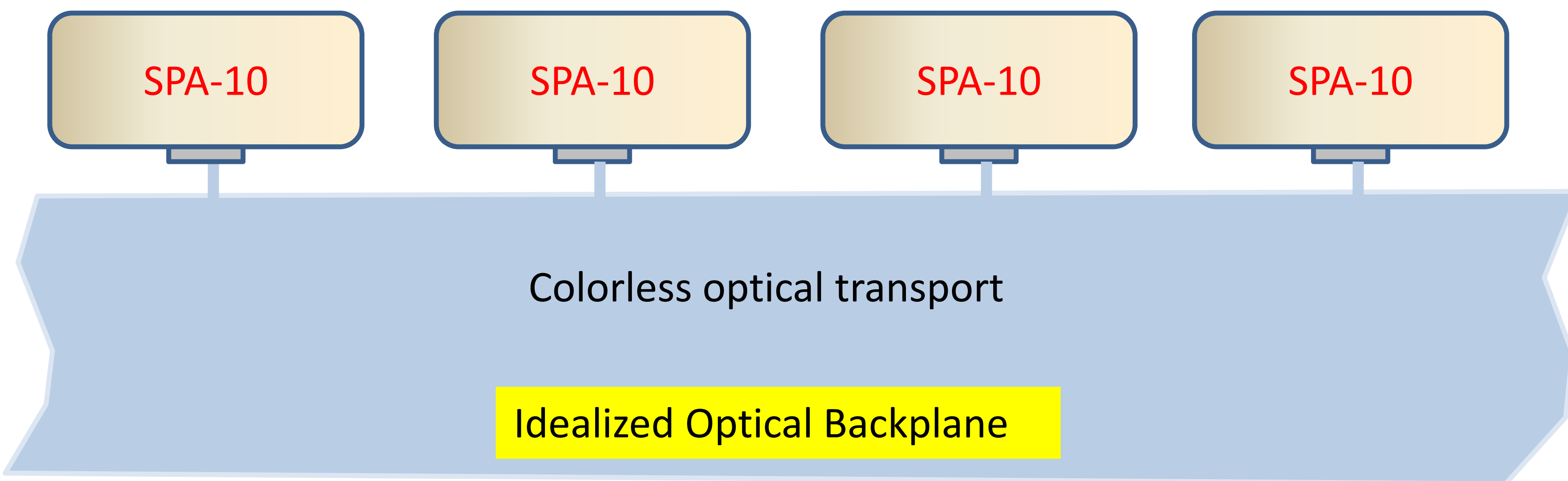
Transferral to Idealized Backplane



SPA-10 Modules



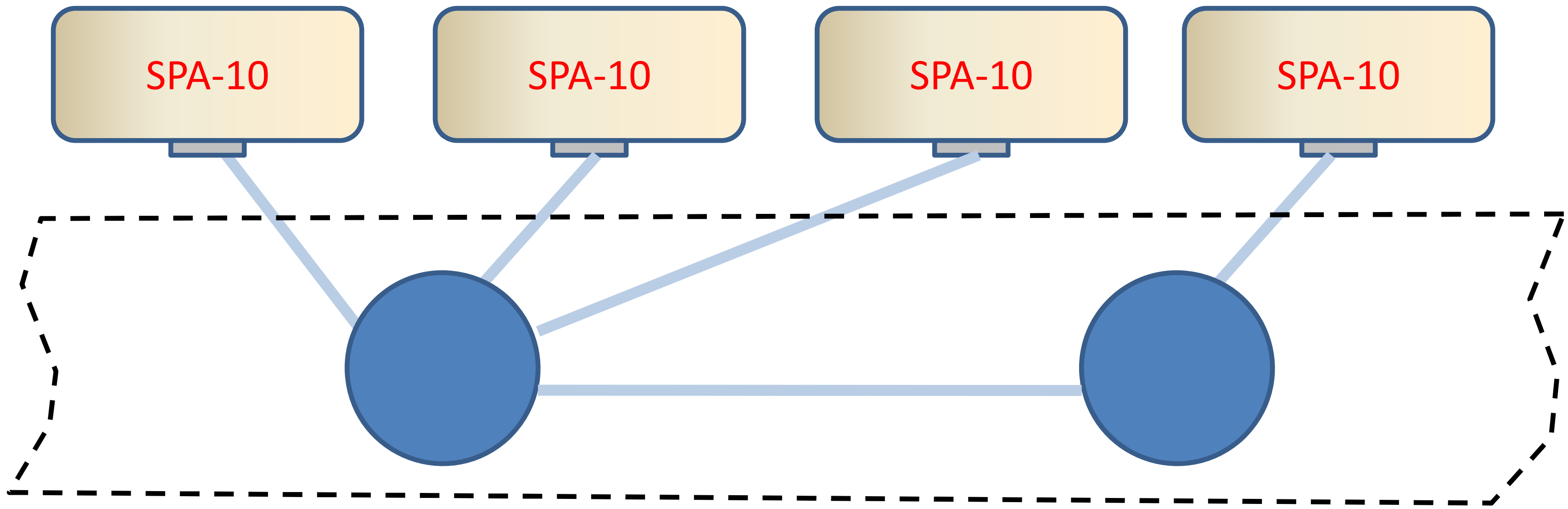
(Wavelength multiplexing drawn as spatial multiplexing for illustrative purposes)


SPA-10
SPA-10
SPA-10
SPA-10
Colorless optical transport
Idealized Optical Backplane

Idealized (vs. practical) optical backplanes

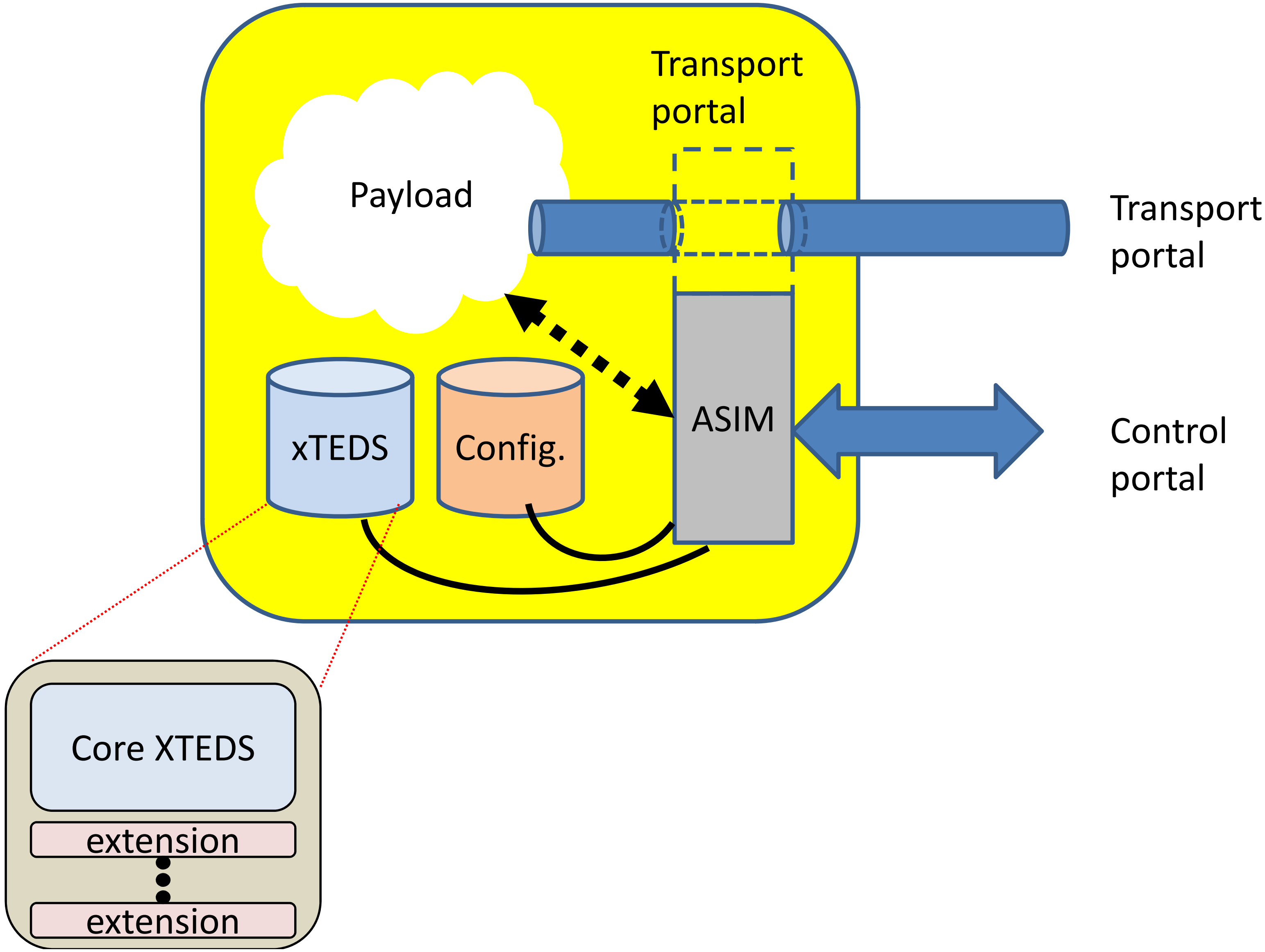
- Idealized: as described in Gilder's *Telecosm*
  - Infinite resource, every actor has own wavelength
- Practical: limited by finite resources and protocol barriers
  - Limited number of physical channels (fibers)
  - Limited number of wavelengths (CWDM,DWDM)
  - Differing channel characteristics (transceiver data rates, single-vs-multi-mode, transceiver spectral characteristics)
  - Time-slotting (time-division multiple access)
  - Protocol assignment (matching disparate OSI stacks)
  - Limitations of optical resources (e.g., outages due to time necessary to implement switch re-assignments)

Practical implementation

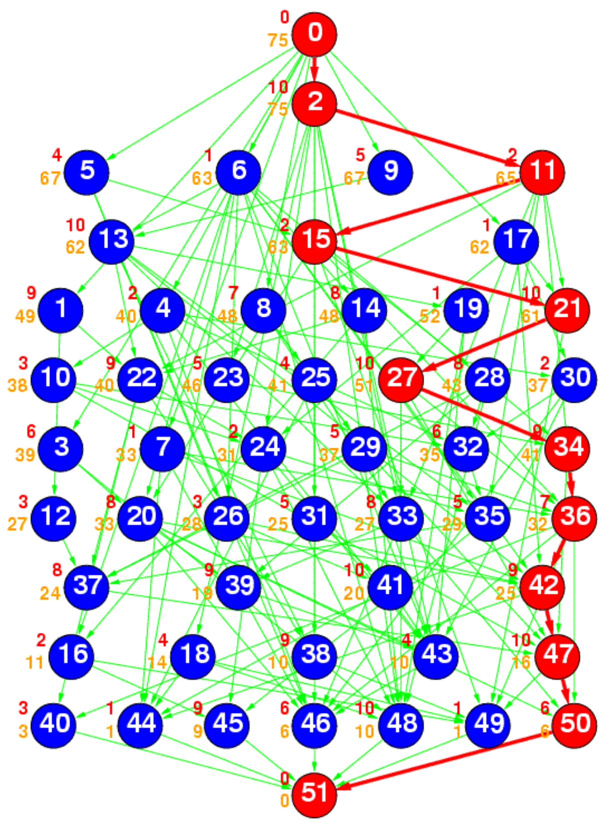


How to "LEGO-ize" Anything

(generalization of plug-and-play)



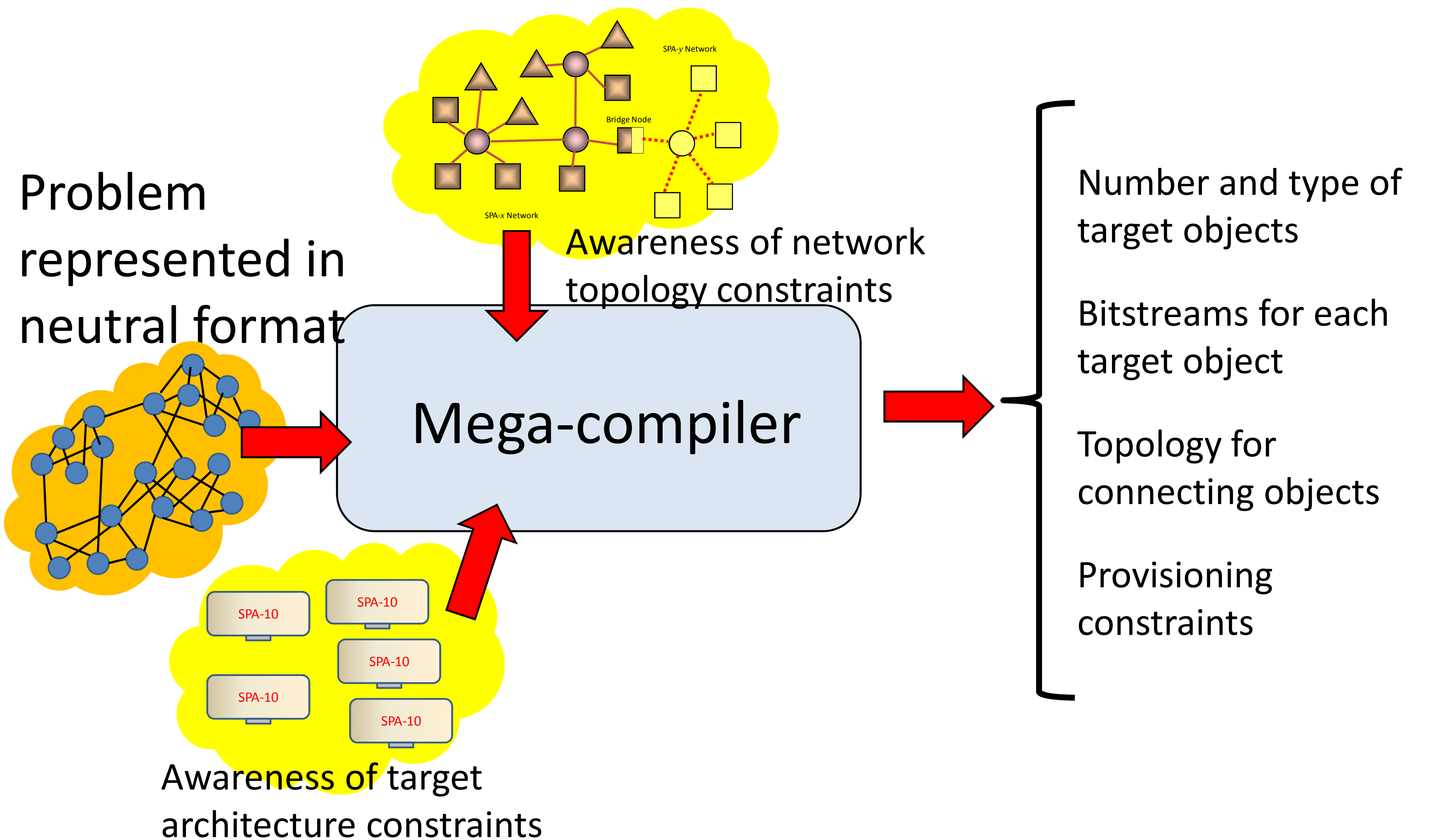
Challenges in “plug-and-play” provisioning



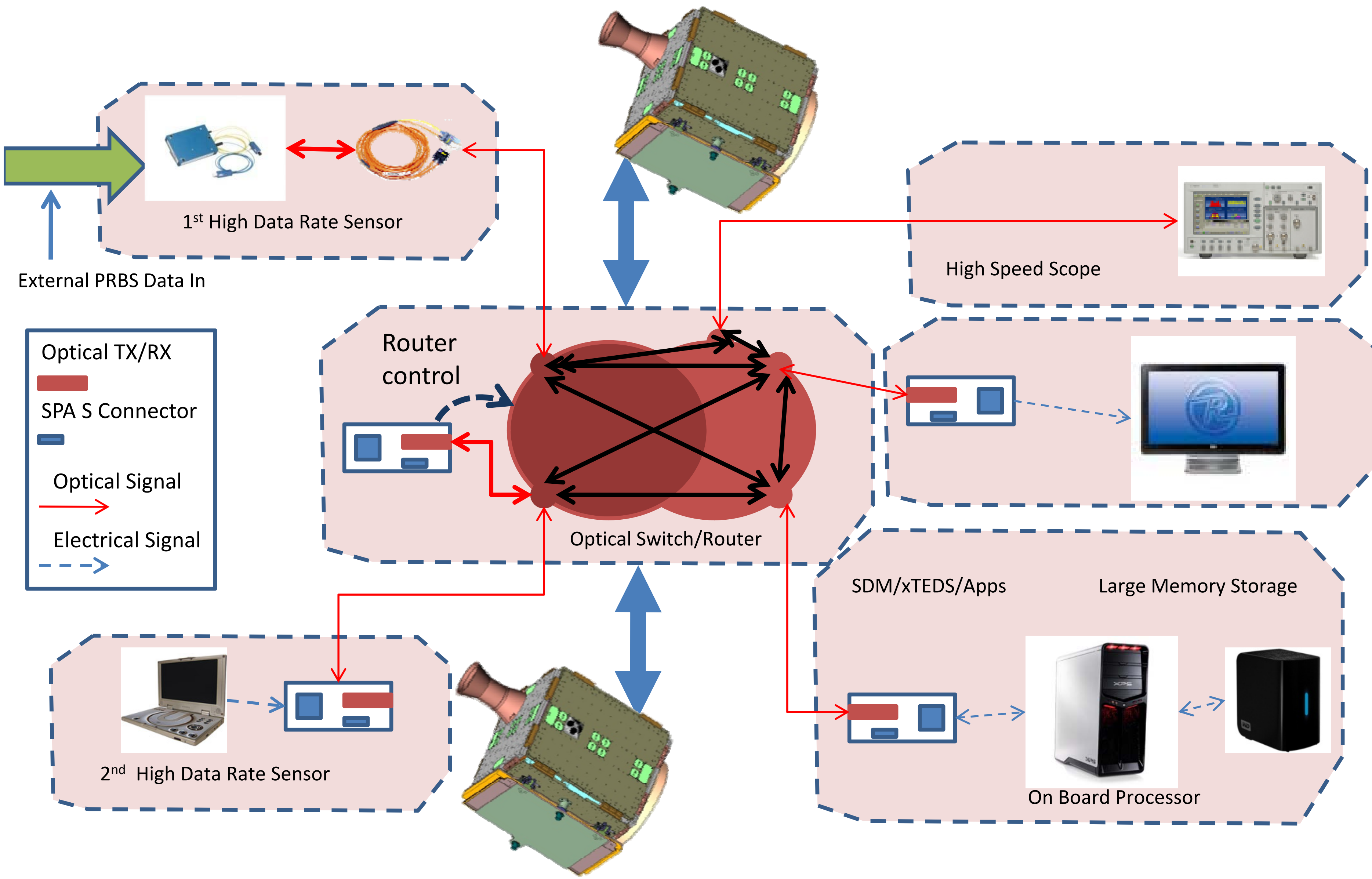
Source:
http://www.kasahara.elec.waseda.ac.jp/schedule/

- Mapping algorithms into a variety of node types
  - FPGA-based
  - Single/multicore processors
- Coordinating socketing
  - Messaging protocol
  - Establishing finite fabric resource allocation effectively with tolerable gaps in time due to transitions in provisioned configurations

Advent of Megacompilers?



In-house SPA-O R&D Testbed (plan)



Summary

- Space plug-and-play (SPA) continues to gain momentum (completion of PnPSat 1, start of PnPSat 2, TacSat 5, ORS Chileworks, CubeFlow, standardization)
- SPA-Optical / SPA-10 represents a collection of concepts to extend SPA to high-performance embedded computation
- Early work on SPA-Optical testbed underway at AFRL (Kirtland AFB)