Specificity vs. Flexibility: On the Embedding Cost of a Virtual Network

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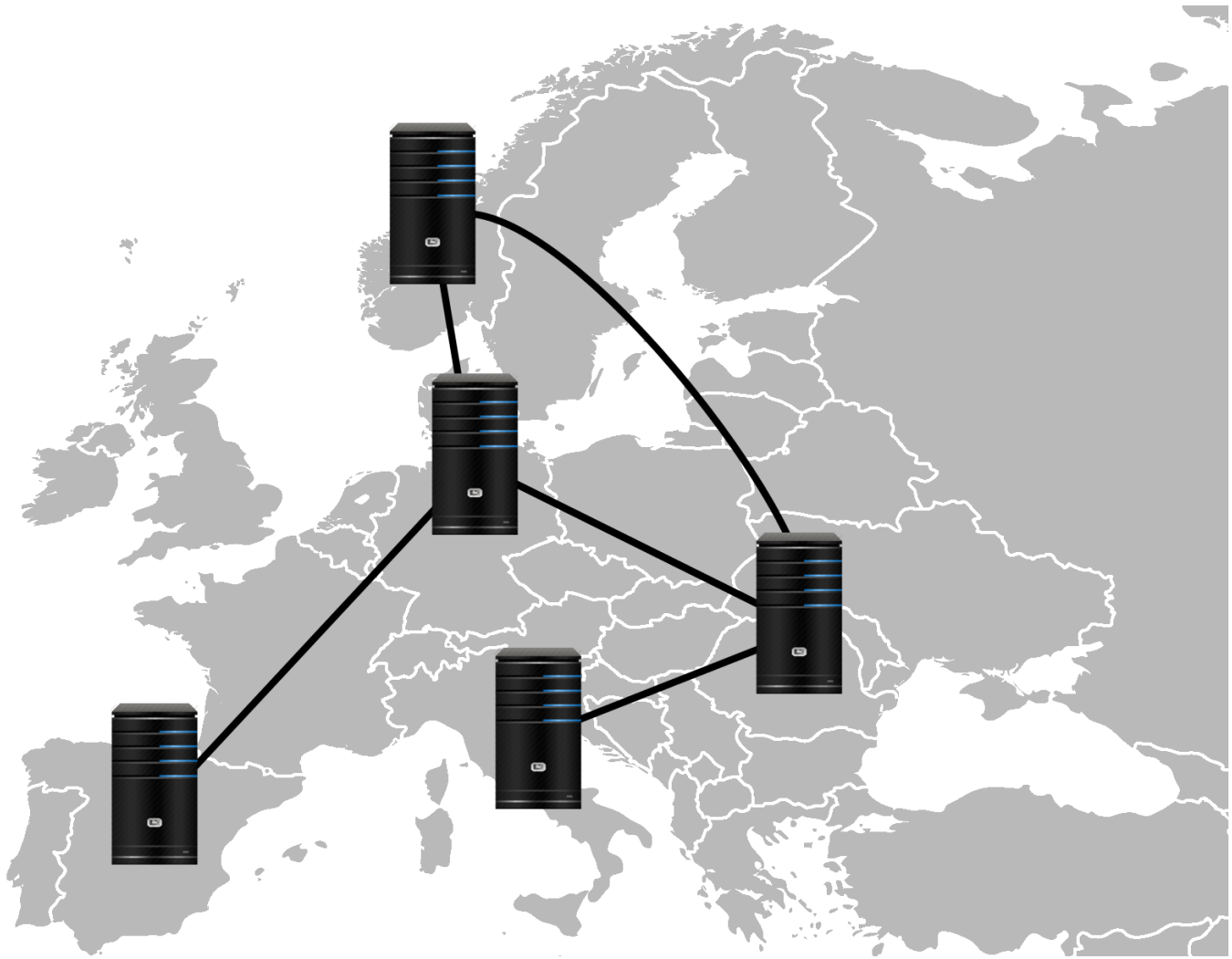
Motivation



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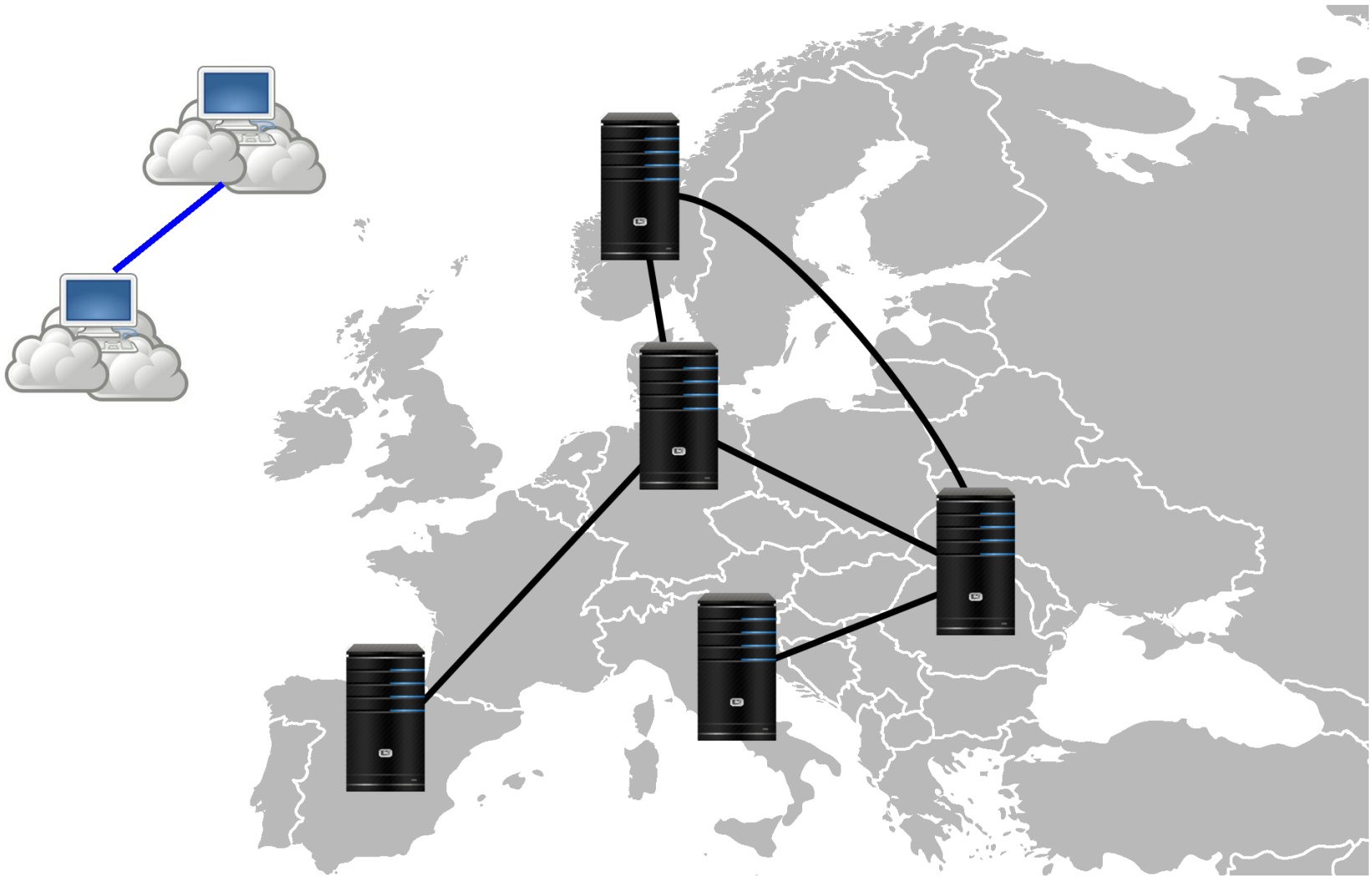

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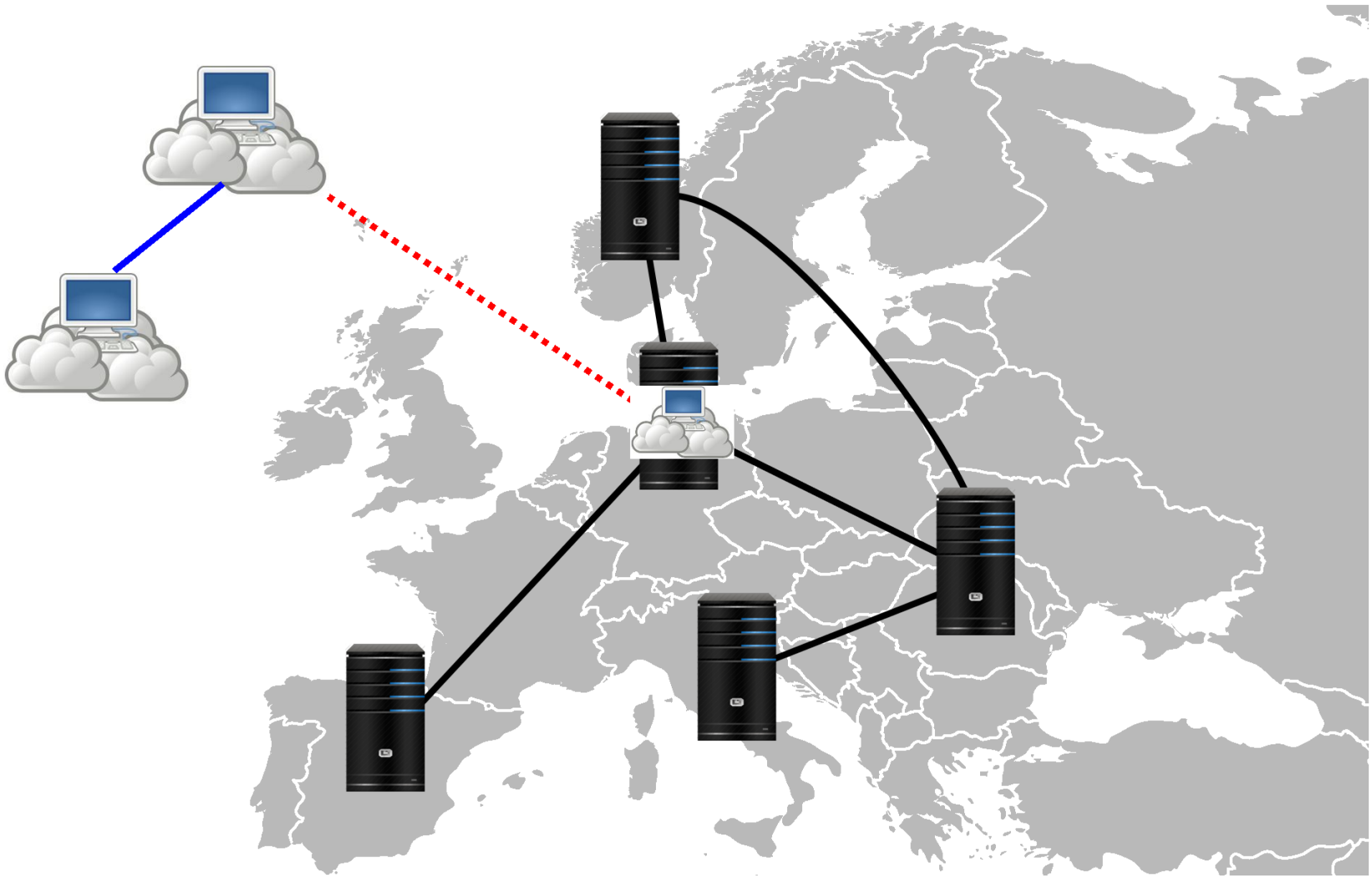

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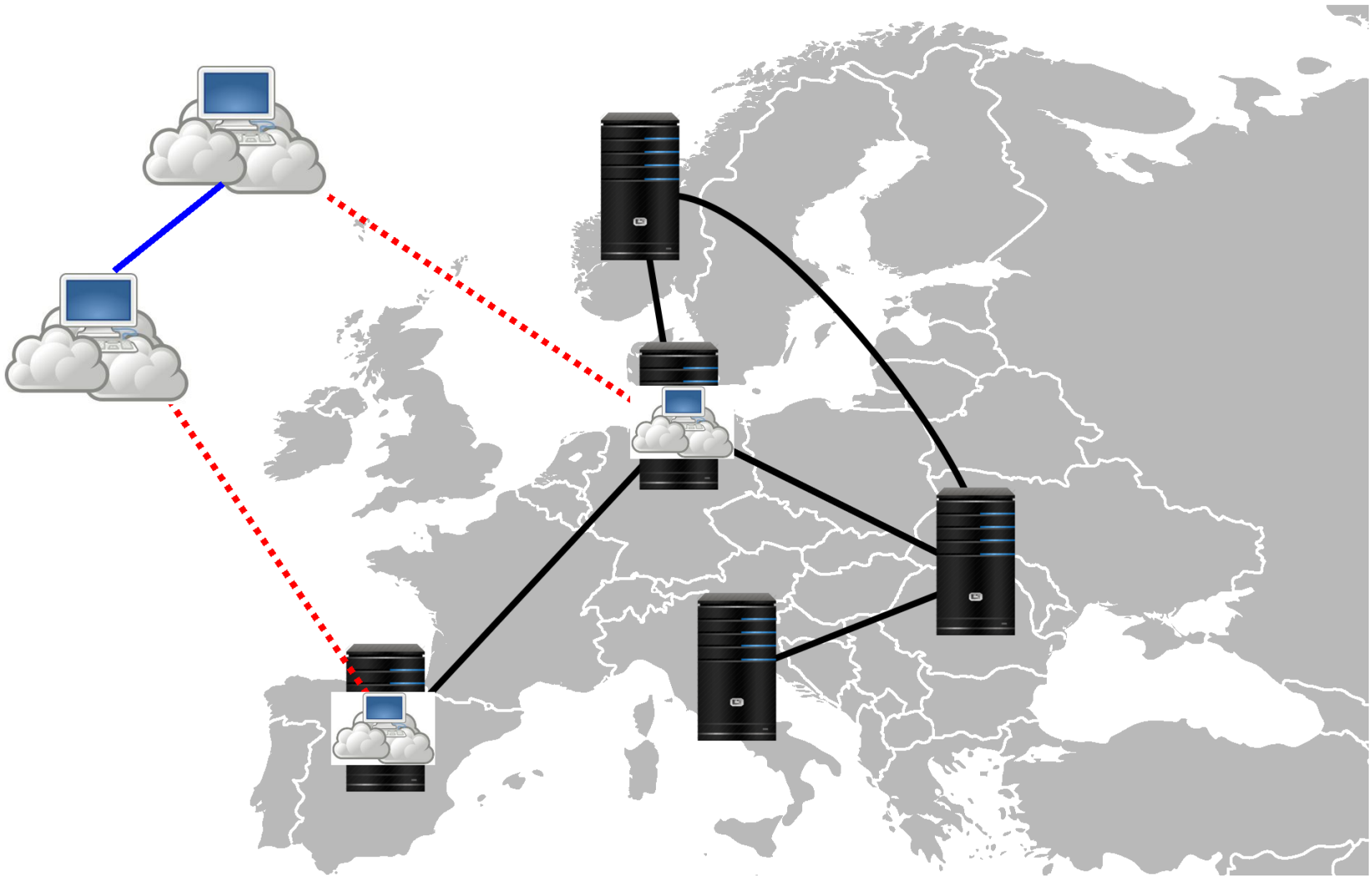

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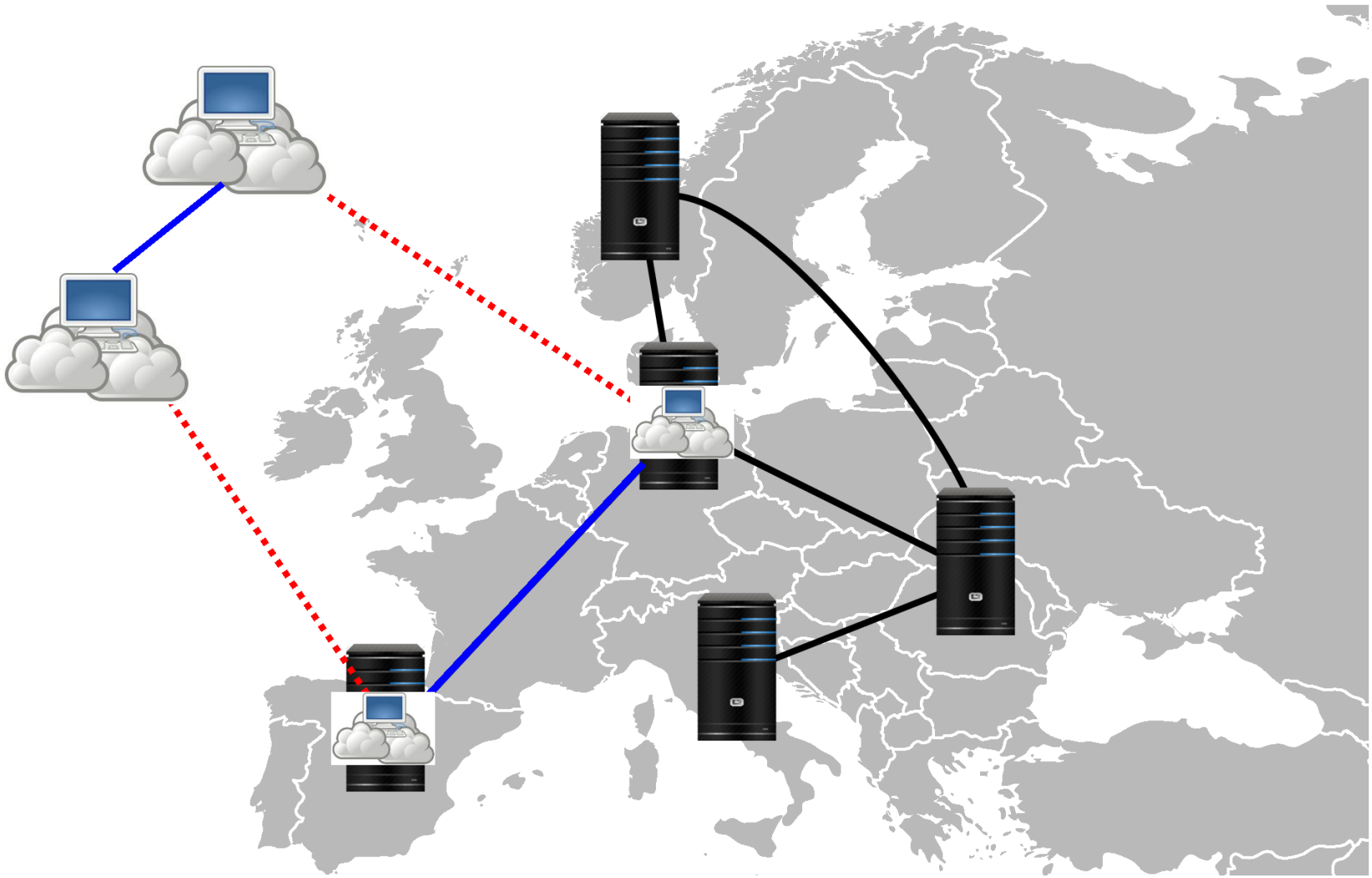
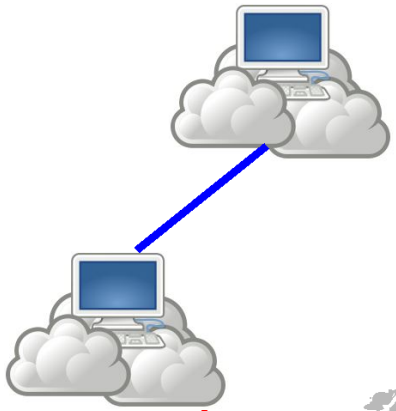
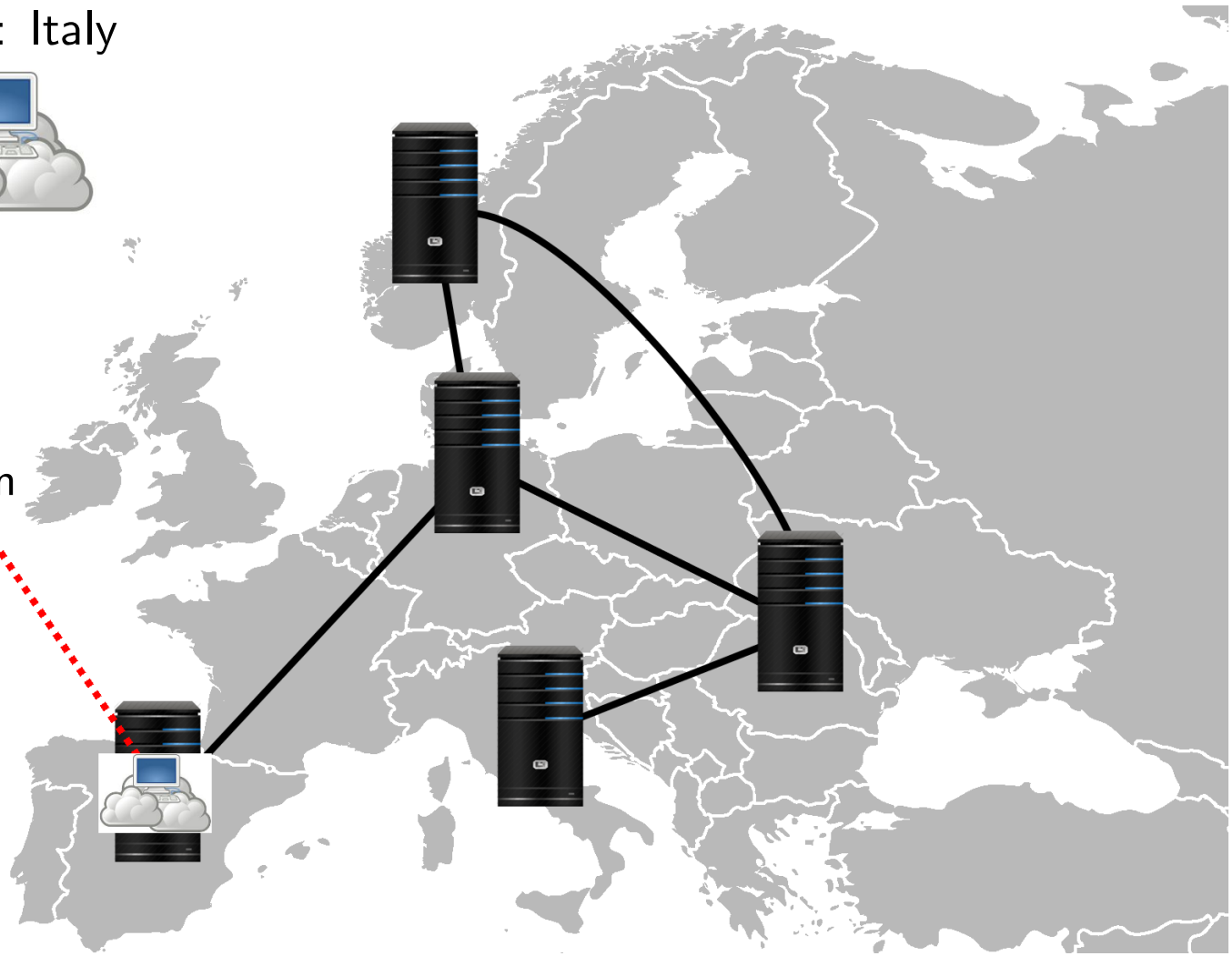


Motivation

- Location: Italy



- Location: Spain



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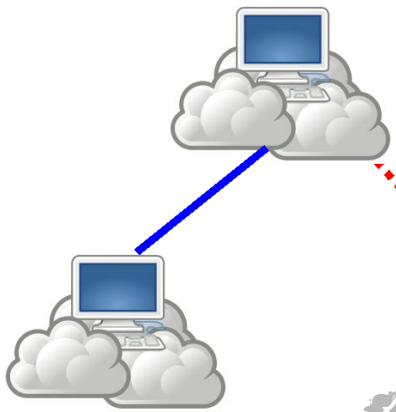

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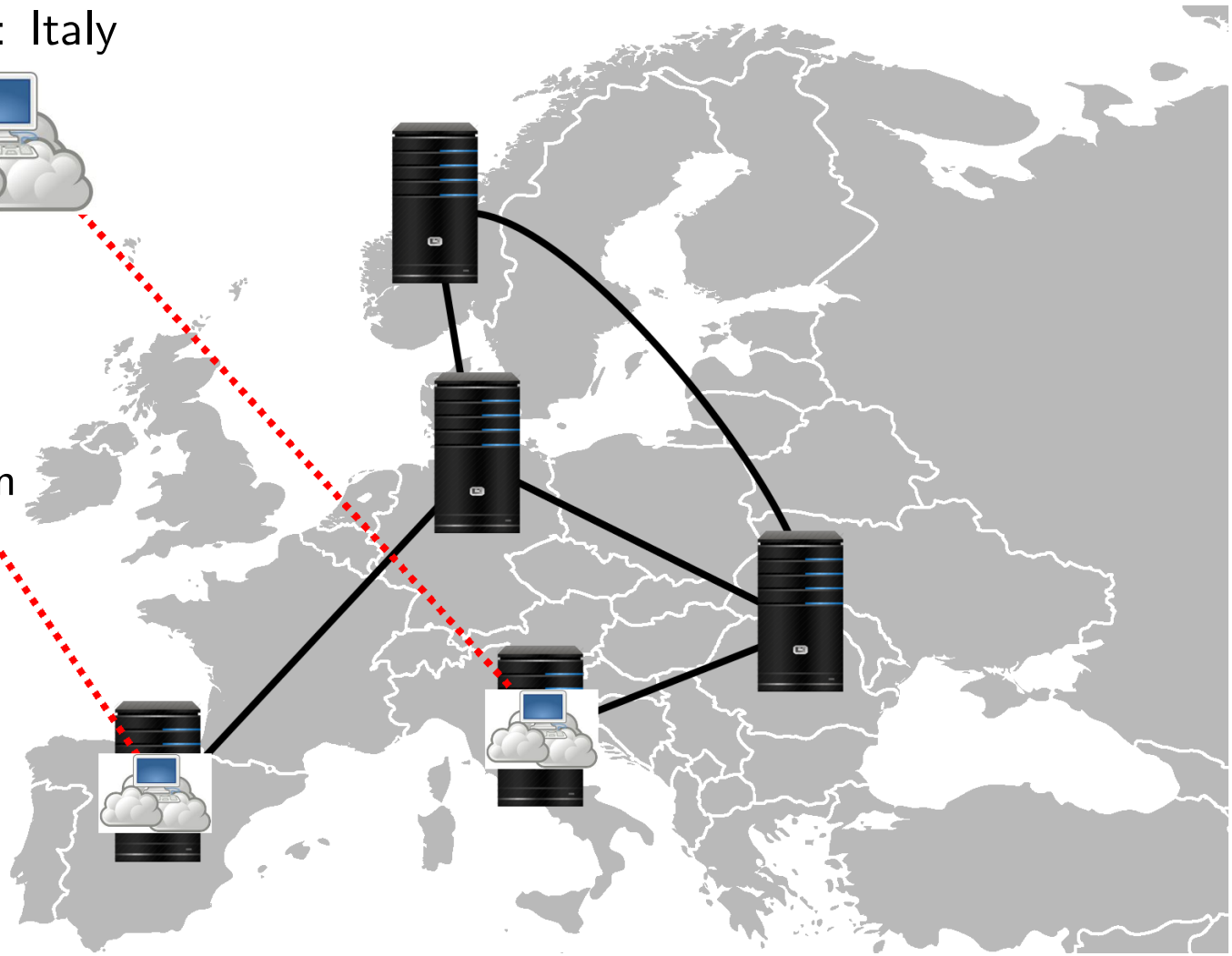

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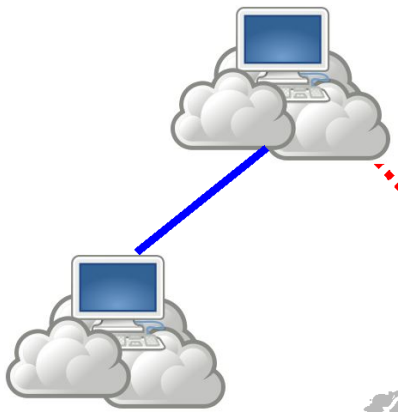

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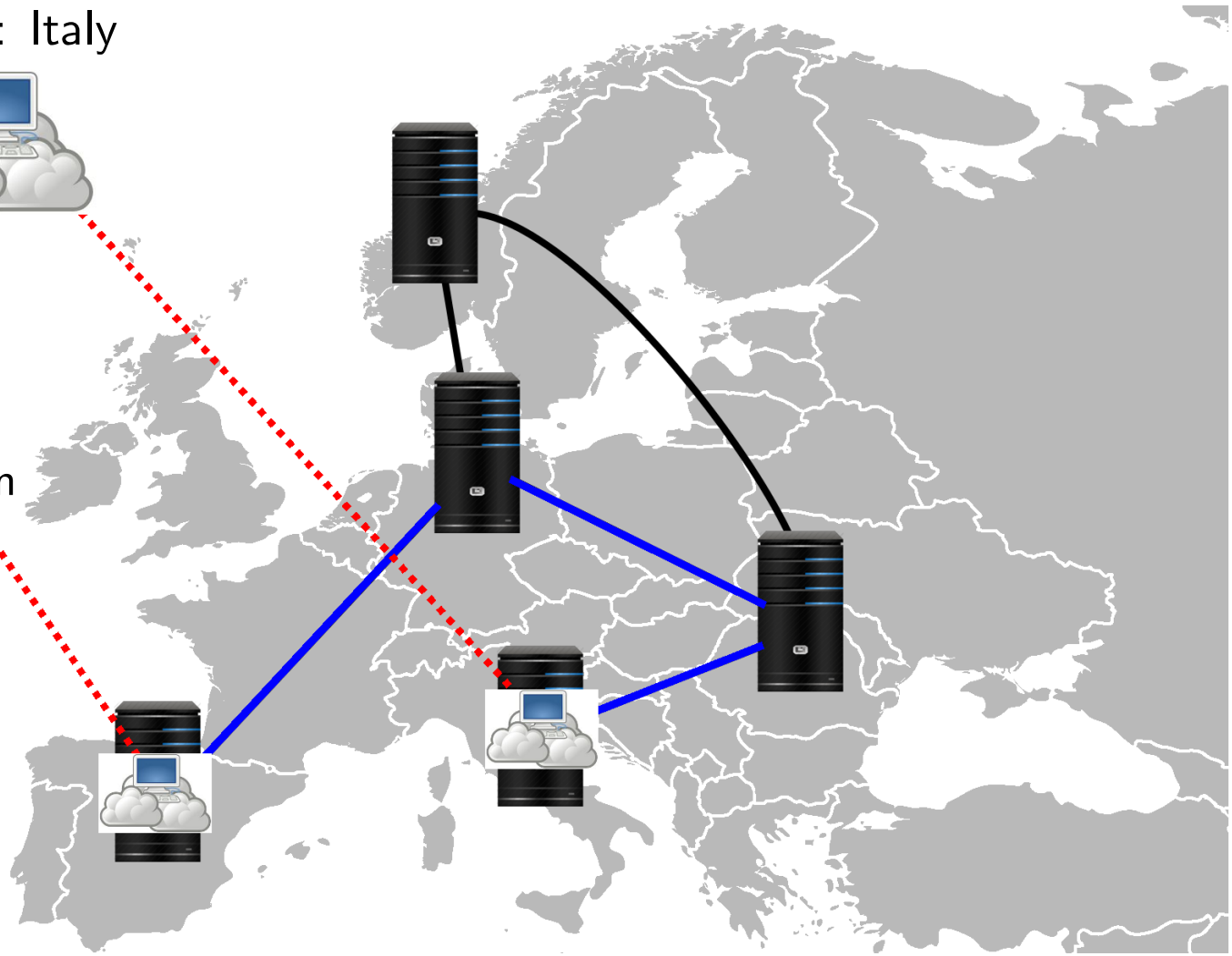
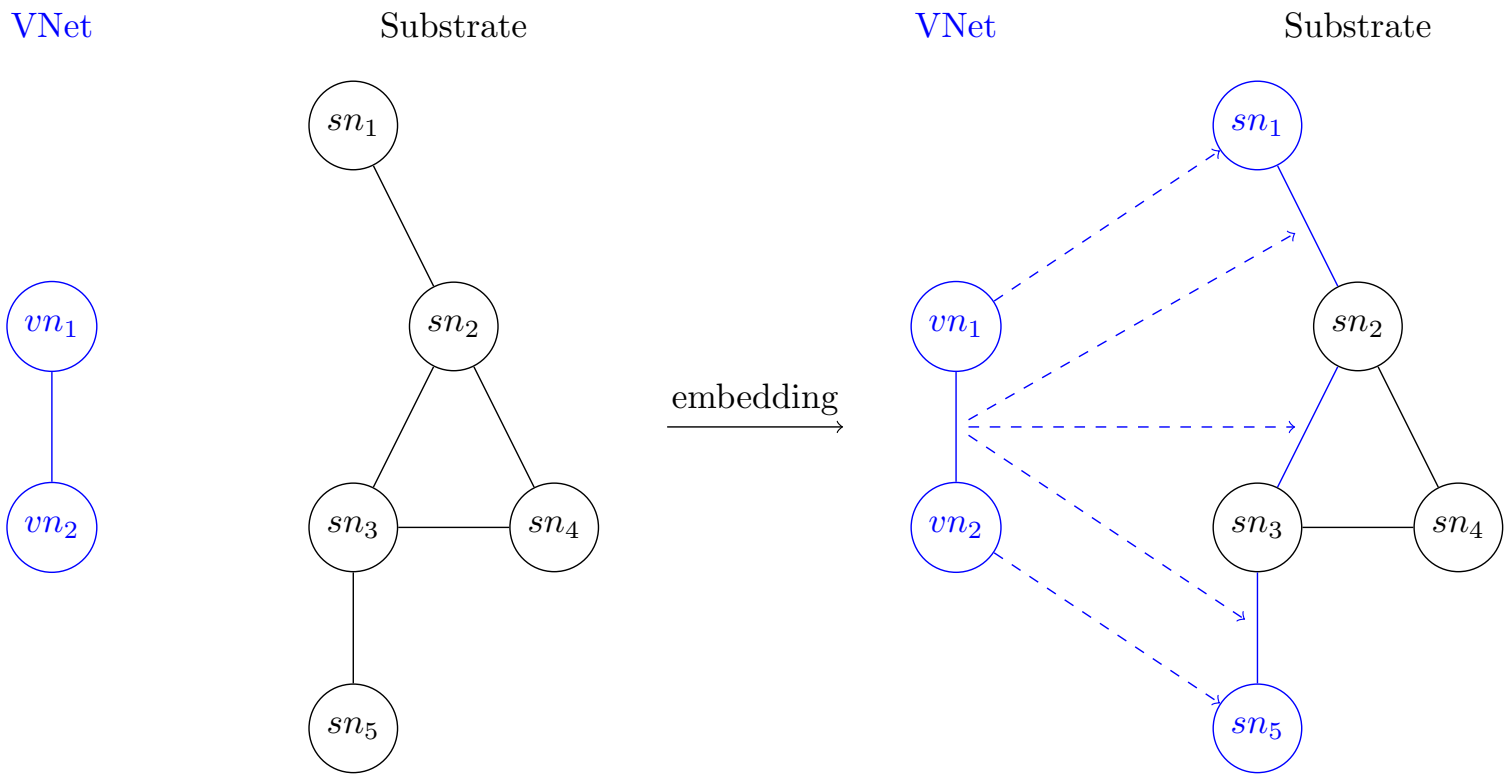


Standard Problem



How can flexibility be quantified?

Dimensions of Specifications - Properties

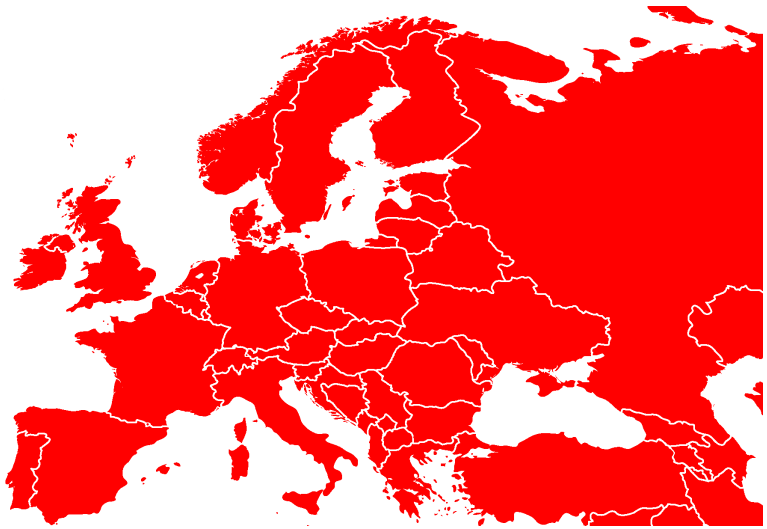
Focus on node properties

- Different properties:
  - Location
  - Virtualization technology
  - Operating system
  - etc.
- Substrate nodes have exactly one type per property
  - VNet node requests can specify multiple types
- All properties combined form a configuration
  - Example: {Italy, Xen, RedHat 7.3}

Specificity - Definition

Specificity σ = percentage of lost alternatives

$(\Rightarrow \sigma = \frac{\text{forbidden configurations}}{\text{all configurations -1}})$



- $\sigma = 0$: free choice of nodes

- $\sigma = 1$: only nodes with exactly defined types

VNet specificity: average specificity of its nodes

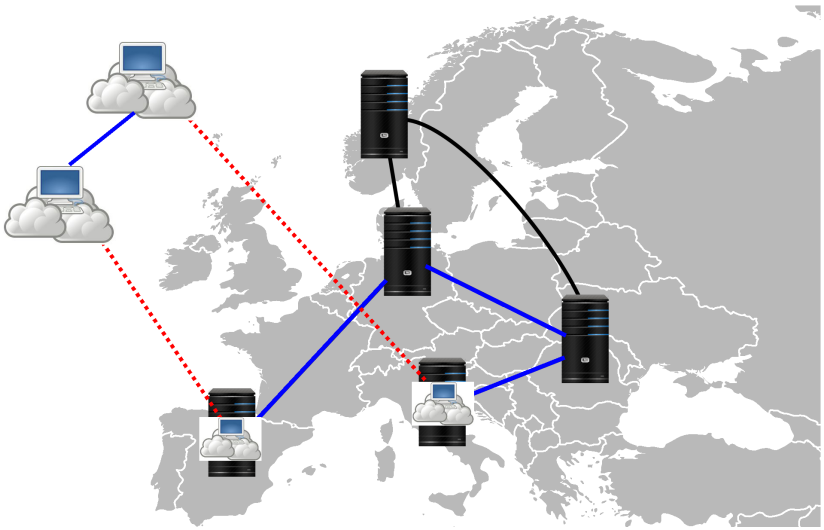
Price of Specificity (PoS) - Definition

- Cost_σ: cost under a given specificity $\sigma(VNet)$
- Cost_0: cost without specification constraints

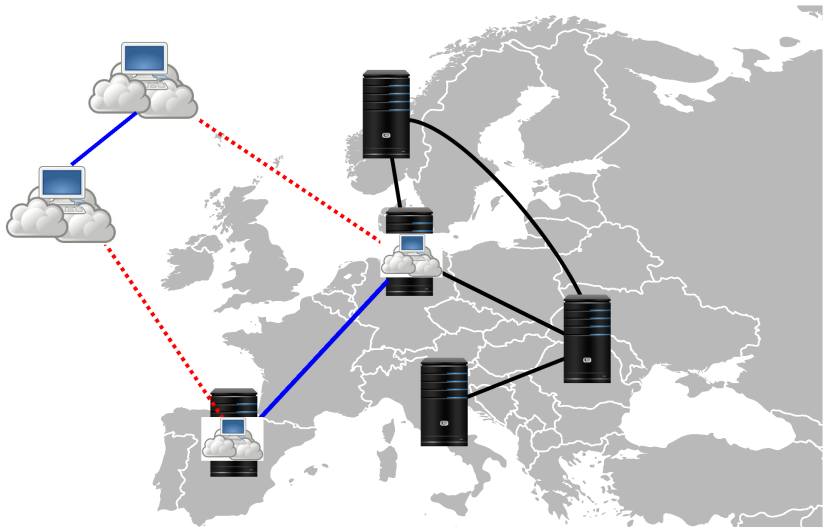
Price of Specificity definition:

$$PoS = \text{Cost}_\sigma / \text{Cost}_0$$

PoS - Example



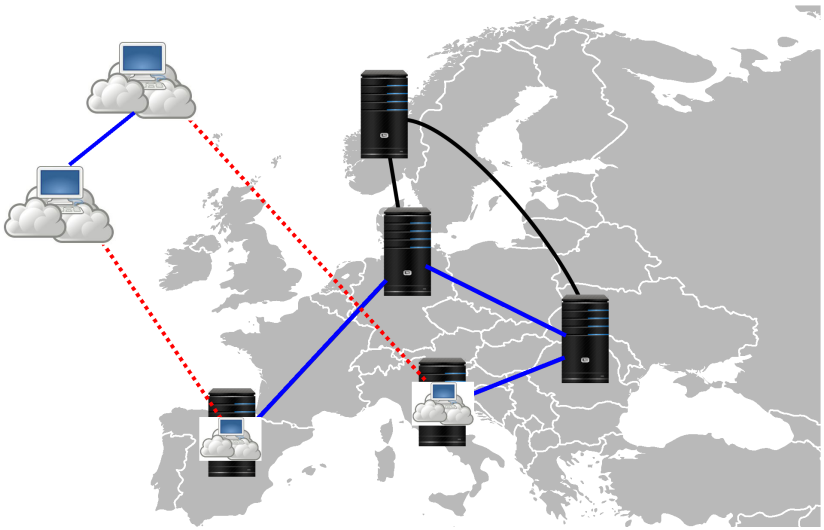
- Spec.: Spain + Italy ($\sigma = 1$)



- No specification ($\sigma = 0$)

PoS - Example

Cost metric: Number of hops



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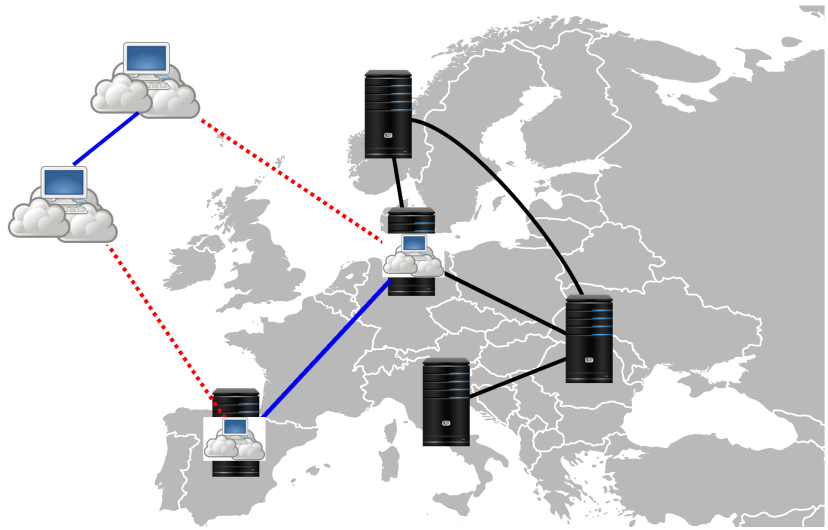
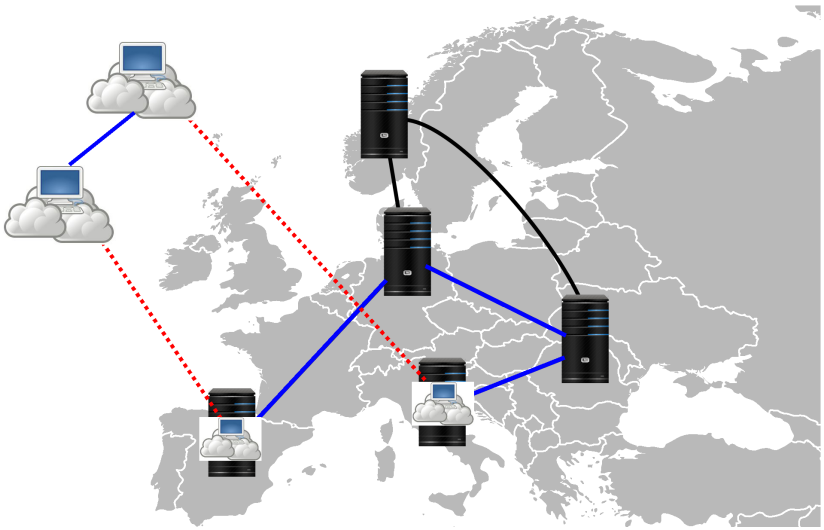
- 3 hops



- No specification ($\sigma = 0$)
- 1 hop

PoS - Example

Cost metric: Number of hops



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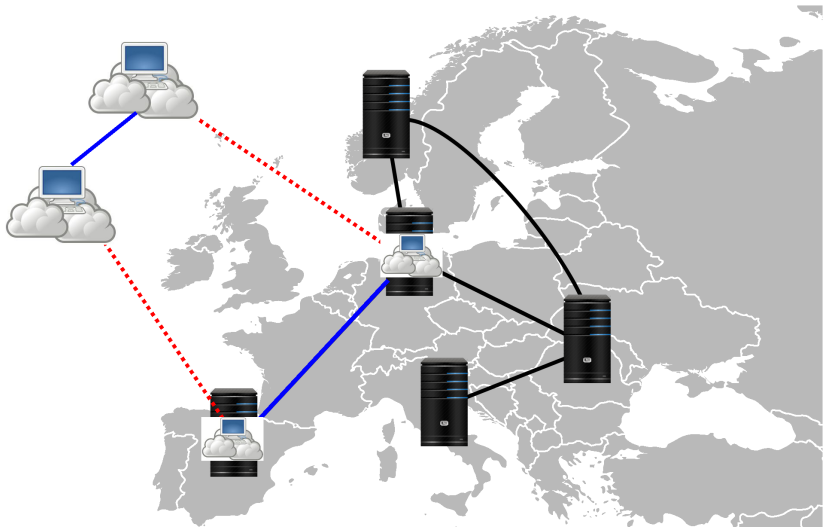

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$$PoS = \frac{3}{1} = 3$$

Overview

Introduction

- Embedding problem
- Specification, *PoS*

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- Embedding problem
- Specification, *PoS*

Upcoming

- Embedding algorithm
- Impact of different factors on the PoS

Optimal Algorithm

Constants:

Substrate Vertices : V_s
Substrate Edges : $E_s : V_s \times V_s$
Unique : $uni\_check_s : \forall (s_1, s_2) \in E_s : (s_2, s_1) \notin E_s$
SNode Capacity : $snc(s) \rightarrow \mathbb{R}^+, s \in V_s$
SLink Capacity : $slc(e_s) \rightarrow \mathbb{R}^+, e_s \in E_S$

Requests : R
Virtual Vertices : $V_v(r), r \in R$
Virtual Edges : $E_v(r) :\rightarrow V_v(r) \times V_v(r), r \in R$
Unique : $uni\_check_v : \forall r \in R, (v_1, v_2) \in E_v(r) : (v_2, v_1) \notin E_v(r)$
VNode Demand : $vnd(r, v) \rightarrow \mathbb{R}^+, r \in R, v \in V_v(r)$
VEdge Demand : $vld(r, e_v) \rightarrow \mathbb{R}^+, r \in R, e_v \in E_v(r)$

Edges-Reverse : $ER_s : \forall (s_1, s_2) \in E_s \exists (s_2, s_1) \in ER_s \wedge |E_s| = |ER_s|$
Edges-Bidirectional : $EB_s : E_s \cup ER_s$
Migration Cost : $mig\_cost(r, v, s) \rightarrow \mathbb{R}^{+\ |V_v(r)| \times |V_s|}, r \in R, v \in V_v(r), s \in V_s$
Possible Placements : $place(r, v, s) \rightarrow \{0, 1\}^{|V_v(r)| \times |V_s|}, r \in R, v \in V_v(r), s \in V_s$

Variables:

Node Mapping : $n\_map(r, v, s) \in \{0, 1\}, r \in R, v \in V_v(r), s \in V_s$
Flow Allocation : $f\_alloc(r, e, eb) \geq 0, r \in R, e \in E_v(r), eb \in EB_s$

Constraints:

Each Node Mapped : $\forall r \in R, v \in V_v(r) : \sum_{s \in V_s} n\_map(r, v, s) \cdot place(r, v, s) = 1$
Feasible : $\forall s \in V_s : \sum_{r \in R, v \in V_v(r)} n\_map(r, v, s) \cdot vnd(r, v) \leq snc(s)$
Guarantee Link Realization : $\forall r \in R, (v_1, v_2) \in E_v(r), s \in V_s \sum_{(s, s_2) \in V_s \times V_s \cap EB_s} f\_alloc(r, v_1, v_2, s, s_2) -$
$\sum_{(s_1, s) \in V_s \times V_s \cap EB_s} f\_alloc(r, v_1, v_2, s_1, s) = vld(r, v_1, v_2) \cdot (n\_map(r, v_1, s) - n\_map(r, v_2, s))$
Realize Flows : $\forall (s_1, s_2) \in E_s \sum_{r \in R, (v_1, v_2)} f\_alloc(r, v_1, v_2, s_1, s_2) + f\_alloc(r, v_1, v_2, s_2, s_1) \leq slc(s_1, s_2)$

Objective function:

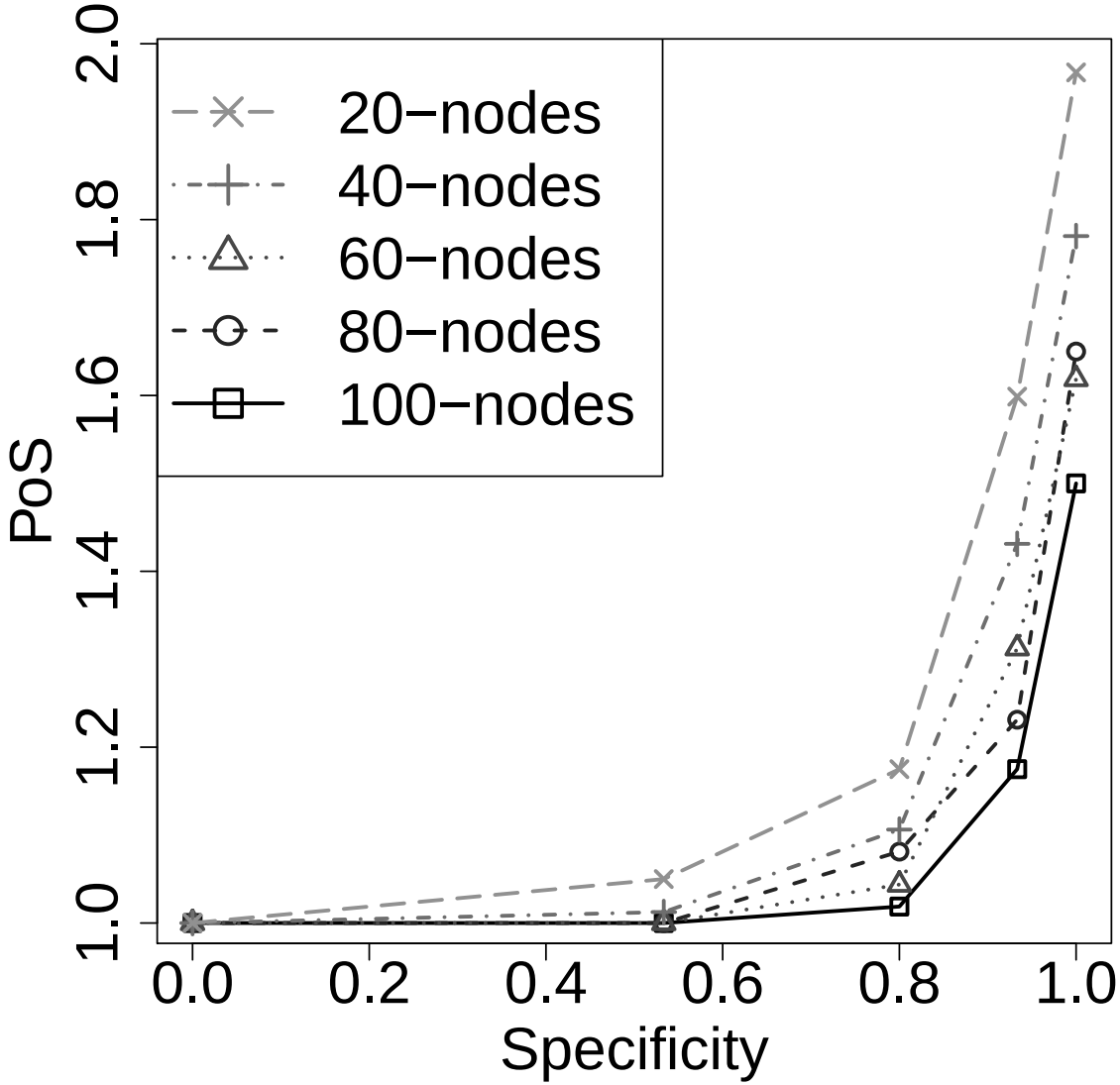
Minimize Embedding Cost : $min : \sum_{r \in R, (v_1, v_2) \in E_v(r), (s_1, s_2) \in E_s} f\_alloc(r, v_1, v_2, s_1, s_2) + f\_alloc(r, v_1, v_2, s_2, s_1)$

Optimal Algorithm

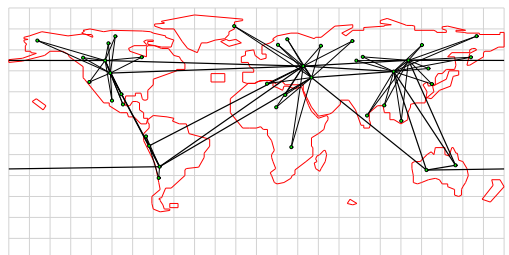
MIP (Mixed-integer program)

- Objective function: Minimize Link Cost
- Constraints to ensure feasibility
- Migration
- Different types of links
- Optimal embeddings

Impact of Substrate Size



- 5-star VNet
- Node capacity of one
- Substrates created with *Igen topology generator*



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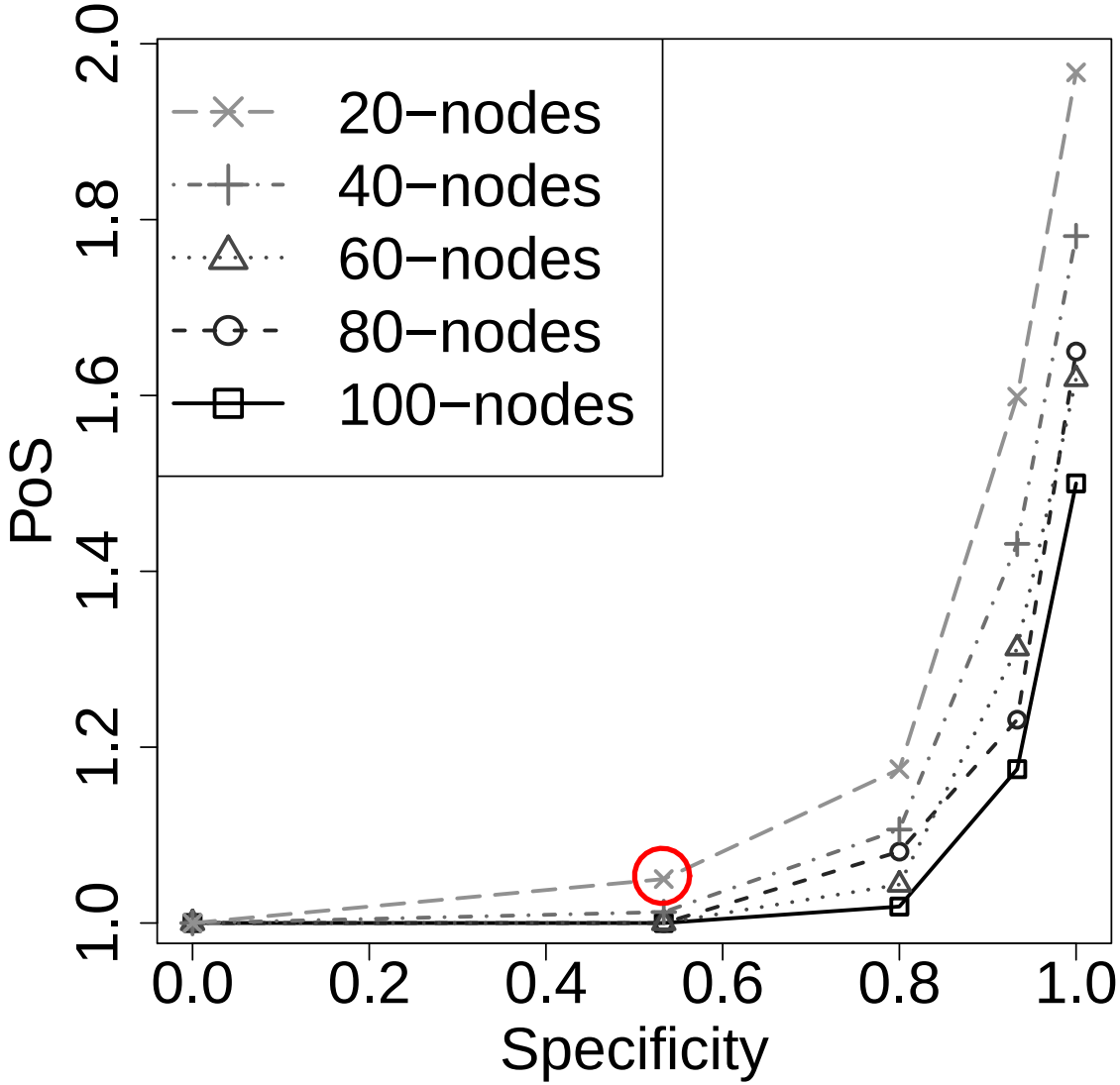

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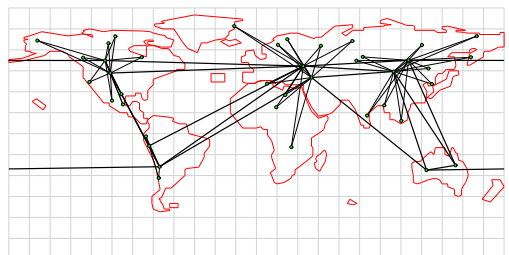

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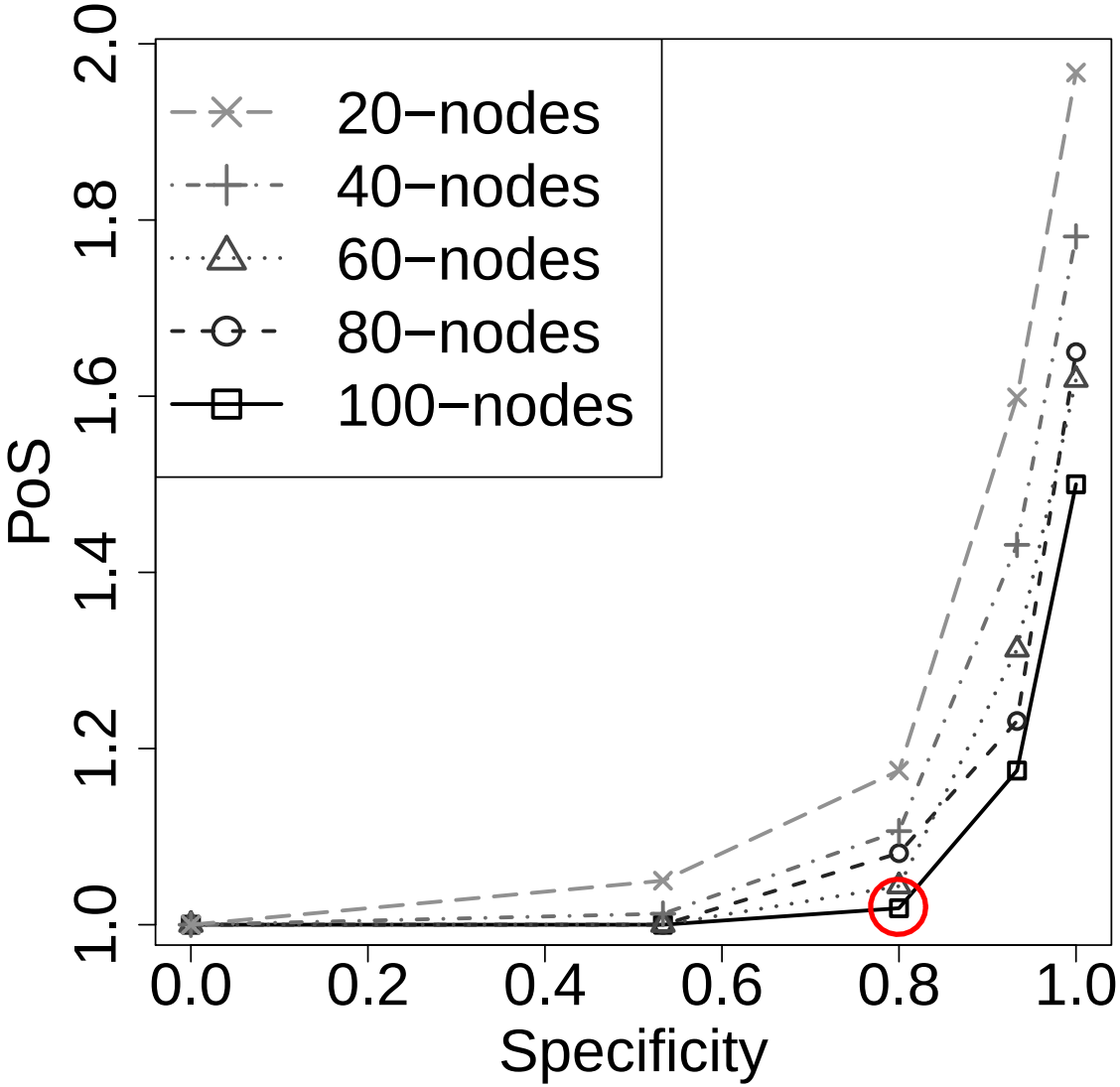

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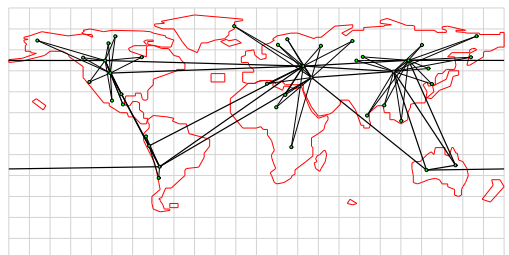

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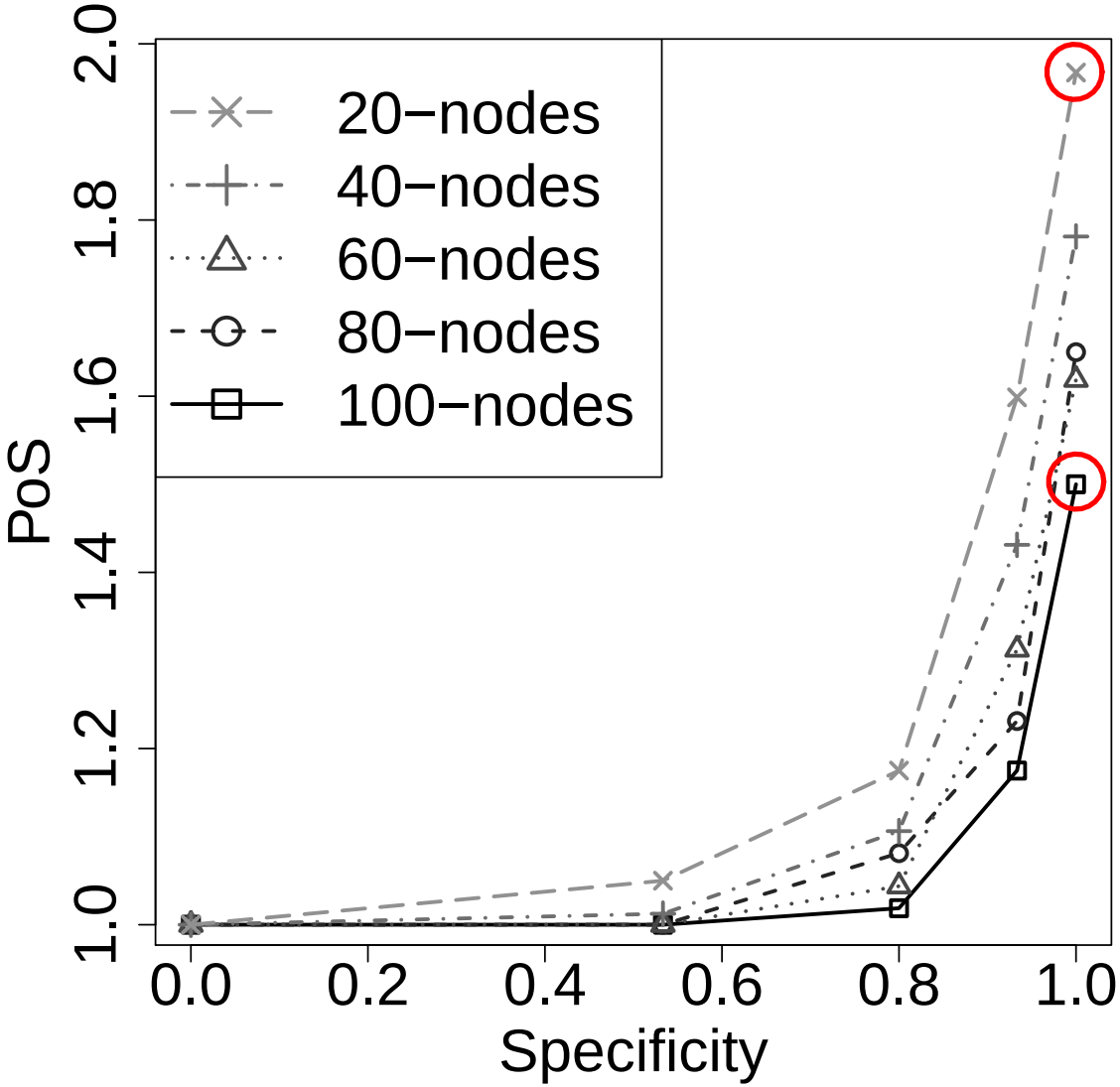

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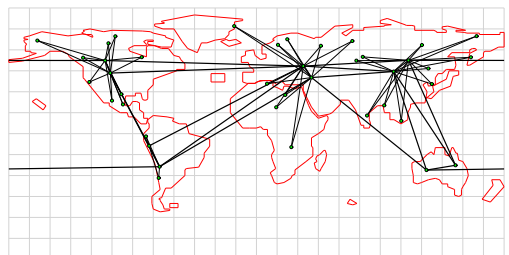
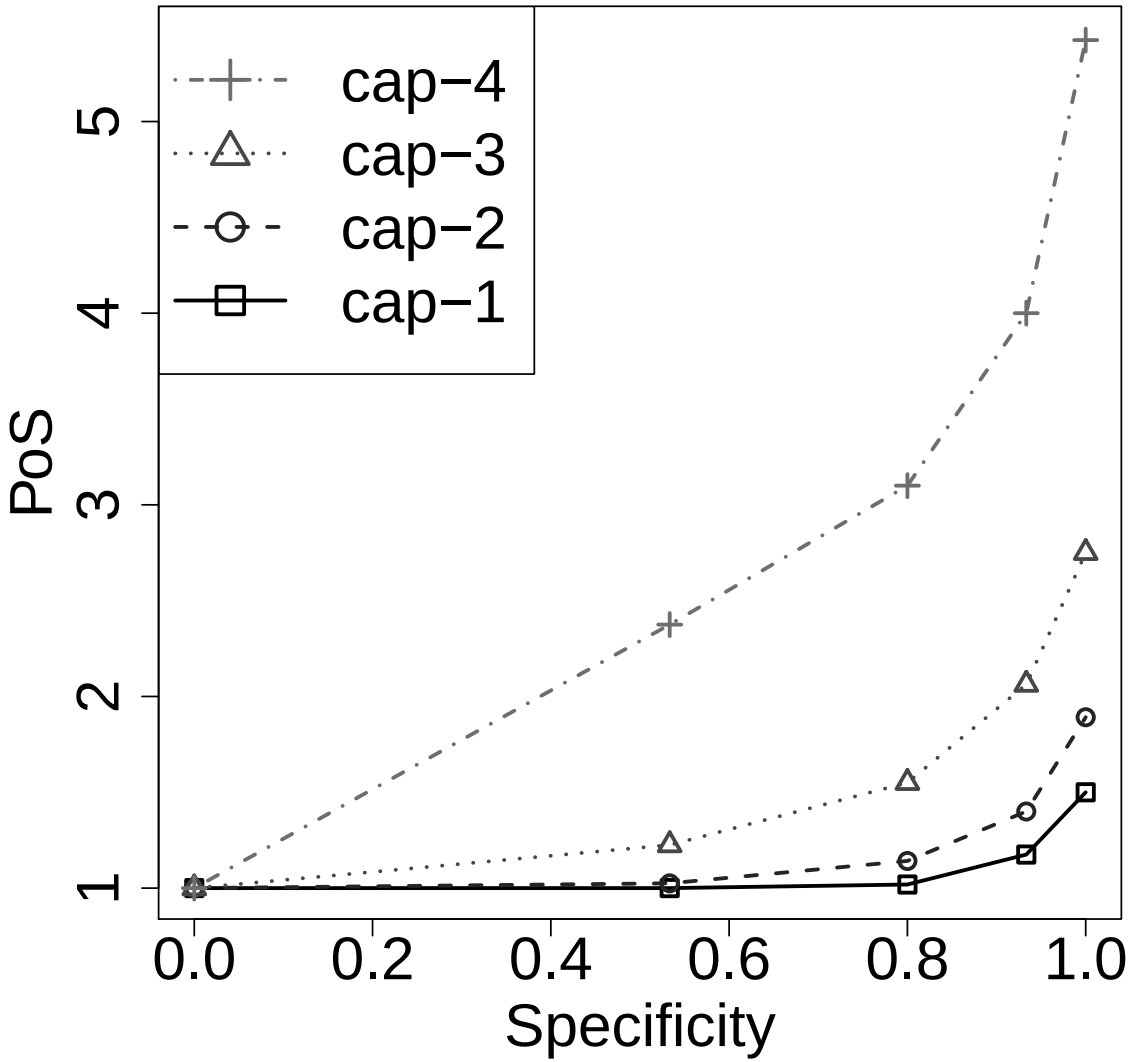
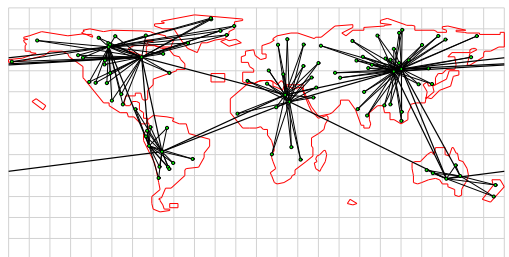


Impact of Node Capacity



- 5-star VNet
- Colocation allowed
- 100 nodes substrate created with *Igen*



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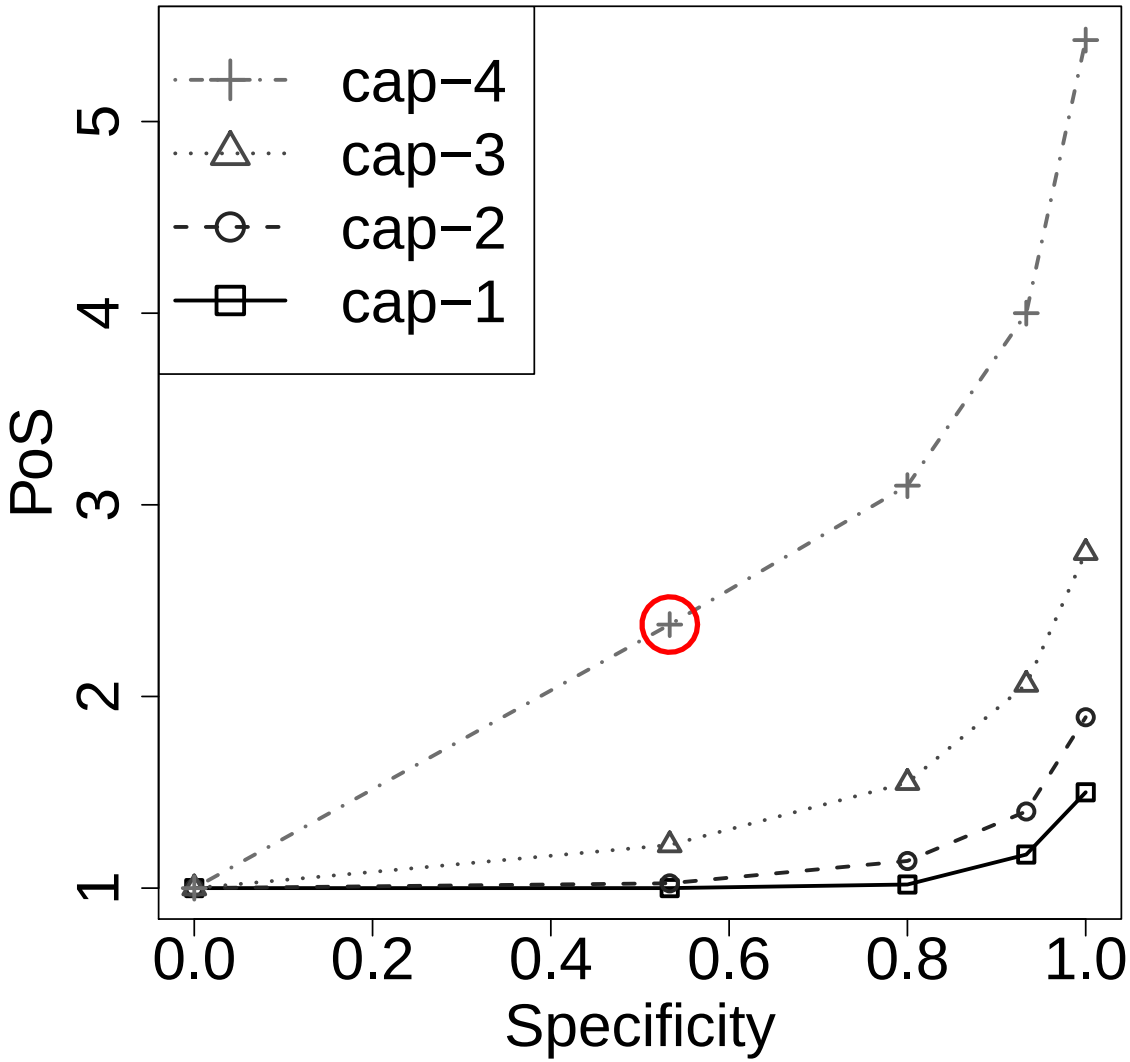

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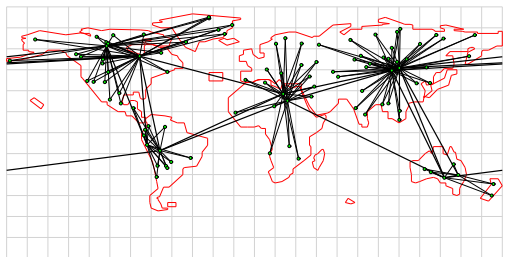

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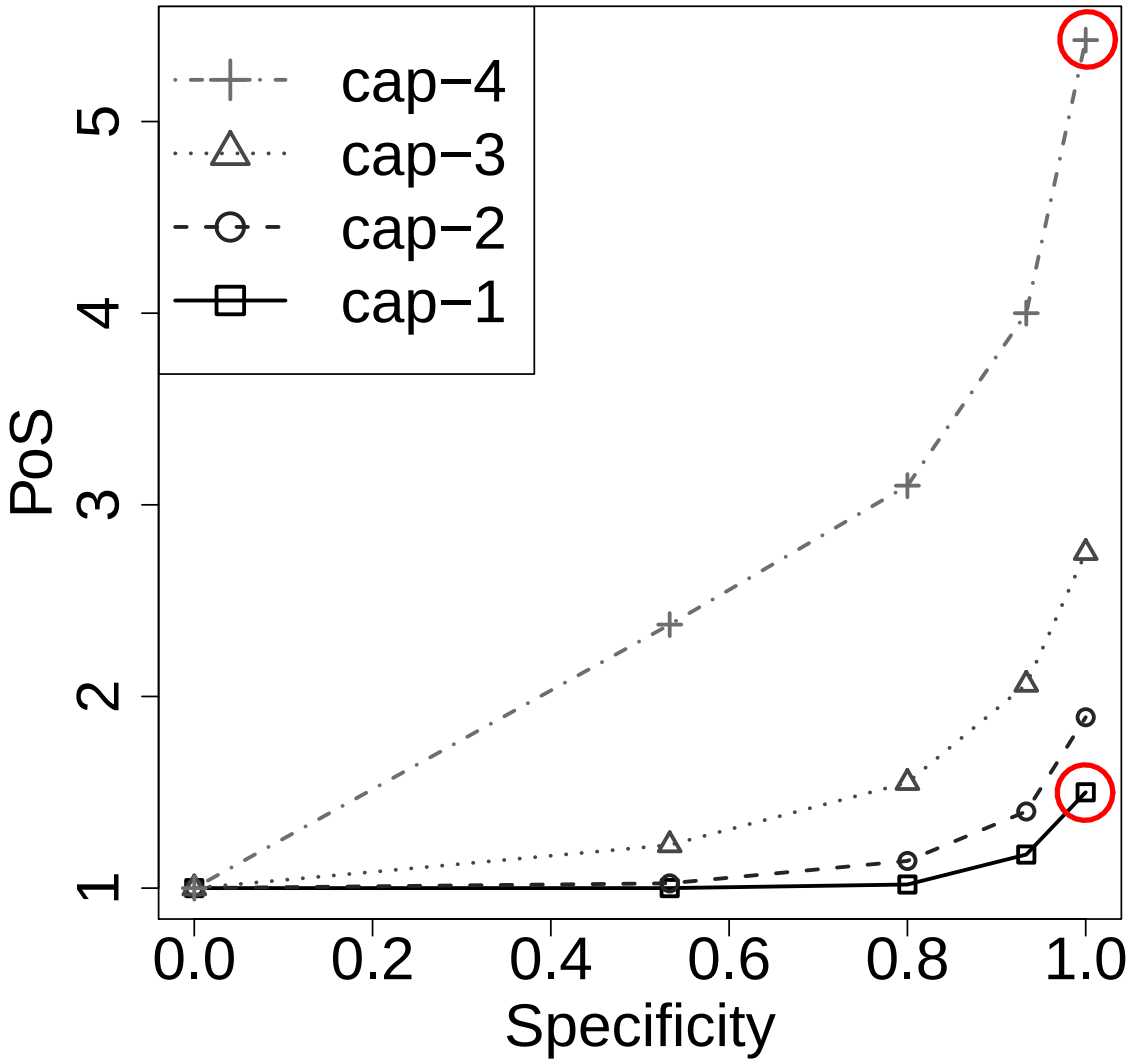

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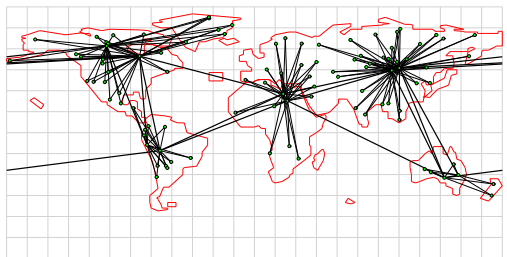
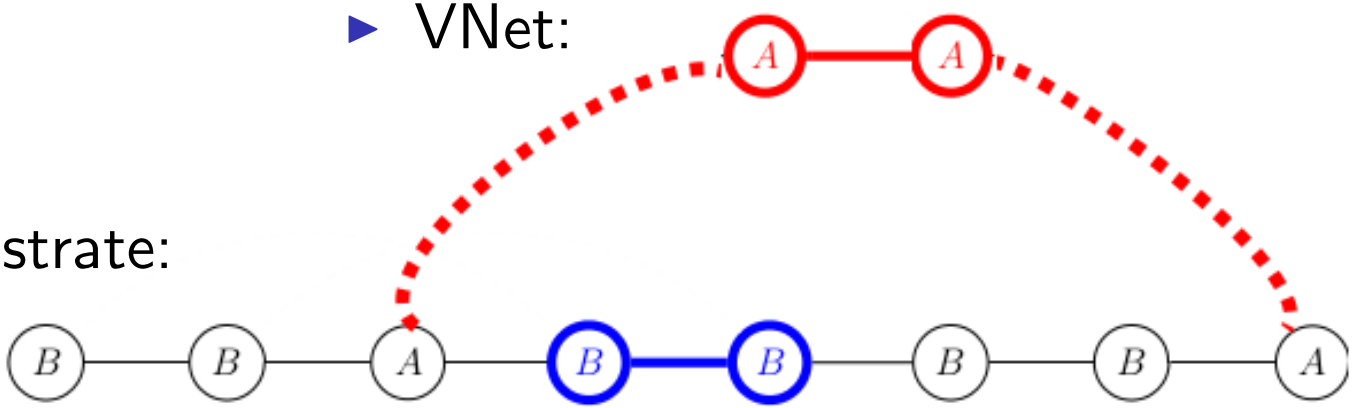


Migration

- Substrate:

Migration

- VNet:

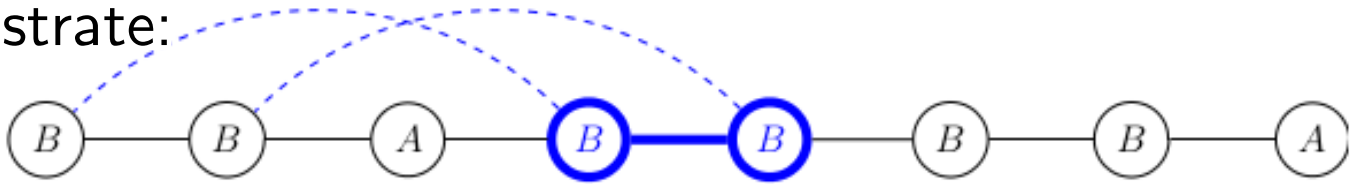


- Substrate:

Migration

- VNet:

- Substrate:



Migration

- VNet: 

- Substrate:

Migration

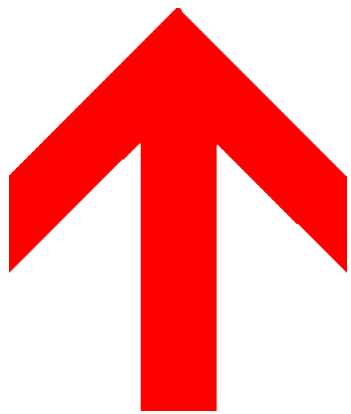
- VNet: 

- Substrate:

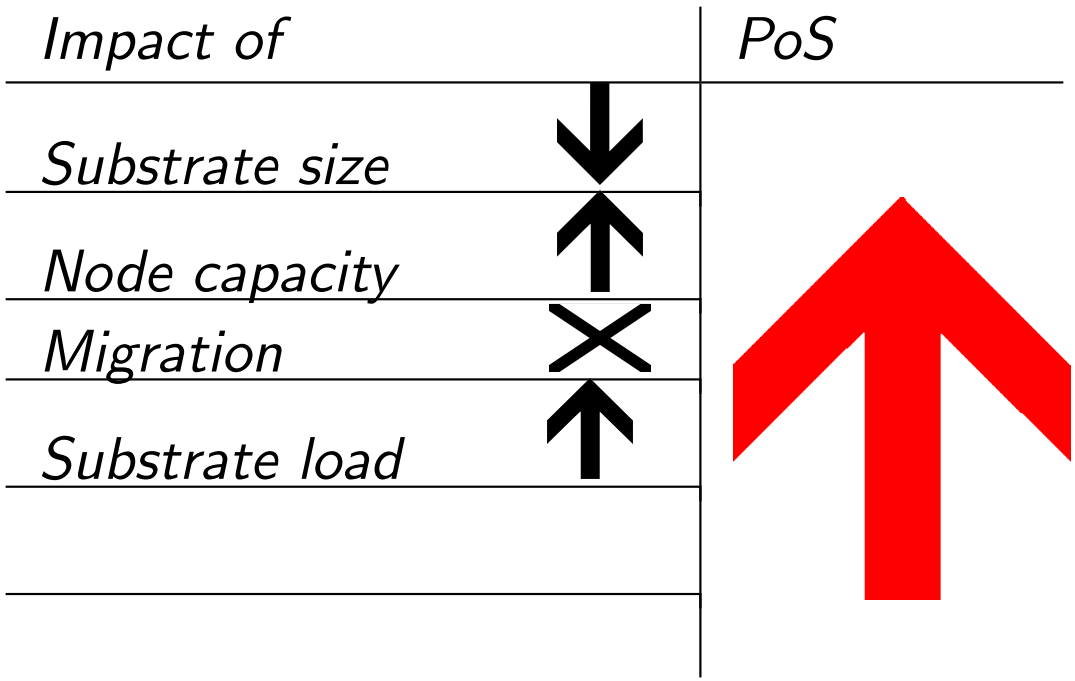
Impact of Migration

- Migration lowers average resource cost in general
- Depends on access policy
- Various impacts on PoS

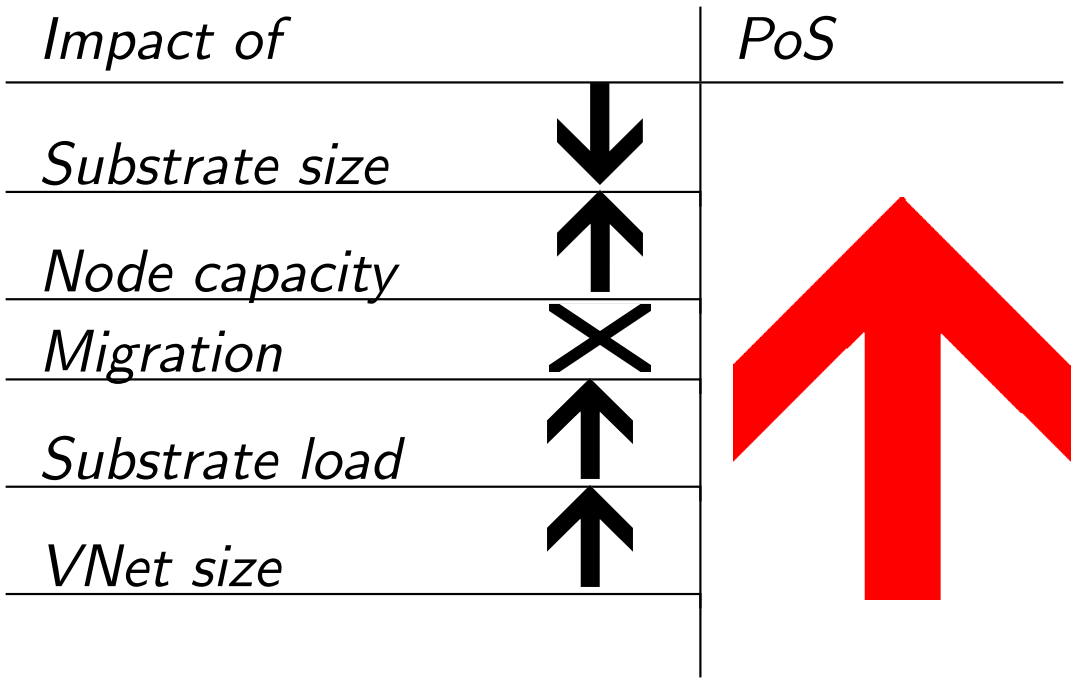
Summary

Impact of	*PoS*
Substrate size	
Node capacity	
Migration	

Summary


Impact of
PoS
Substrate size
Node capacity
Migration
Substrate load

Summary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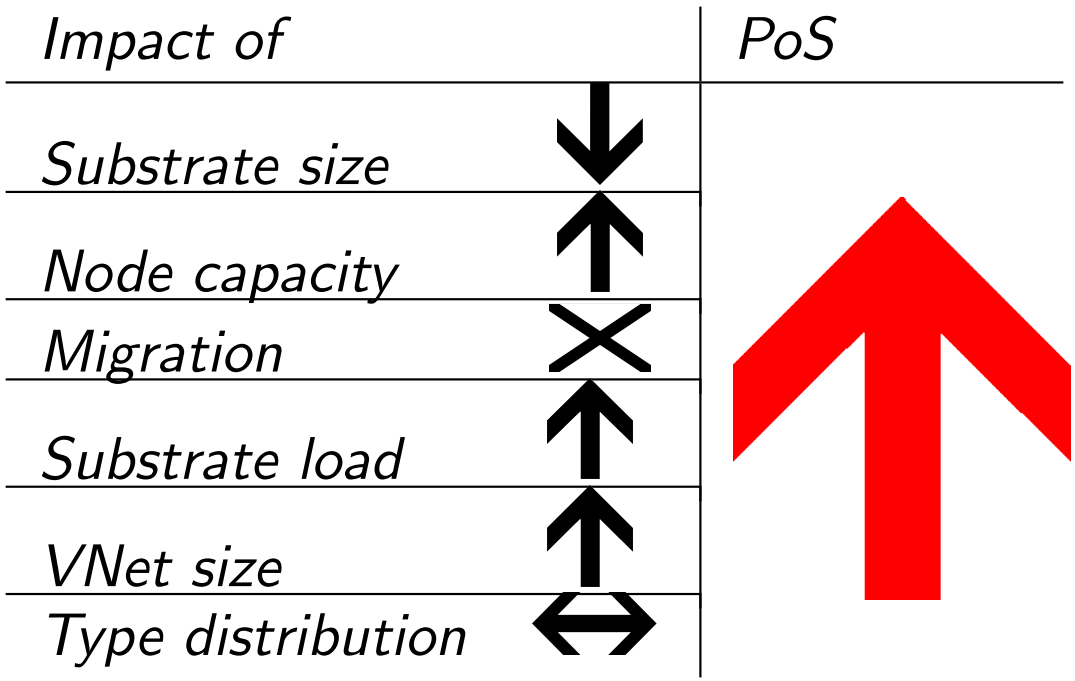
Impact of
PoS
Substrate size
Node capacity
Migration
Substrate load
VNet size
Type distribution

Conclusion

- Impact of VNet specification on the embedding cost
- Optimal embeddings
- General embedding algorithm
- PoS, tool to adjust pricing and embedding (applied as a factor?)

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- Optimal embeddings
- General embedding algorithm
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- Prototype (open source)
- Specification language *FLERD*
- Project website*

*www.net.t-labs.tu-berlin.de/~stefan/virtu.shtml