
# Resilient Space-based Software Defined Networks

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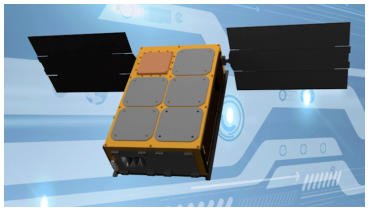
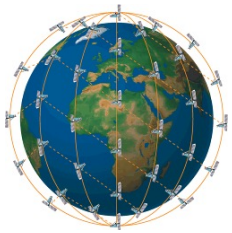
***Integrity ★ Service ★ Excellence***

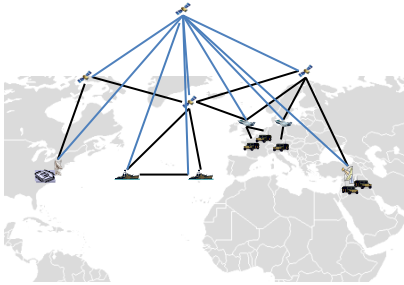
# Future Space Communications (FSC)

- Vision
  - Give warfighters resilient and ambient connectivity (enabled with space technology)



- How Communications Should Work
  - "**Always on**" – there when you need it
  - "**Path agnostic**" – exploit any all links and pathways
  - "**Automagic**" – sort connectivity autonomously for human /machine clients, apps
  - **Secure** – in a fluent, natural way – make and break virtual networks on demand cryptographically solid isolation ("polychromatic" – multi-level security) and cyber-secure (minimize attack surfaces)
  - **Invisible** – Low probability of intercept (LPI) – elastically trade bandwidth and non-detection

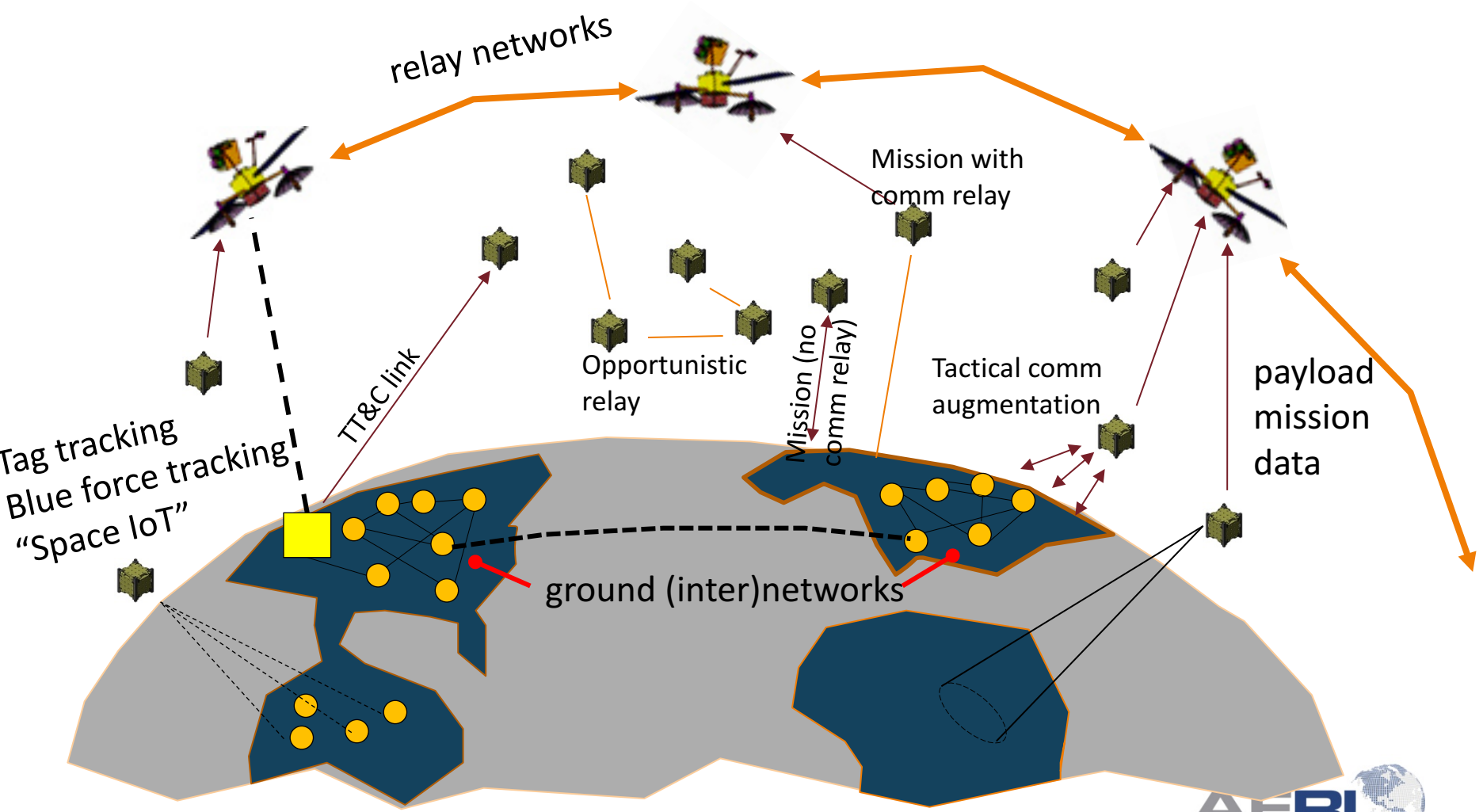




**Goal:** Ambient connectivity

AFRL

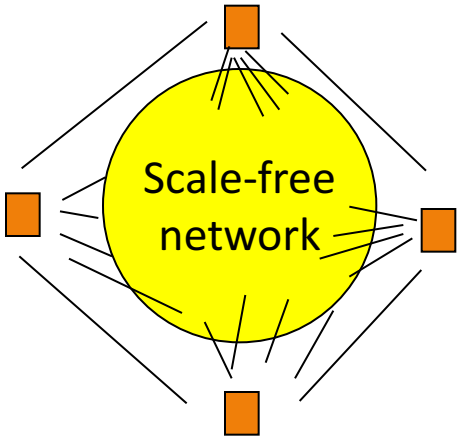
# Desired Use Cases

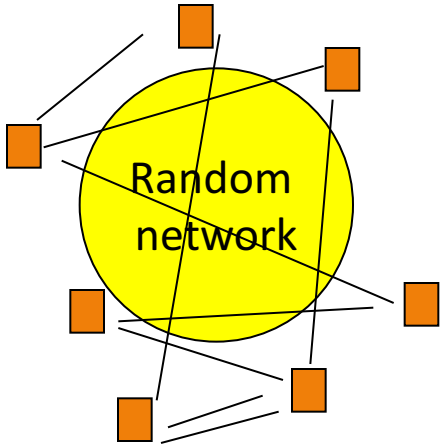


# Achieving Ambient Connectivity

- Self-forming networks (topology agnostic)
- Every platform can be a contributing node
- Every physical layer (rf, optical) can be a contributing link
- Every node is potentially an opportunistic relay (with configurable “opt in/out” settings)
- Network sessions are virtualized over the actual physical network on-demand

# A Tale of Two Graph Models




**Scale-free networks (e.g. Power-Law distribution)**

- Few super-big pipes
- Lots of little pipes
- Vulnerable to attacks on biggest pipes

**Random networks (e.g. Erdos-Renya)**

- Egalitarian, uniform node-degree hubs (may relax this constraint)
- No per se weakest links
- Nodes and edges connected with high probability (percolation)

Recommended reading: A. Lazlo-Barabasi, *Linked*

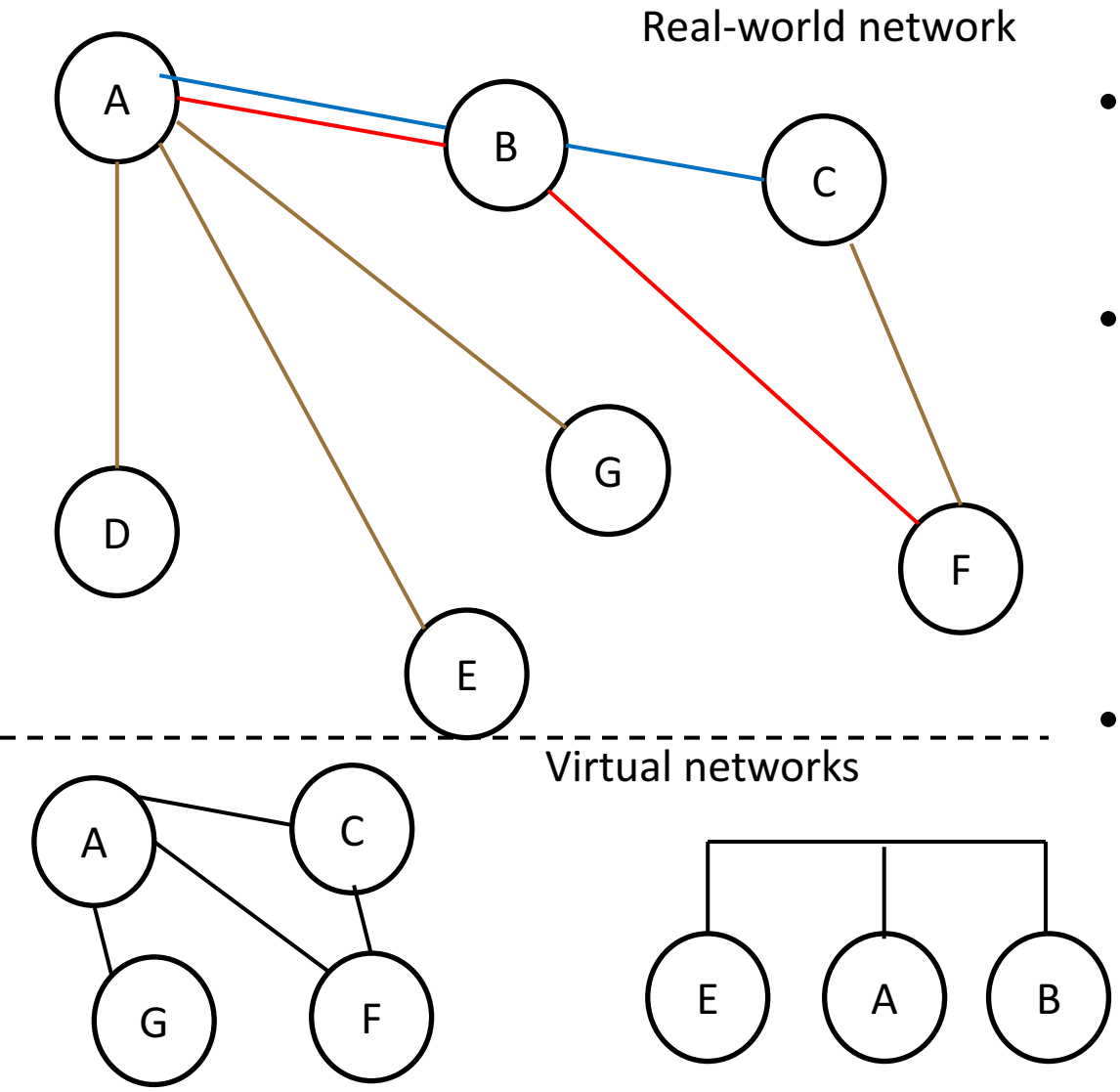
# Resilience and “GNATS”

- One path to achieving resilience is to exploit the Erdos-Renya random graph by enriching space with as many spacecraft as possible (cubesats, big sats, ..)
- The concept of a flexible, self-hosting network hub with arbitrary mixture of physical layers we term a Global Network Access Terminal (GNAT)
- A satellite with a GNAT is a GNAT satellite (GNATS)
- Like the annoying insects, “gnats” are easy to kill individually, but hard as an ensemble – resilience!

# Software Defined Networks in Contested Environments

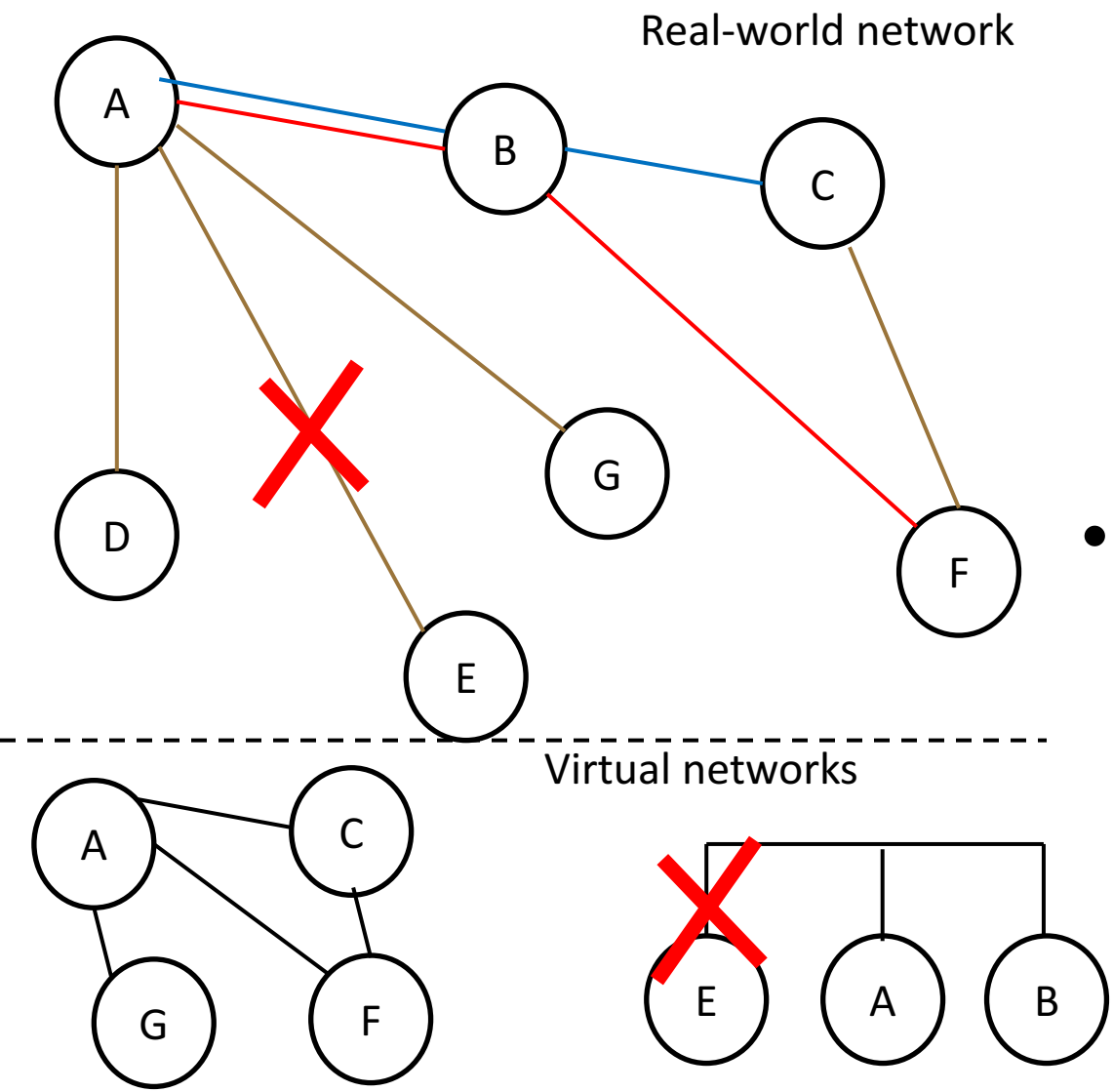
- Building a network of connected links is one thing, harnessing it effectively is another
- Consider concepts from software-defined networks (SDN) and network functional virtualization (NFV) with a couple of twists:
  - Heterogeneous nodes and edges
  - Design for resiliency to failures

# Network Graphs – Supply and Demand




- Real-world connectivity is a supply graph
- We create a set of virtual networks on demand (demand graph)
- They "seem real" in every significant way
  - Have defined Quality of Service (QoS)
  - Cryptographically isolated (seem air-gapped)
- They work only so long as the "real-world" networks have adequate connectivity and QoS

# Contested environment

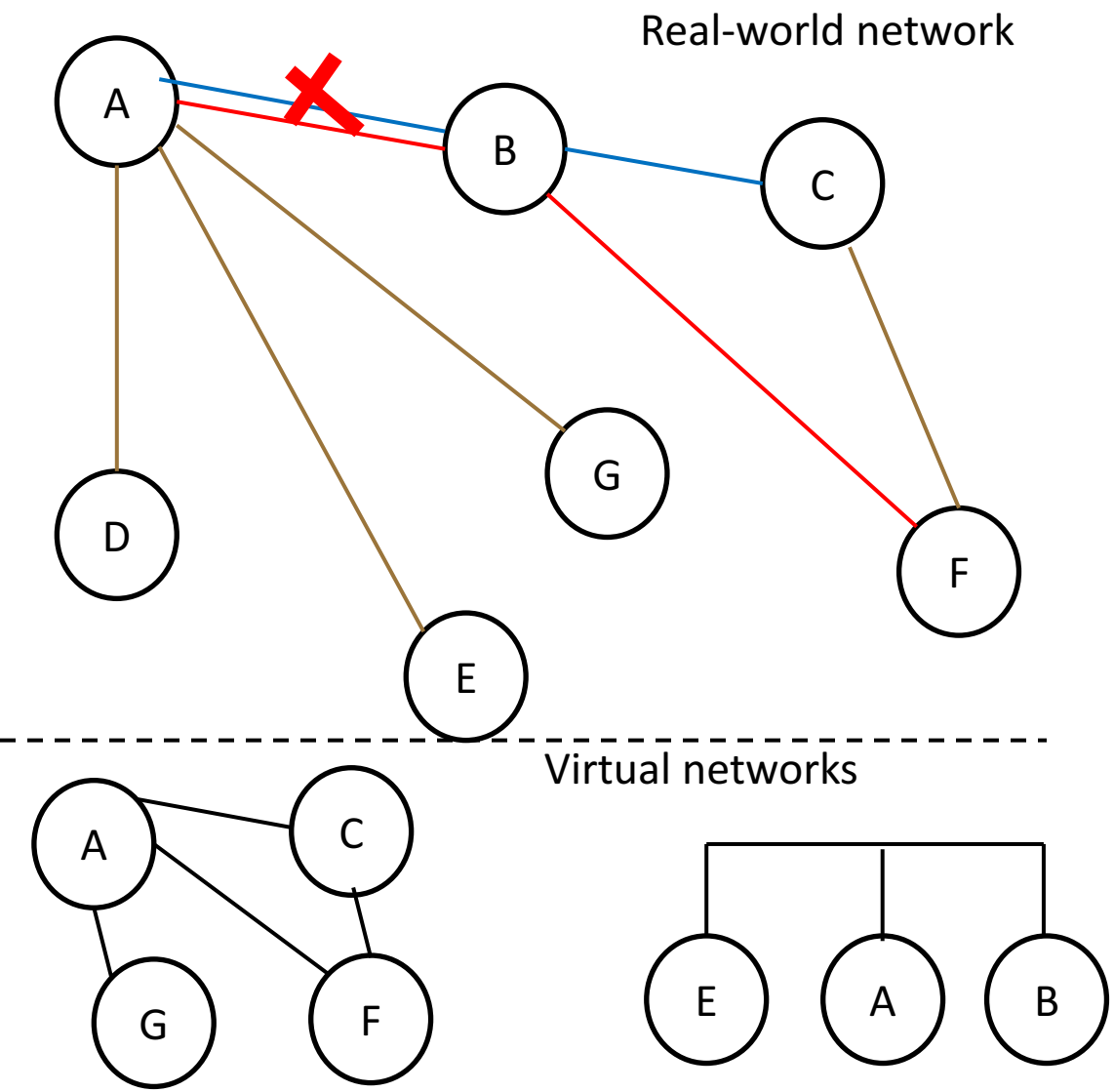



- One or more links might break due to jamming, weather, or violation of QoS (not enough bandwidth)
- Example, we lost S-band link and it was the only connection, so all VNs involving that link are broken

# What is Different in SDNs for Contested Environments

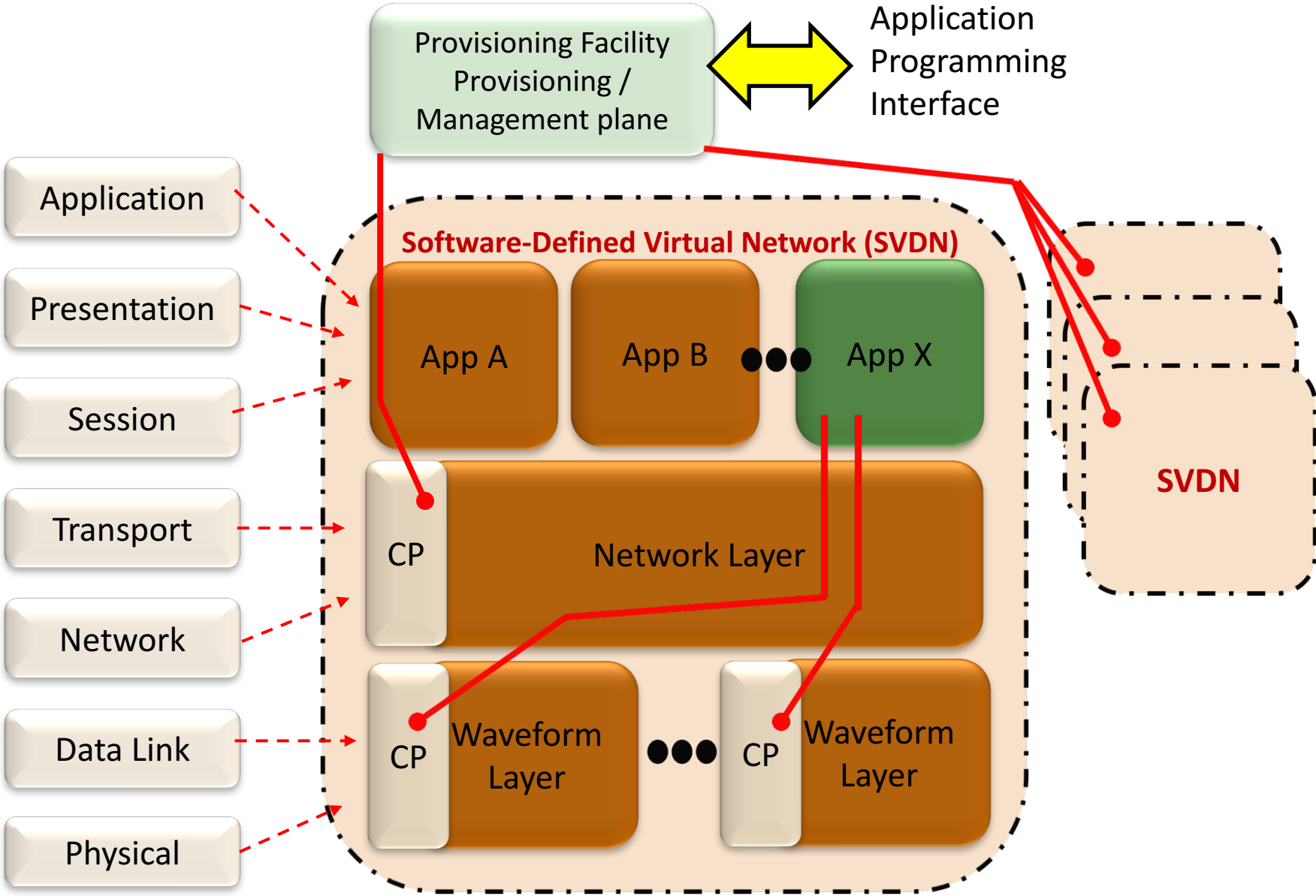
- far more dynamic: complex evolving geometric relationships, links may be attacked or impaired, nodes may be destroyed,
- disparate/heterogeneous node and link (wired, RF, optical) structure;
- flexible and distributed provisioning (it may be necessary to allow hierarchical delegation of provisioning and control policies, processes);
- diverse QoS with a focus on the best effort can be provided in a contested area (from disruption tolerant to real-time)
- QoE (Quality of Experience) for the user's mission planning in a contested area;
- egalitarian (mostly) network nodes (not necessarily distinguished masters)

# Contested environment example2

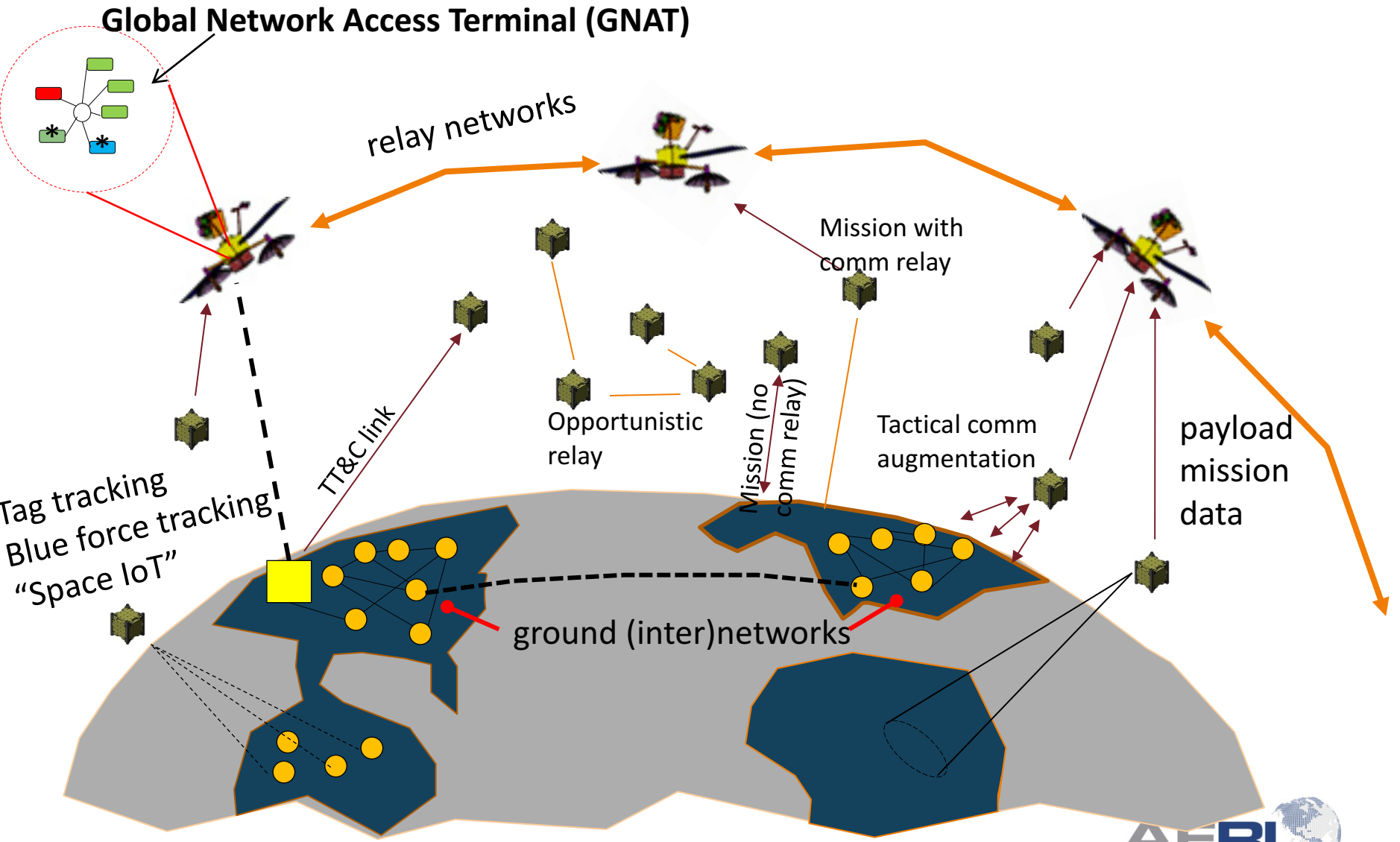



- Ka-band broke (A<->B) but the optical link didn't
- Therefore, the VNs can maintain connectivity
- Call this idea "SDN in contested environments"
- Seek the purist representation of networks in terms of flows, data (data forwarding) plane, control plane, management plane

# Revisiting Open Systems Interconnect Model



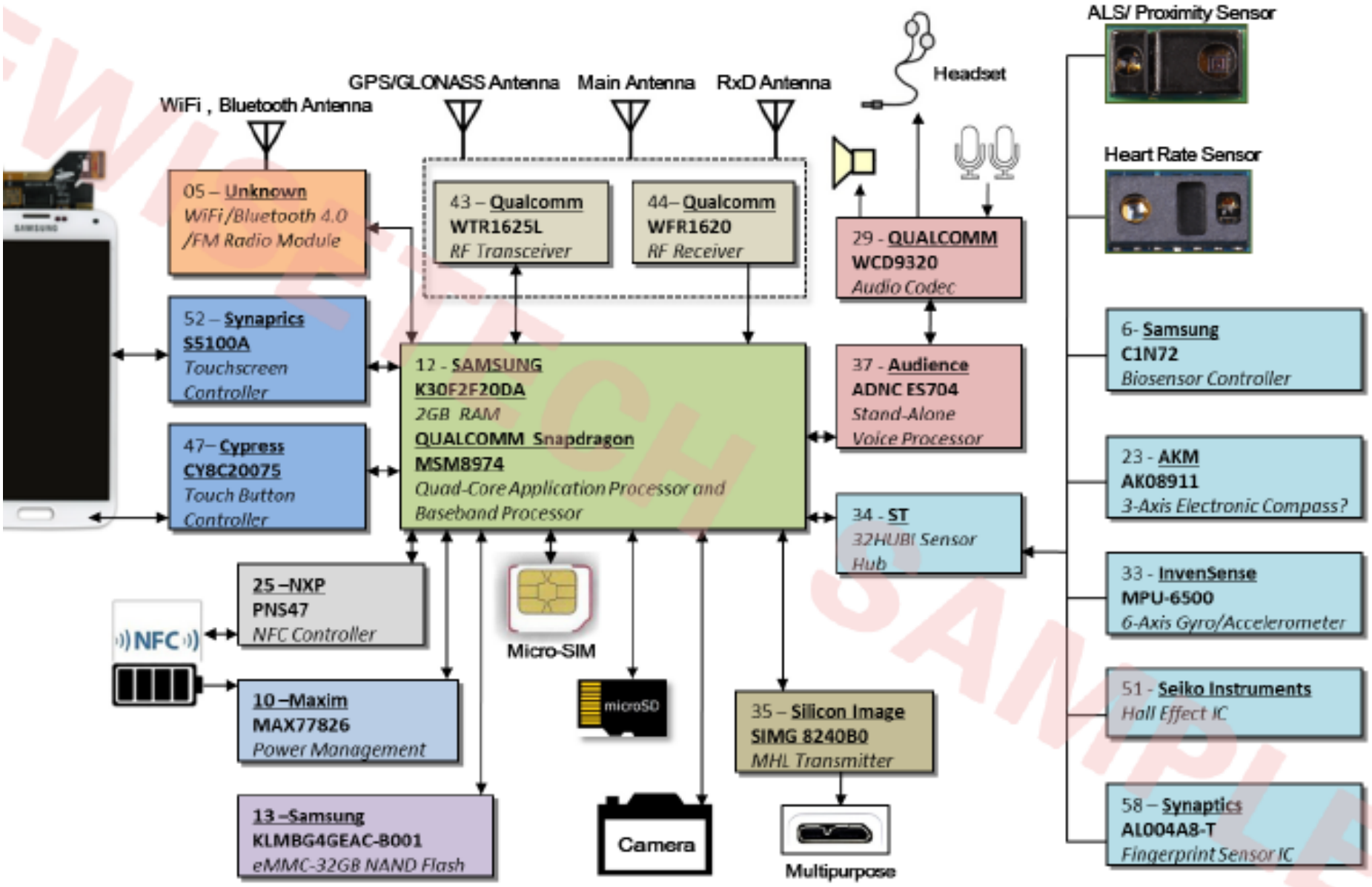
# Desired Use Cases
# "Smartphones for Space"



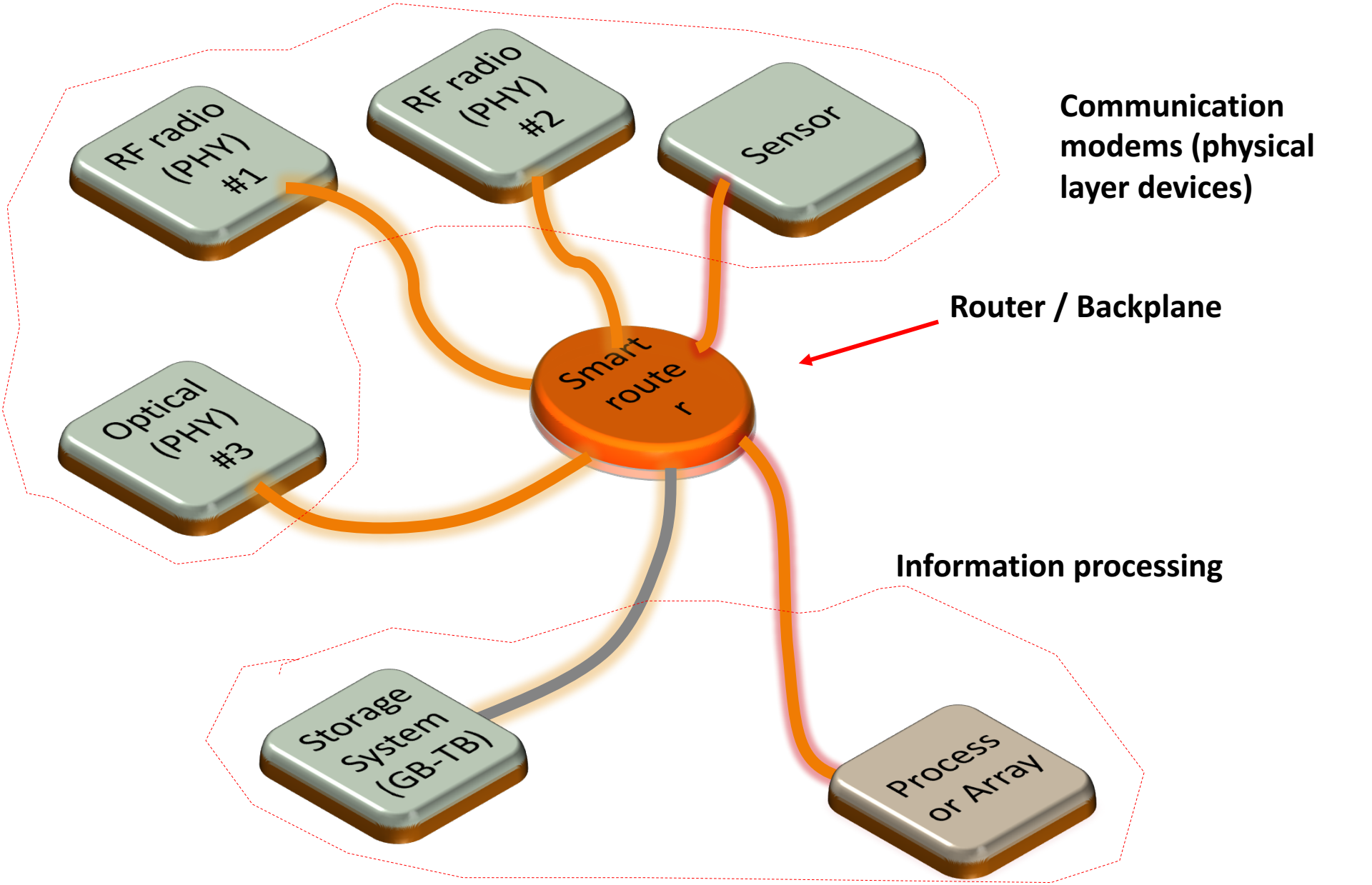
# GNAT:
# A Smartphone for Space

- We have smartphones
- Spacecraft do not
- The phones they have are very limited
- We can change that

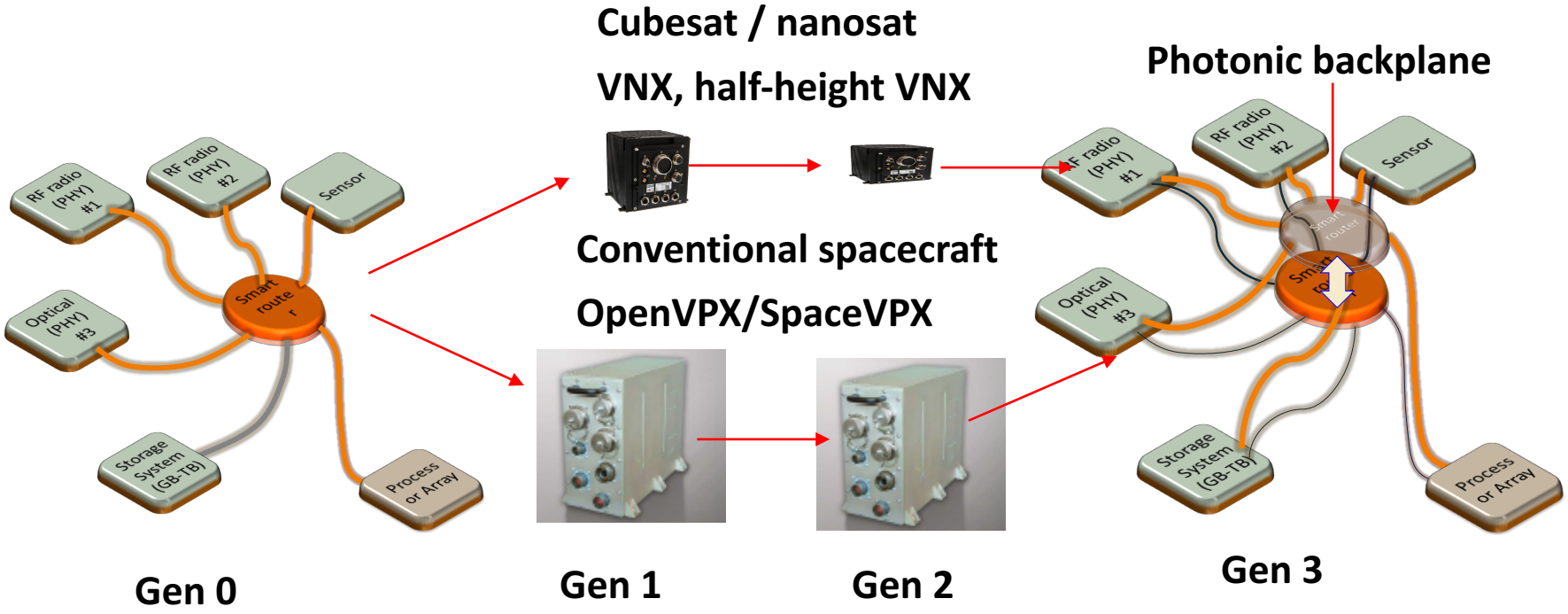
# Example Real World Smartphone - Samsung Galaxy S5



# GNAT /Smart-Phone Abstraction
## (Information Convergence Device)



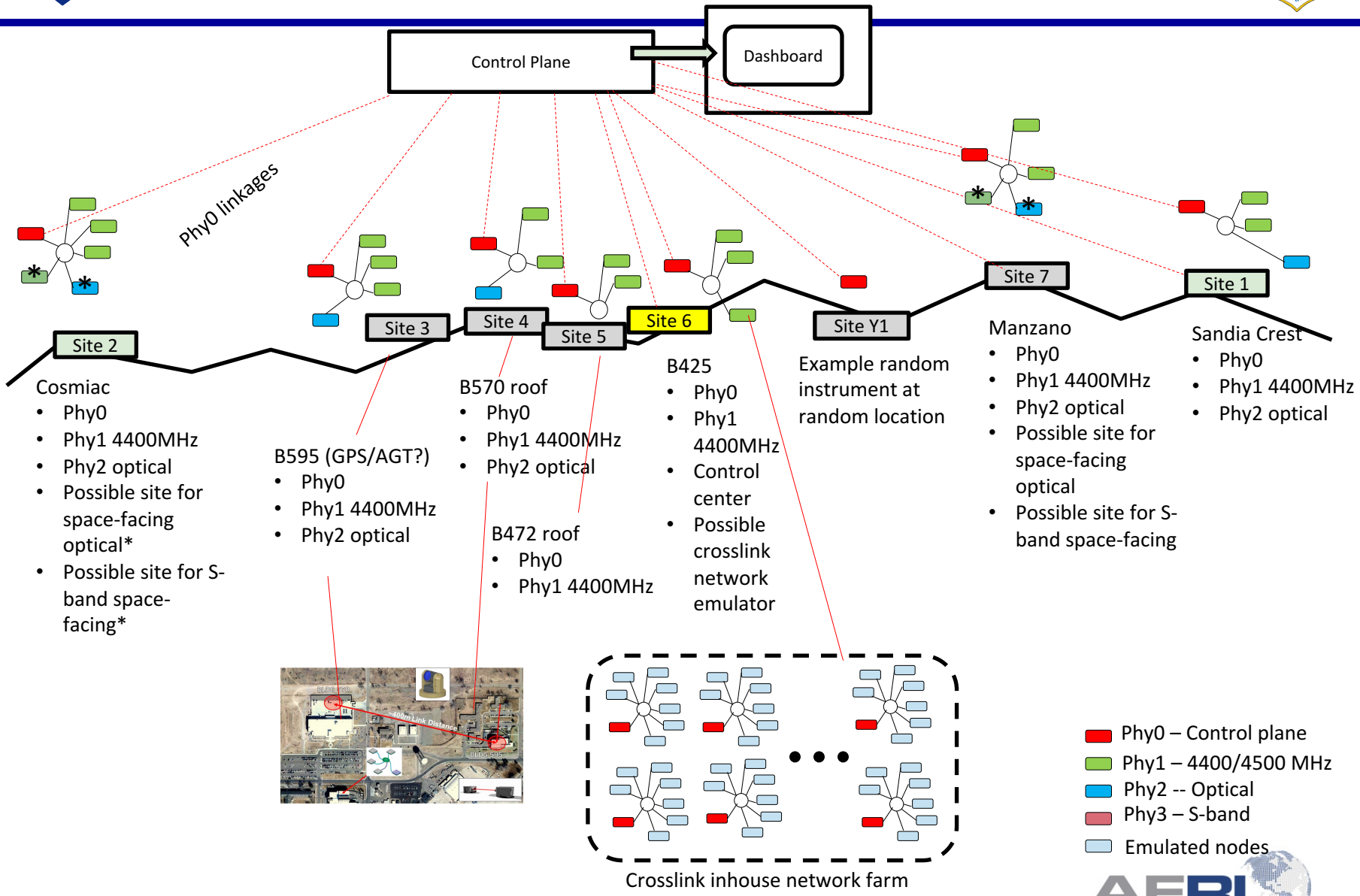
# A Possible “GNAT Roadmap”




| Feature | Gen0 | Gen1 | Gen2 | Gen3 |
|---|---|---|---|---|
| BackPlane | Custom/OEM | SpaceVPX (SVPX) | SVPX | Photonic/SVPX |
| Cube | ---- | "SpaceVNX" | Half-height VNX | Half-height VNX |
| I/O | 100MbE,SpW | 1GbE,SRIO | 1/10/40GbE | 1GbE+optical |

# A testbed for GNATS

## The "RESINATE" testbed at Kirtland AFB, NM



Reconfigurability, Adaptive Hierarchy, and the Role of Cognitive $x$

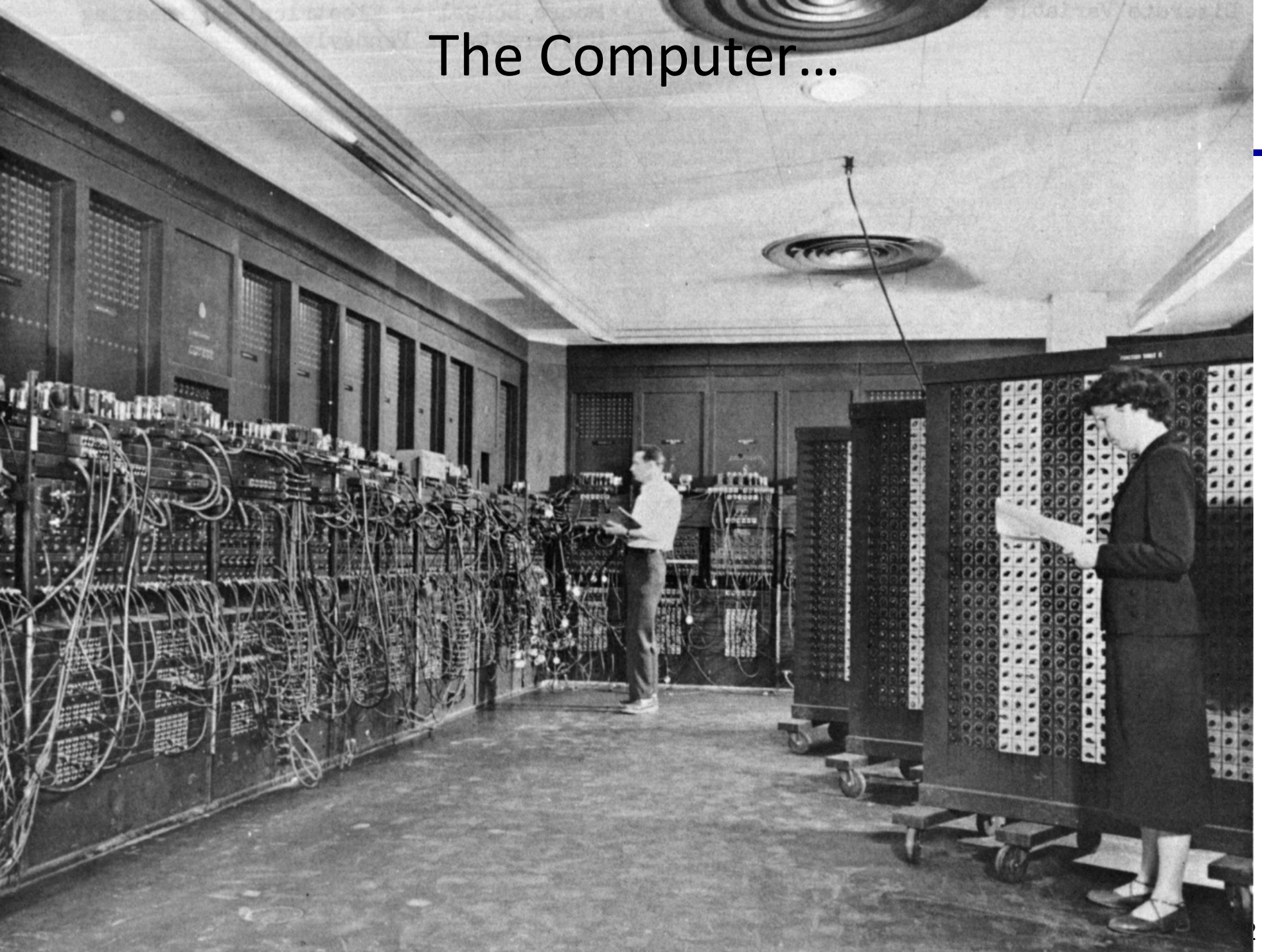
# What are Reconfigurable Systems


- Involves an ability to alter structure and/or function under software control
- Software-defined hardware
- Functional reconfigurability vs. Physical reconfigurability

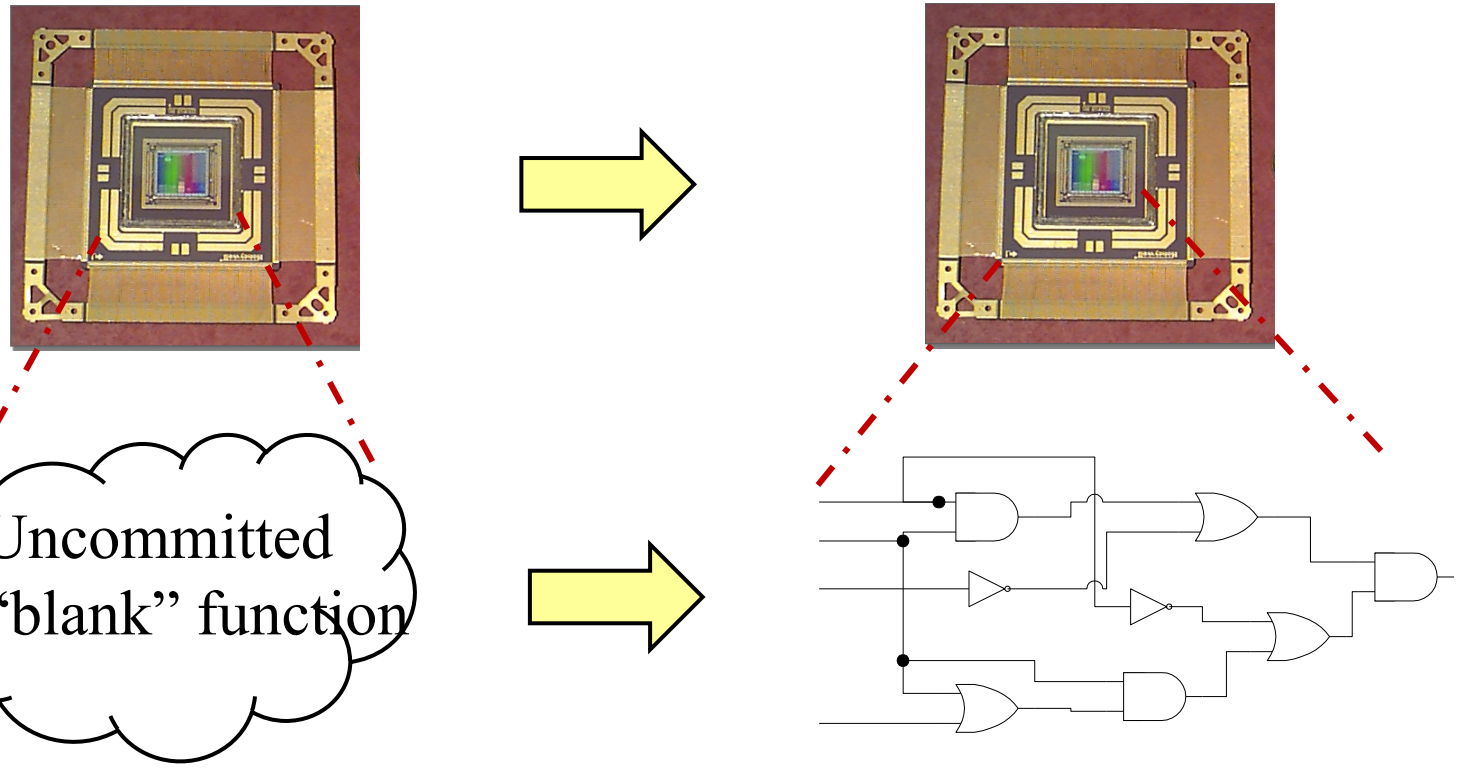
# Why have reconfigurability ?

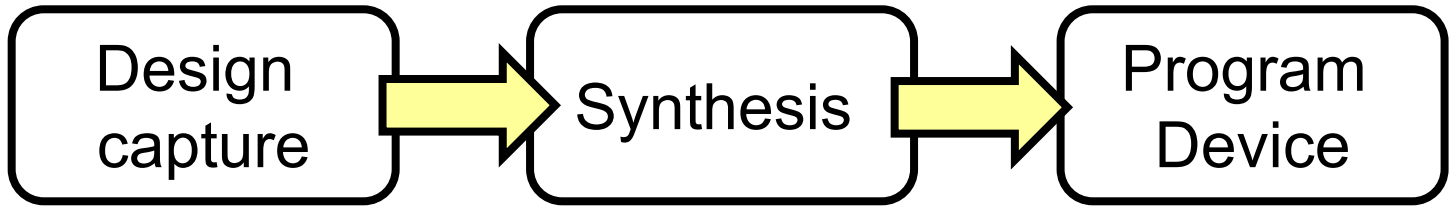
- Flexibility
- $x$ – on demand (development speed)
- Reduce inventory (replace $n$ parts with 1)
- Field updates (features, bug fixes)
- Resiliency (work around faults, self-heal)
- Adaptive, dynamic reconfiguration (time-share silicon)

# The Computer…

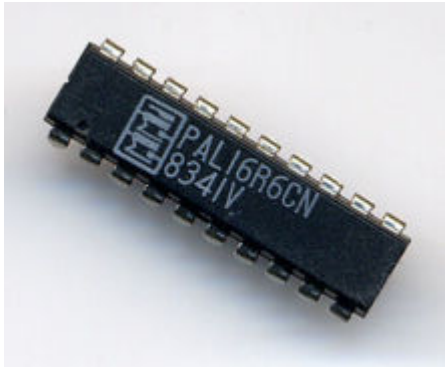


# The Field Programmable Gate Array (FPGA)



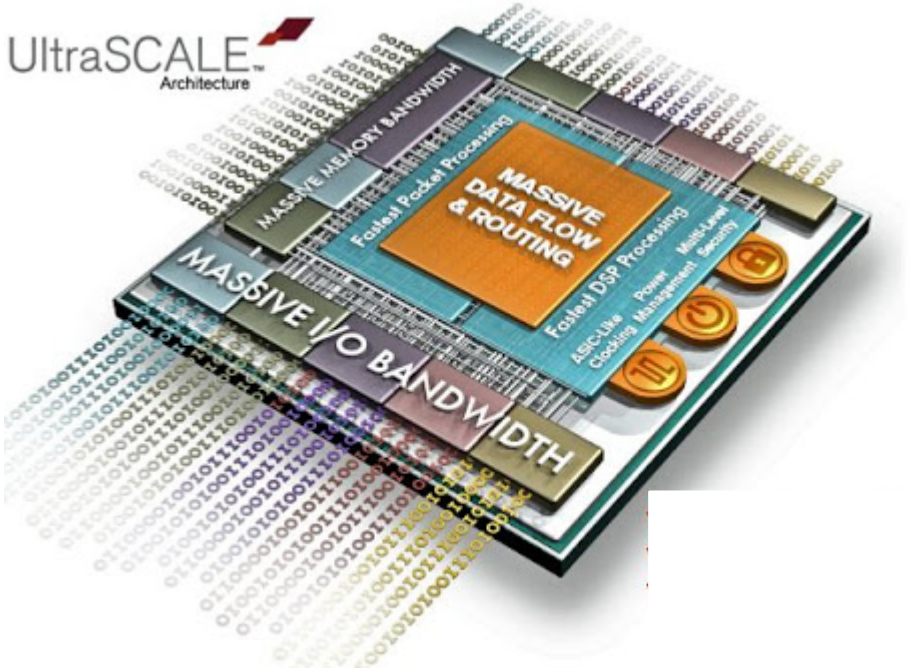



Past -1977




- A handful of logical "truth tables"

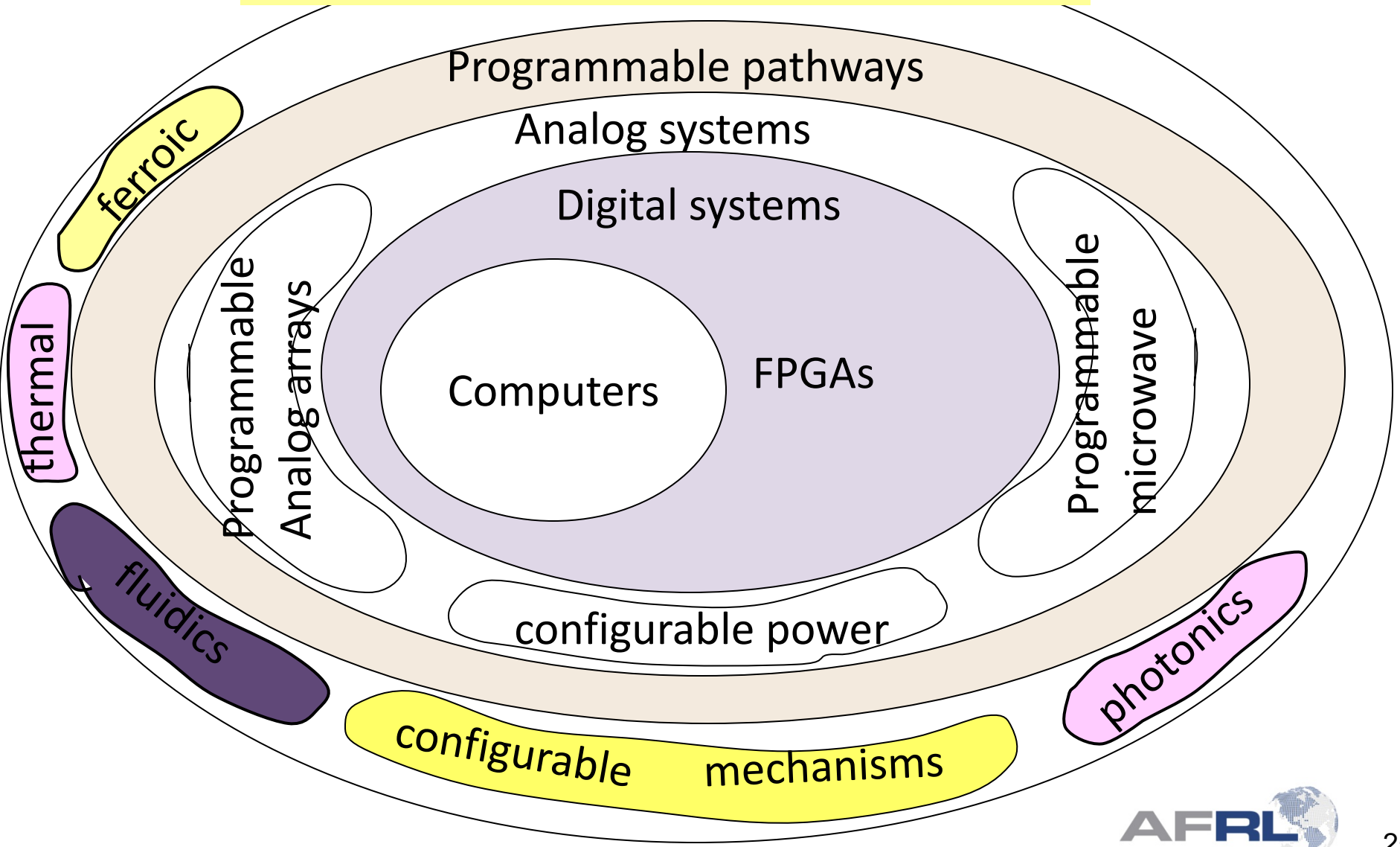
Today



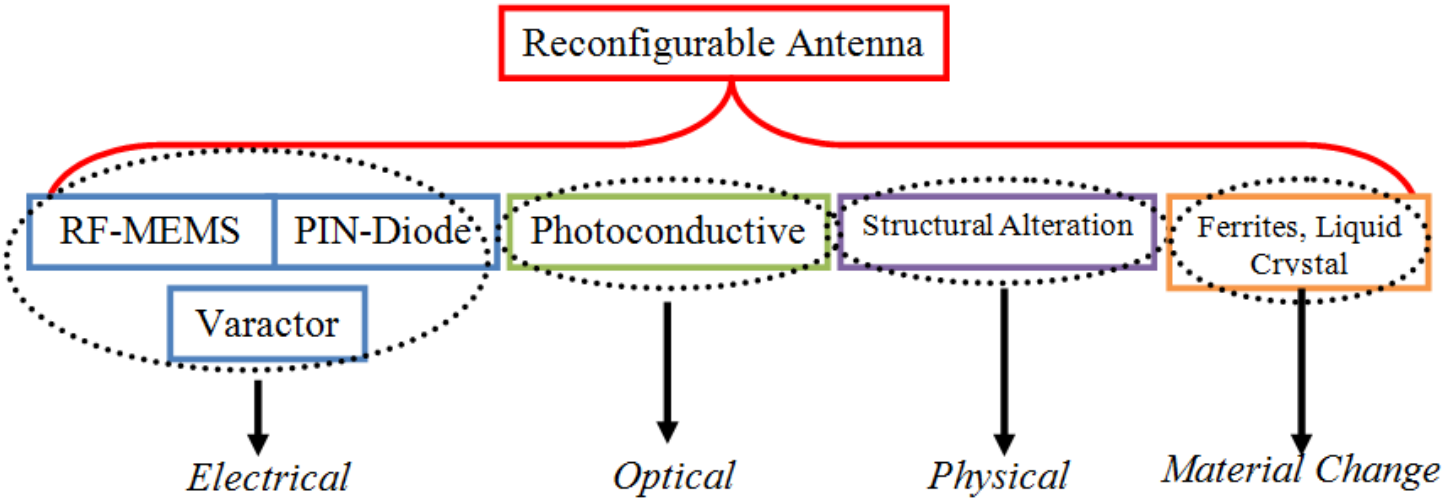

- **Billions of transistors**
- **Millions of logical "truth tables"**

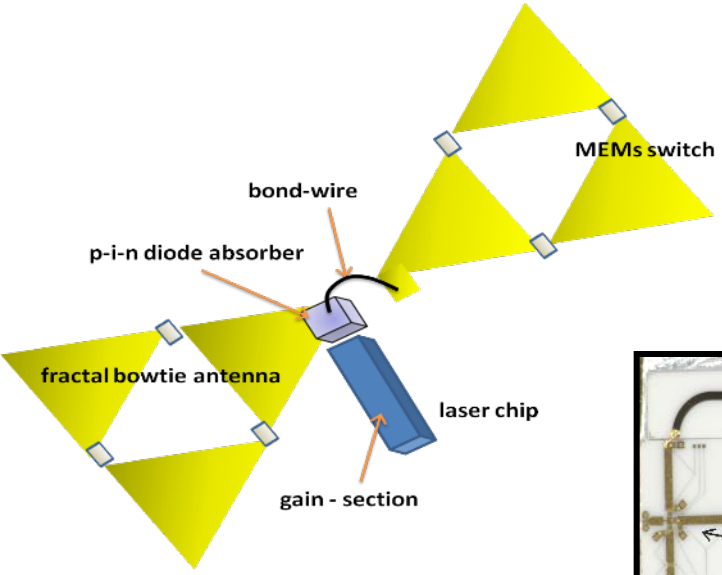
# General Reconfigurable Systems

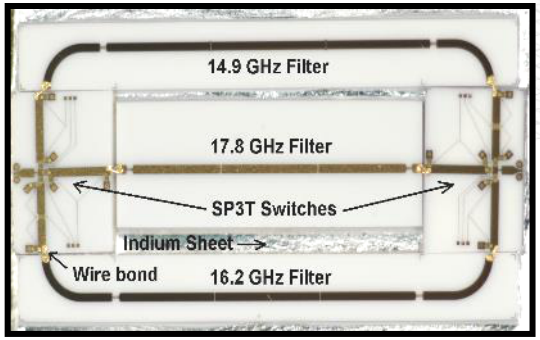
Programmable mechanisms, materials

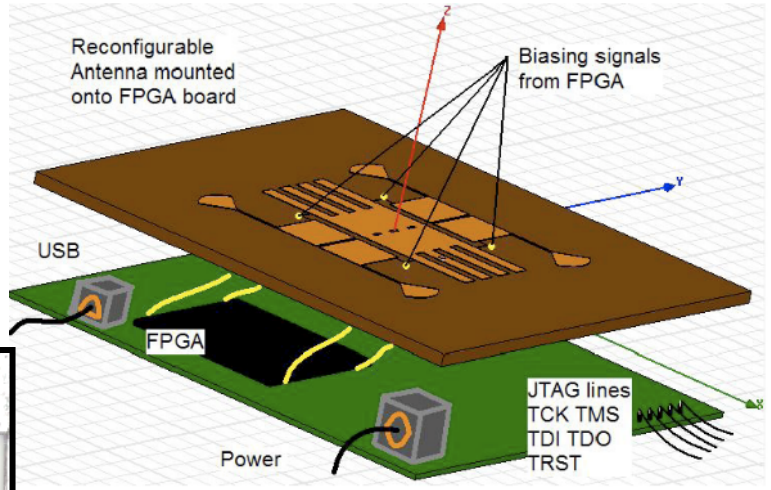


# Reconfigurable RF

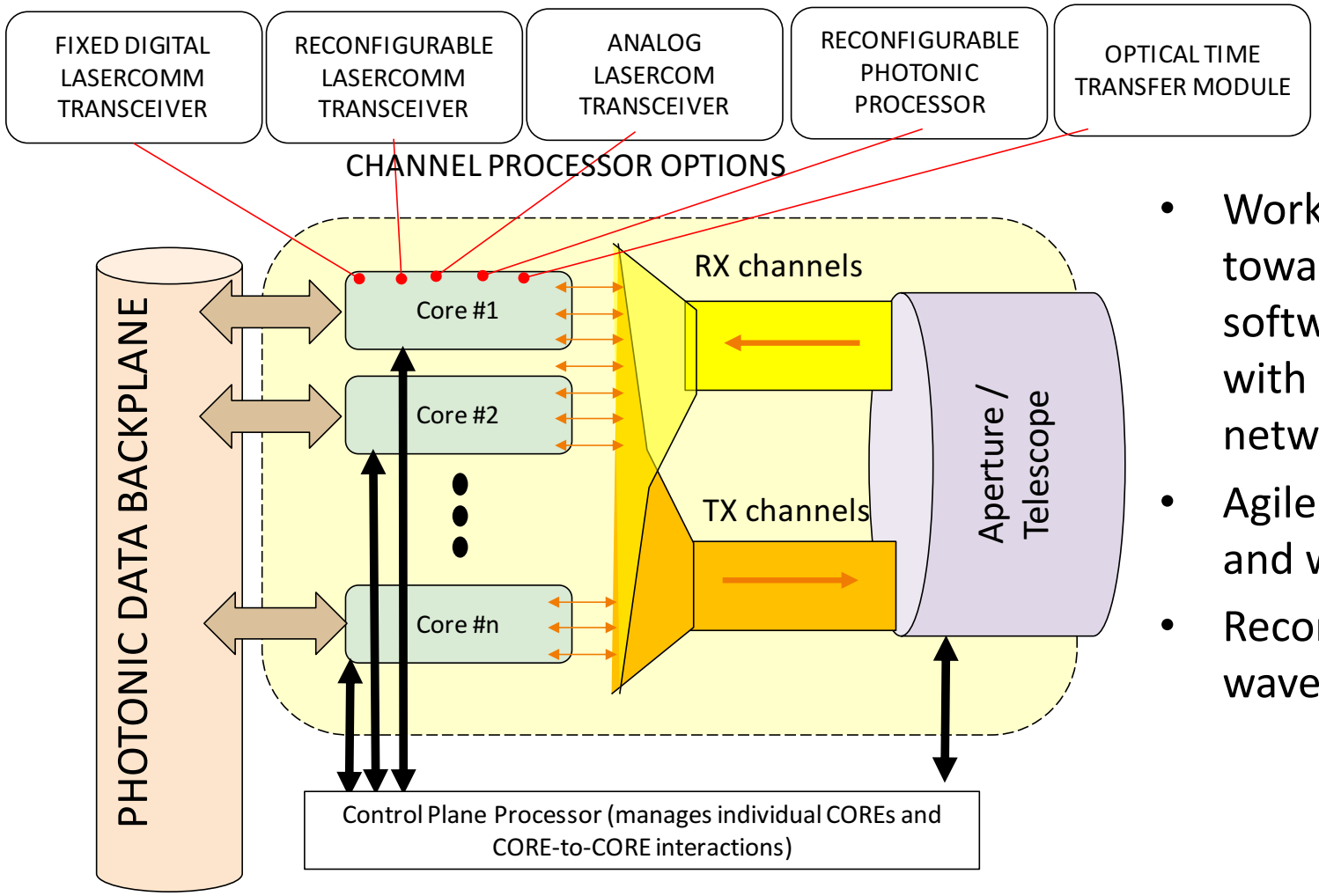


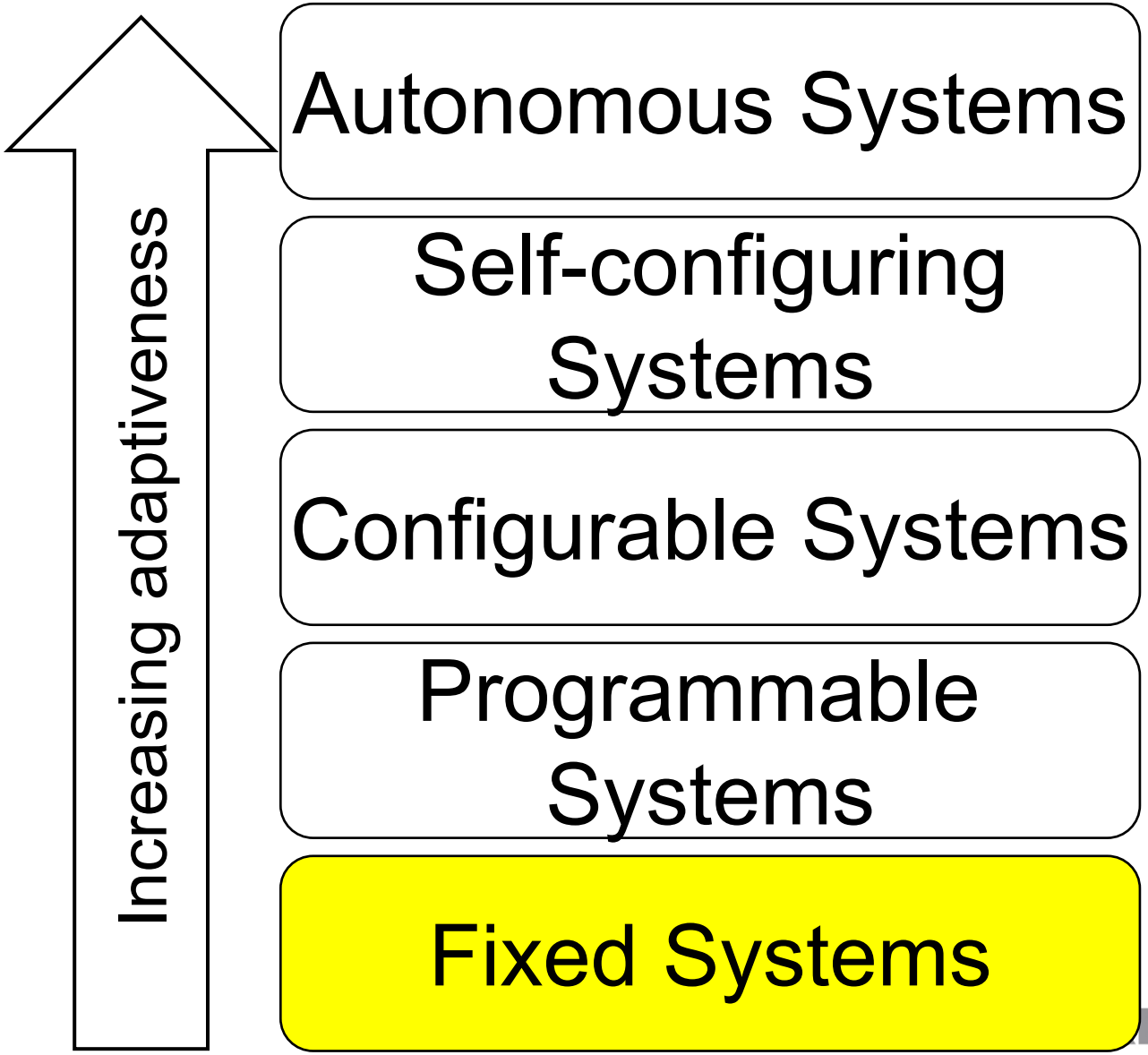
# Reconfigurable Laser Communications and Photonic Networks

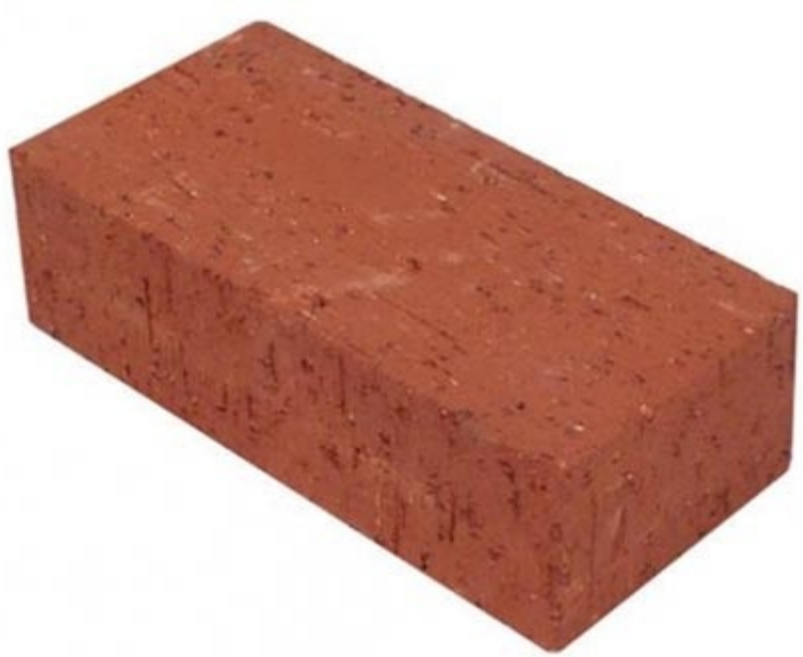



- Work (under ARAP) towards a "photonic software defined radio" with reconfigurable networks
- Agilely tunable beam and wavelength
- Reconfigurable waveform / protocol

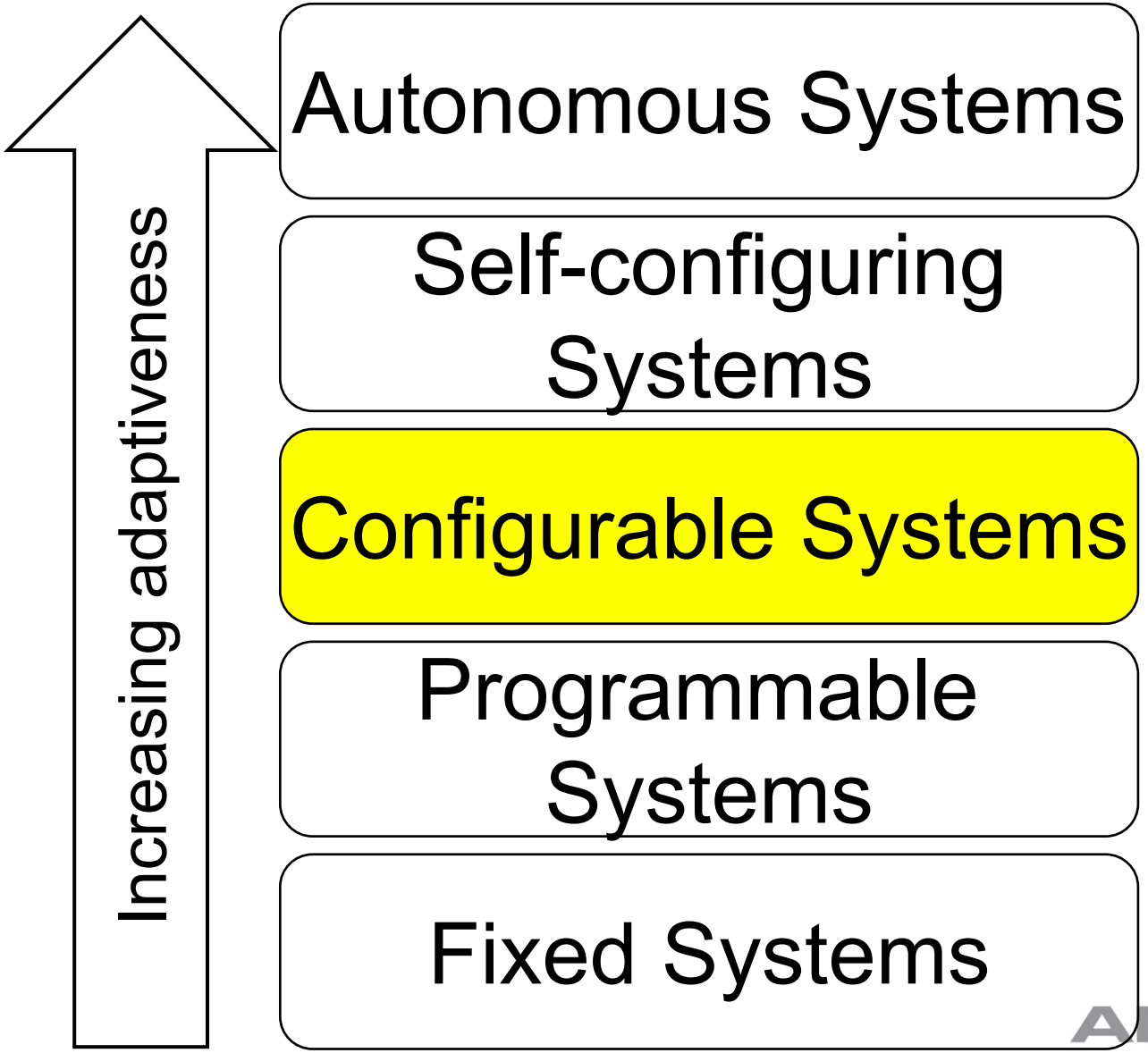
Optical Reconfigurable Channel Processor (ORC-P)

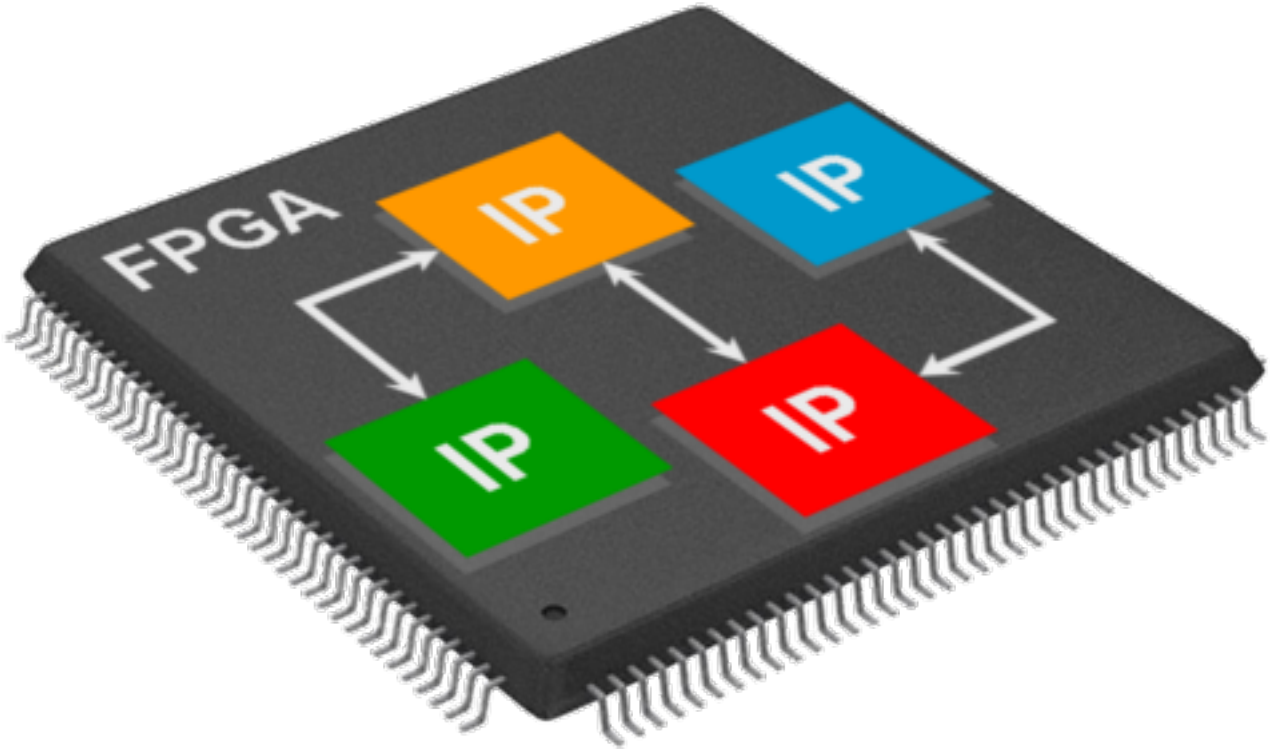
# Adaptive Hierarchy





# Autonomy Hierarchy

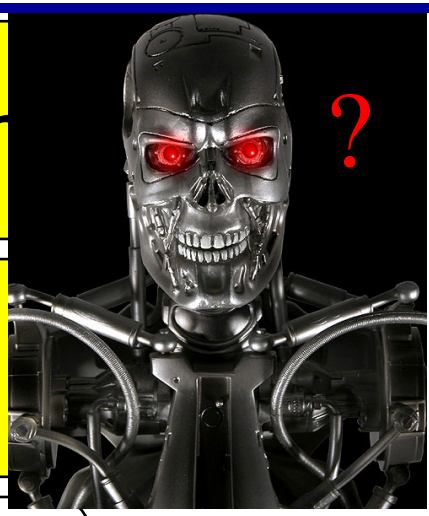



FPGA
IP
IP
IP
IP

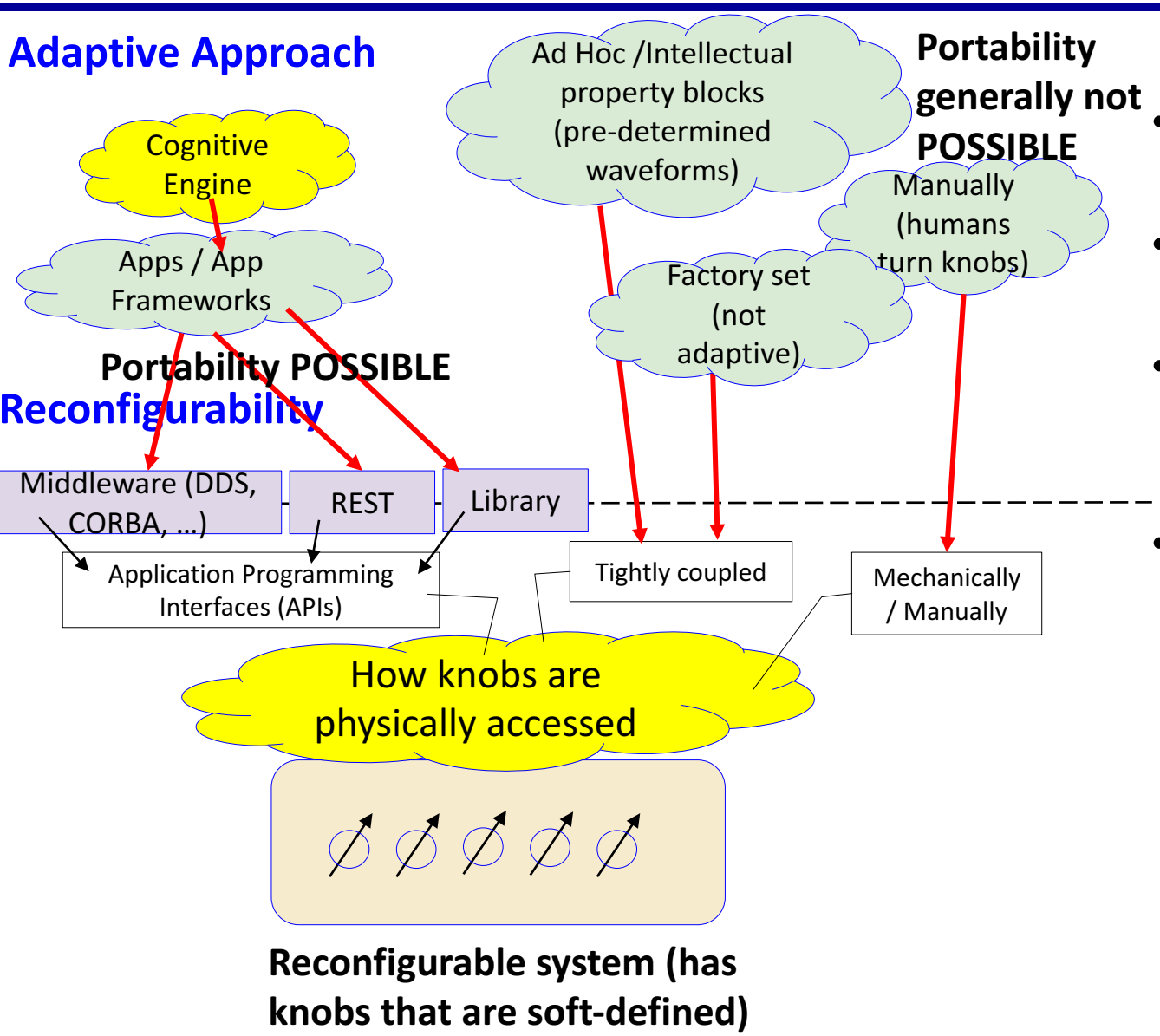
# Autonomy Hierarchy

Increasing adaptiveness

- Autonomous System
- Self-configuring Systems
- Configurable Systems
- Programmable Systems
- Fixed Systems

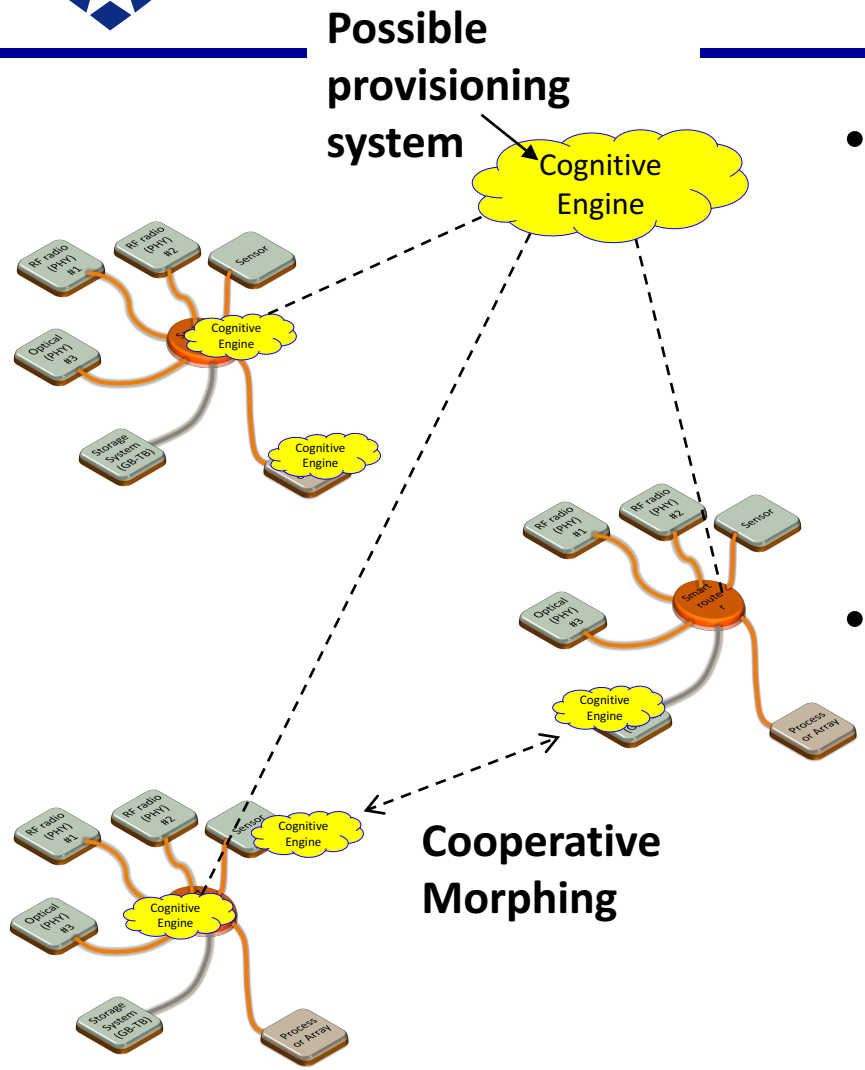


# Cognitive Engines
# Possible Frameworks



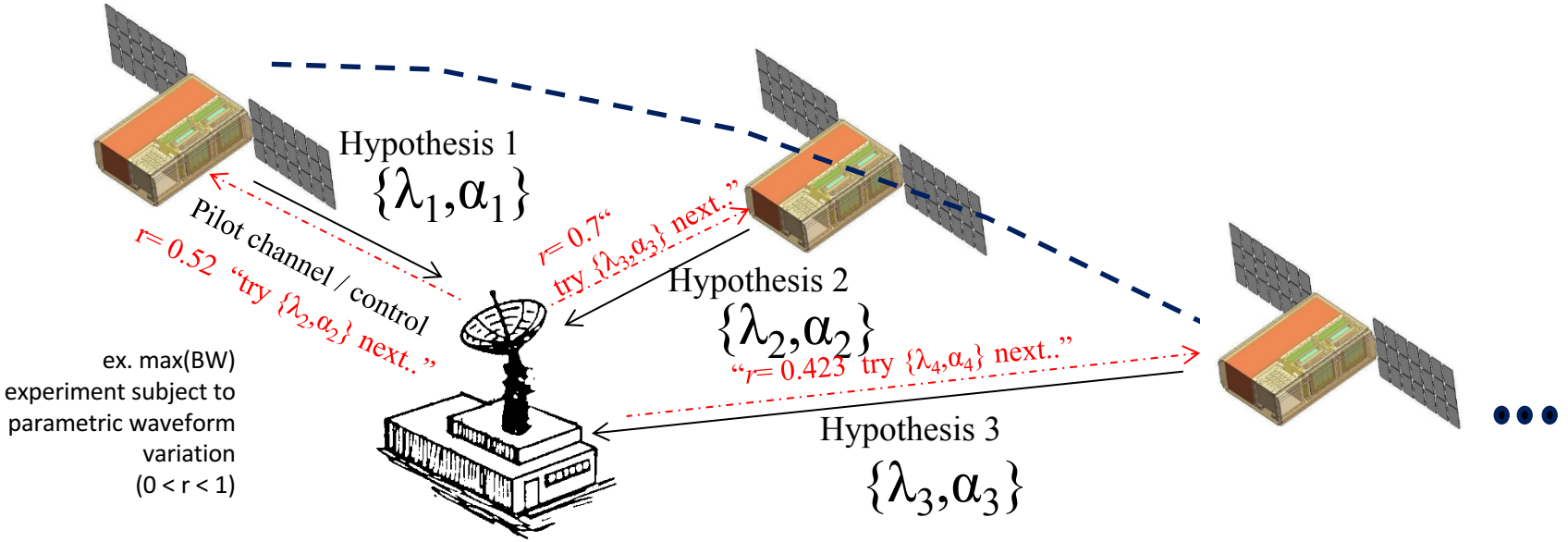

- Most software radios aren't (set at factory)
- Have software, but can't change
- APIs establish the central mechanism for cognition
- APIs are non-unique and not mutually exclusive (REST can co-exist with libraries and manually turned knobs)

# Distributed cognitive engine




- Cognitive communications is a cross-layer problem
  - A point-to-point link might apply cognitive morphing (frequency hopping)
  - A set of network nodes might apply cognitive network
- As such, we must consider not only how to design portable cognitive engines but how to
  - Make them interoperable
  - Allow elasticity to push-down (delegate) rules when possible

# Cooperative Morphing Concept




- Promotes the creation of single-purpose (disposable) waveforms

# Summary

- Ambient connectivity is the aspiration of communications research
- Patterns of communications should be on demand
- "Software-defined networks in contested environments" is the von Neumann-esque quest for reliable networks with unreliable links and nodes (cyber-resilient with poly-chromatic security)
- We need every platform to have/be a smartphone
  - Every platform is a GNAT, some less/more capable than others
  - GNATs seek each to build opportunistic networks
- Besides building the GNAT-SDN infrastructure, the "smartphones" can be extended to information convergence, EM convergence hubs
- GNAT networks are great testbeds for cognitive engines
  - Reconfigurability and adaptiveness are not the same concepts
  - Consideration of cooperating /cross-layer cognitive engines