A Decomposition-Based Architecture for Distributed Virtual Network Embedding

Flavio Esposito

Advanced Technologies

St.Louis, MO

Ibrahim Matta

Computer Science Department

Imagine a world without knobs

We have knobs to tune what's important to us

House's Behavior (Electrical)

oven, air conditioning, …

Car's Behavior (Mechanical)

speed, music volume, …

Organ's Behavior (Biological)

diabetes, dopamine, hormones, …

Wouldn’t it be great to have knobs for protocols too?

Algorithmic tradeoffs

e.g., converge speed vs performance optimality

Design tradeoffs

e.g., centralized or distributed

Implementation tradeoffs

e.g., support for delay or BW sensitive app

Ad-hoc protocol development prevents quick adaptation

Small Cloud-based **Startup**

Adaptation is the key to survive
code to customers needs quickly

Medium-size **Enterprise**

Slower growth: can't afford clean-slate
too much to change: this one works!
…till when?

Big Cloud **Provider**

Ossification (see Internet)
only few dominate the cloud market

Need for a Cloud easier and cheaper to manage

"Management is responsible for 80% of IT budget"

yankee group *responsible for 62% of outages"*

Millions of dollars are spent in support of many protocols and apps with different requirements

Virtual Network Embedding is a Constrained Graph Matching

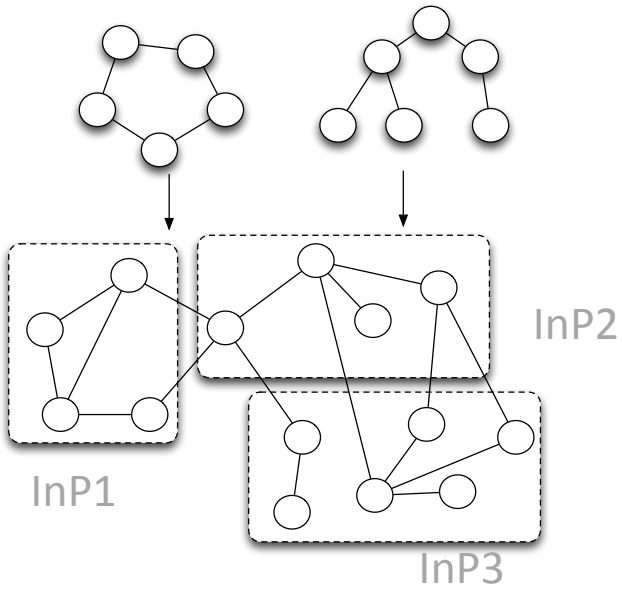
Shared Infrastructure

Virtual networks

Possibly multiple:

Service **P**roviders (SPs)

Infrastructure **P**roviders (InPs)



Use our architecture to customize distributed VN embedding solutions

Apply decomposition techniques to VN Embedding solved as network utility maximization problem.

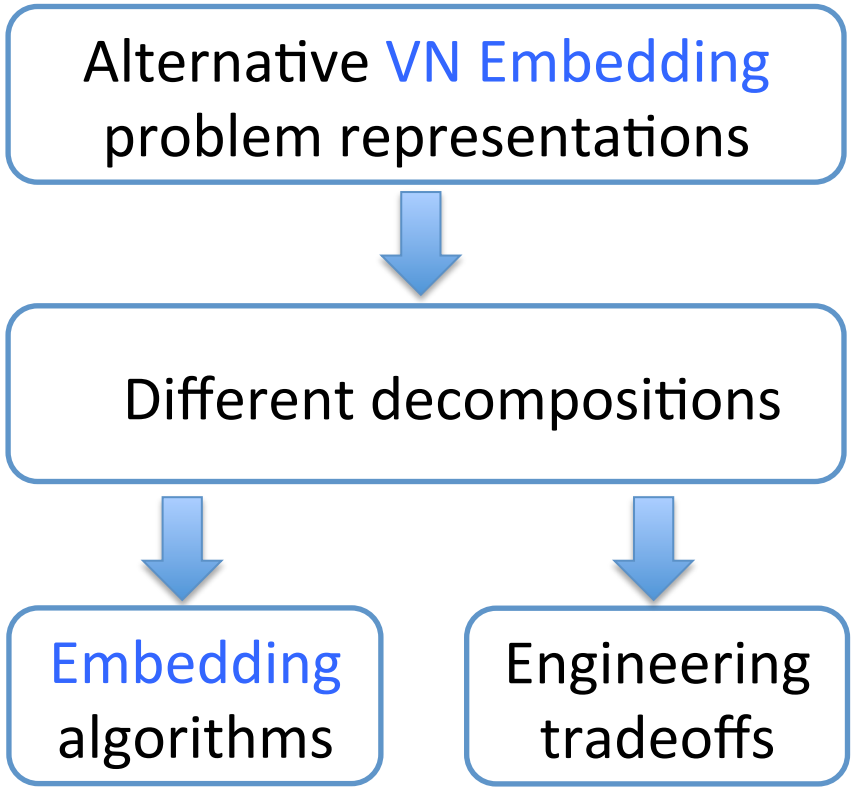
Obtain distributed algorithms with different goals that suit needs of specific applications

Can you model your problem as Network Utility Maximization?

Different instantiation of the optimization problem

Different policies

Different implications



Our Contributions (Talk Outline)

To separate policies from VN embedding mechanisms

Unifying VN Embedding Architecture
identifying the invariances of the problem

To adapt embedding to providers' goals

Design new and subsume embedding solutions
instantiating different decomposition policies

To enable experiments with new VN embedding policies

Tradeoff analysis over simulation & prototype
implemented over a local Linux-based testbed

Identification of Mechanisms

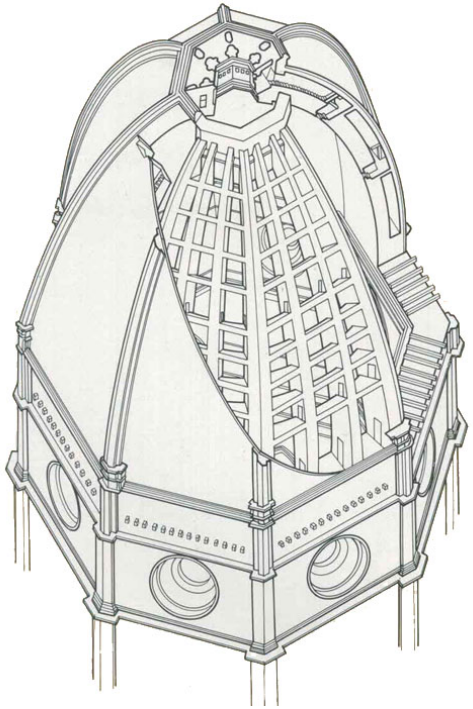
To separate policies from VN embedding mechanisms

Unifying VN Embedding Architecture
Identifying the invariances of the problem

Design new and subsume embedding solutions
Instantiating different decomposition policies

Tradeoff analysis over simulation & prototype implemented over a local Linux-based testbed

An architecture identifies the invariances in a problem



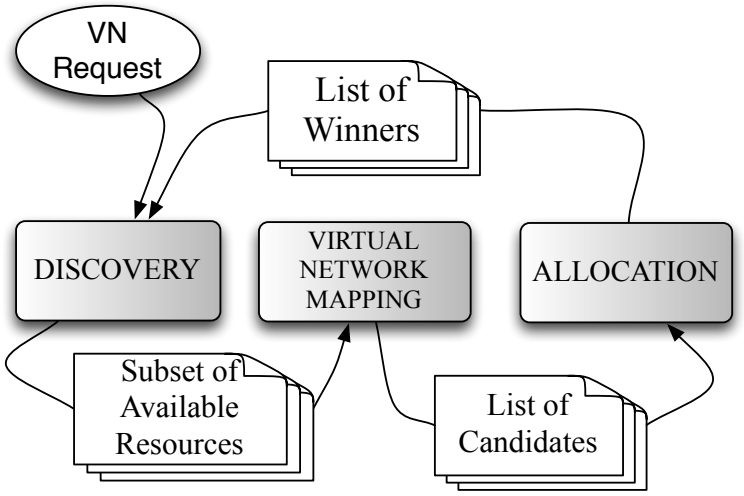
What is an architecture?

1. Identify **mechanisms**
   (invariances)
2. Identify **who does what**
   (separation of functionalities)

What is a policy? (variant aspect of a mechanism)

Provider policies
to host virtual nodes & links

Three common mechanisms interfaced by binding constraints

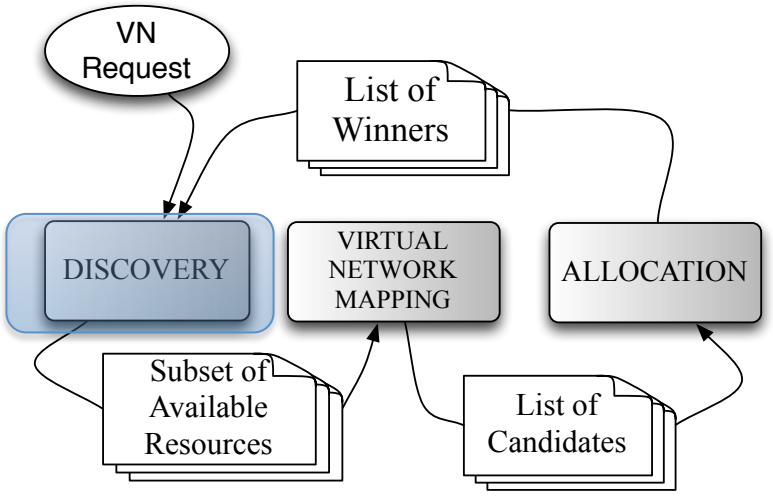


Three common mechanisms interfaced by binding constraints

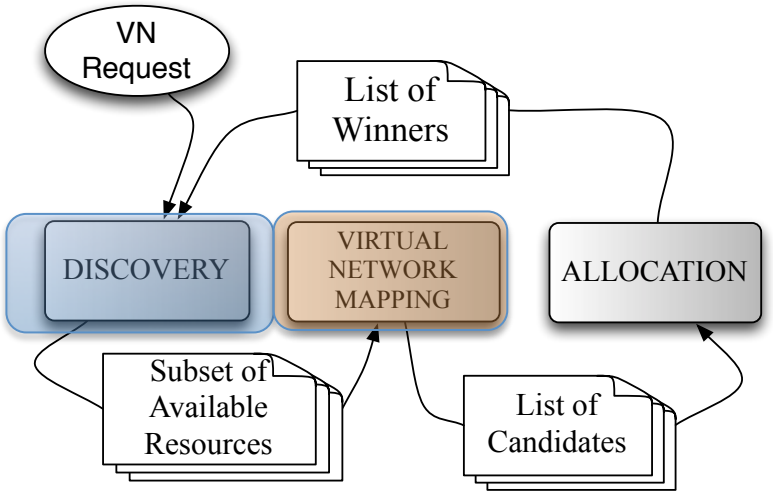
Maximize Discovery

subject to: Discovery p-nodes

Discovery p-paths



Three common mechanisms interfaced by binding constraints



Maximize Discovery Mapping

subject to: Discovery p-nodes

Discovery p-paths

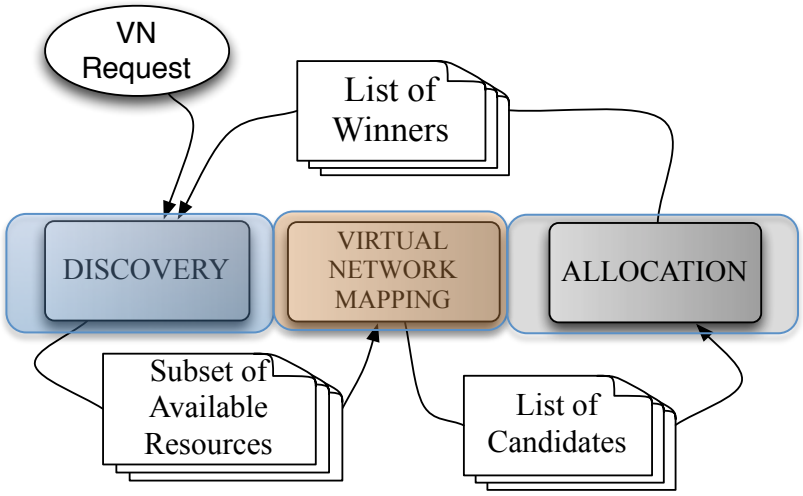
Mapping all v-nodes

Mapping all v-links

Map v-nodes to p-nodes

Map v-links to p-paths

Three common mechanisms interfaced by binding constraints



Maximize Discovery Mapping Allocation

subject to:

Discovery p-nodes

Discovery p-paths

Mapping all v-nodes

Mapping all v-links

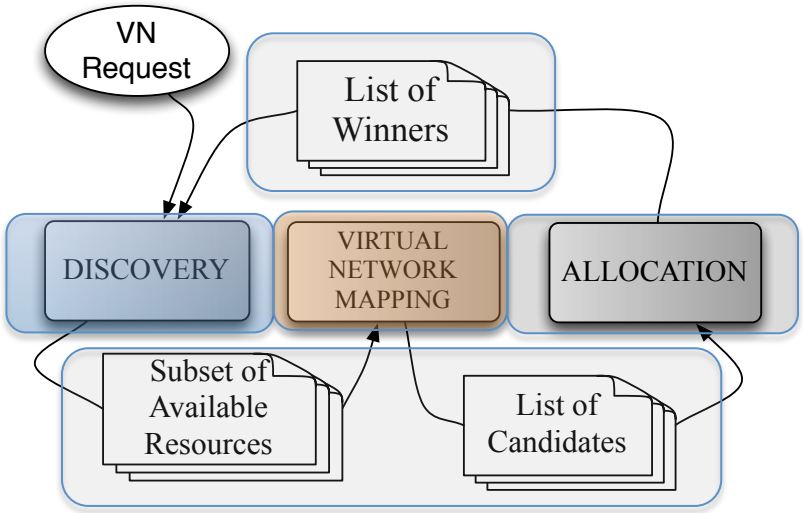
Map v-nodes to p-nodes

Map v-links to p-paths

P-nodes capacity

P-links capacity

Three common mechanisms interfaced by binding constraints



Maximize Discovery Mapping Allocation

subject to:

Discovery p-nodes

Discovery p-paths

Mapping all v-nodes

Mapping all v-links

Map v-nodes to p-nodes

Map v-links to p-paths

P-nodes capacity

P-links capacity

Binding Constraints

Different decompositions for different distributed (VN embedding) solutions

To separate policies from VN embedding mechanisms

Unifying VN Embedding Architecture identifying the invariances of the problem

To adapt embedding to providers' goals

Design new and subsume embedding solutions instantiating different decomposition policies

Enable experiments with new embedding policies

Tradeoff analysis over simulation & prototype implemented over a local Linux-based testbed

The structure of the problem is rich
so many decompositions are possible

Primal Decomposition

Dual Decomposition

The structure of the problem is rich so many decompositions are possible

Solve fixing **Variables:** **Primal** Decomposition

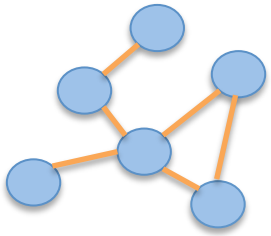
Solve relaxing **Constraints:** **Dual** Decomposition

The structure of the problem is rich so many decompositions are possible

Solve fixing **Variables:** **Primal** Decomposition
Master: assigns ph.resources to subproblems
Subproblems: embed given available resources

Solve relaxing **Constraints:** **Dual** Decomposition
Master: sets prices of all virtual resources
Subproblems: embed given resource prices

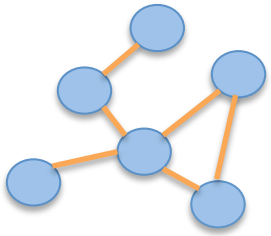
Primal: decompose fixing decision variables



Fix nodes & links
decision variables

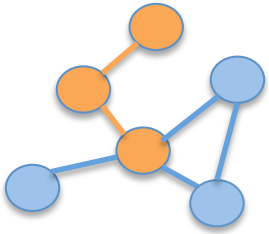
Optimize virtual nodes then links
using the optimal node embedding
see e.g. [9,20]

Primal: decompose fixing decision variables



Fix nodes & links decision variables

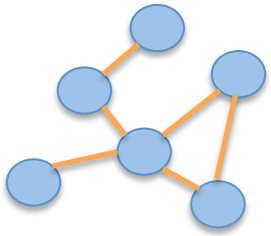
Optimize virtual nodes then links
using the optimal node embedding
see e.g. [9,20]



Fix sub-VN decision variables

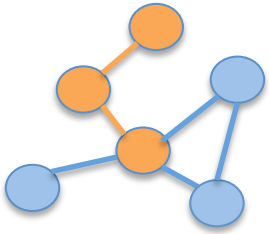
Optimize nodes & links of first VN partition
then nodes & links of the next VN partition
see e.g. [14,15]

Primal: decompose fixing decision variables



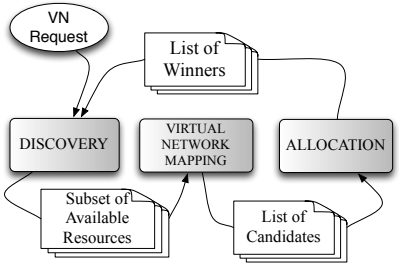
Fix nodes & links decision variables

Optimize virtual nodes then links
using the optimal node embedding
see e.g. [9,20]



Fix sub-VN decision variables

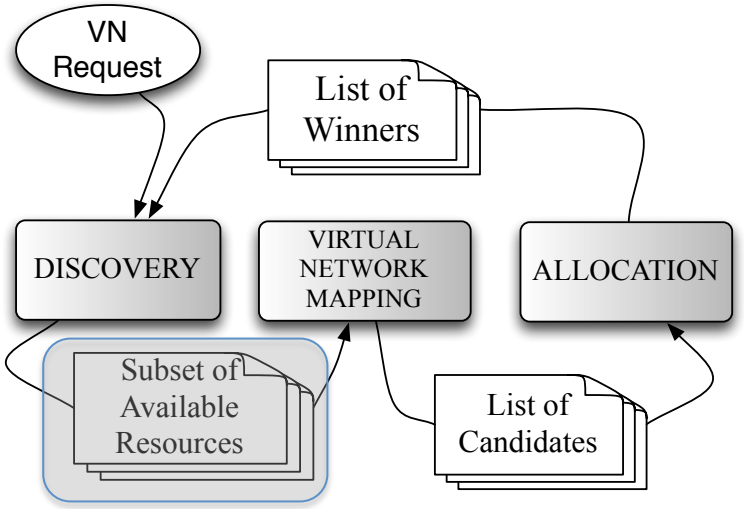
Optimize nodes & links of first VN partition
then nodes & links of the next VN partition
see e.g. [14,15]



Fix subproblems decision variables

Discovery and/or Mapping and/or Allocation
Optimize only some embedding mechanisms
see e.g. [6,18]

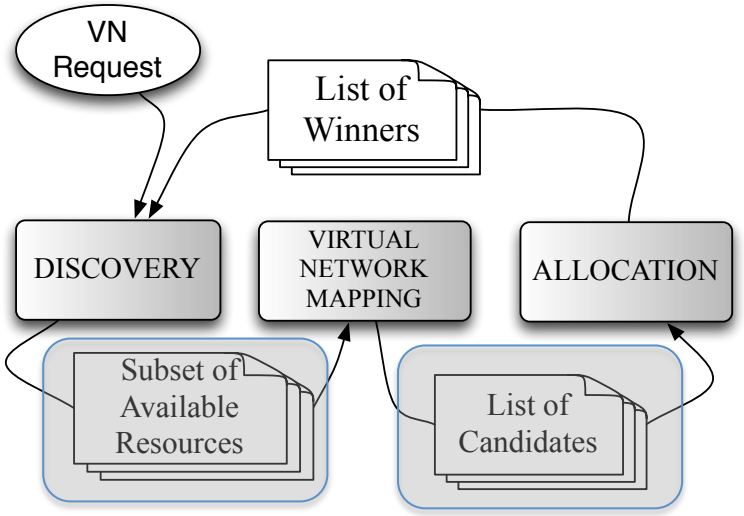
Dual: decompose relaxing constraints



Relax binding constraints between Discovery and VN Mapping phase

see e.g. [2,12]

Dual: decompose relaxing constraints



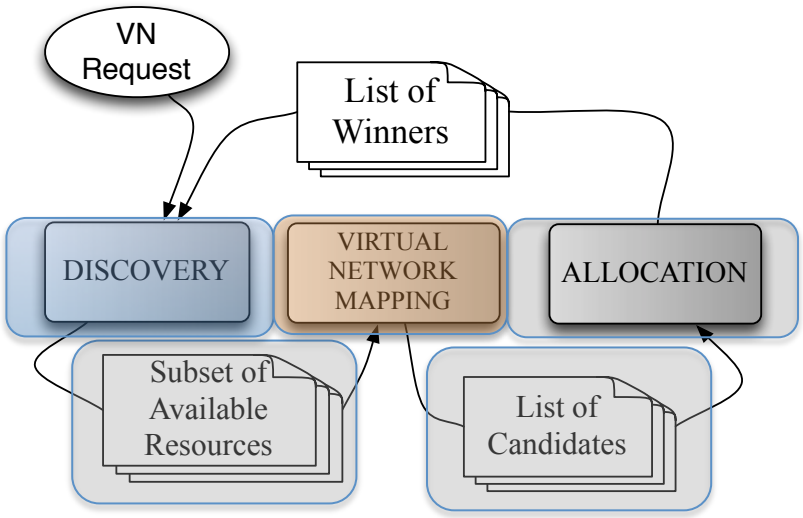
Relax binding constraints between Discovery and VN Mapping phase

see e.g. [2,12]

Relax binding constraints between VN Mapping & **Allocation phase**

see e.g. [14]

Dual: decompose relaxing constraints



Relax binding constraints between Discovery and VN Mapping phase

see e.g. [2,12]

Relax binding constraints between VN Mapping & **Allocation phase**

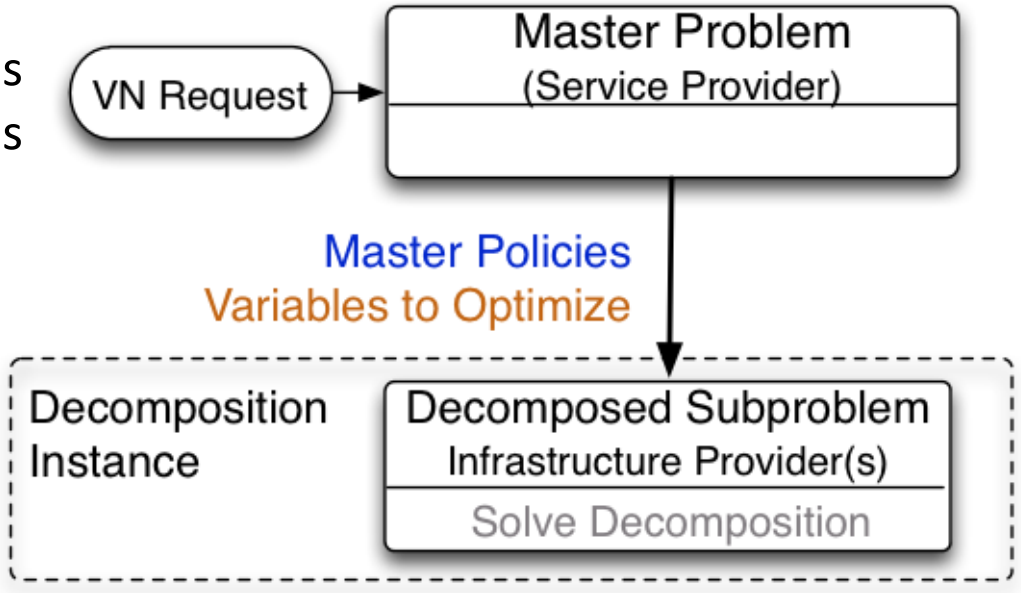
see e.g. [14]

Relax any non-binding constraints

[your papers here]

Use primal and dual to design your VN embedding solution

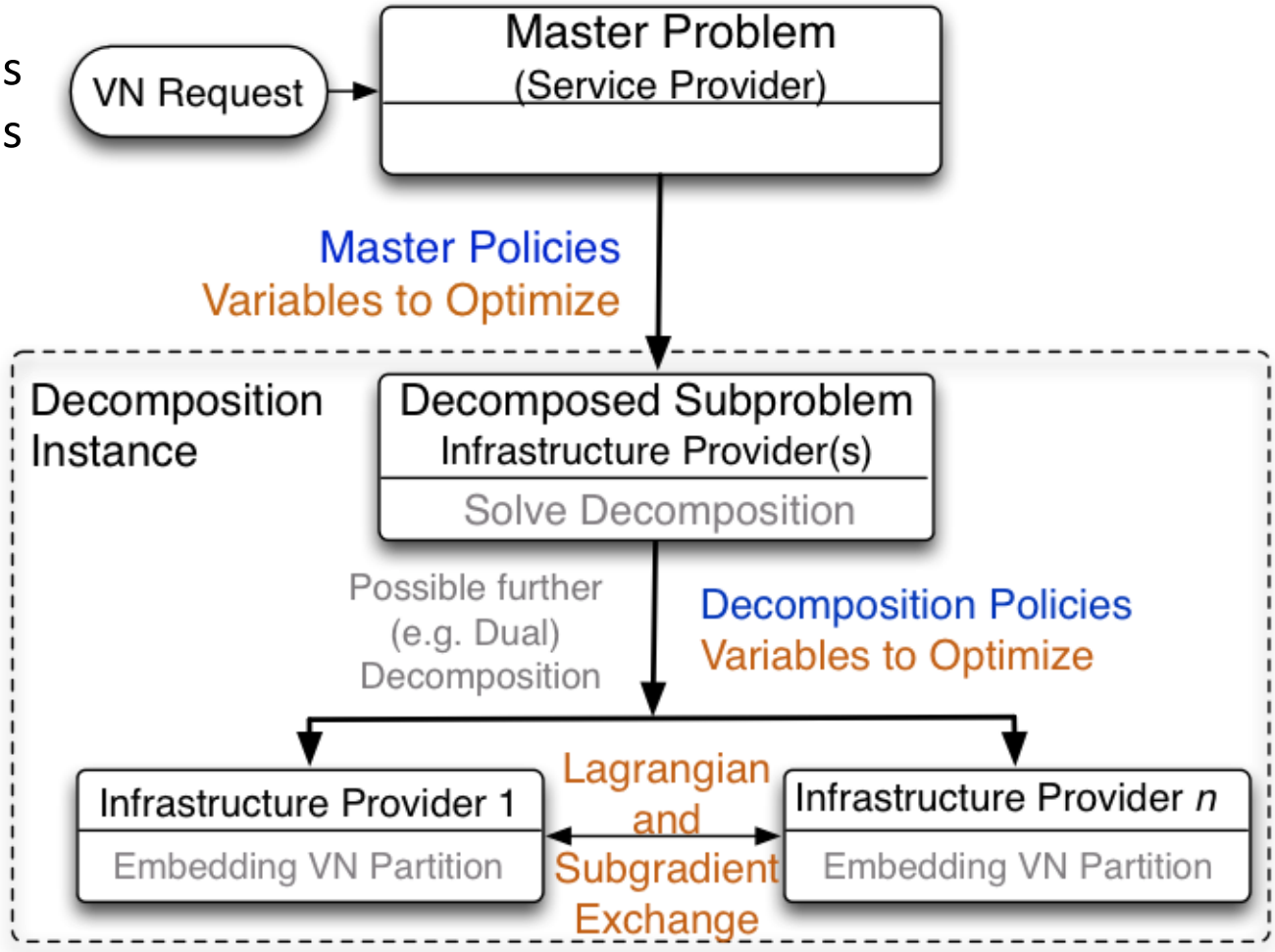
Service Provider instantiates according to its policies



Use primal and dual to design your VN embedding solution

Service Provider instantiates according to its policies

Infrastructure Providers Solve it (decomposing)

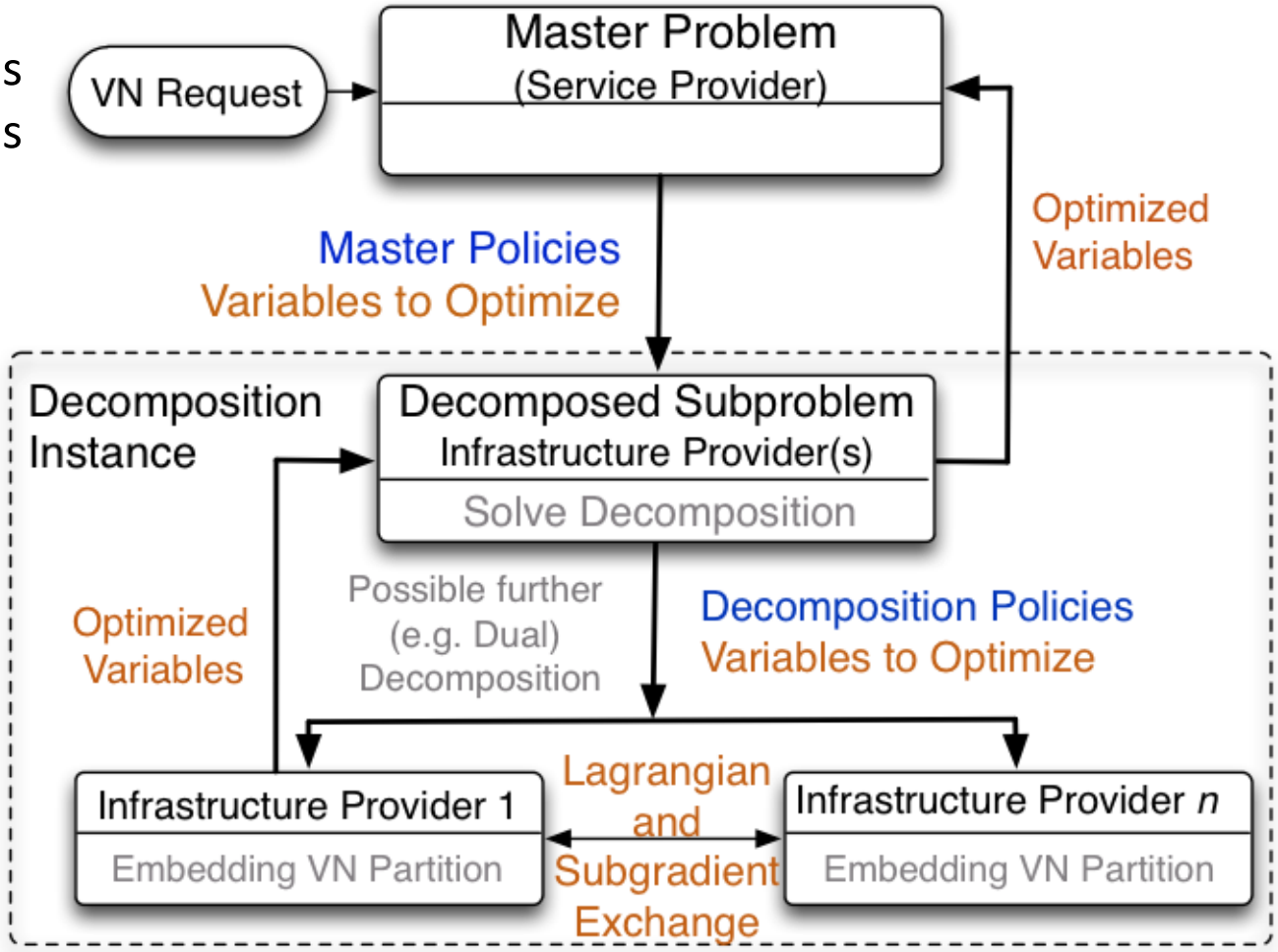


Use primal and dual to design your VN embedding solution

Service Provider instantiates according to its policies

Infrastructure Providers Solve it (decomposing)

Optimal are returned to SP that releases next VN



Testing different decompositions over our VN embedding Prototype

To separate policies from VN embedding mechanisms

Unifying VN Embedding Architecture
Identifying the invariances of the problem

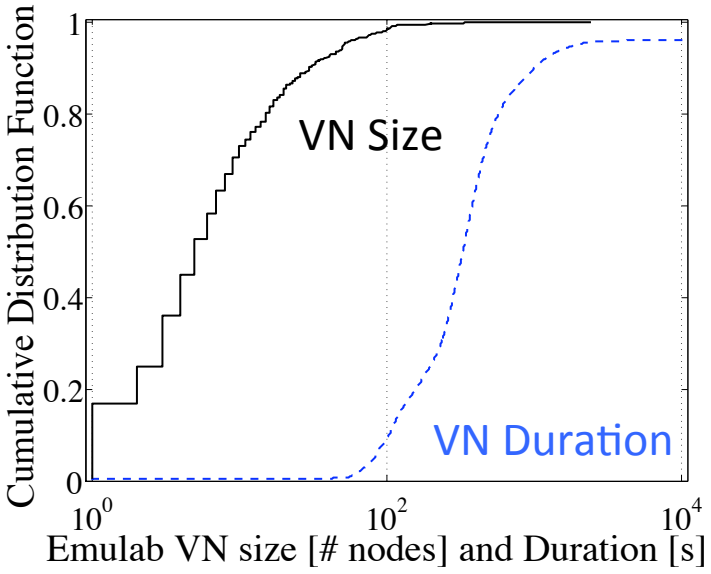
To adapt embedding to providers' goals

Design new and subsume embedding solutions
Instantiating different decomposition policies

Enable experiments with new embedding policies

Tradeoff analysis over simulation & prototype
Implemented over a local Linux-based testbed

8 Years of real Emulab VN requests used in our CPLEX Simulations



62,000 Emulab requests ’01 to ’09

Virtual Topologies

Range of VN size [1, 100]

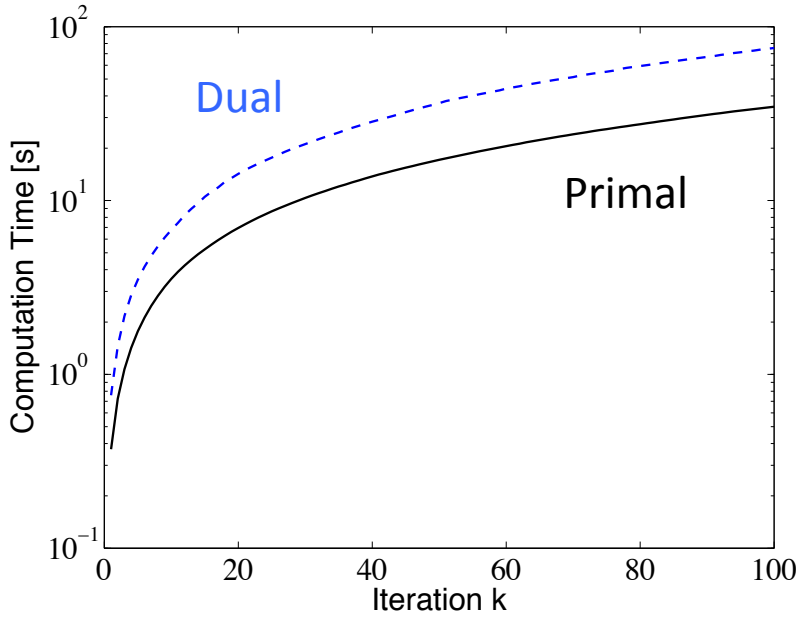
Physical Topologies

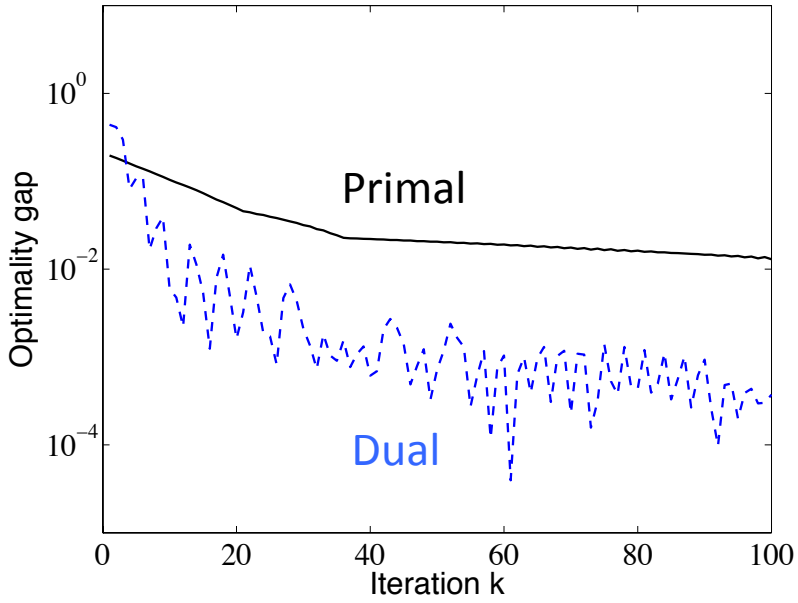
Waxman and Barabasi-Albert with BRITE

Performance Metrics

Computational Time, Optimality

Primal has lower computation time
Dual has lower optimality gap





CPLEX-based VN Embedding Simulator

We release our VINEA testbed for VINO objects instantiation

VIrtual Network Embedding Architecture

VIrtual Network Objects (VINO)

We release our VINEA testbed for VINO objects instantiation

VIrtual Network Embedding Architecture

VIrtual Network Objects (VINO)

VINEA nodes join a private overlay
after authentication and policy exchange

InPs run the VN Mapping Protocol
asynchronous consensus-based

Virtual resources are reserved
using vSwitch and Linux traffic control

We release our VINEA testbed for VINO objects instantiation

VIrtual Network Embedding Architecture

VIrtual Network Objects (VINO)

Discovery

VINEA nodes join a private overlay
after authentication and policy exchange

VN Mapping

InPs run the VN Mapping Protocol
asynchronous consensus-based

Allocation

Virtual resources are reserved
using vSwitch and Linux traffic control

The embedding protocol runs on a private overlay

Virtual Network Embedding Architecture

Virtual Network Objects

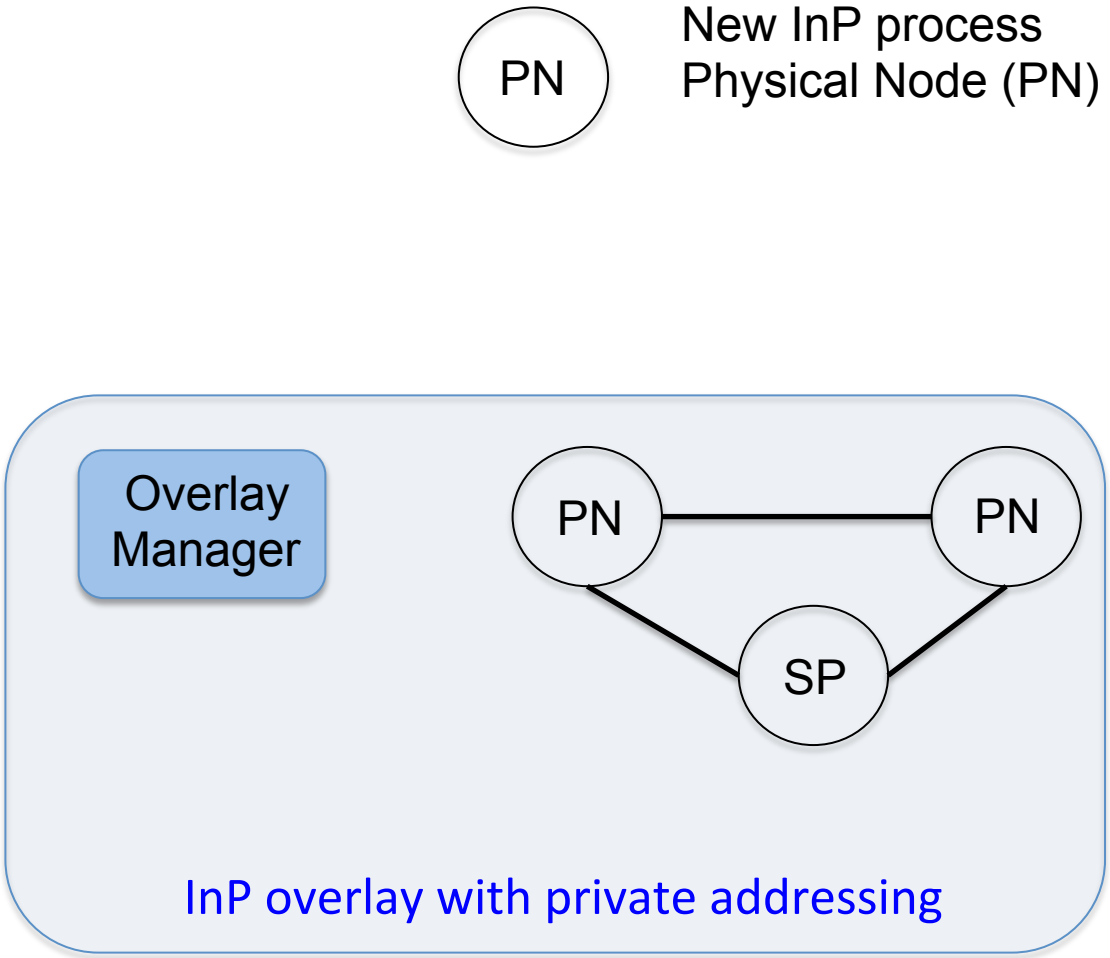
Discovery

VINEA nodes join a private overlay
after authentication and policy exchange

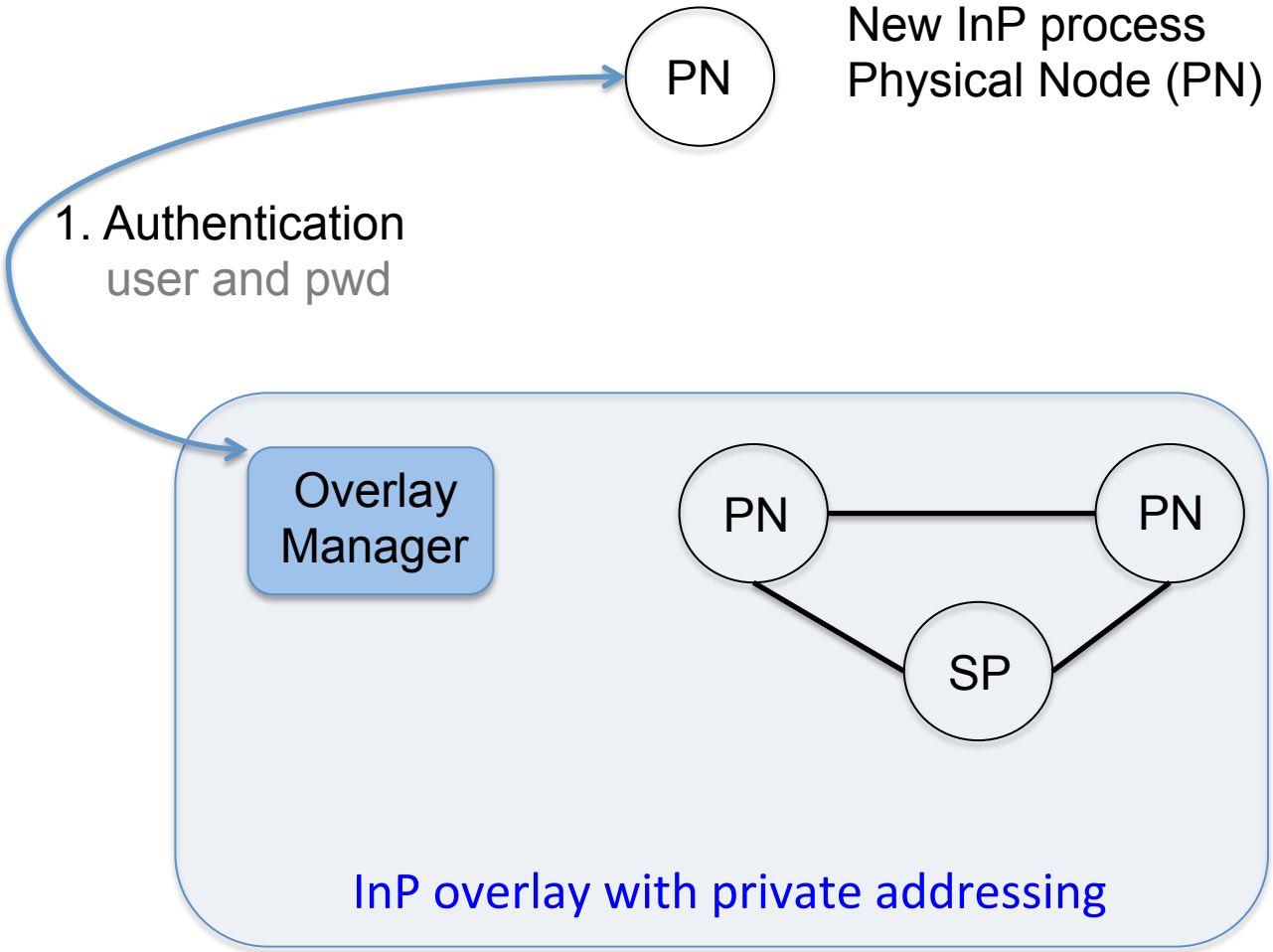
VN Mapping
InPs run the VN Mapping Protocol
asynchronous consensus-based

Allocation
Virtual resources are reserved
using vSwitch and Linux traffic control

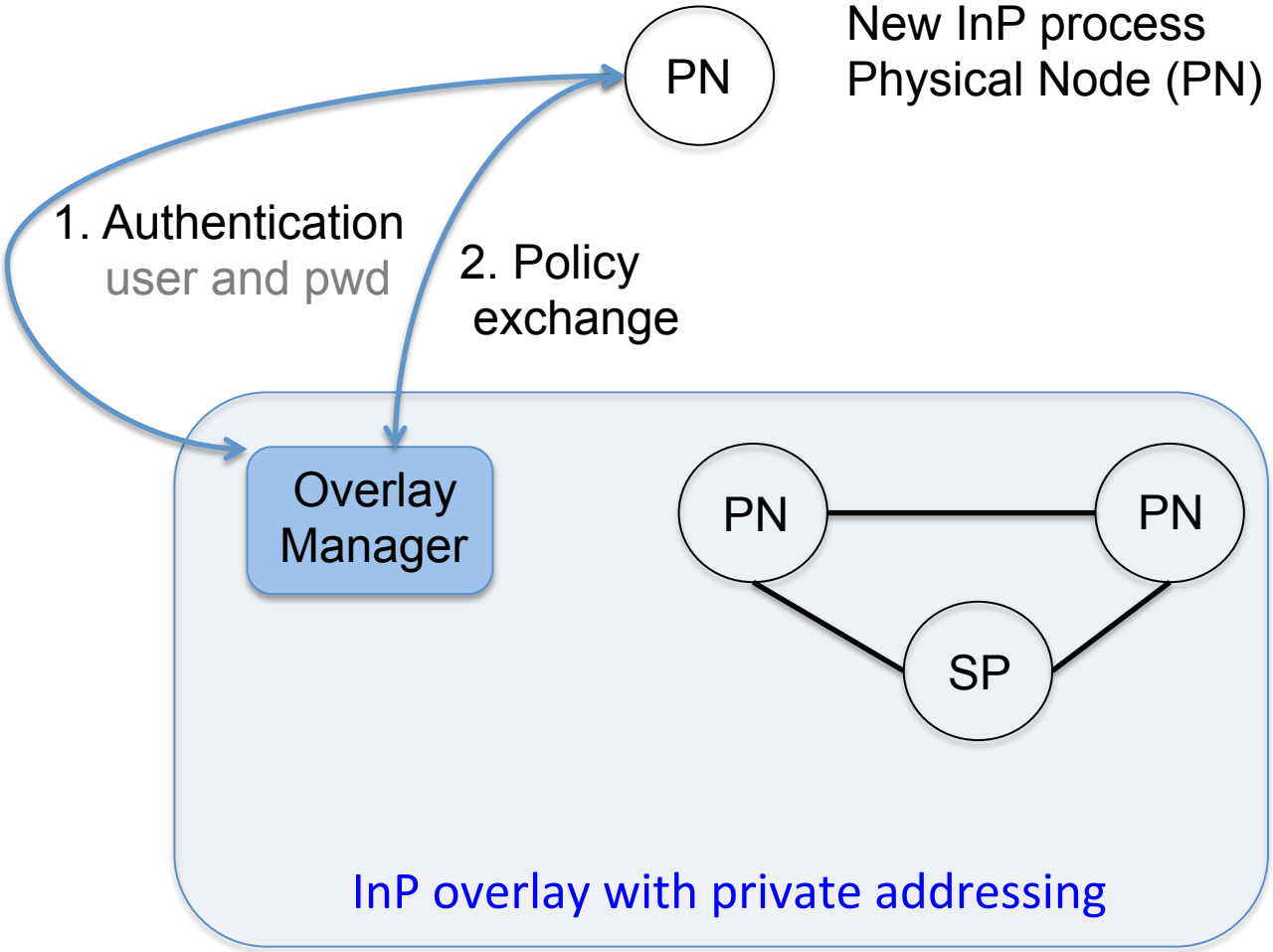
Resource Discovery: SP and InPs processes enroll in a private overlay



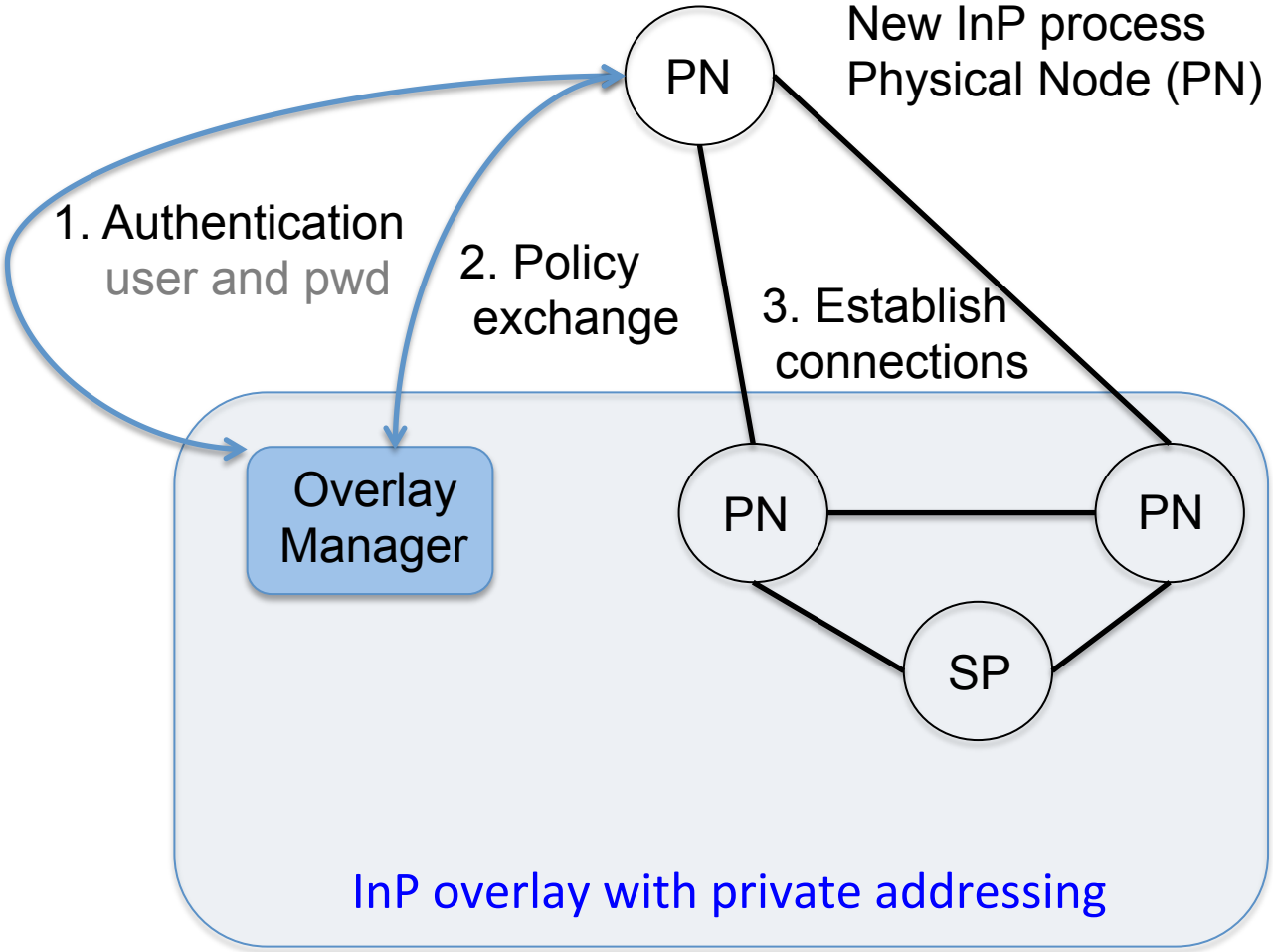
Resource Discovery: SP and InPs processes enroll in a private overlay



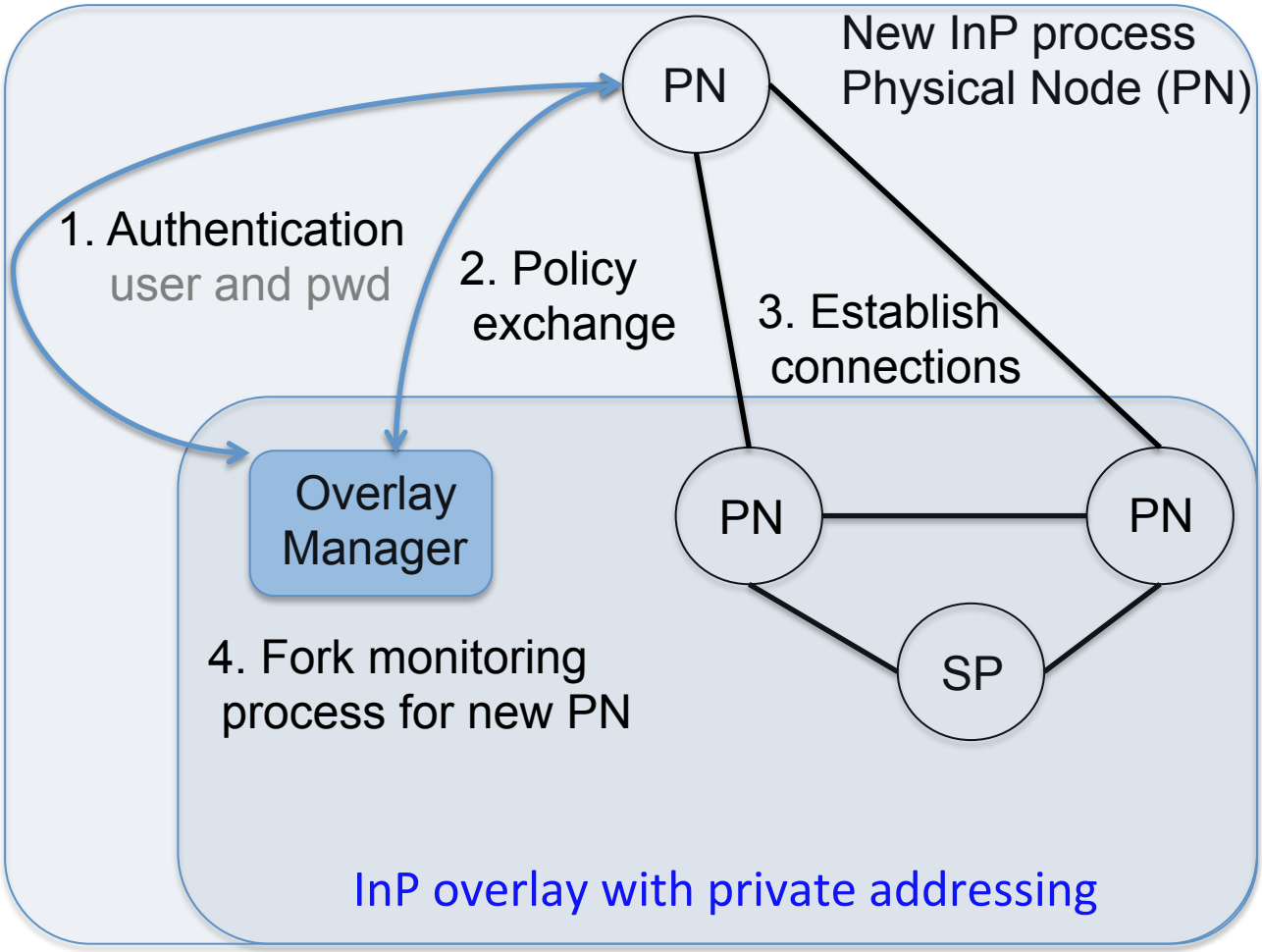
Resource Discovery: SP and InPs processes enroll in a private overlay



Resource Discovery: SP and InPs processes enroll in a private overlay



Resource Discovery: SP and InPs processes enroll in a private overlay



VN Mapping: physical nodes decide which hosts paying the lowest price

Virtual Network Embedding Architecture

Virtual Network Objects

Discovery

VINEA nodes join a private overlay
after authentication and policy exchange

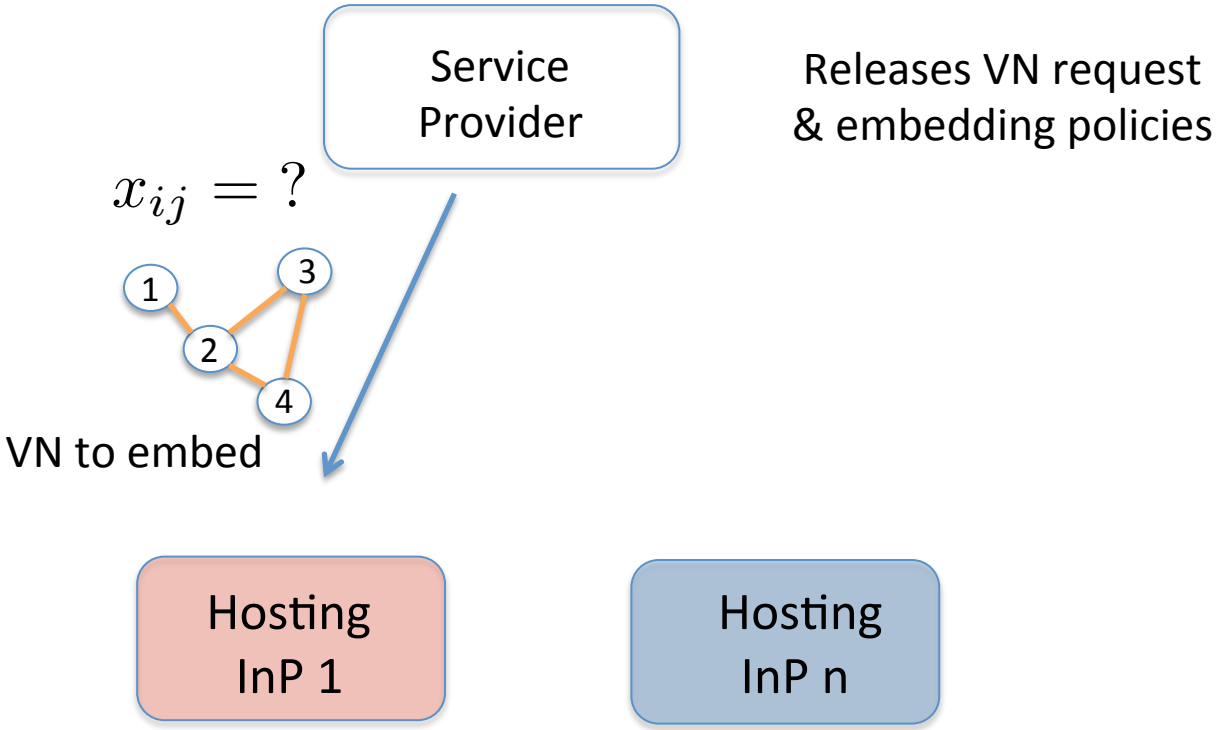
VN Mapping

InPs run the VN Mapping Protocol
asynchronous consensus-based

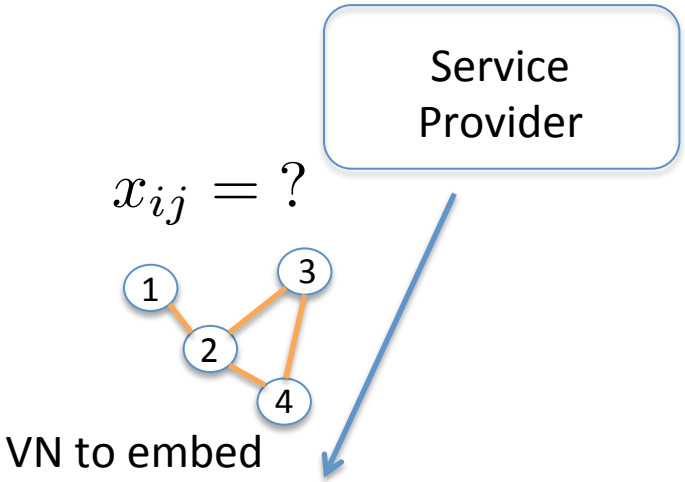
Allocation

Virtual resources are reserved
using vSwitch and Linux traffic control

VN Mapping: physical nodes decide which hosts paying the lowest price



VN Mapping: physical nodes decide which hosts paying the lowest price



Releases VN request & embedding policies

$\mathbf{x}_1 = \{1, 1, 0, 0\}$

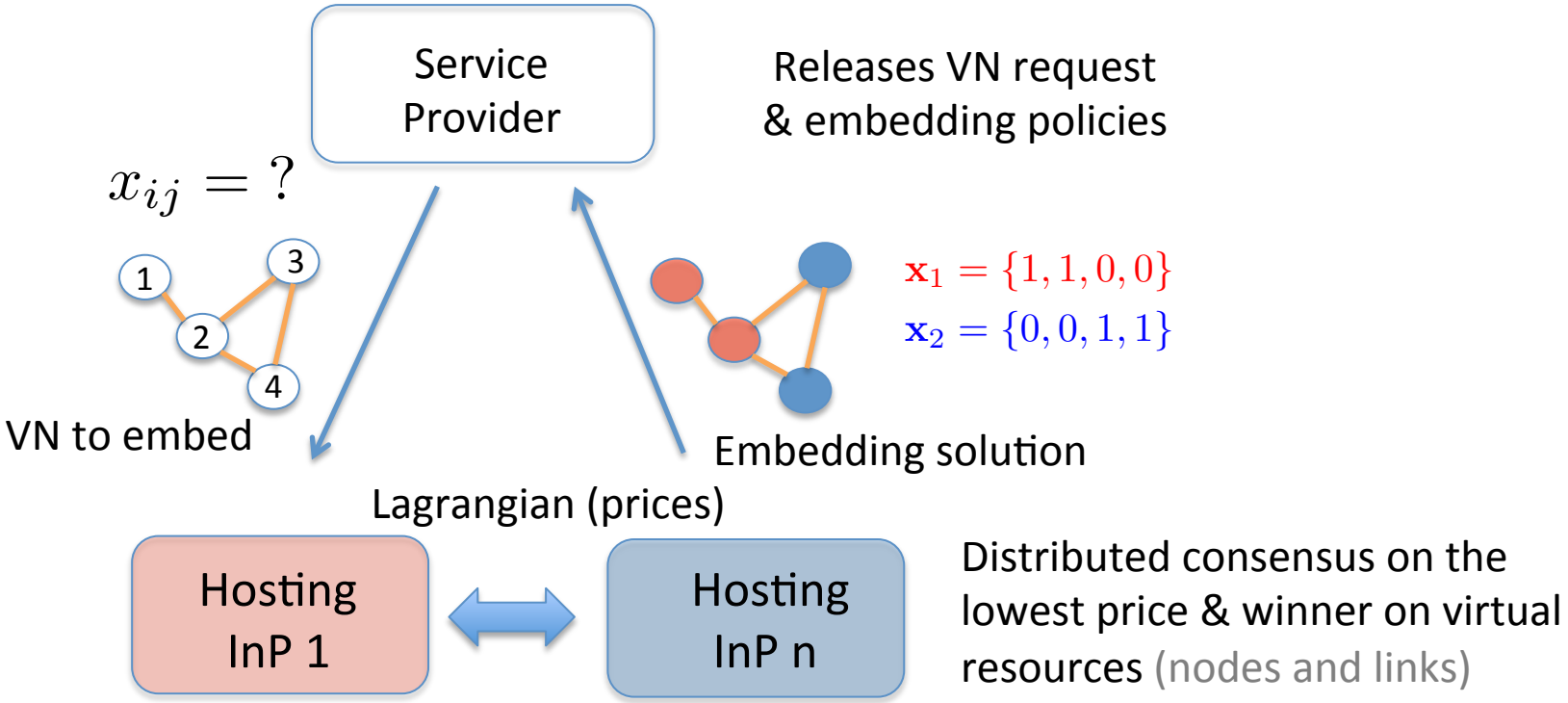
$\mathbf{x}_2 = \{0, 0, 1, 1\}$

Lagrangian (prices)

Hosting InP 1 ⟷ Hosting InP n

Distributed consensus on the lowest price & winner on virtual resources (nodes and links)

VN Mapping: physical nodes decide which hosts paying the lowest price



Allocation: User-space vHost, Kernel vSwitches & BW is reserved with Linux tc

Virtual Network Embedding Architecture

Discovery

VINEA nodes join a private overlay
after authentication and policy exchange

VN Mapping

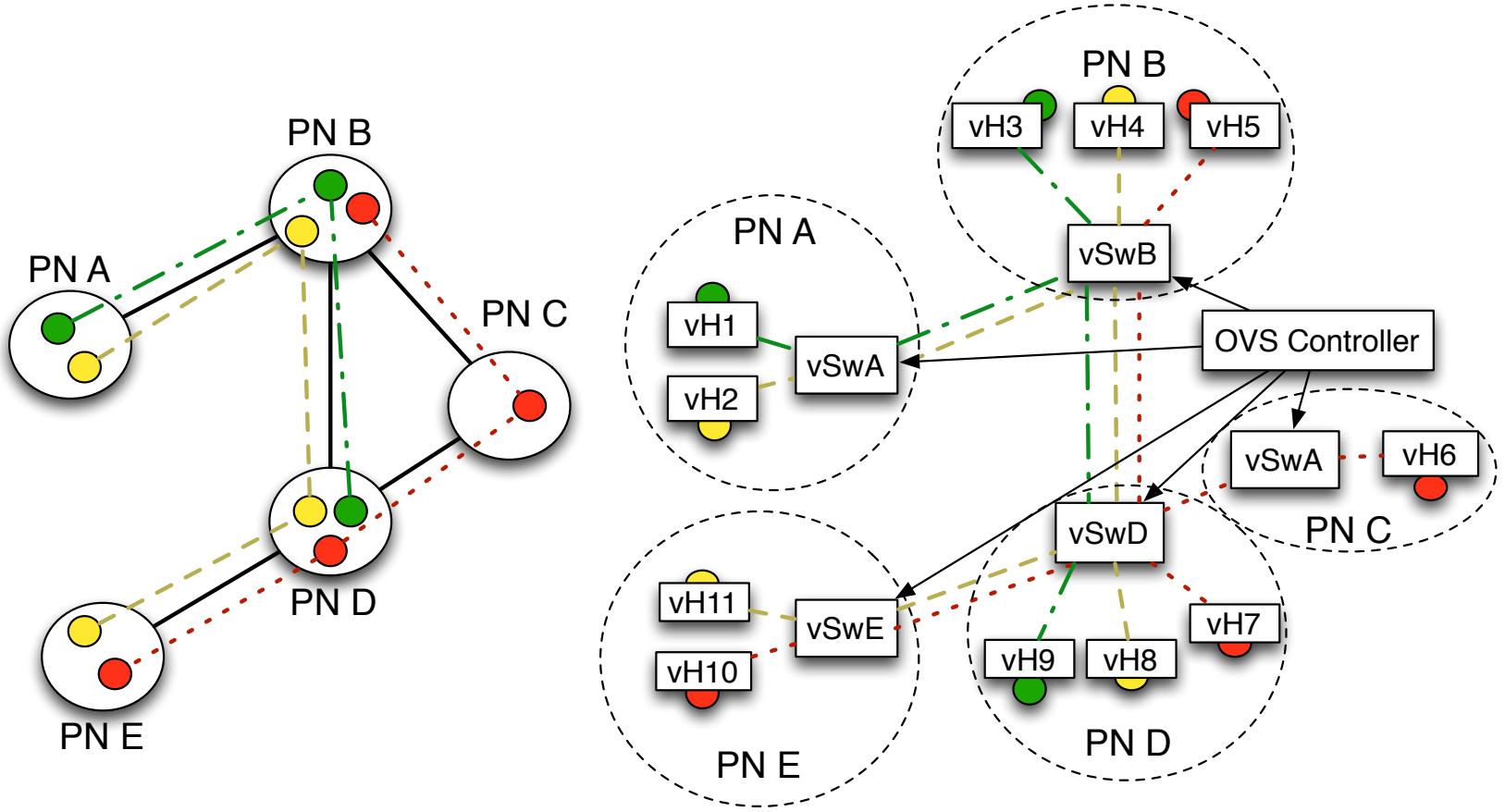
InPs run the VN Mapping Protocol
asynchronous consensus-based

Allocation

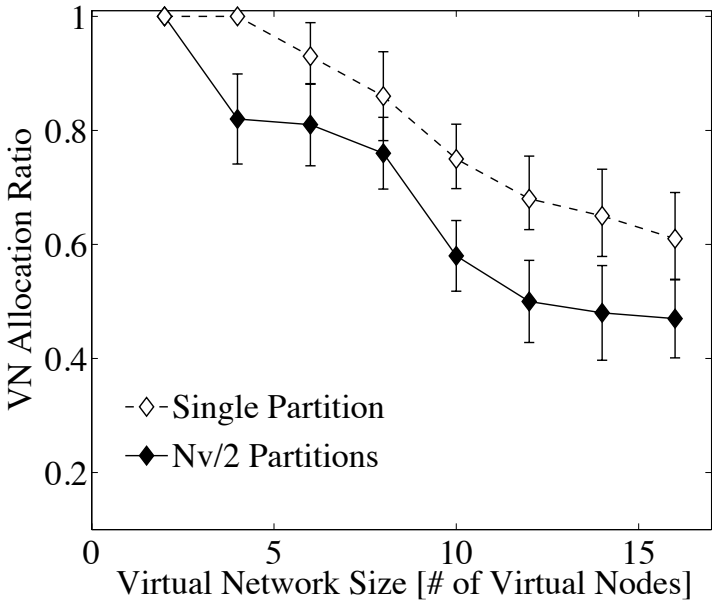
Virtual resources are reserved
using vSwitch and Linux traffic control

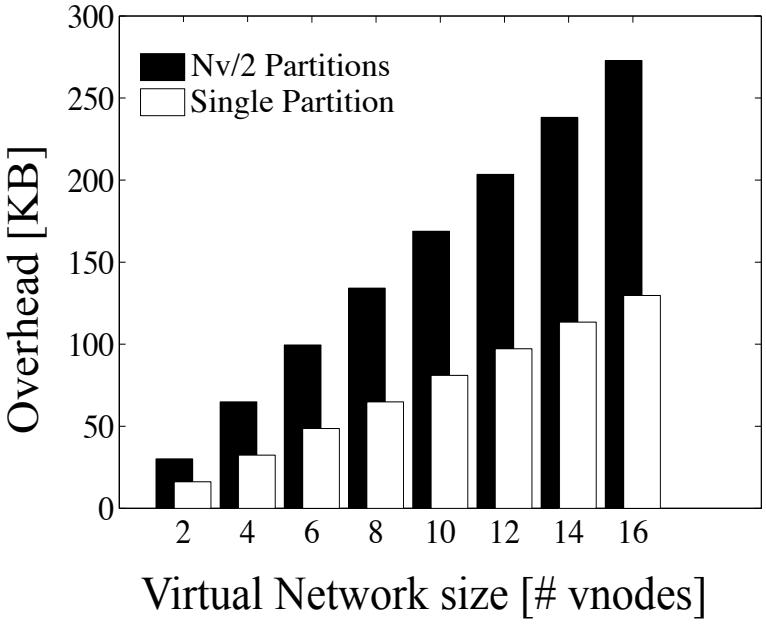
Virtual Network Objects

Allocation: User-space vHost, Kernel vSwitches & BW is reserved with Linux tc



Partitioning lowers the allocation ratio and increases the network overhead





VN embedding Prototype

Existing solutions [14] require VN partitioning

What to remember from this talk?

Ad-hoc protocols
prevent adaptation

What to remember from this talk?

Ad-hoc protocols
prevent adaptation

Decomposition is a useful tool for distributed cloud algorithm design and tradeoff analysis

What to remember from this talk?

Ad-hoc protocols
prevent adaptation

Decomposition is a useful tool for distributed cloud algorithm design and tradeoff analysis

Use our VINEA testbed to test
your own embedding policies
http://csr.bu.edu/vinea

A Decomposition-Based Architecture for Distributed Virtual Network Embedding

Flavio Esposito

exegy

Ibrahim Matta

BOSTON UNIVERSITY

Thank you

Computer
Science
Research

Virtual
Network
Embedding
Architecture

http://csr.bu.edu/vinea

Boston
University