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Network Virtualization: A Tutorial

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Outline

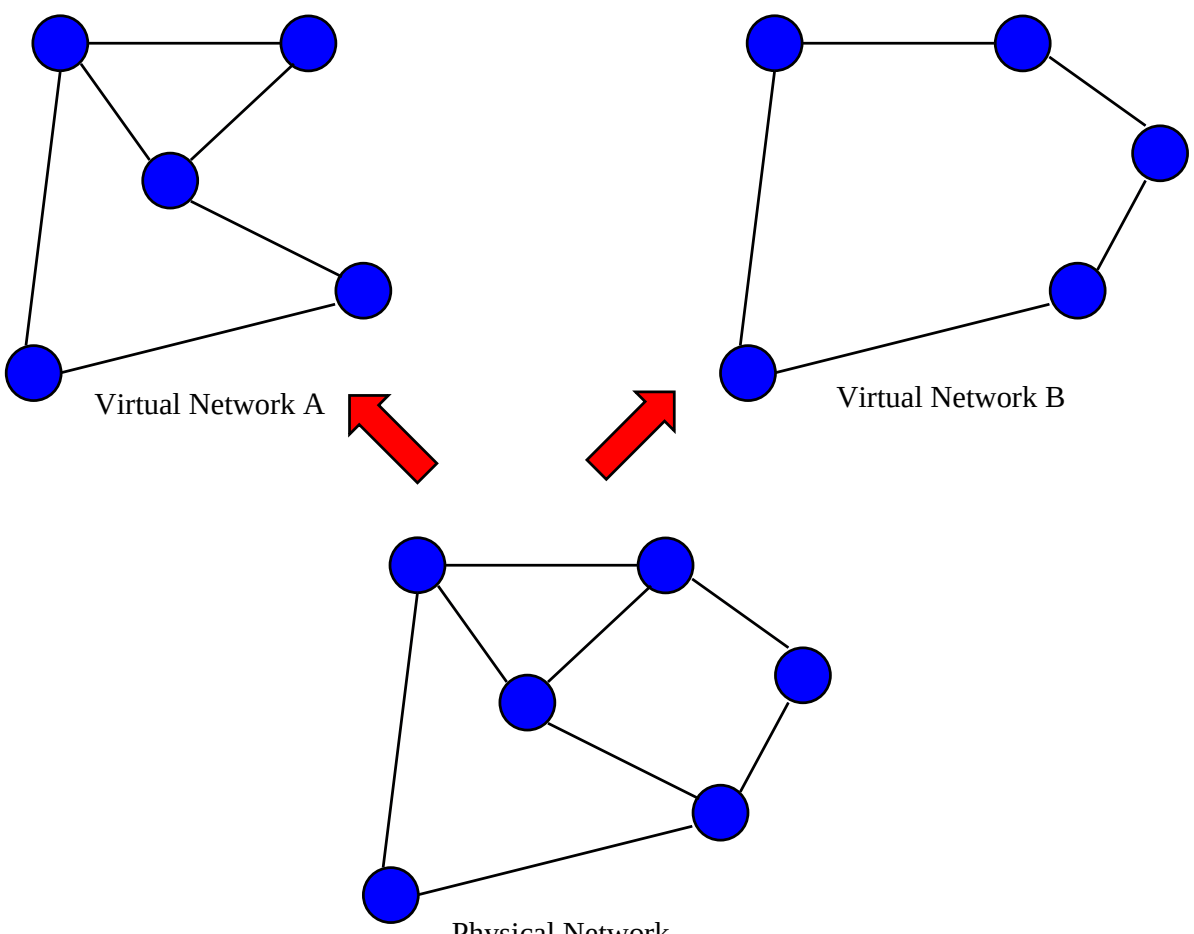
- Introduction and Historical Perspective
- Reference Model, Architectural Principles and Objectives
- Network Virtualization Projects
- Challenges and Future Directions

Virtualization As Resource Abstraction

- Virtualization: transparent abstraction of the physical computing platform and resources that supports multiple logical views of their properties
- Virtual anything
  - virtual memory
  - OS platform $\longrightarrow$ virtual machines
  - storage $\longrightarrow$ virtual SAN
  - computing $\longrightarrow$ virtual data centers

Network Virtualization

- Single physical network appears as multiple logical networks



Network Virtualization Environment

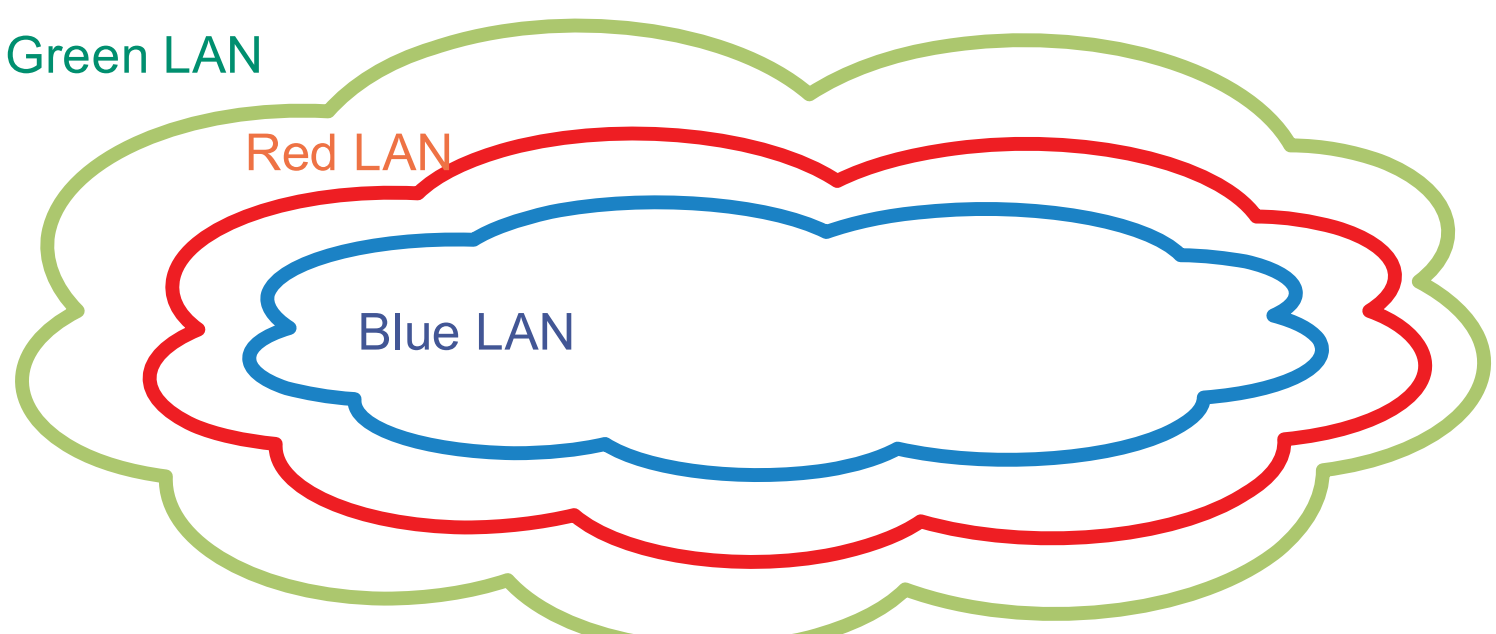
- Allows the creation of multiple virtual networks on same substrate
- Each virtual network:
  - is a collection of virtual nodes and virtual links
  - is a subset of underlying physical network resources
  - co-exists with, but is isolated from, other virtual networks

Historical Perspective

- Virtual LAN (VLAN)
- Virtual service network (VSN)
- Virtual private network (VPN)
- Active and programmable networks
- Overlay networks

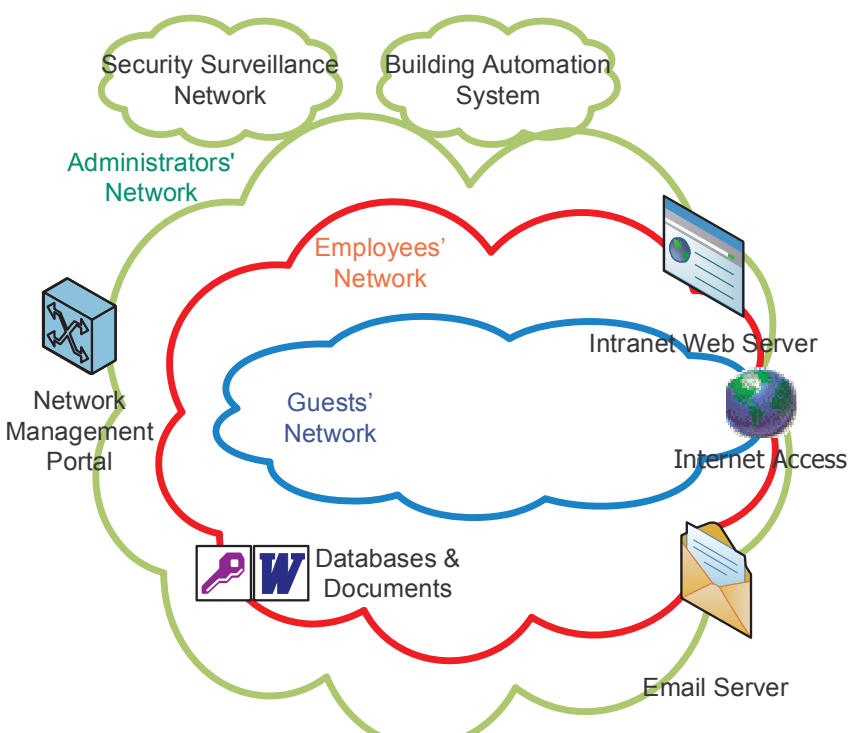
Virtual LANs

- L2 constructs, share same physical LAN infrastructure
- Groups of hosts with common interests, regardless of connectivity
- Segmented within boundary of broadcast domains → frame coloring
- High levels of trust, security, isolation, easy to configure



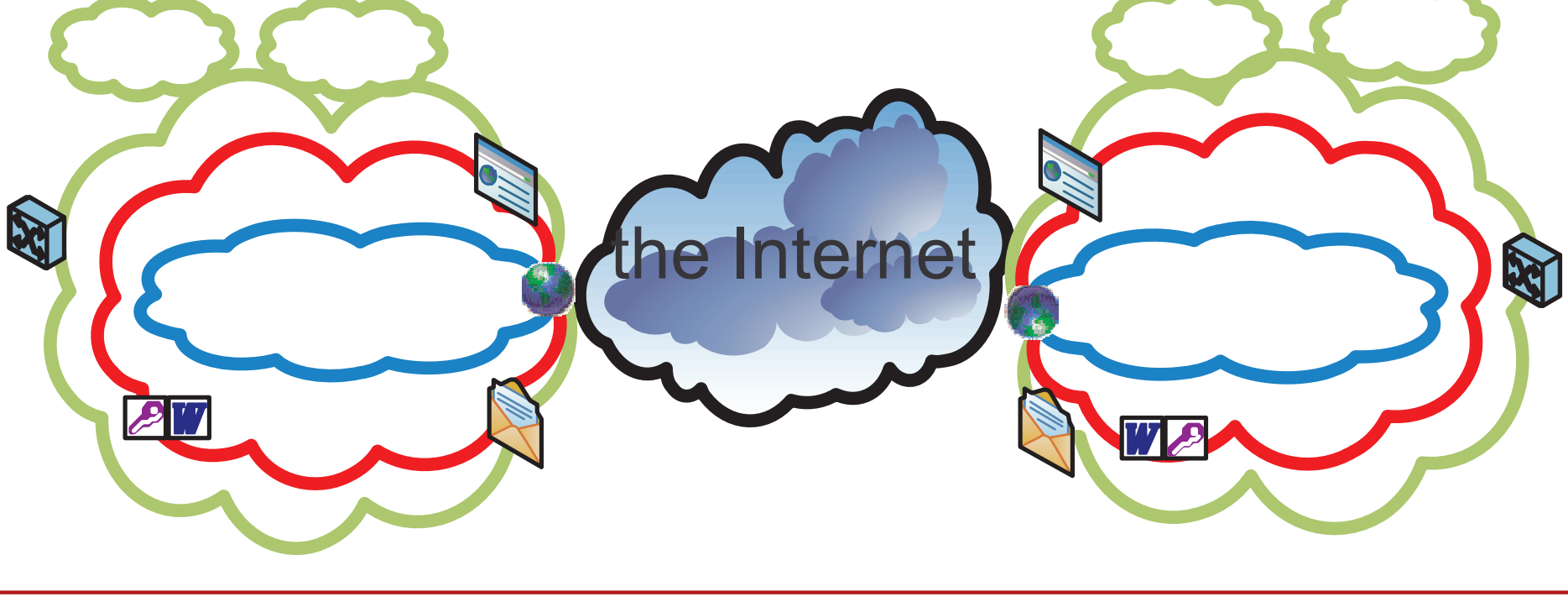
Virtual Service Networks

- Generalization of VLAN concept to broader network
- Define multiple network instances that
  - share the physical resources
  - are properly segmented (functionality, access permissions, etc.)



Virtual Private Networks

- Connect multiple sites using tunnels over public network
- L3/L2/L1 technologies
- Intranet vs. extranet
- Limited customization

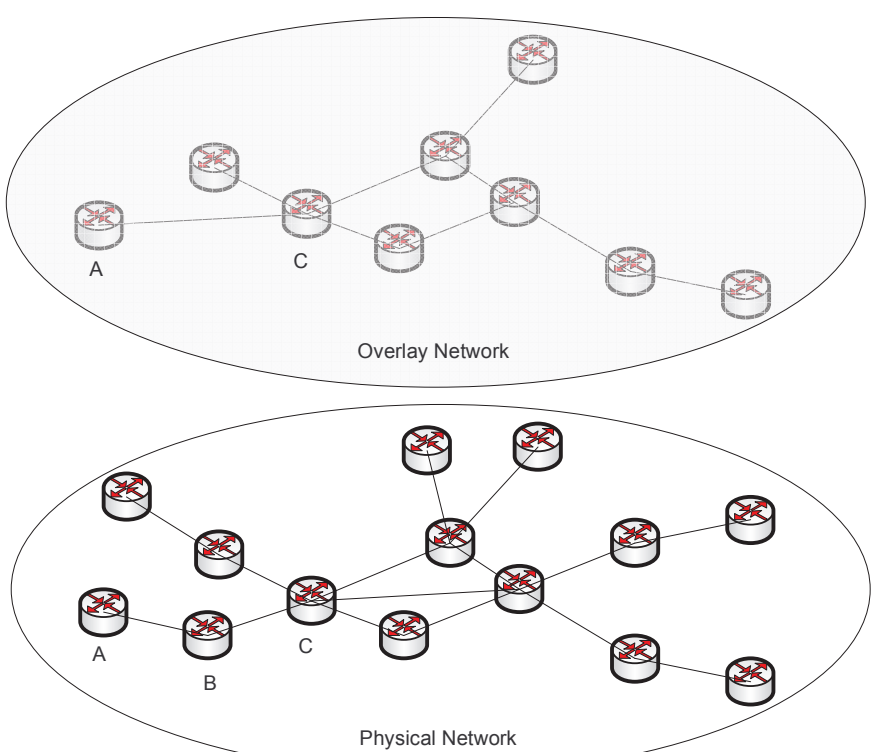


Active and Programmable Networks

- Support co-existing networks through programmability
- Customized network functionality through
  - programmable interfaces to enable access to switches/routers
  - active code
    - call functions already installed
    - allow user to execute own code at switches/routers
- Operators must open networks to third parties $\longrightarrow$ not used

Overlay Networks

- Application layer virtual networks
- Built upon existing network using tunneling/encapsulation
- Implement new services without changes in infrastructure
- Application-specific, not flexible enough



Motivation (1)

- The Internet is ossified:
  - significant innovation at application and link layers
  - only incremental changes to core protocols
    - half-layer solutions (MPLS, IPSec)
    - adapt to new contexts (TCP over wireless)
    - application overlays (CDN, ALM, OverQoS, SOS, P2P, . . .)

Motivation (2)

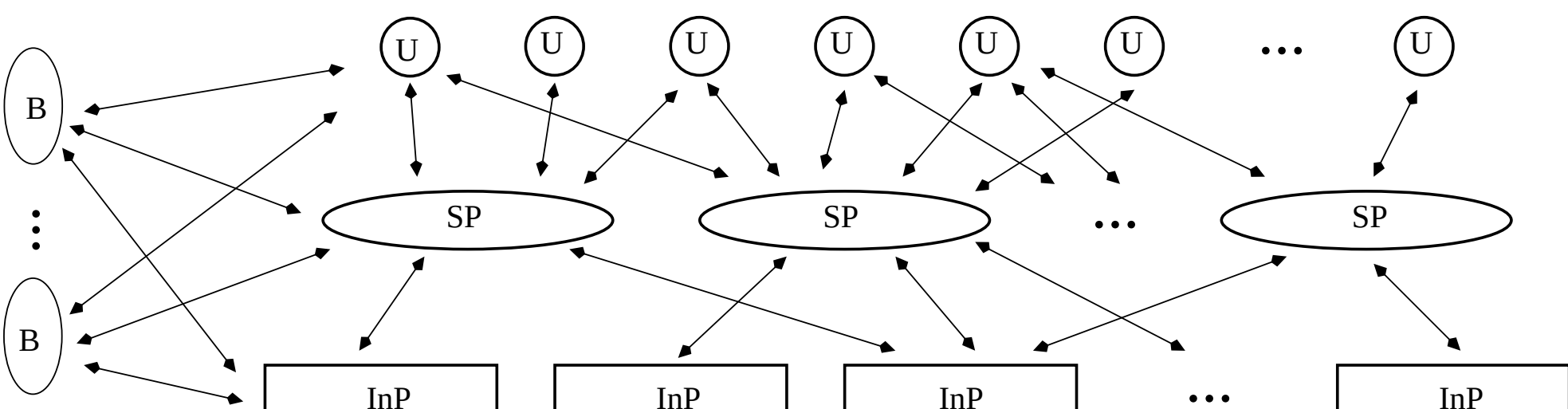
- Clean-slate architecture impossible to deploy
  - multiple stakeholders
    - conflicting goals/policies $\longrightarrow$ difficult to reach agreement
    - almost no economic incentives to introduce changes
  - defining one-size-fits-all architecture a challenge
    - depends on focus and context $\longrightarrow$ 4 distinct FIA projects
    - future needs unknown, difficult to predict
  - must accommodate installed base

Motivation (3)

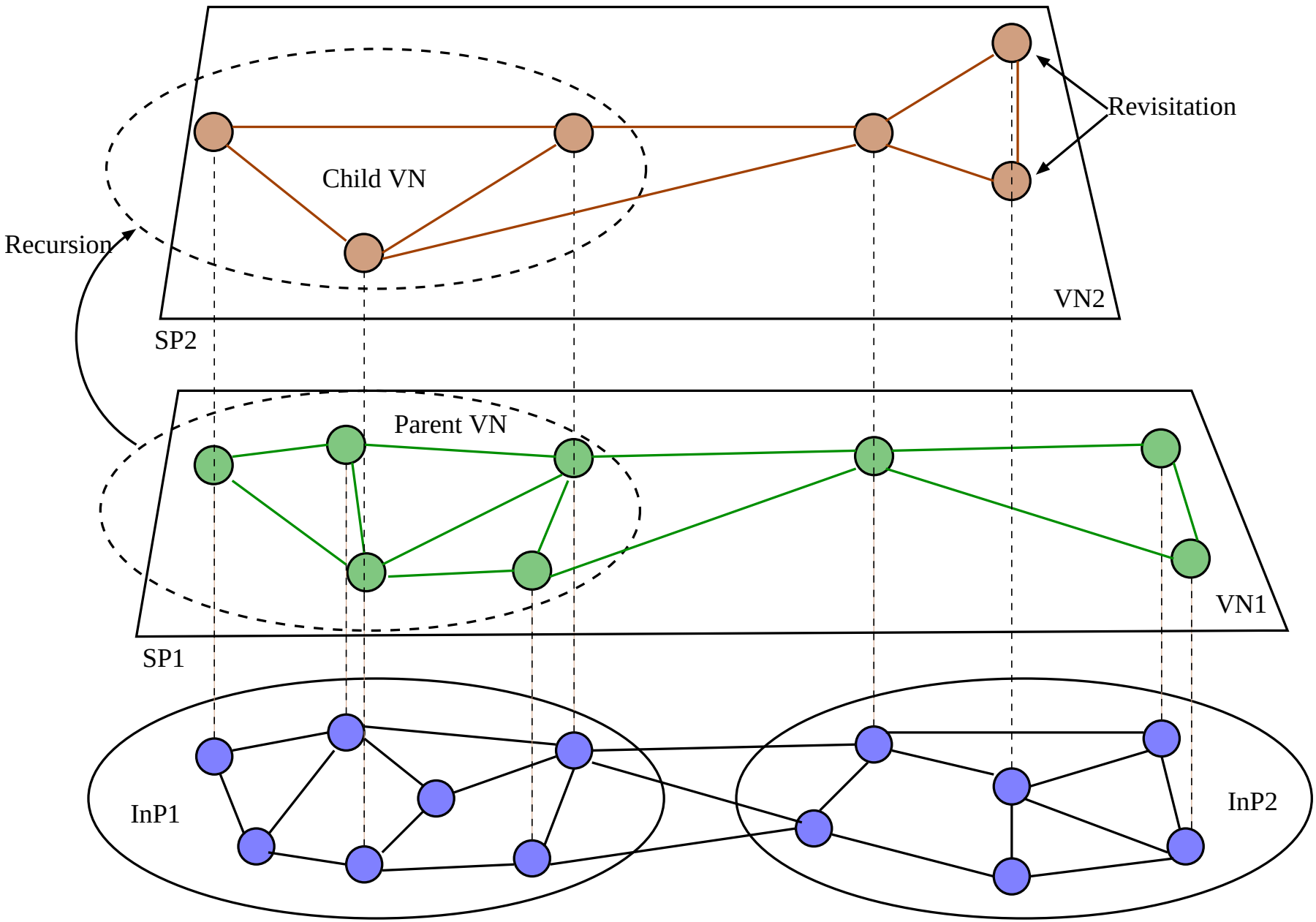
- Network virtualization offers all-sizes-fit-into-one solution
- Open and expandable model
  - multiple heterogeneous architectures on shared physical substrate
  - promotes innovation and customized services/applications
- Testbed for deployment/evaluation of new network architectures and protocols

Reference Model

- Infrastructure providers: manage physical networks
- Service providers:
  - create and manage virtual networks
  - design and deploy end-to-end services
- Users: select from competing services offered by providers
- Brokers: aggregate offers, match requirements to services/resources



Architectural Principles (1)



Architectural Principles (2)

- Concurrency:
  - multiple service providers compete
  - multiple virtual networks coexist $\longrightarrow$ diversity
- Nesting: virtual network hierarchy
  - child VNs derived from parent VNs
- Inheritance: child VN inherits architectural attributes
  - creation of value-added services
  - VN economics
- Revisitation: single physical node hosts multiple virtual nodes
  - deploy diverse functionalities
  - simplify operation and management

Design Objectives (1)

- Isolation
  - in terms of logical view, resources, operation
  - attacks, failures, bugs, misconfigurations do not affect other VNs.
- Flexibility
  - service providers may assemble VNs with customized
    - network topology
    - control and data plane functionality

    without the need to coordinate with each other
- Scalability
  - support multiple VNs
  - utilize resources efficiently

Design Objectives (2)

- Programmability
  - deploy customized protocols/services in network elements
  - at packet level or below (e.g., optical devices?)
  - how to expose to service providers/users
  - opens up vulnerabilities (active networks redux?)
- Heterogeneity
  - support a diverse set of
    - physical network technologies (wireless, sensor, optical, $\cdots$)
    - virtual network capabilities
- Manageability
  - mechanism $\longleftrightarrow$ policy
  - "know what happened" $\longrightarrow$ SPs and InPs held accountable

Design Objectives (3)

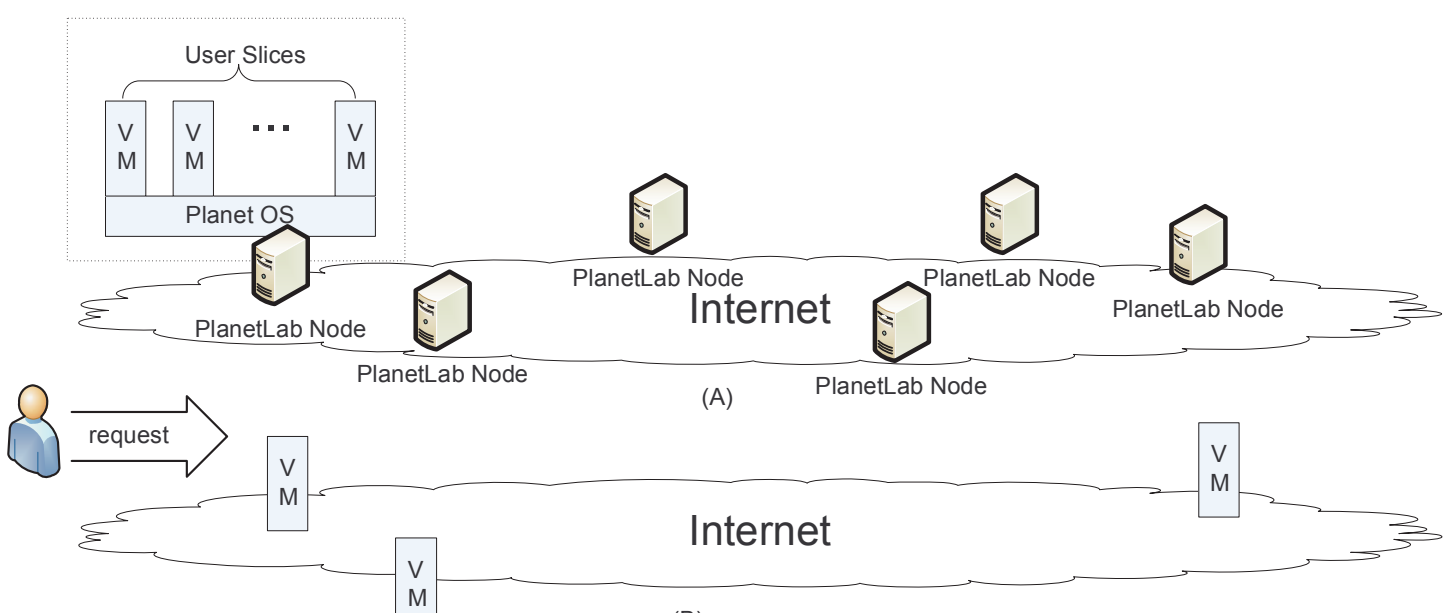
- Dual use
  - experimental and deployment facility
  - design, evaluate, and deploy new services
  - plausible pathway for adopting radically new network architectures
  - PlanetLab, GENI, VINI
- Legacy support
  - existing Internet: another instance of a VN
  - deploy IPv6 as VN $\longrightarrow$ compete with IPv4

Network Virtualization Projects: Classification

- Targeted technology
  - wired, wireless, IP, heterogeneous
- Layer (in network stack) where virtualization is introduced
  - physical $\longrightarrow$ application
- Application domain
  - specific problem domain addressed $\longrightarrow$ wide range
- Virtualization granularity
  - node, link, full

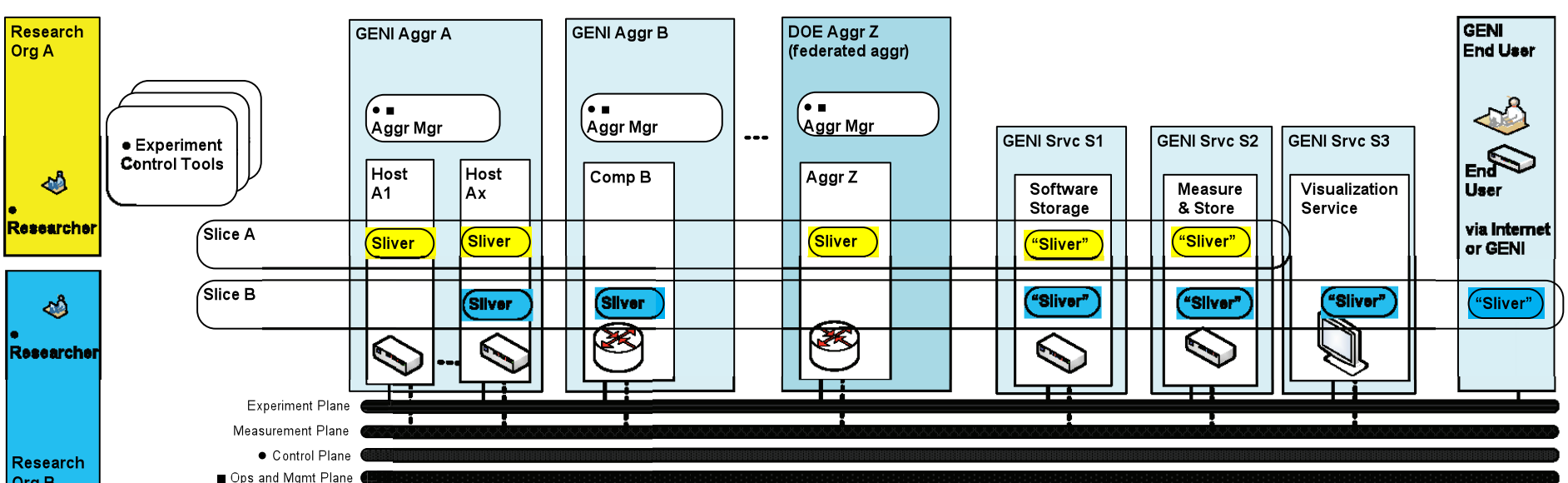
PlanetLab

- Overlay testbed for geographically distributed network services
- Service-oriented network architecture:
  - sliceability → applications acquire and run on a slice
  - decentralized control → each node subject to local policies
  - management sub-services running on own slices
  - existing, widely adopted API that does not change



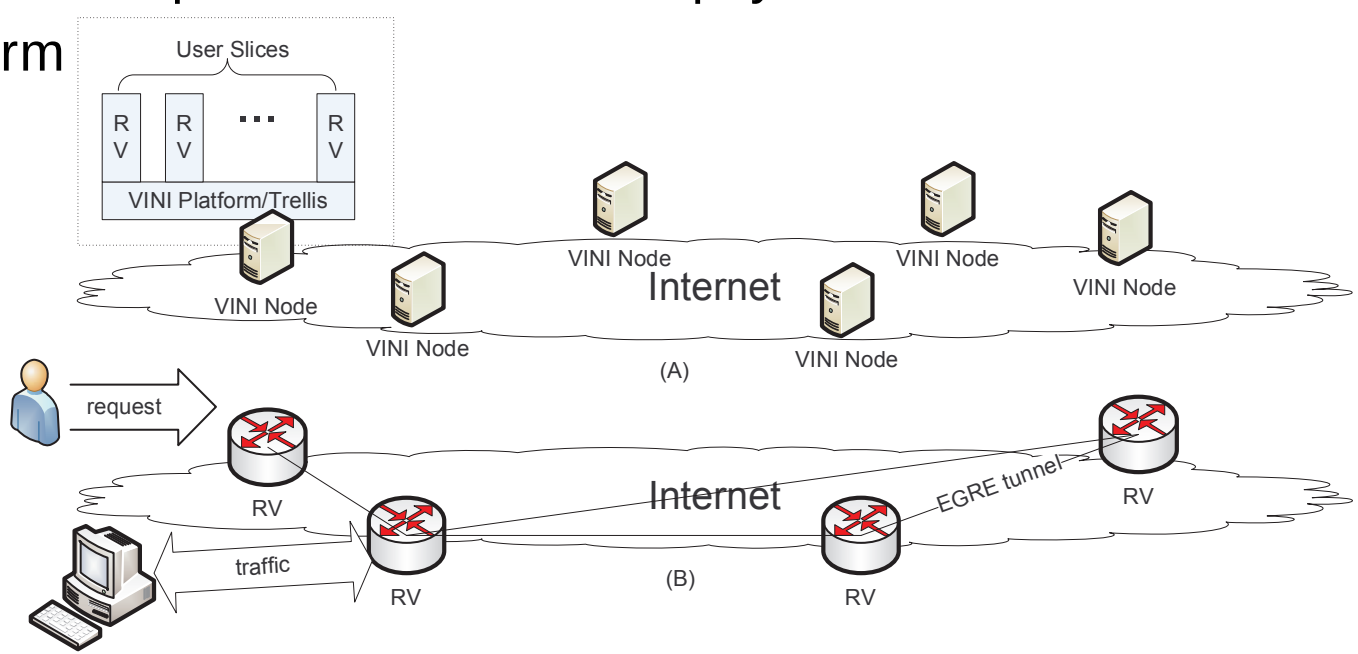
GENI

- Open large-scale experimental facility
  - for researchers: deploy and evaluate new network architectures
  - for users: carry real traffic
  - connects to Internet to reach external sites
- Supports slices of resources partitioned in space and time



VINI and Trellis

- Virtual network infrastructure: infrastructure + support for VNs
- Extends PlanetLab:
  - each virtual node is a router → better routing control
  - tools to create tunnels between virtual nodes
  - realistic simulations by directing traffic to/from outside world
- PL-VINI PlanetLab implementation → own physical testbed w/ Trellis software platform



VIOLIN

- Application level virtual network architecture
- Virtual networks created in software
  - vRouters, vLANs, vHosts $\longrightarrow$ VMs on physical overlay hosts
- Complete isolation between VNs using VM technologies
- Secure, confined, dedicated environment for
  - performing risky experiments
  - deploy untrusted applications
- VIOLIN software implemented within Linux UML container
  - may run in PlanetLab slide
  - independent of PlanetLab, may run on other testbeds

Network Management

- X-Bone: a tool to deploy overlay networks across the Internet
  - automated configuration and management of overlay networks
  - support for resource discovery/allocation, monitoring, isolation
  - $\longrightarrow$ VI: IP net of tunneled links among virtual hosts/routers
- UCLP: set of software tools in the form of Web services
  - end users dynamically provision/reconfigure optical networks (L1)
    - concatenate/divide lightpaths within domain or across domains
    - create customized logical IP networks

Full Virtualization

- CABO: concurrent architectures are better than one
  - exploits virtualization to separate InPs from SPs
  - supports programmable routers
    - users cannot program the network
    - SPs customize their network to provide end-to-end services
  - virtual router migration, accountability, multi-layer routing
- 4WARD: early-stage effort, little implementation
  - promises to bring NV to end users, not just experimenters
  - carrier-grade virtualization of network resources
  - trusted commercial setting for instantiation/inter-operation of VNs
  - InPs, VNPs (similar to SPs), VNOs (brokers, connect customers to services)

The Holy Grail of Network Virtualization

- A network environment in which multiple SPs:
  - lease underlying physical resources from multiple InPs
  - dynamically compose heterogeneous VNs
    - co-exist in isolation within same physical infrastructure
  - compete with each other by
    - deploying customized E2E services on-the-fly
    - managing the services on the VNs for the end users
    - effectively sharing and utilizing the physical resources

How to Get There: Future Directions (1)

- Instantiation: creating VNs
  - resource discovery (within/across InP domains, discovery plane?)
  - VN mapping: online/offline $\longrightarrow$ NP-hard problem
  - signaling VN requests, bootstrapping VNs
  - API (request format, programmability of NEs)
- Logistics: operating VNs
  - virtual routers: performance, scalability, migration
  - virtual links: link scheduling, cross-InP links
  - resource (CPU, disk, link b/w) scheduling $\longrightarrow$ max VN instances
  - naming and addressing
  - failure handling: isolation, no cascade effects

How to Get There: Future Directions (2)

- Management:
  - mobility of end users, virtual routers, logical mobility of users across VNs
  - configuration and monitoring, down to low level NEs
  - responsibilities of InPs $\leftrightarrow$ SPs
  - support for multiple management paradigms
- Participant interactions:
  - technology agnostic: E2E VNs across wireless, sensor, optical, $\cdots$, resources
  - inter-VN sharing of information
  - economics: resource trading, market creation