NC STATE UNIVERSITY

Perspectives on Future Internet Design

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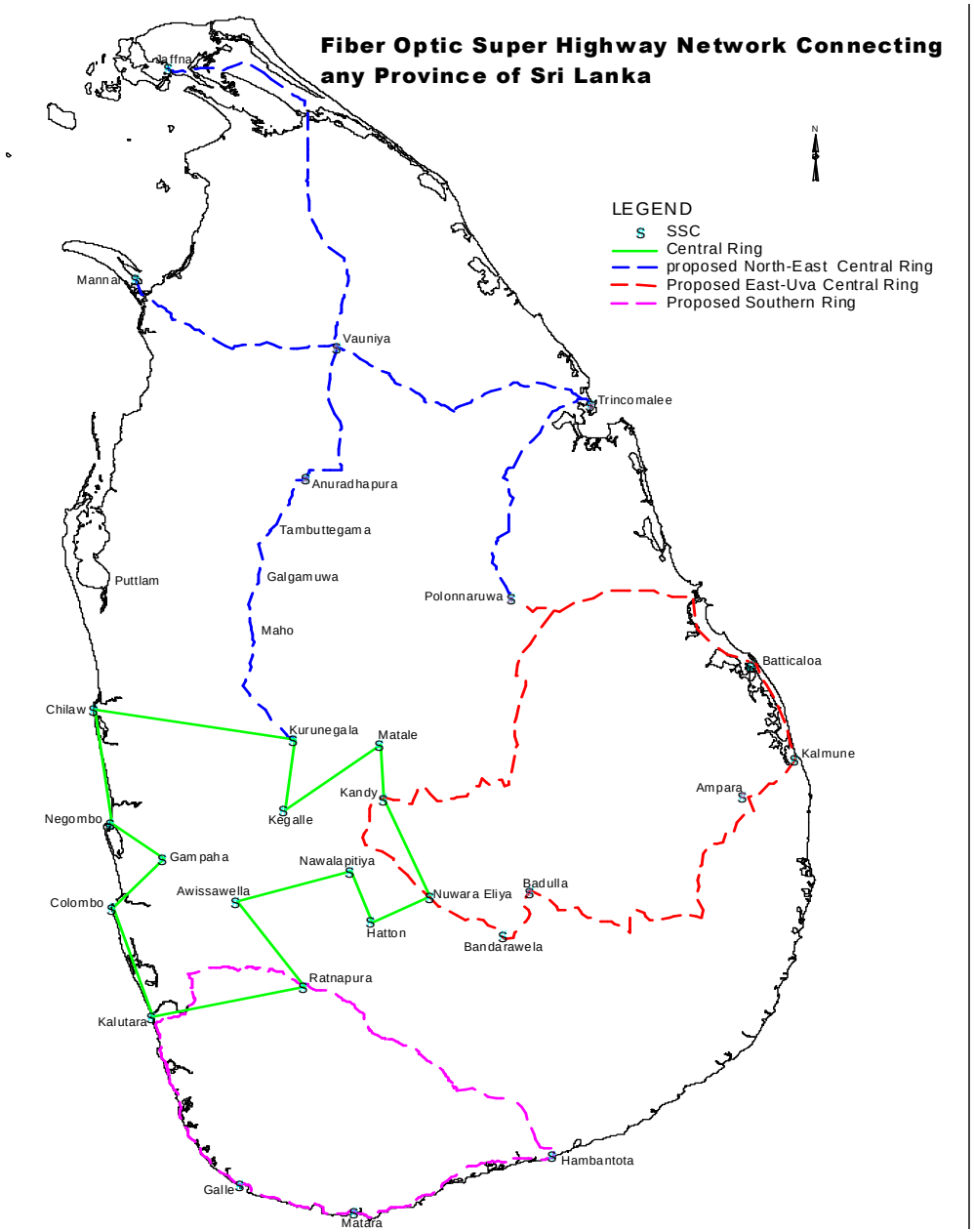
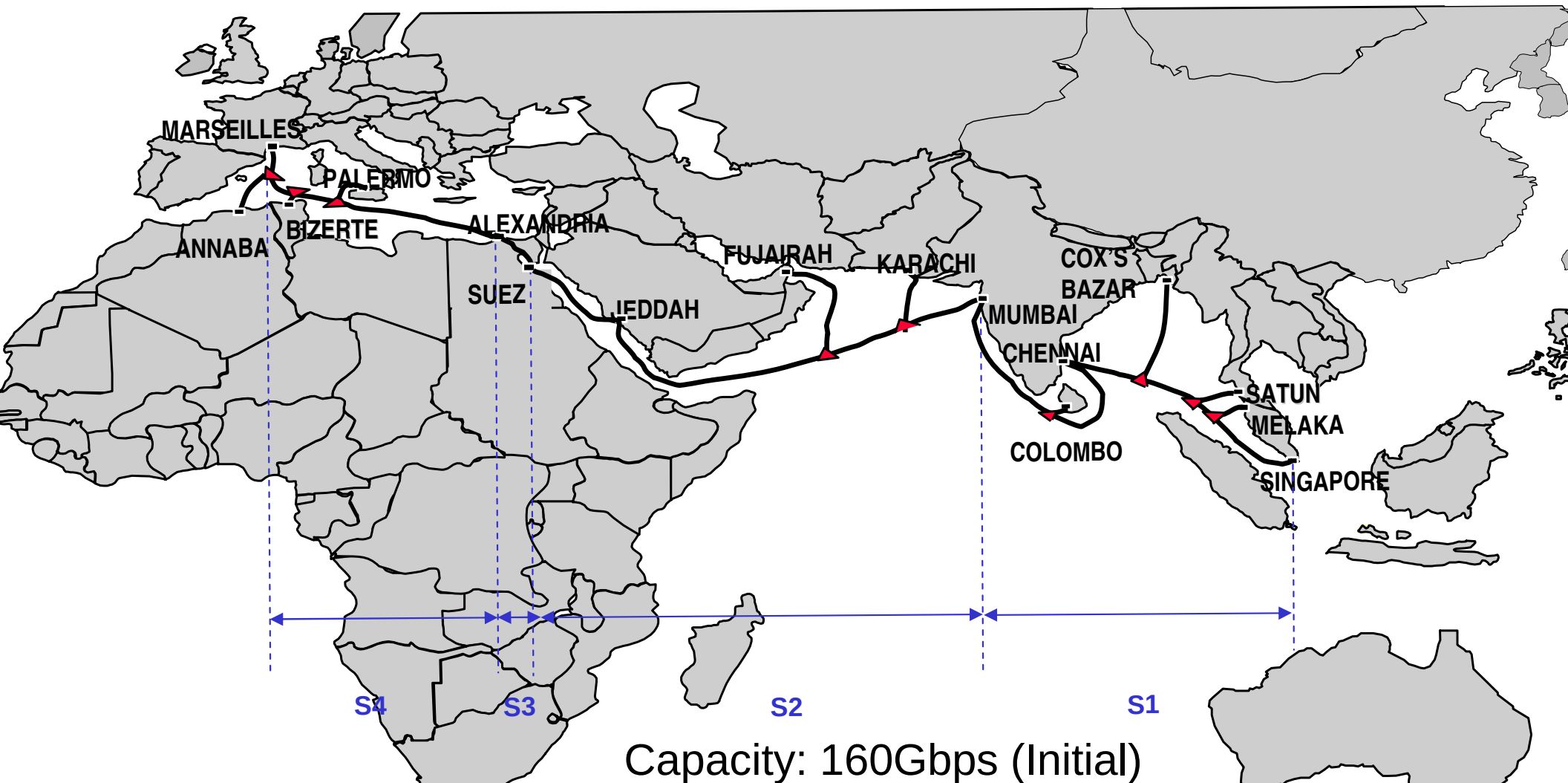
Outline

- Research on Future Internet Architectures
- Our Experience:
  - SILO and GENI IMF: Design for Change
  - ChoiceNet: Design for Choice

Sri Lanka Fiber Connectivity

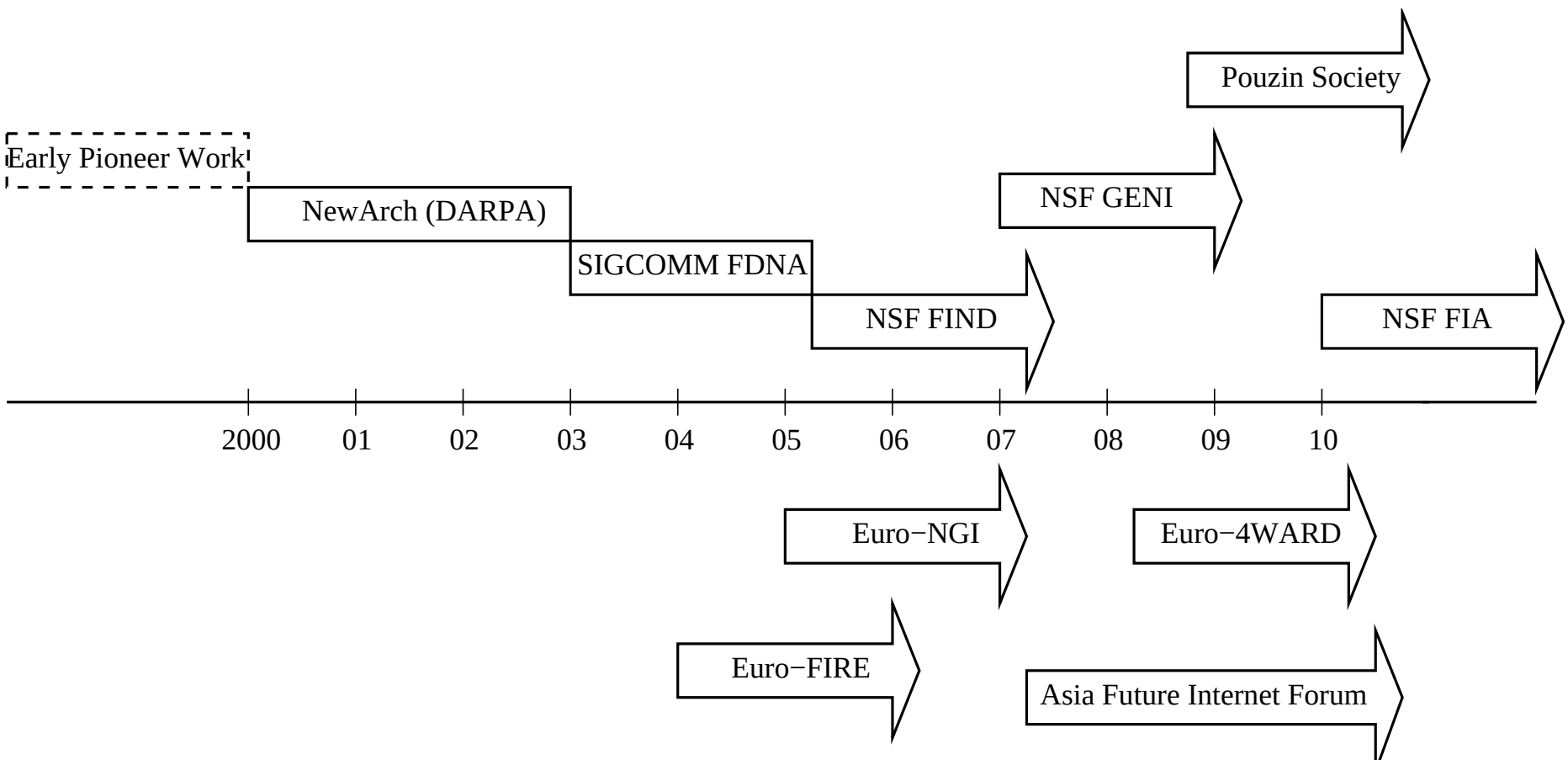


SEA-ME-WE-4

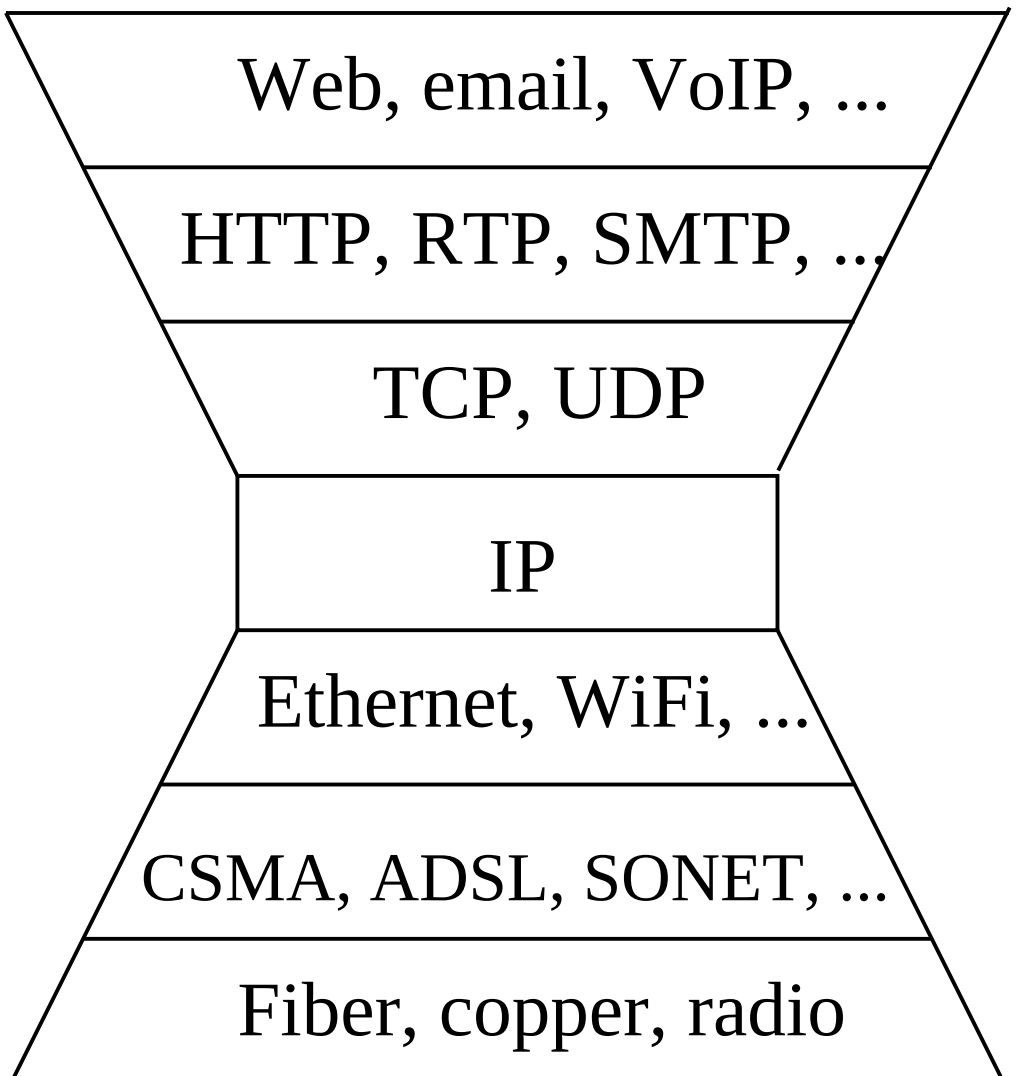


Capacity: 160Gbps (Initial)
Capacity: 1.2Tbps (Final)
Distance: 20,000km

Historical Perspective



Current Internet Architecture



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- Focus: Machine-to-machine $\rightarrow$ Human-to-human

Additional Considerations

- Flexibility and evolvability to future changes
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  → TCP over wireless/large bw/delay product networks
- Implement own UDP-like data transfer
  → no reuse or kernel optimizations
- Abandon the old: new implementations for sensor networks
  → Internet balkanization

Clean Slate Design

- Design a system “from scratch”:
  - without being restrained by existing system
  - using accumulated knowledge and experience
  - having a fresh, unbiased look at the problem space
- Several challenges:
  - holistic approach considering all aspects
    $\longrightarrow$ overall redesign of the architecture
  - experimentation “at scale”
    $\longrightarrow$ gain insight, mitigate risk
  - accommodate future changes

Three-Step Approach

1. Innovations in various specific aspects of the Internet
   - US: NSF Future Internet Design (FIND)
     ≈ 50 projects: SILO, PoMo, NetServices, $\cdots$
   - EU: Network of the Future
     ≈ 90 projects: Trilogy, Eiffel, Sensei, $\cdots$
   - Japan: New Generation Network (NWGN, shorter term)
   - China: New Generation Trustworthy Networks, New Generation Network Architectures

Three-Step Approach (cont'd)

2. Collaborative projects: integrate innovations into overall architecture
   - US: NSF Future Internet Architecture (FIA)
     NDN, MobilityFirst, NEBULA, XIA
   - EU: Future Internet Assembly (FIA)
     4WARD
   - Japan: NWGN (longer term)
     AKARI
   - China: Future Internet Architectures

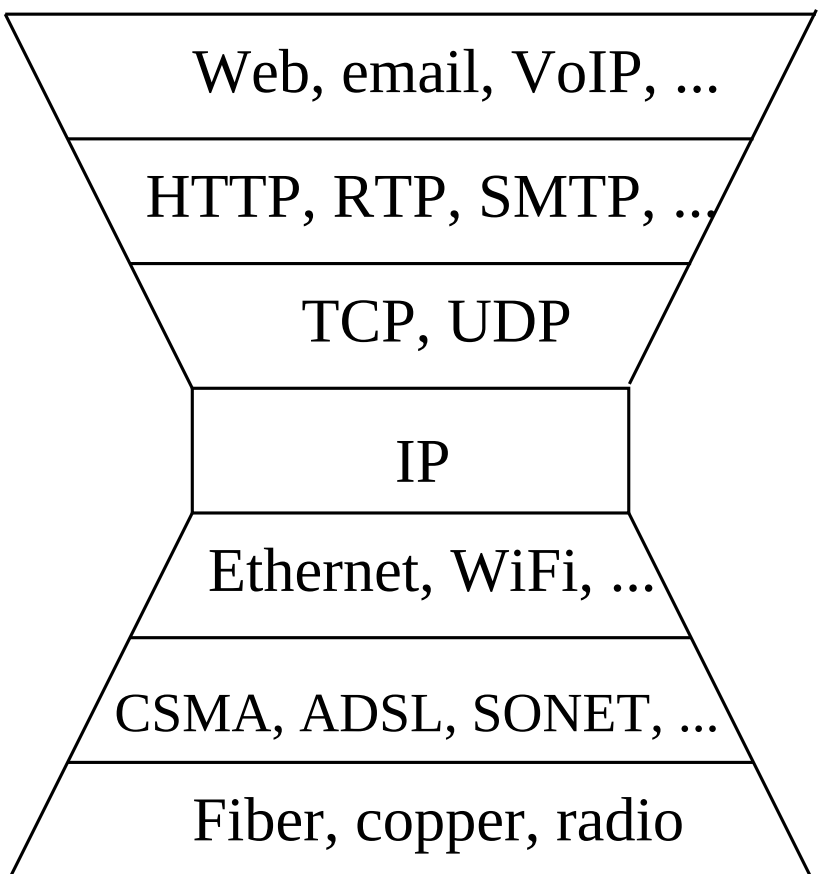
Three-Step Approach (cont'd)

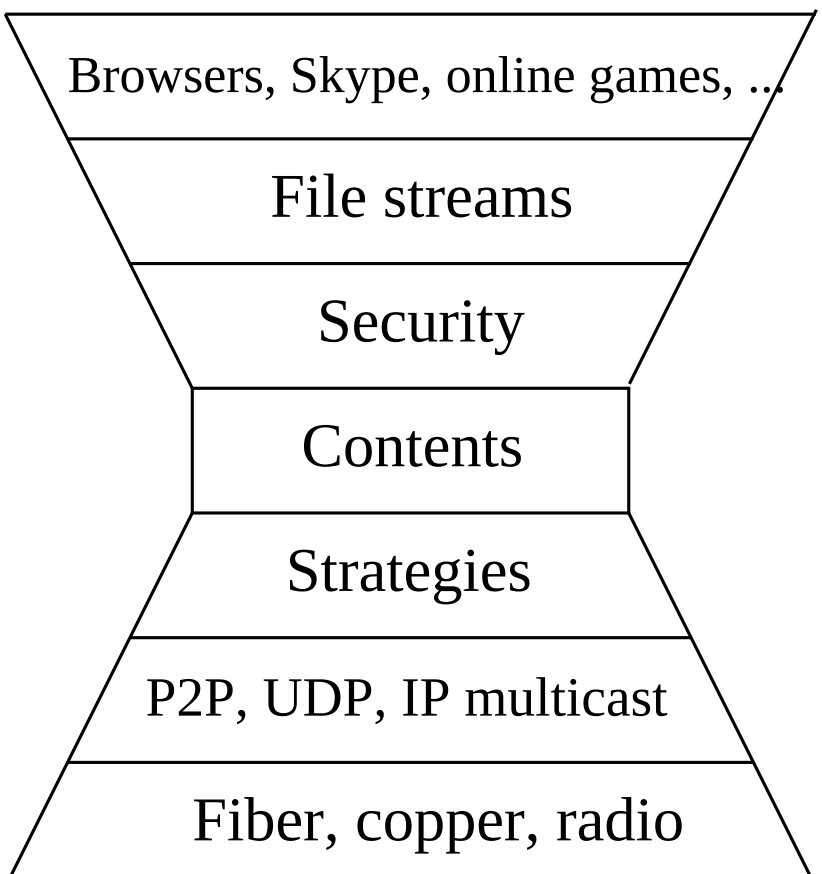
3. Testbeds for real-scale experimentation
   - US: Global Environment for Network Innovations (GENI)
   - EU: Future Internet Research and Experimentation (FIRE)
   - Japan: JGN2+, JGN-X
   - China: China Next Generation Internet (CNGI)

US FIA Projects

1. Named Data Networking (NDN) – UCLA (lead)
   - content-centric, focus on “what” not “where”
   - secure data, not transmission channel or data path
2. MobilityFirst – Rutgers (lead)
   - address cellular convergence (4-5B devices), connect vehicles
   - pervasive system to interface humans with physical world
3. NEBULA – UPenn (lead)
   - reliable, high-speed core interconnecting data centers
   - mobile “roaming” users connect to nearest data center
4. eXpressive Internet Architecture (XIA) – Carnegie Mellon (lead)
   - rich set of communication entities as network principals
   - intrinsic security using self-certifying identifiers

Narrow Waist of NDN

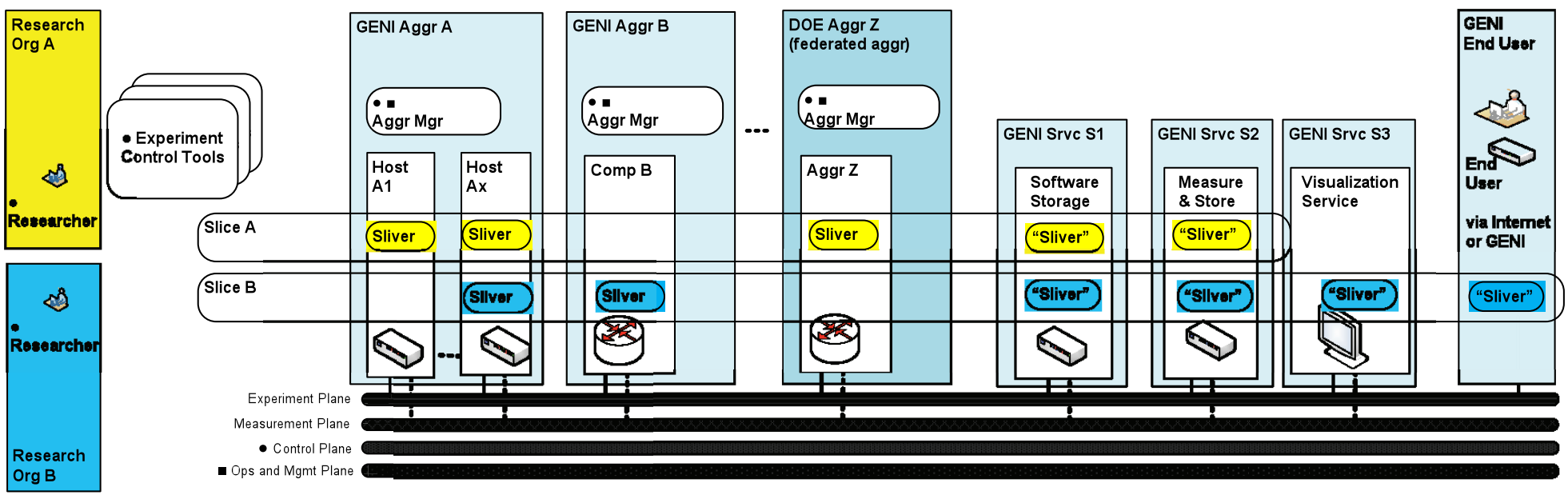




GENI: Core Concepts

- Programmability:
  - download SW into GENI nodes to control their behavior
- Virtualization/Resource Sharing
  - nodes implement virtual machines $\longrightarrow$ shared infrastructure
  - experiments run within own, isolated slice of GENI resources
- Federation
  - different parts of GENI suite owned/operated by different entities
- Slice-Based Experimentation
  - connected set of reserved resources in diverse locations
  - remotely discover, reserve, program, operate, manage, teardown

GENI Slices


Research Org A
Researcher
Researcher
Research Org B
Experiment Control Tools
Slice A
Slice B
GENI Aggr A
Aggr Mgr
Host A1
Host Ax
Sliver
Sliver
Sliver
Sliver
GENI Aggr B
Aggr Mgr
Comp B
Sliver
Sliver
DOE Aggr Z (federated aggr)
Aggr Mgr
Aggr Z
Sliver
Sliver
GENI Srvc S1
Software Storage
"Sliver"
"Sliver"
GENI Srvc S2
Measure & Store
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GENI Srvc S3
Visualization Service
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GENI End User
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Experiment Plane
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- Our definition:

> it is precisely the characteristics of the system that does not change itself, but provides a framework within which the system design can change and evolve

Meta-Design Framework

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The goal is not to design the “next” system, or the “best next” system, but rather a system that can sustain continuing change

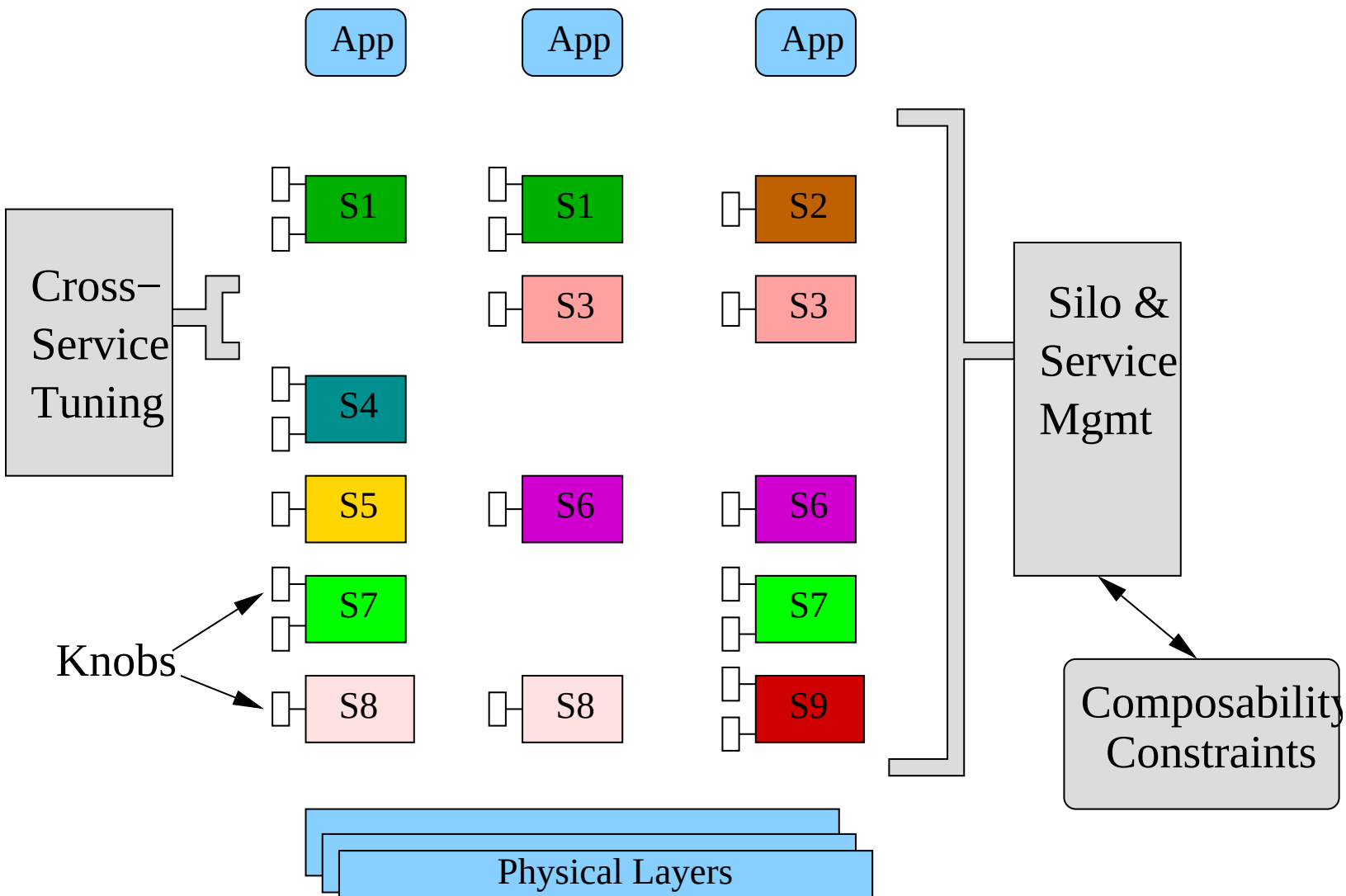
SILO Architecture Highlights

- Building Blocks: services of fine-grain functionality
- Design Principles:
  1. Generalize traditional layer stack
  2. Enable inter-layer interactions:
     - knobs: explicit control interfaces
  3. Design for change:
     - facilitate introduction of new services
  4. Separate control from data functions

Generalization of Layering

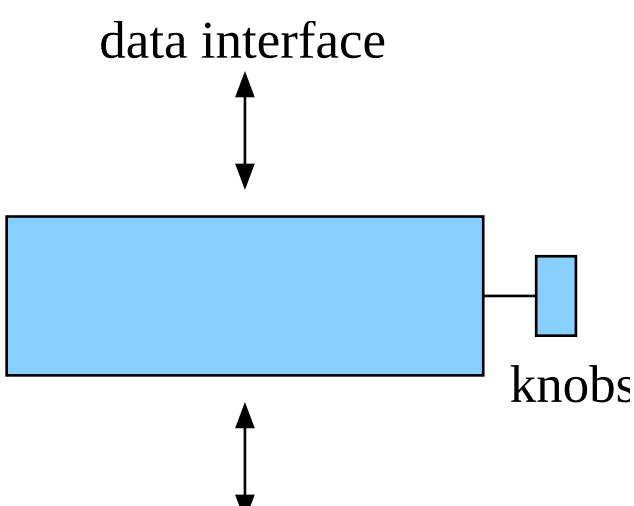
- Silo: vertical composition of services
  → preserves layering principle
- Per-flow instantiation of silos
  → introduces flexibility and customization
- Decoupling of layers and services
  → services introduced at point in stack where necessary

Silos: Generalized Protocol Stacks



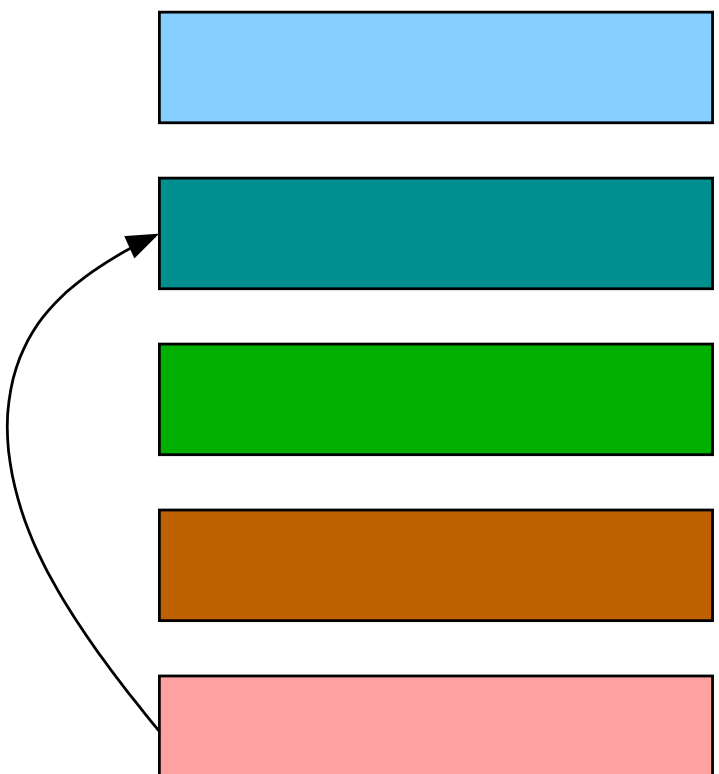
Inter-Layer Interactions (1)

- Knobs: explicit control interfaces
  - adjustable parameters specific to functionality of service
  - enable info exchange among services
- Algorithms may optimize jointly the behavior of services in a silo



Inter-Layer Interactions (2)

Upward information passing



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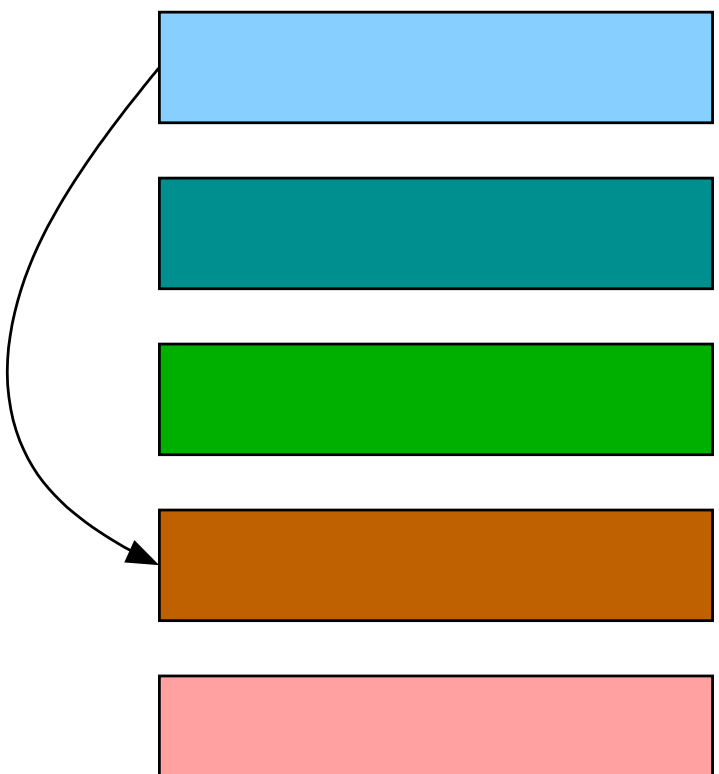
Downward information passing



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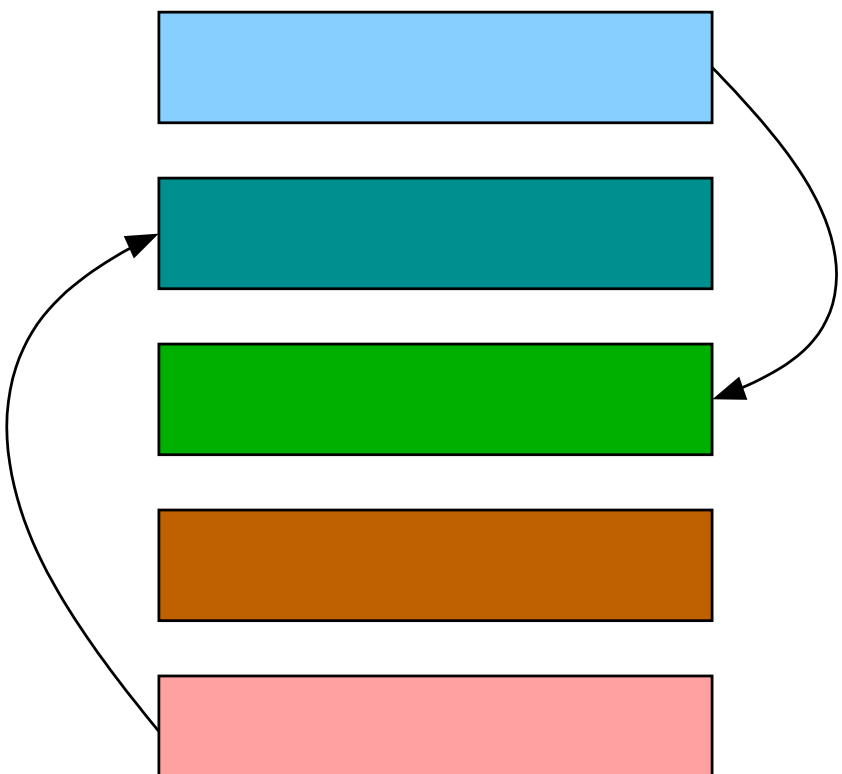
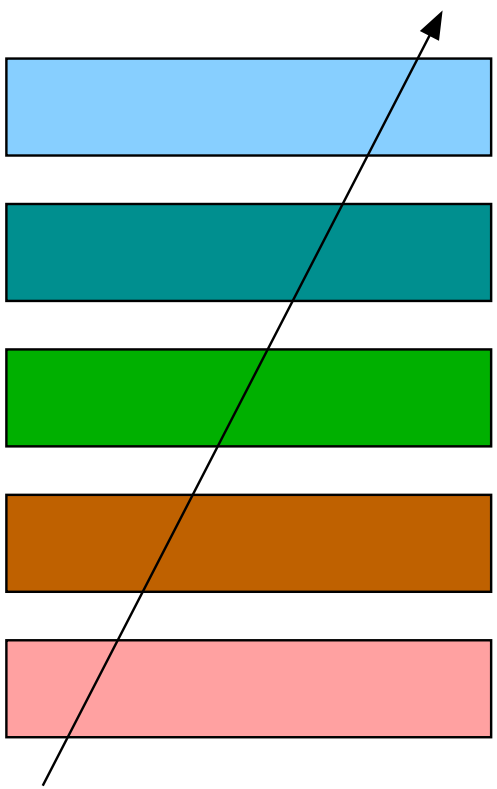
Up-and-down information passing



Inter-Layer Interactions (2)

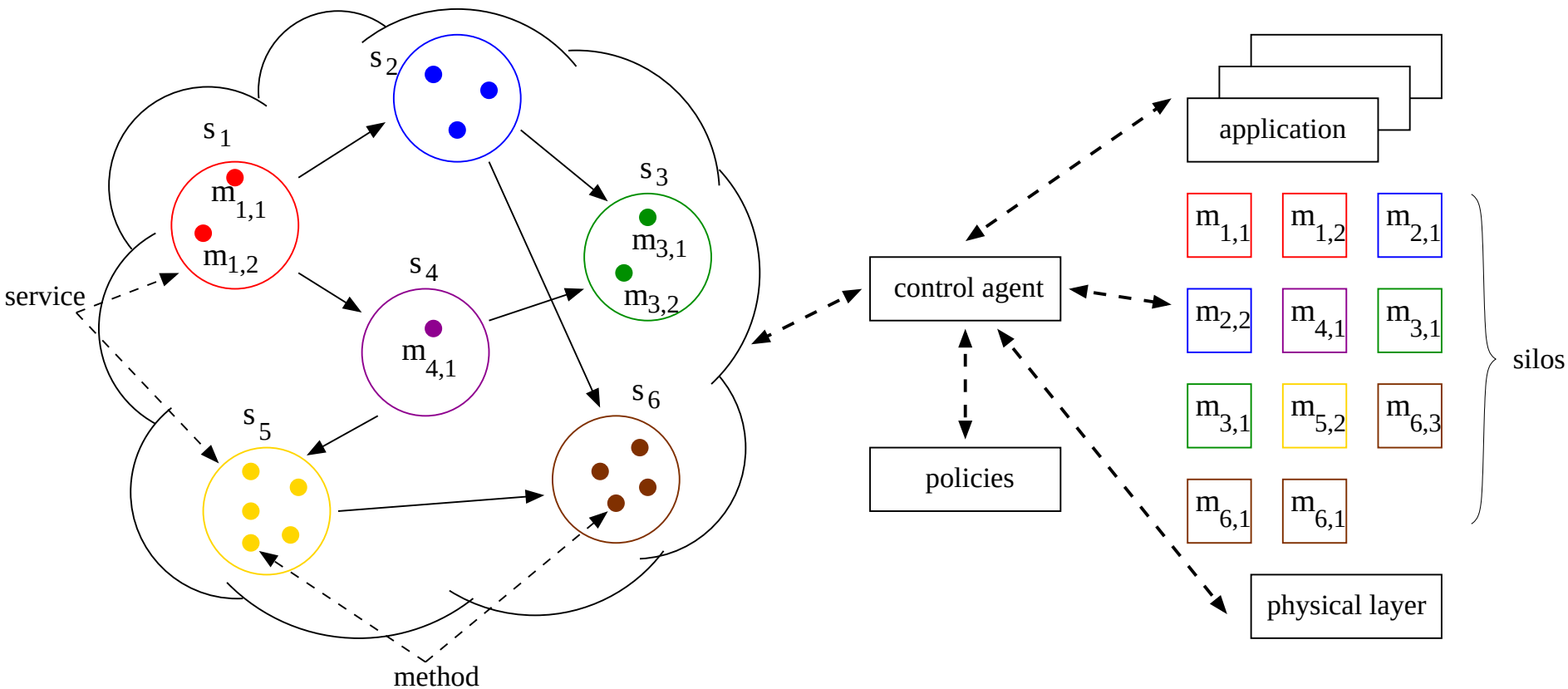
Silo-wide optimization/calibration



Design for Change

- Architecture does not dictate services to be implemented
- Provide mechanisms to:
  - introduce new services
  - compose services into silos
- Ontology of services: describes
  - service semantics $\longrightarrow$ function, data/control interfaces
  - relationship among services $\longrightarrow$ relative ordering constraints

Ontology – Networking Knowledge

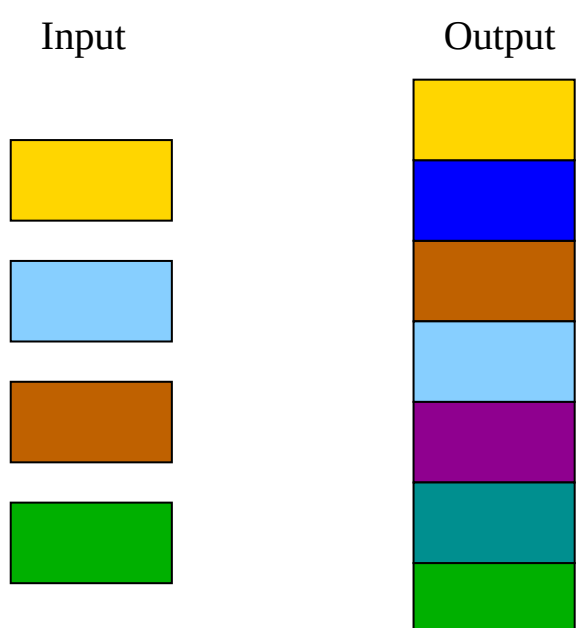


Service Composition

- Constraints on composing services A and B:
  - A requires B
  - A forbids B
  - A must be above (below) B
  - A must be immediately above (below) B
  - Negations, AND, OR
- Minimal set:
  - Requires, Above, ImmAbove, NotImmAbove
- All pairwise condition sets realizable
  - Forbids = (A above B) AND (B above A)
  - Above = NOT Below

Service Composition Problem

- Given: a set of essential services ⟵ application
- Obtain a valid ordering of these and additional services
  - or, identify conflicts with constraints
- Simple composition algorithm implemented
- Ongoing research in formalizing the problem



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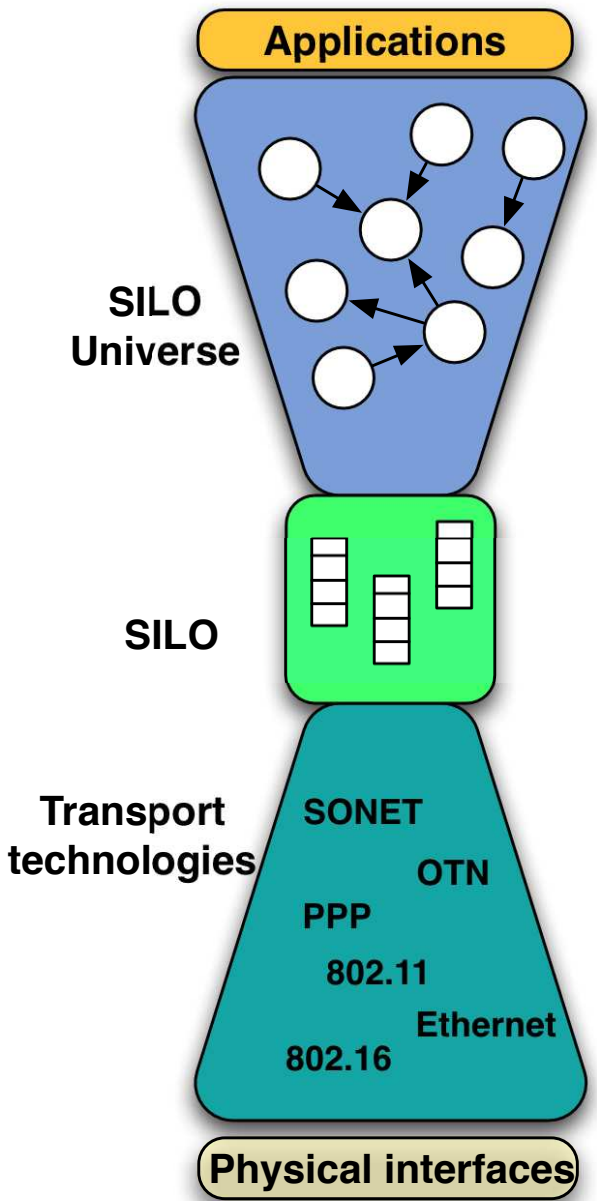
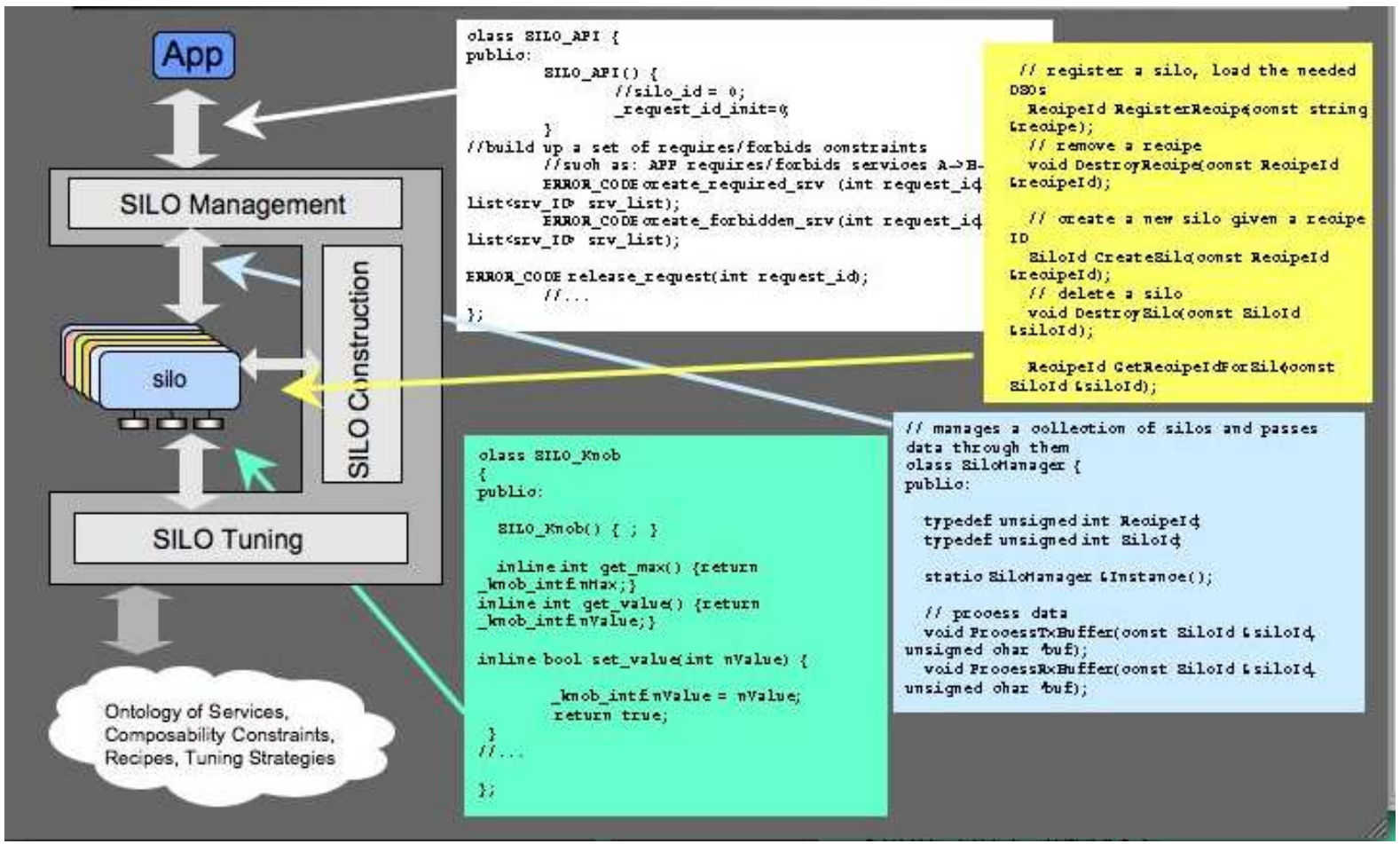
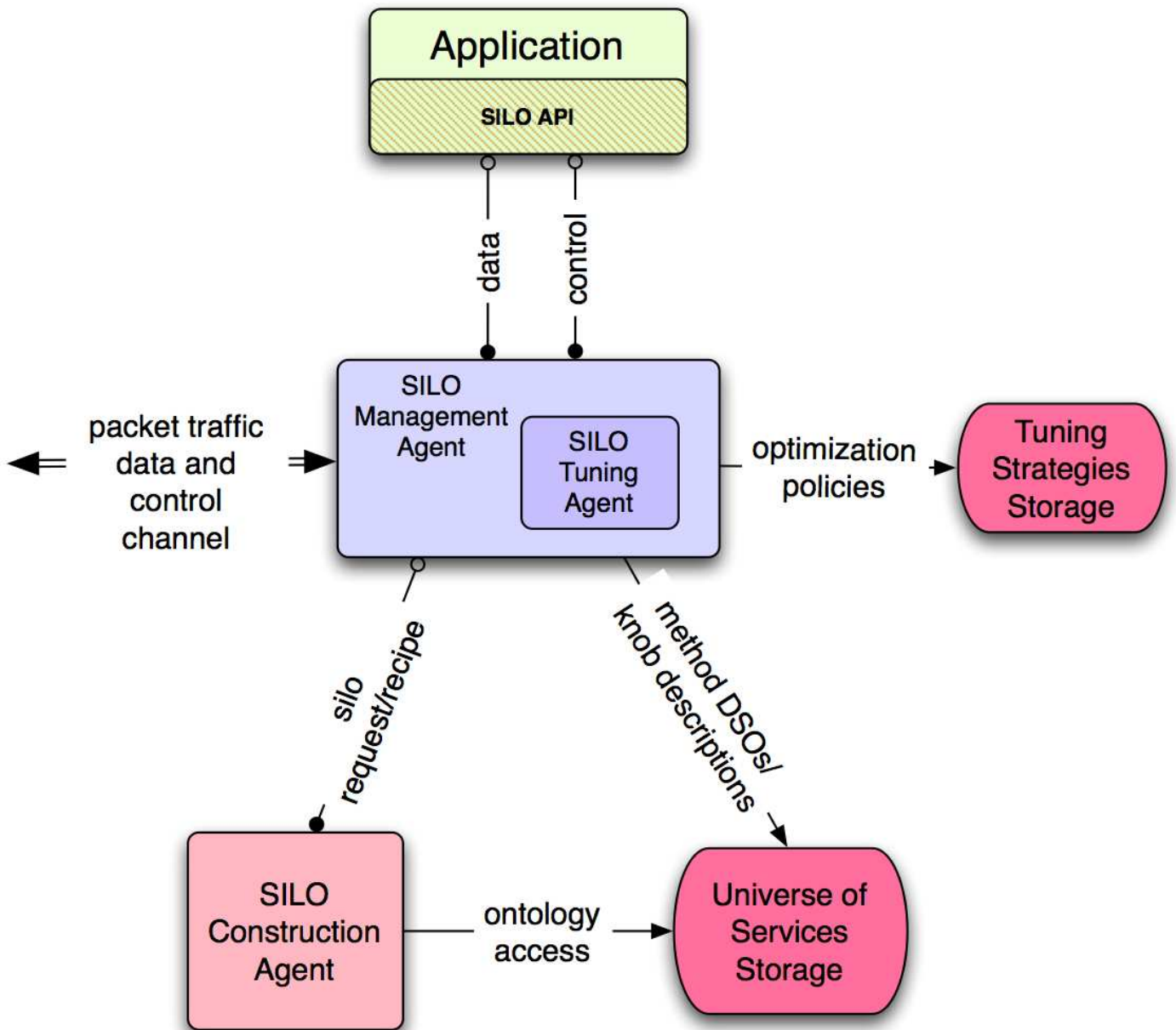


SILO Software Prototype

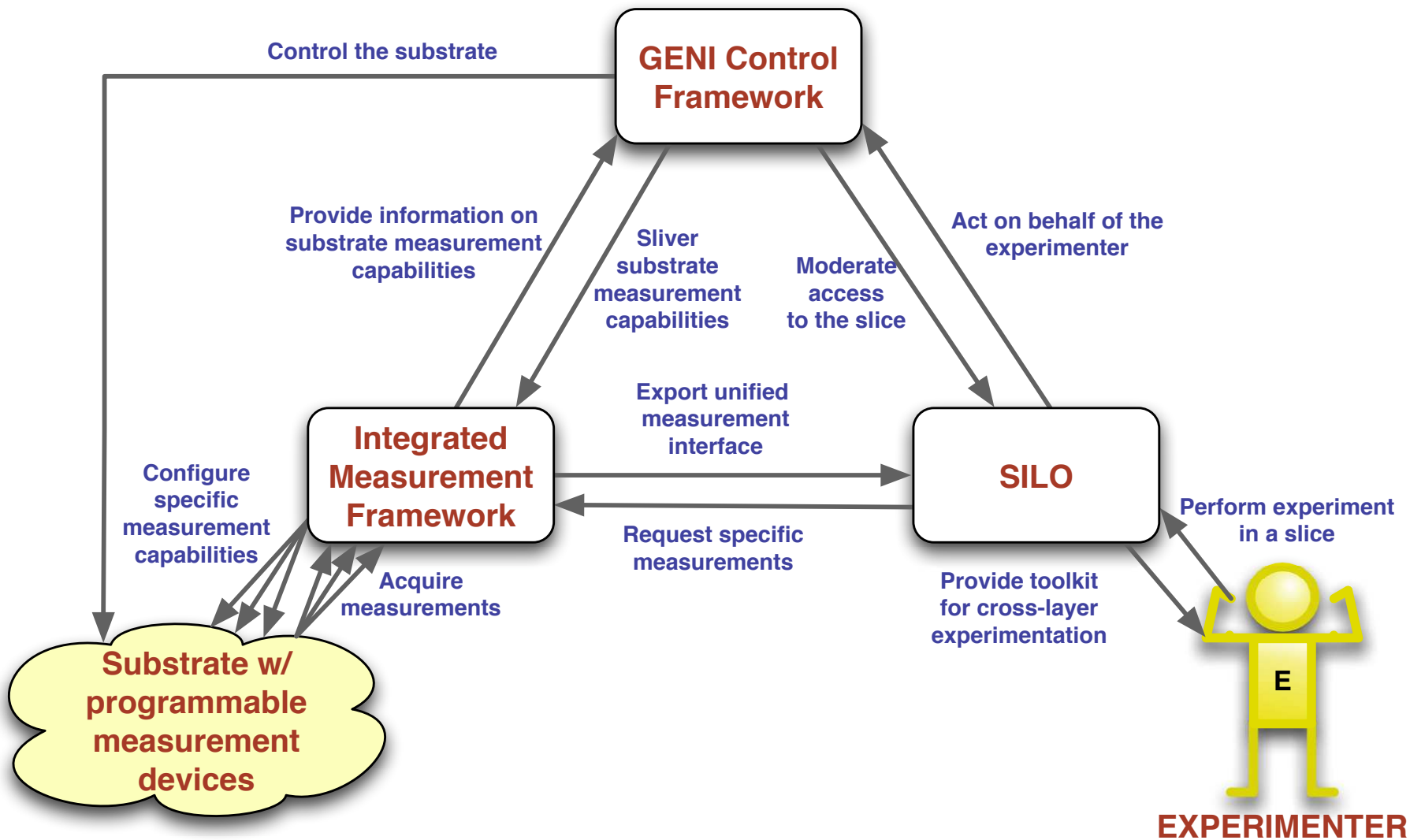


http://net-silos.net/

Prototype Architecture



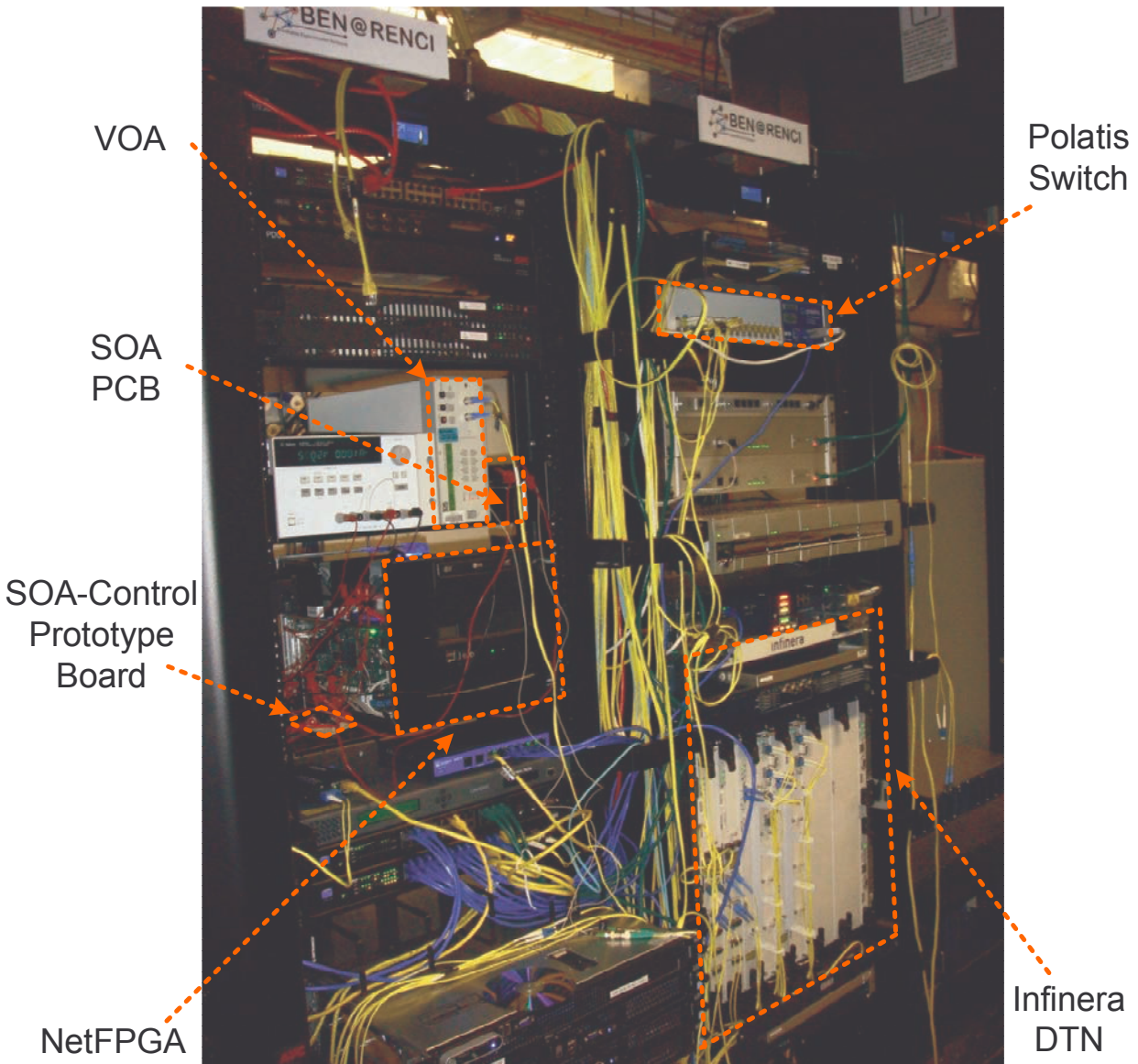
SILO As a Research Tool



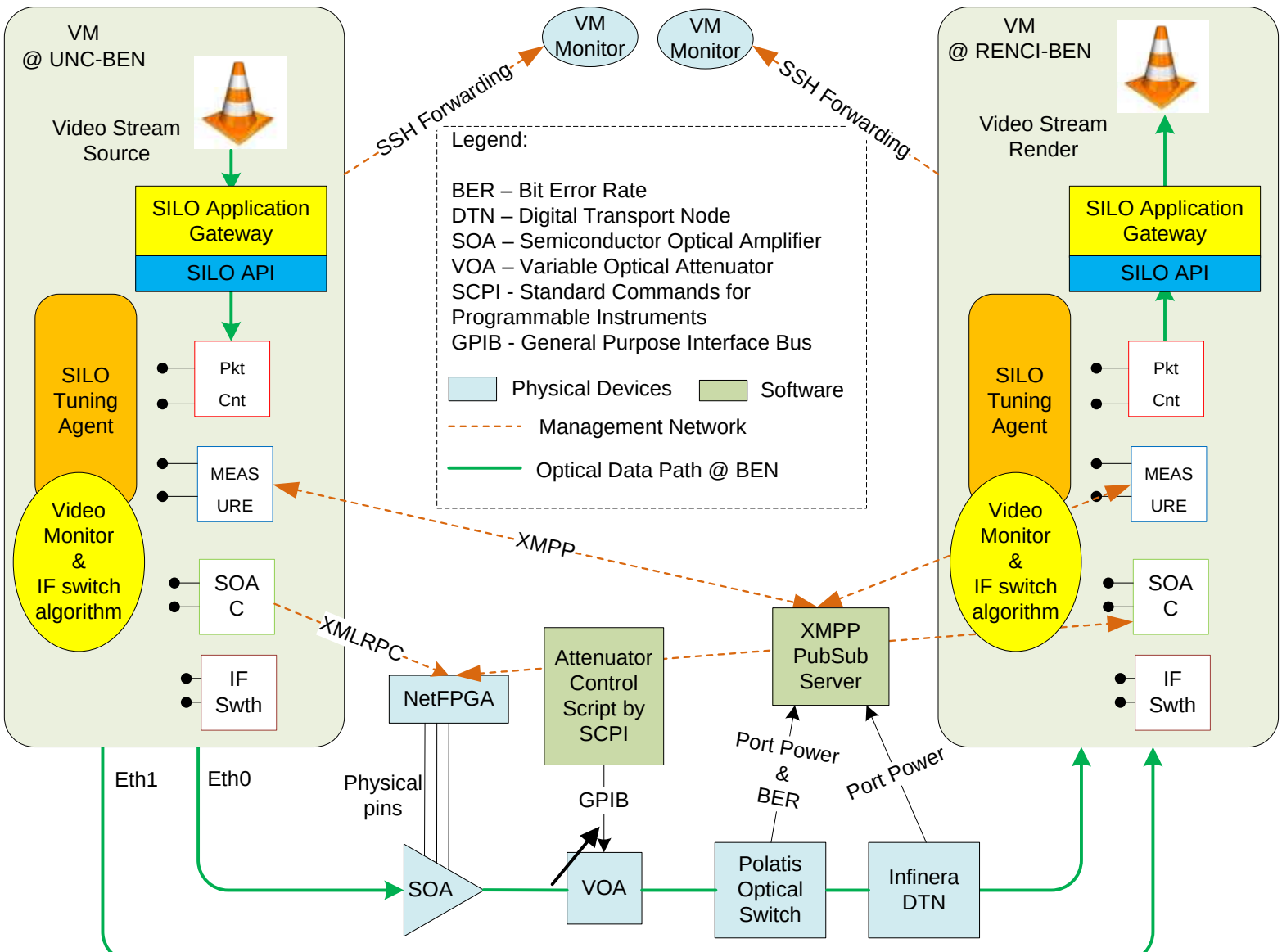
SILO As a Research Tool

- Deploys in a slice
- Researcher brings:
  - custom services
  - tuning algorithms
  - ontology updates
- Connect to measurement framework $\longrightarrow$ cross-layer protocol experimentation tool

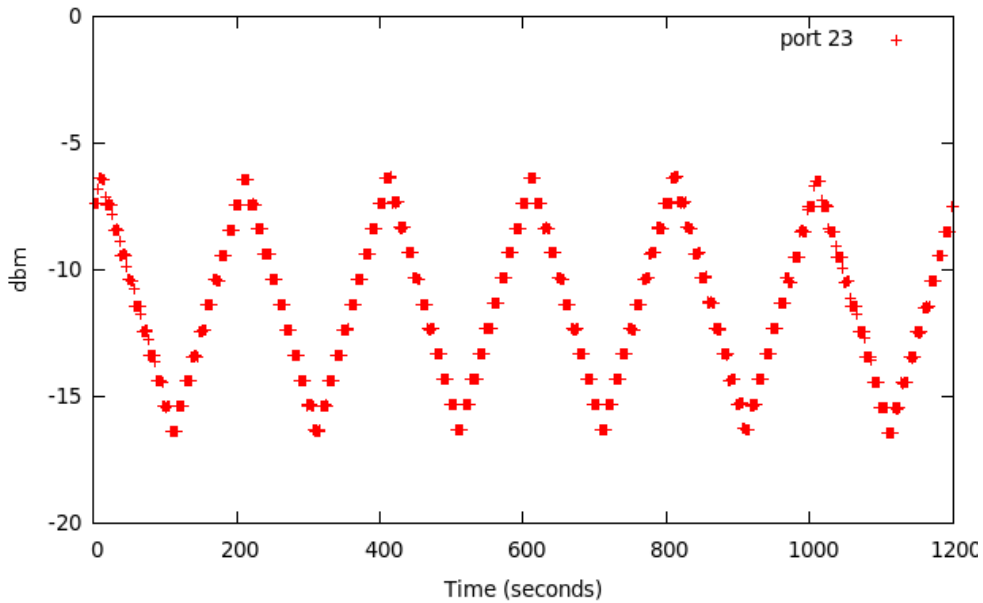
IMF Physical Infrastructure



IMF Cross-Service Demo



IMF Demo – Results



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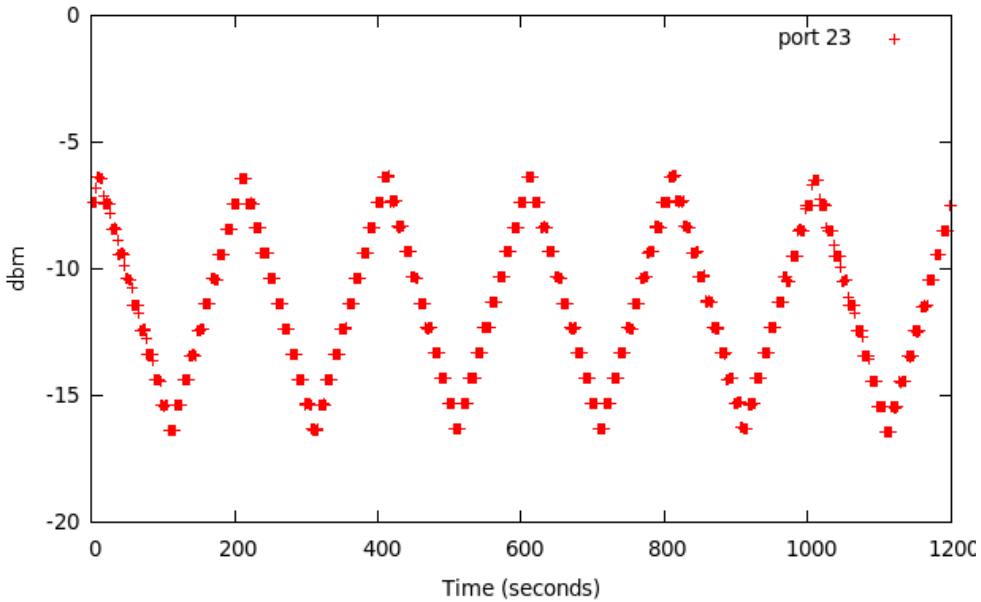
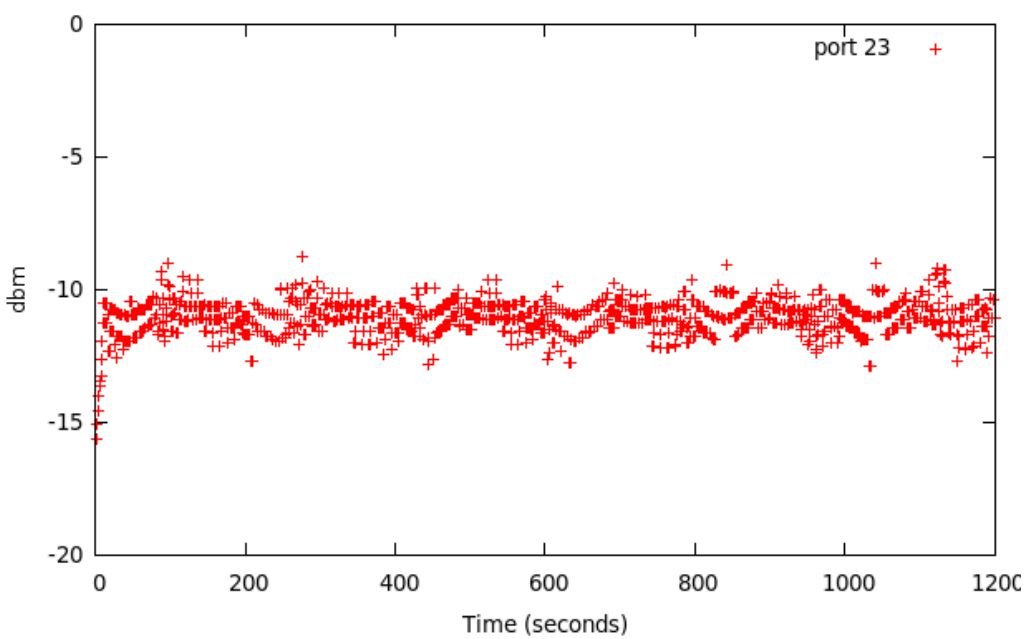
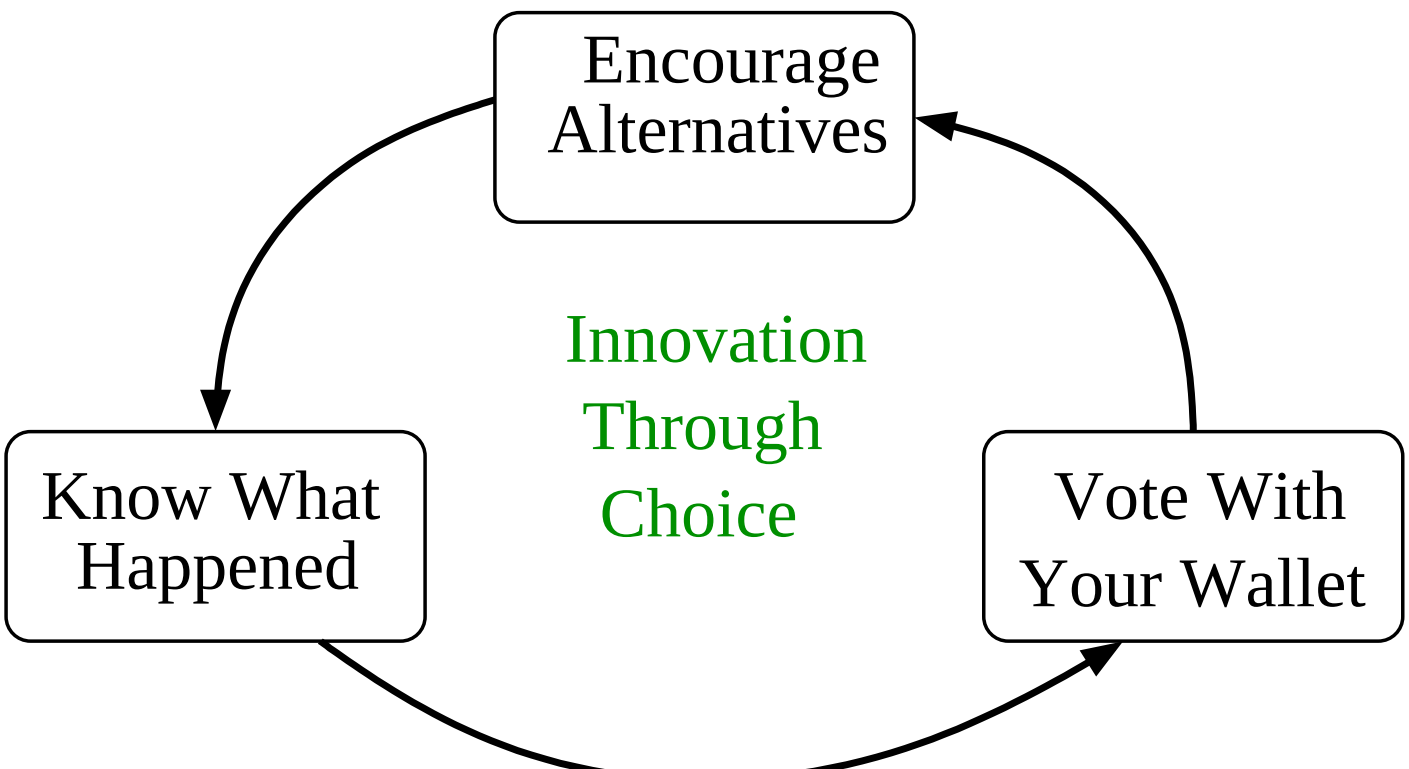




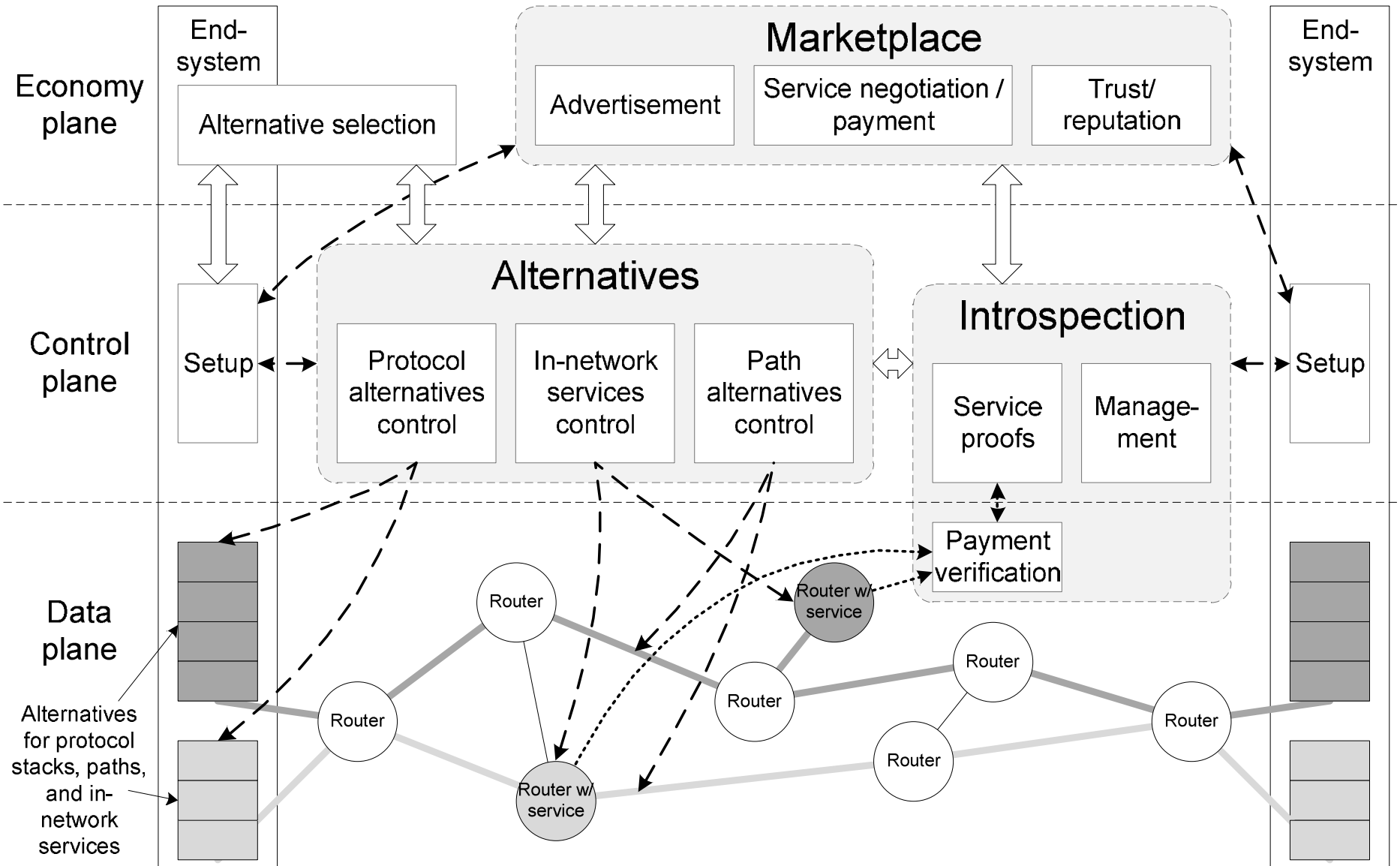
ChoiceNet: Design for Choice

- Choice a key aspect of a network architecture
  $\longrightarrow$ drive transformative innovations
- New features and mechanisms for:
  - dynamically introducing new alternatives
  - selecting among alternatives
  - introducing economic processes and incentives to trigger innovation

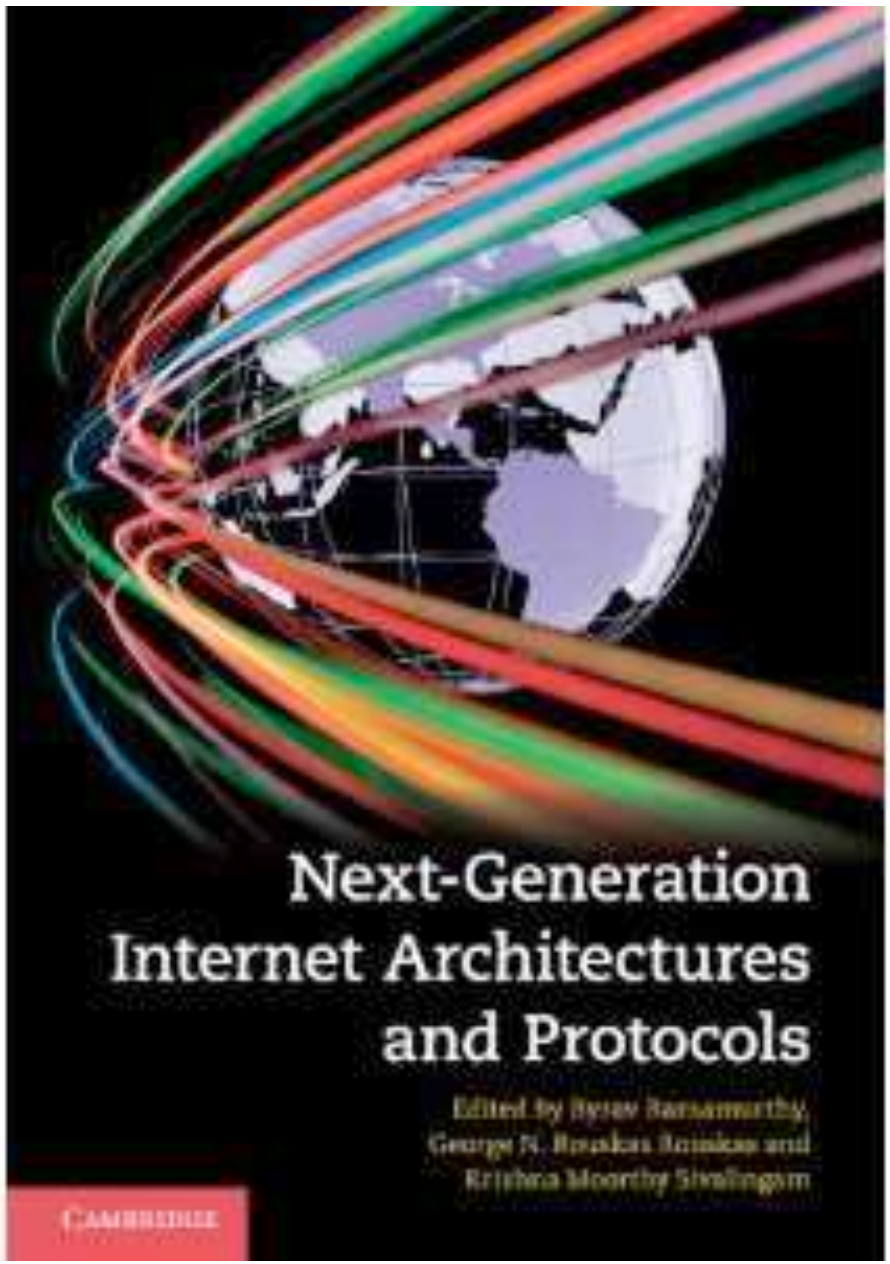
ChoiceNet: Key Principles



ChoiceNet Aspects in a Network



Recent Book


Next-Generation
Internet Architectures
and Protocols
Edited by Byrav Ramamurthy,
George N. Rouskas Rouskas and
Krishna Moorthy Sivalingam
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