Expansion of Virtual-Oriented Infrastructure

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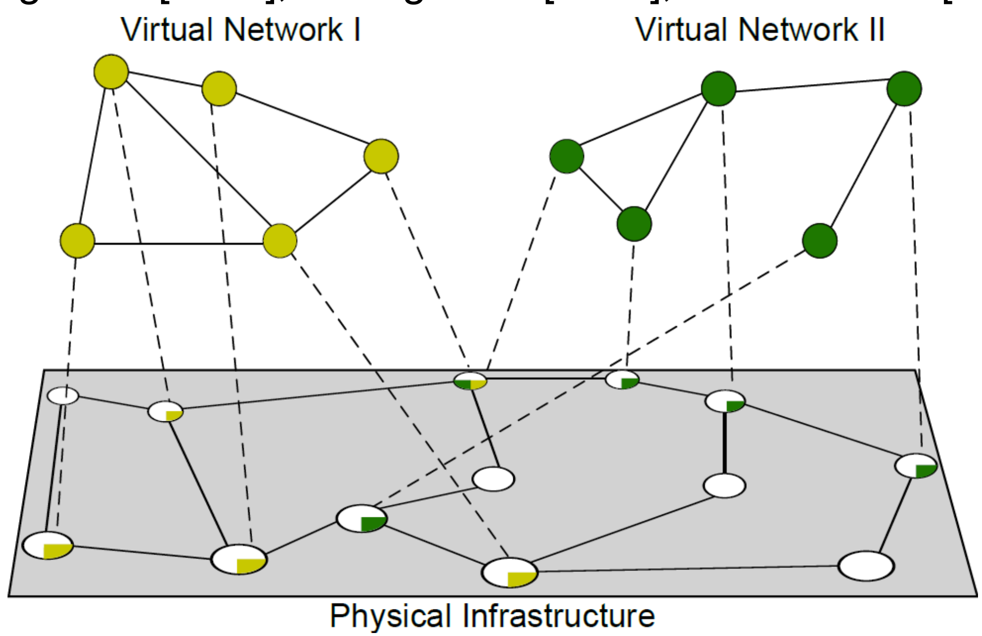
Outline

- Introduction
- Related Work
- InP Network Expansion For Efficient VNE
- Evaluation
- Conclusion and Future Work

Introduction
Context

- **Network virtualization:** allows the coexistence of heterogeneous virtual networks sharing resources of the same physical infrastructure
- **Challenge:** efficient mapping of physical resources to virtual networks (Chowdhury et al. [2009], Houidi et al. [2011], Fajjari et al. [2011], Cheng et al. [2011], Cheng et al. [2012], Alkmim et al. [2013])



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Introduction

Problem Definition and Motivation

- In previous work on Virtual Network Embedding, we observe:
  - **High rejection rates for VN requests** (up to 53%)
- We also verified (Luizelli et al. [2013]):
  - Subset of such rejection is caused by a temporary global outage of physical resources
  - An **expressive number** of rejection occurs in situation in which there are **sufficient resources available**

Introduction
Objective

- Propose a model for planning the expansion of InP networks
  - Reduce rejection rates
  - Increase resource consumption in the infrastructure

- By means of:
  - Formalization of an InP network expansion model in the context of network virtualization
  - Design of a heuristic approach to solve the model

Related Work

Expansion/Planning Approaches

- Backbone network expansion:
  - Mukherjee et al. [1996], Ramaswami et al. [1996], Krishnaswamy et al. [2001], Curtis et al. [2009], Johnston et al. [2011]
- Data center network expansion:
  - Curtis al. [2012], Gao el al. [2012]

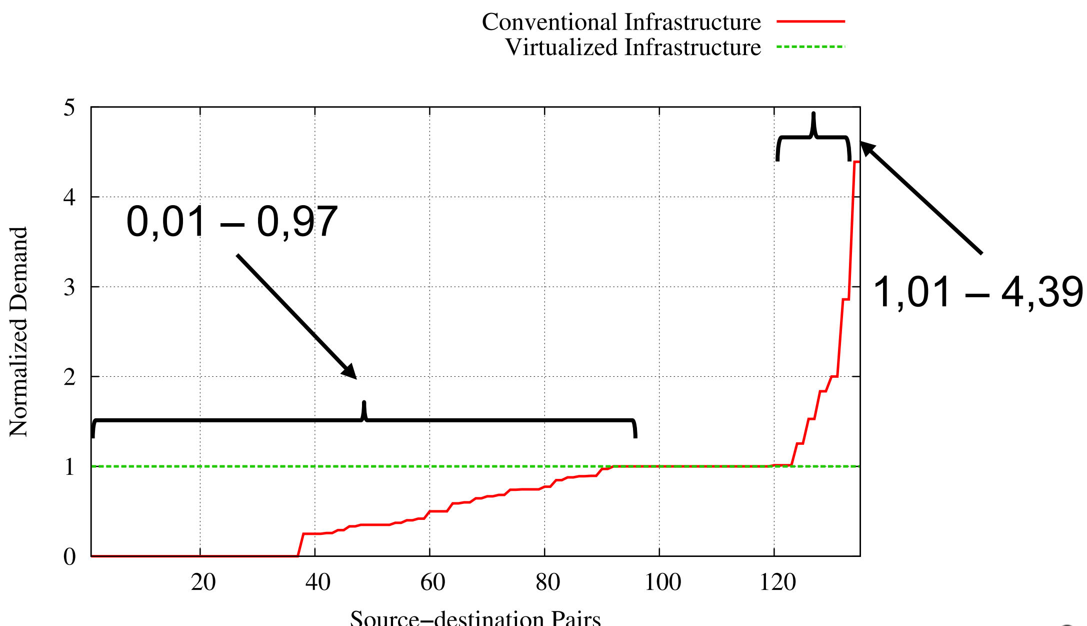
- All of them rely on the use of **demand matrices** to plan the expansions

- **We are not aware of previous attempts to investigate strategies for expanding the physical network of an infrastructure provider with the objective of enabling it to host a higher number of virtual networks**

InP Network Expansion

Why Are Demand Matrices not Suitable for Virtual Network-oriented Infrastructure Planning?

- Traditional expansion approaches based on demand matrices are not suitable for virtualized environments
- Virtualized InP exhibit comparatively more homogeneous resource distribution amongst physical devices



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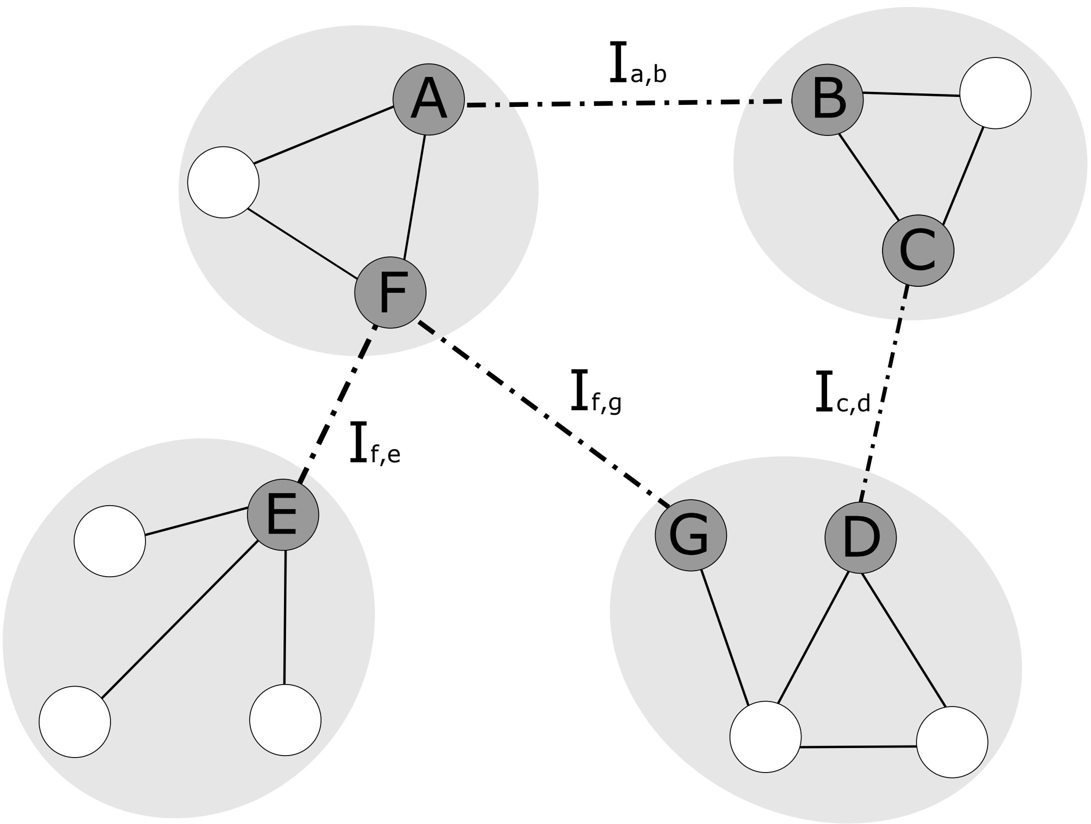
InP Network Expansion: Overview

- One of the major causes of virtual network rejection in the context of VNE is the absence of a suitable partition
- As mentioned, InP networks have available resources
- The occurrence of partitions is directly correlated to the total exhaustion of available resource in specific devices (e.g., hubs and bridges)

The above findings were the motivation for modeling the InP expansion problem

InP Network Expansion: Overview

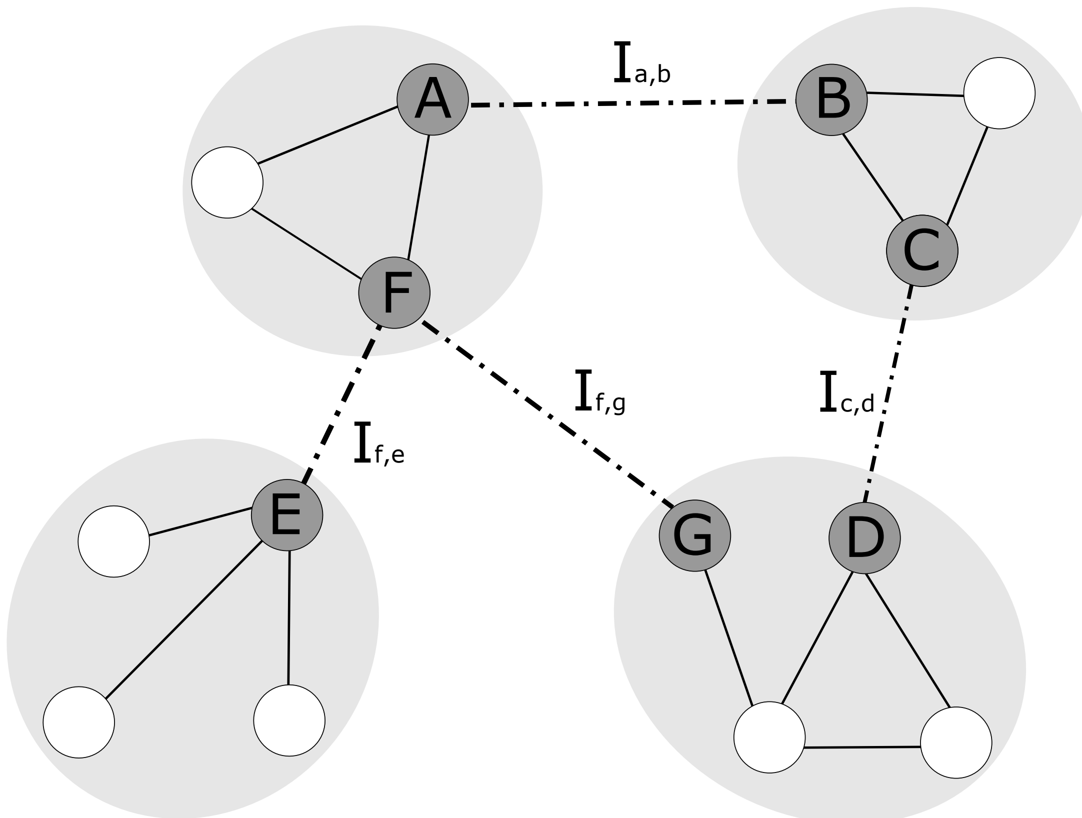
Example



X = {(a,b), (c,d), (f,e), (f,g)}

InP Network Expansion: Overview

Example



X = {(a,b), (c,d), (f,e), (f,g)}

1. **Which elements to expand?**
2. **How much to invest?**

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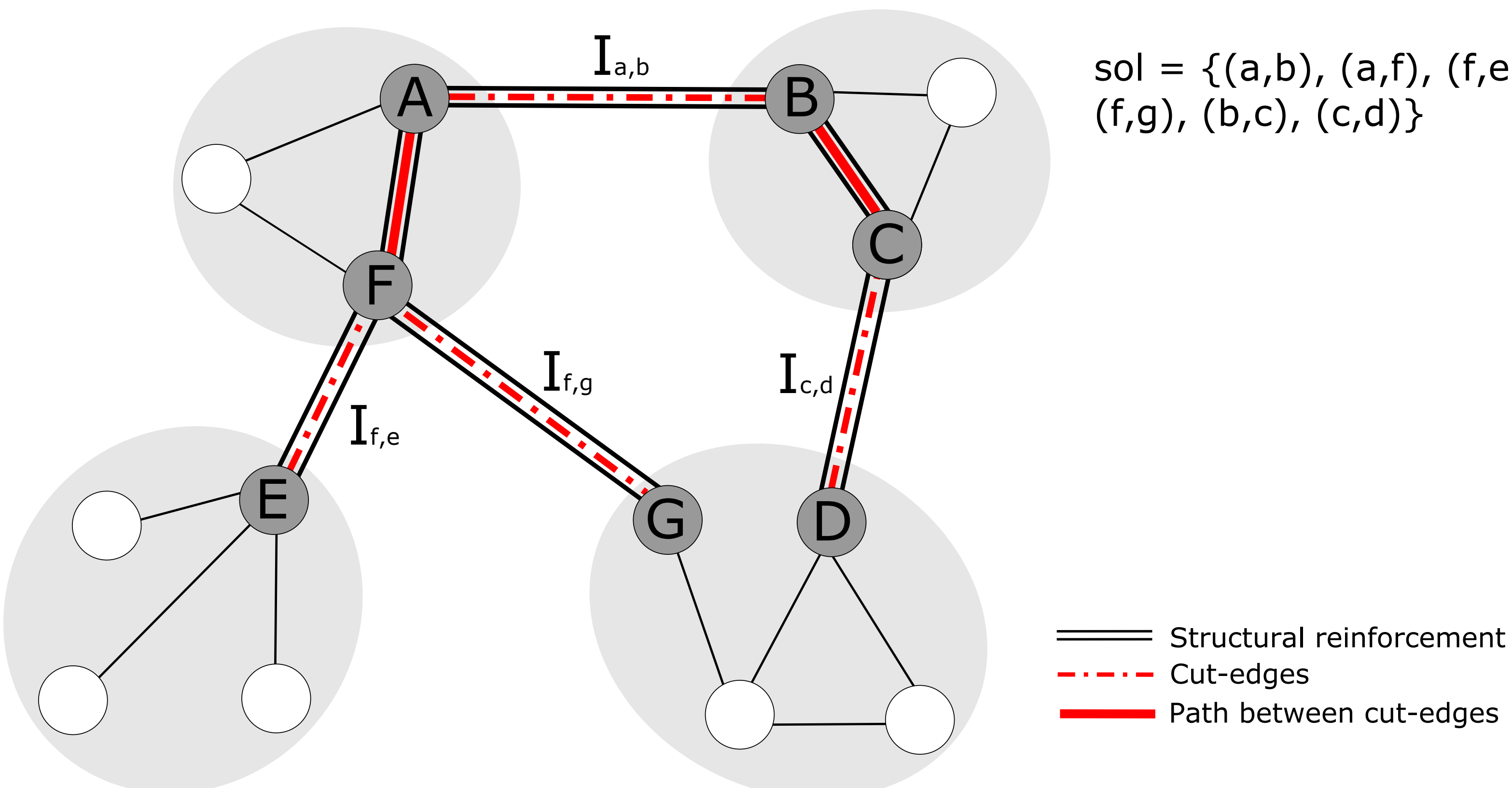
InP Network Expansion: Overview

Example



sol = {(a,b), (a,f), (f,e), (f,g), (b,c), (c,d)}

InP Network Expansion: Exact Model

- Problem constraints
  - Router capacity (memory and CPU)
  - Link capacity (bandwidth)
  - Expansion costs (routers and links)
  - Creation of a new core, acting as a structural reinforcement
  - Ensures the investment will not exceed the available funds of the InP (growth)
  - Ensures that only a subset of physical devices will be affected by the expansion procedure (coverage)

- **Objective**: maximize reconnection between the most important cut-edges

InP Network Expansion: Heuristic

- Similar to the minimum Steiner tree problem, which is known to be NP-hard
- Two-step heuristic:
  1. Identify which devices need to be expanded
  2. Define a strategy for resource distribution among the selected devices
     - Uniformly
     - Probabilistic distribution

InP Network Expansion: Heuristic

For each **time unit**:

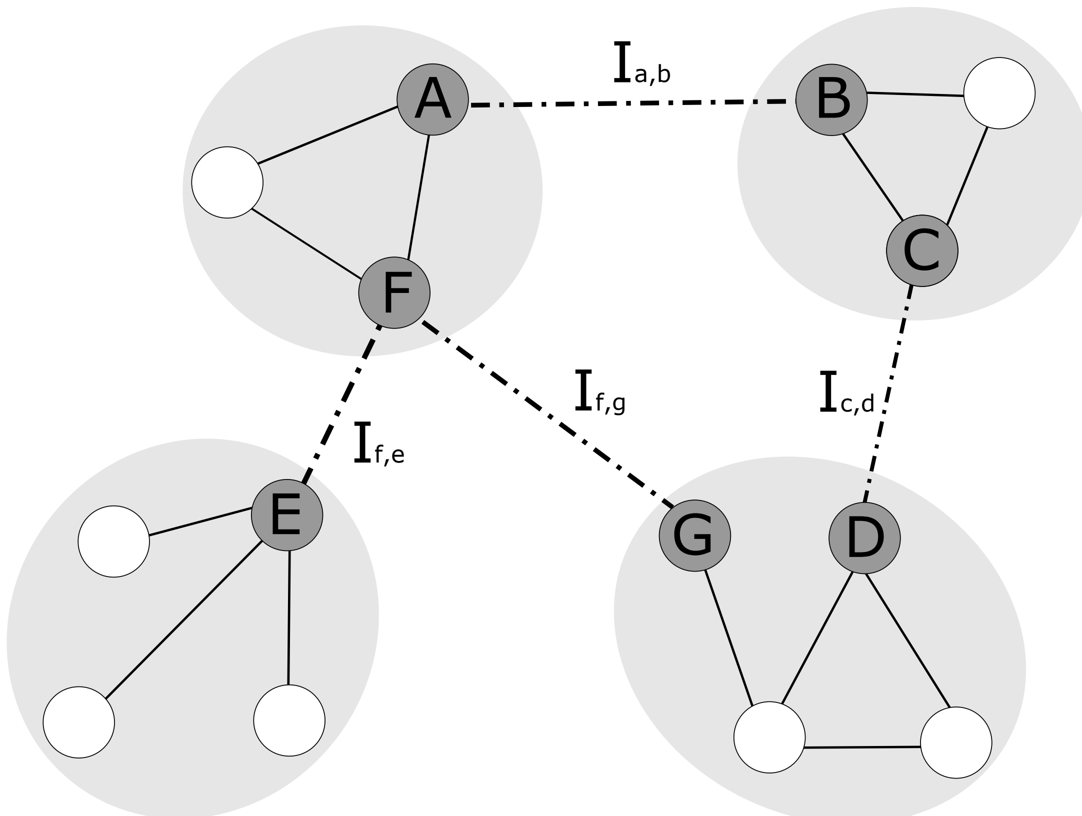
1. Identify and store the set of partitions, as well as the cut-links

If **expansion periodicity**:

1. Compute the importance of each element stored so far
2. Sort accordingly to its importance
3. Select a percentage % of cut-links with highest importance
4. Create a subgraph from such select links
5. MST(subgraph)
6. If |subgraph| > coverge:
    1. Remove the least relevant cut-link from subgraph
7. Else:
    1. Stop

Suggest link/router expansion

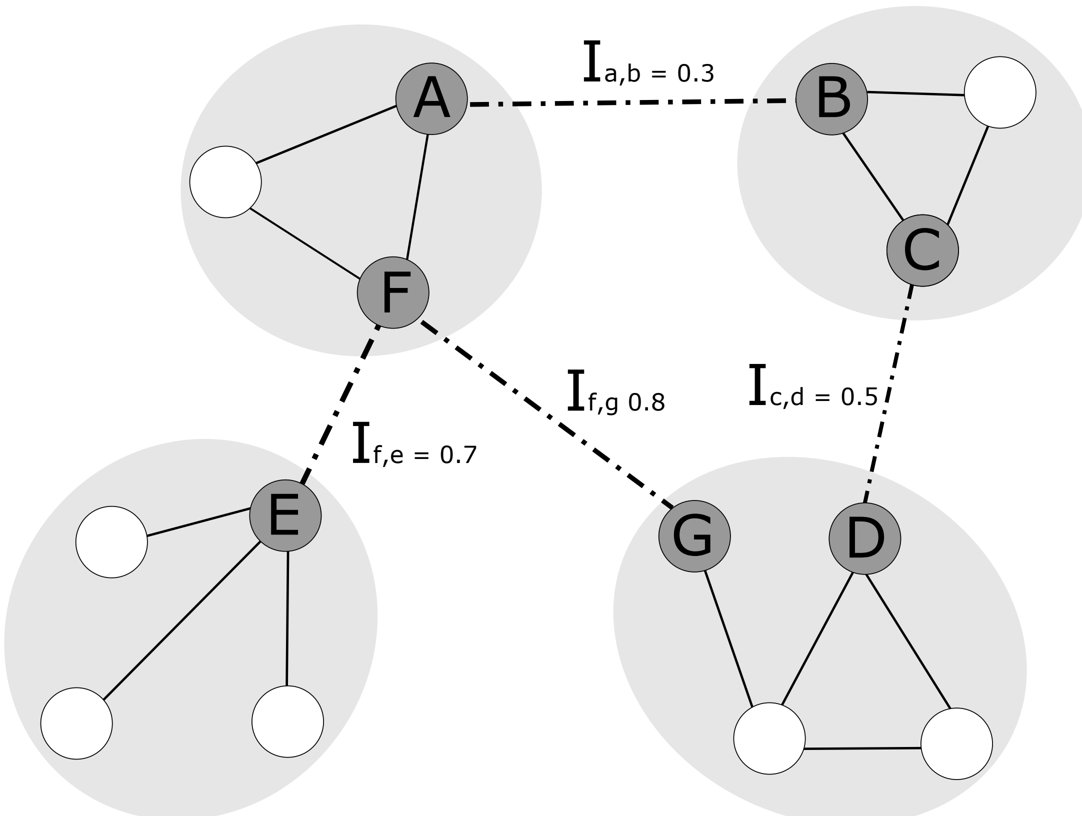
InP Network Expansion: Heuristic



$X = \{(a,b), (c,d), (f,e), (f,g)\}$

1. Identify and store the set of partitions, as well as the cut-links

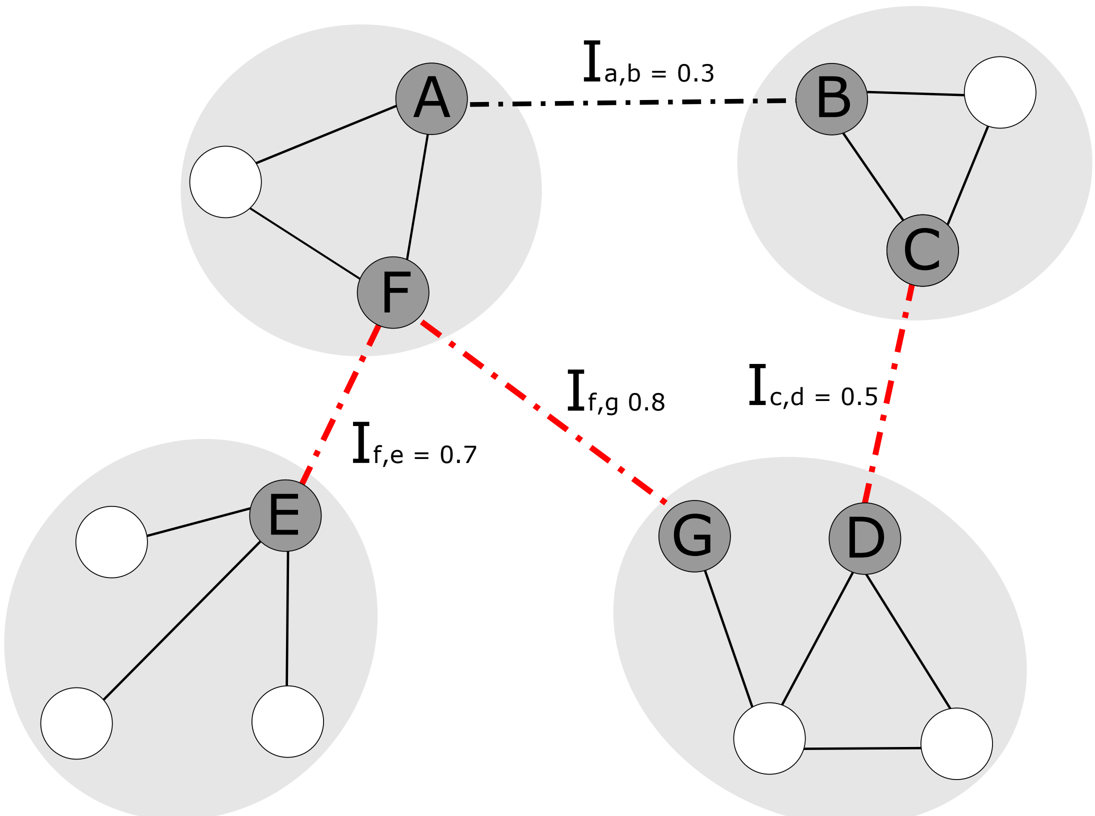
InP Network Expansion: Heuristic



X = {(a,b), (c,d), (f,e), (f,g)}

2. Compute the importance of each element stored so far

InP Network Expansion: Heuristic



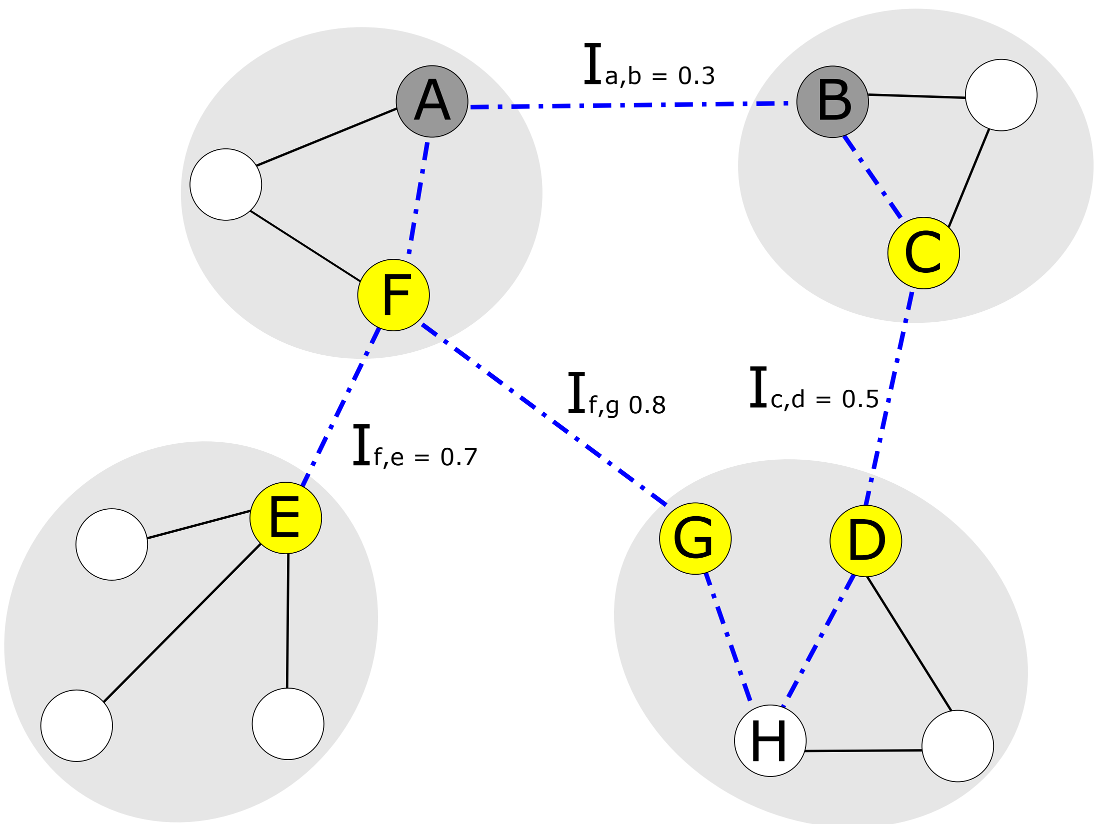
X = {(a,b), (c,d), (f,e), (f,g)}

20% of coverage

3. Sort accordingly to its importance

4. Select a percentage % of cut-links with highest importance

InP Network Expansion: Heuristic



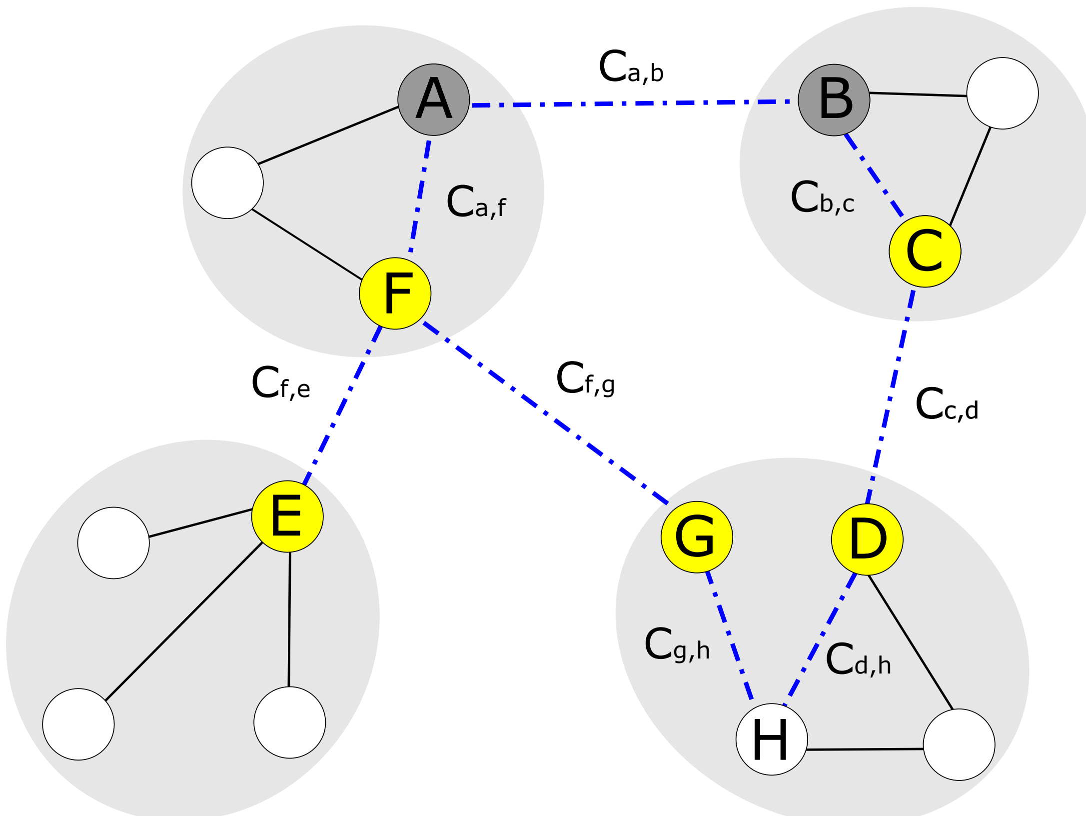
X = {(a,b), (c,d), (f,e), (f,g)}

N = {A,B,C,D,E,F}

E = {(a,b), (c,d), (f,e), (f,g), (a,f), (b,c), (g,h), (h,d)}

5. Create a subgraph from such selected elements

InP Network Expansion: Heuristic



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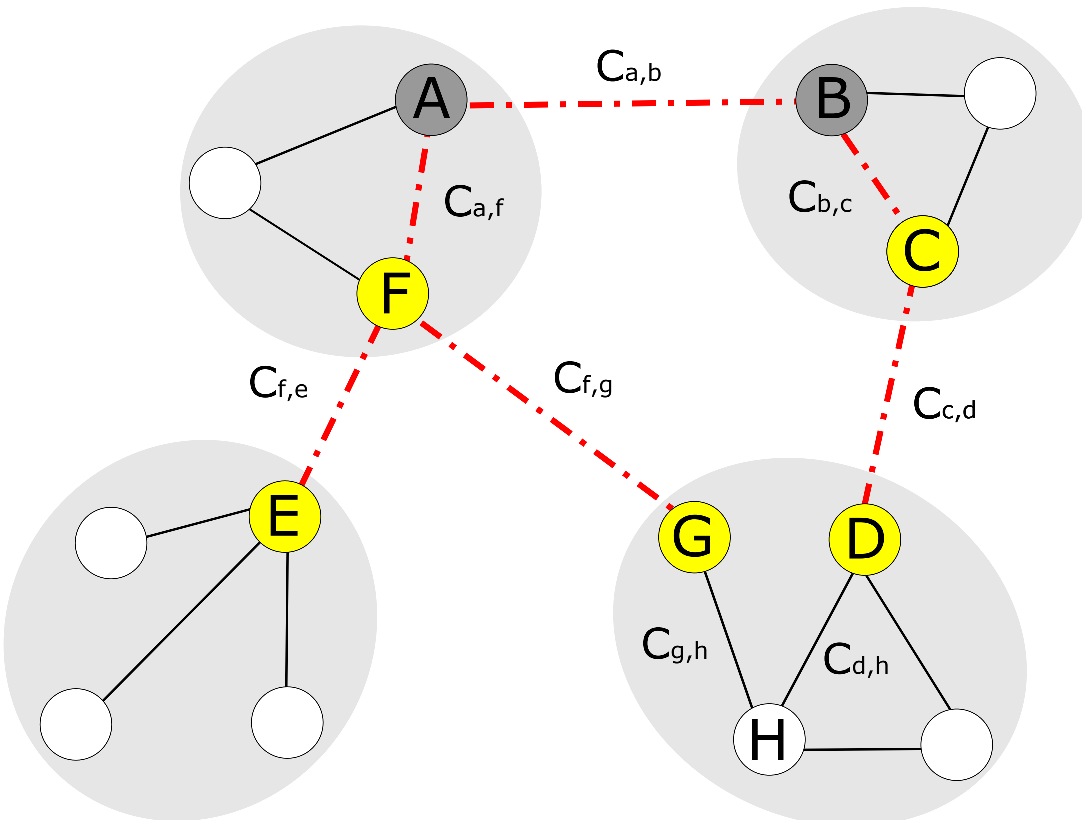
InP Network Expansion: Heuristic



sol = {(a,b), (c,d), (f,e), (f,g), (a,f), (b,c)}

6. sol = mst(subgraph)

7. **If** |sol| > coverage:

Remove the least relevant cut-link from subgraph

Else:

Stop

20% of coverage?

Evaluation
Parameter Selection

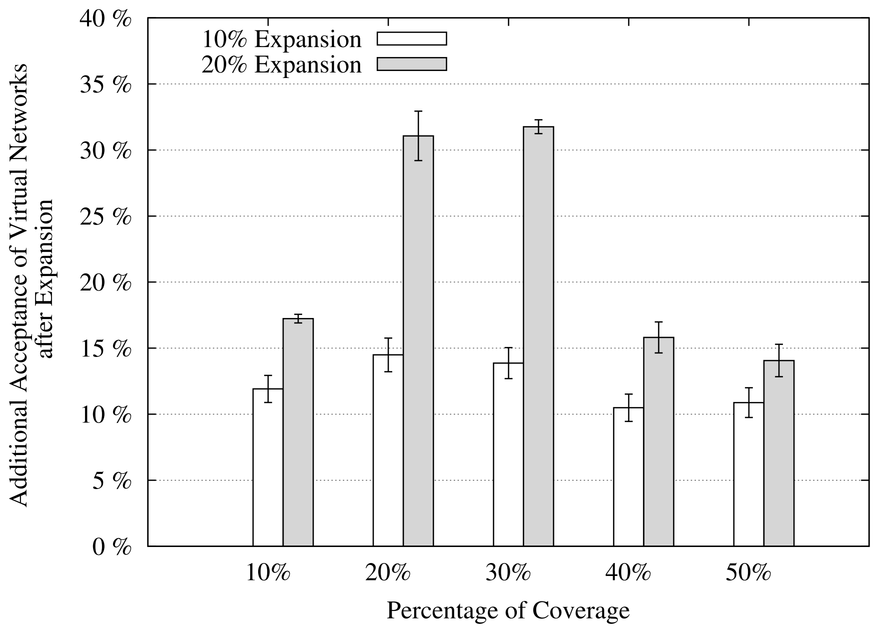
- General Parameters
  - 360 time units
  - 3 VN request at each time unit
  - VNE model proposed by Luizelli et al. [2013]

- Physical Network
  - Topology: *Hub & Spoke*
  - 50 routers: 100% CPU and 256 MB
  - Links: 10 Gbps

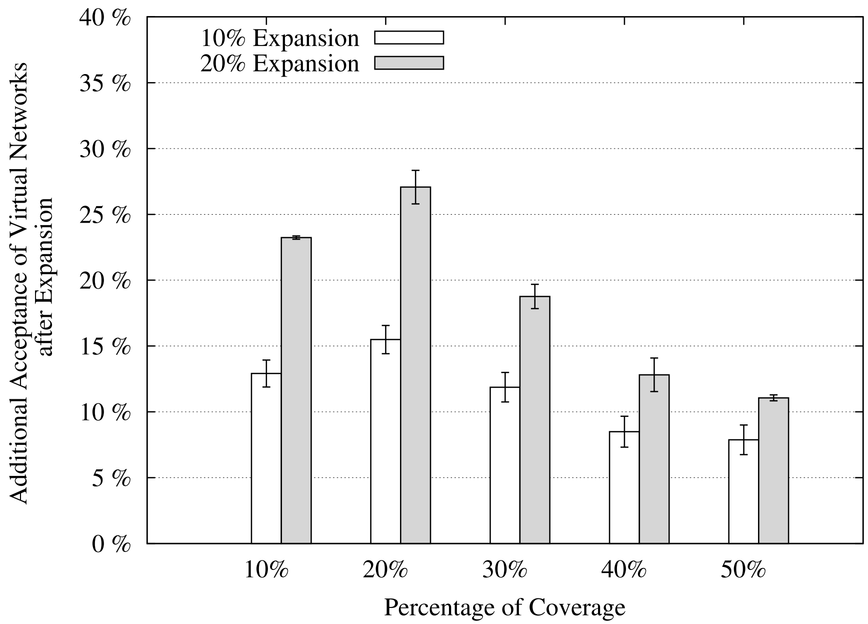
Evaluation
Parameter Selection

- Virtual Network
  - Topologies: ring and random
  - 5 routers: 20% CPU and 48 MB
  - Links: 2.5 Gbps
- Expansion Strategy
  - Periodicity:
    - Expansion at 180ª time unit
    - Consecutively expansions
  - Homogeneous costs
  - Coverage: 10% to 50%
  - Investment: 10% and 20%
- Each experiment was run 30 times
- 95% confidence level

Evaluation
Results



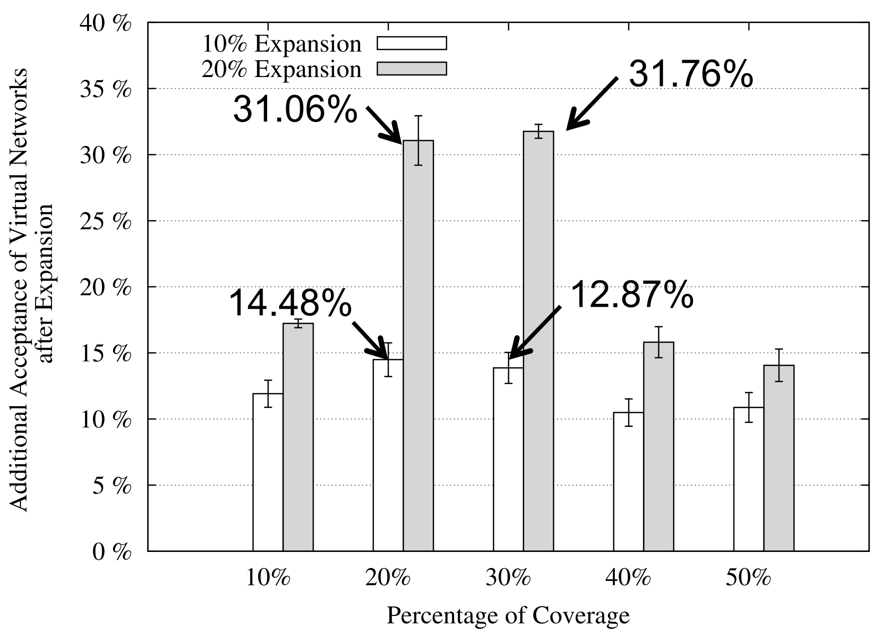
(a) Experiments considering VNs with ring topology.



(b) Experiments considering VNs with random topology.

Average increase in virtual network acceptance after the employment of the expansion strategy.

Evaluation
Results



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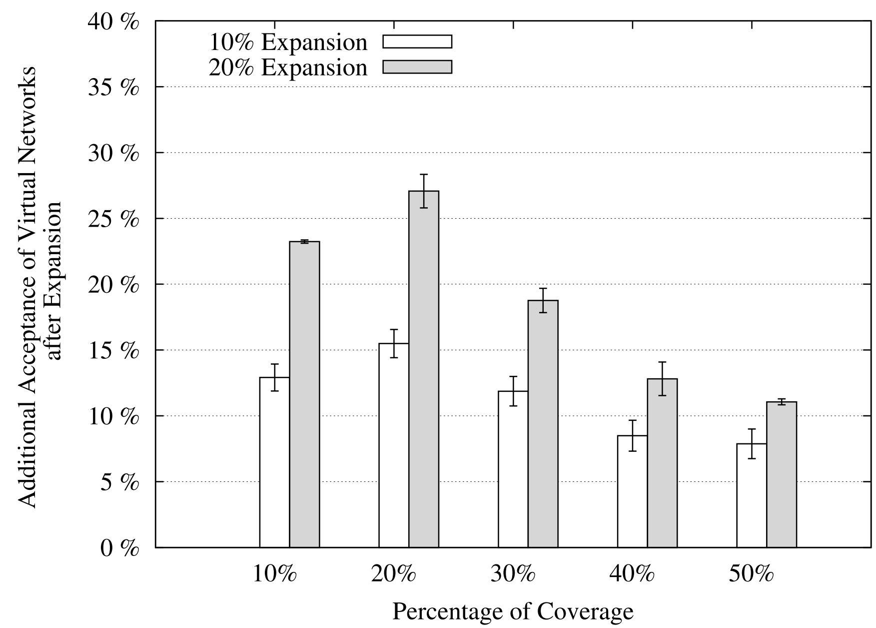

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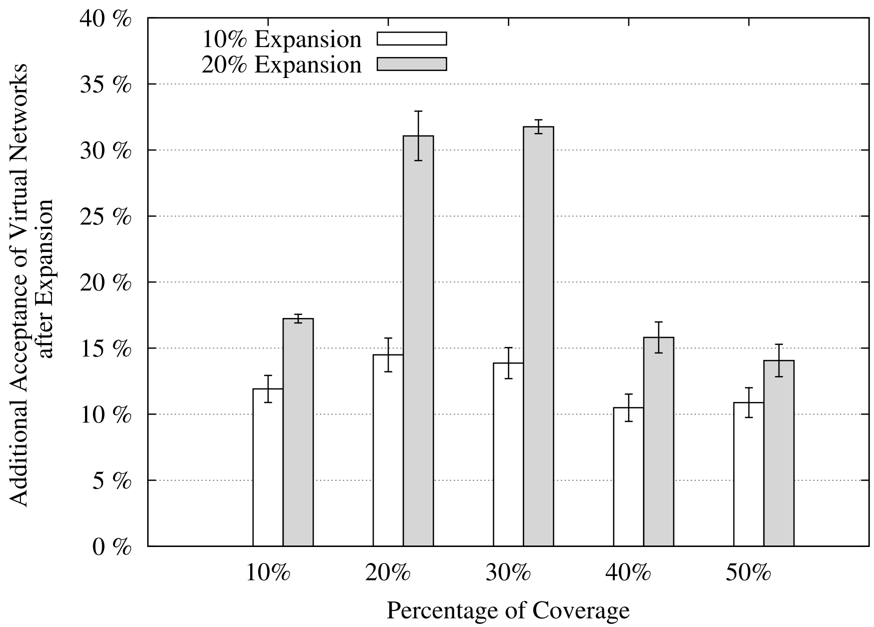

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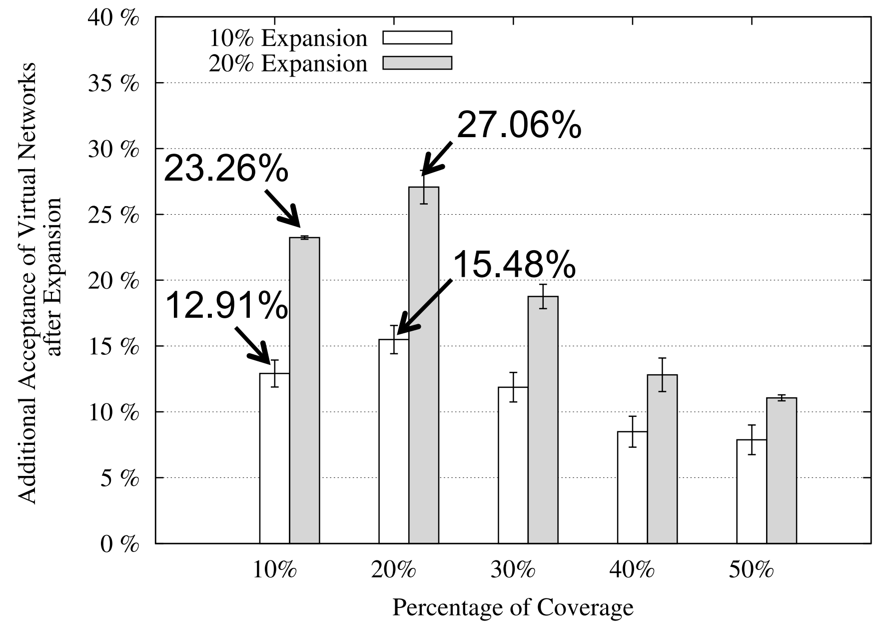
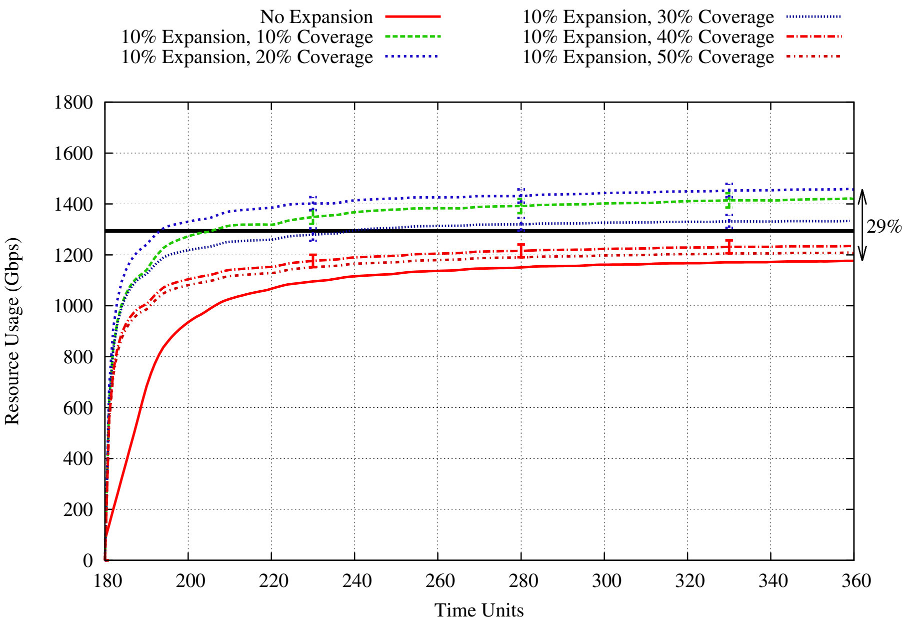


(b) Experiments considering VNs with random topology.

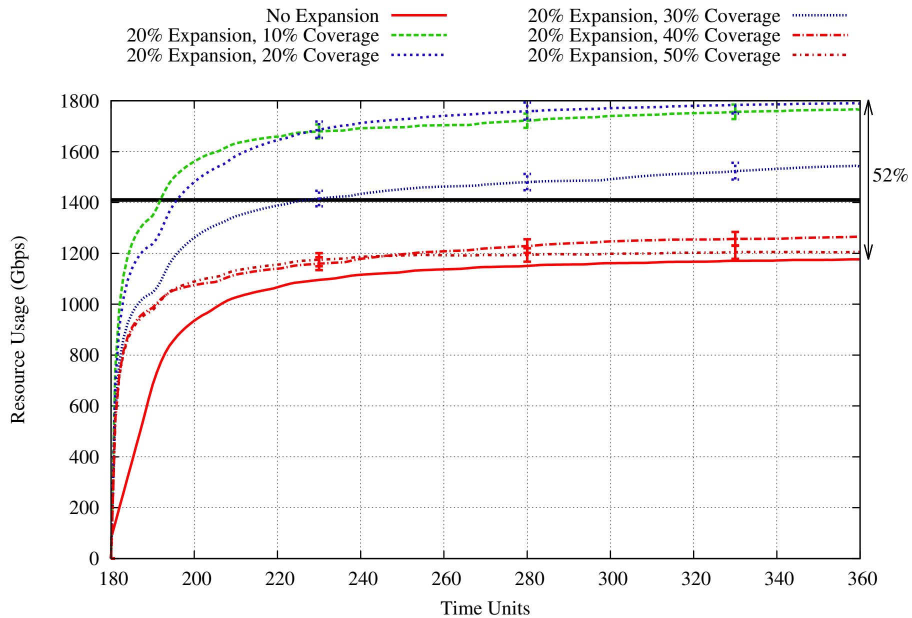
Average increase in virtual network acceptance after the employment of the expansion strategy.

Evaluation

Results – Resource Consumption / Random Topology



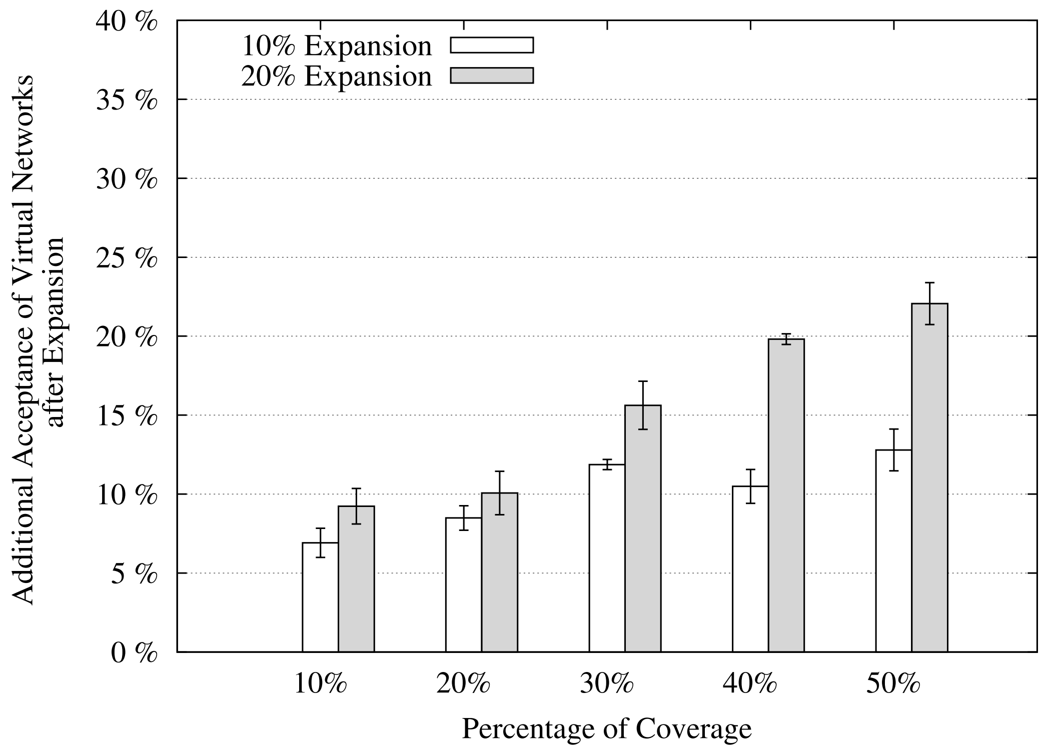
(a) Experiments considering an expansion of 10%.



(b) Experiments considering an expansion of 20%.

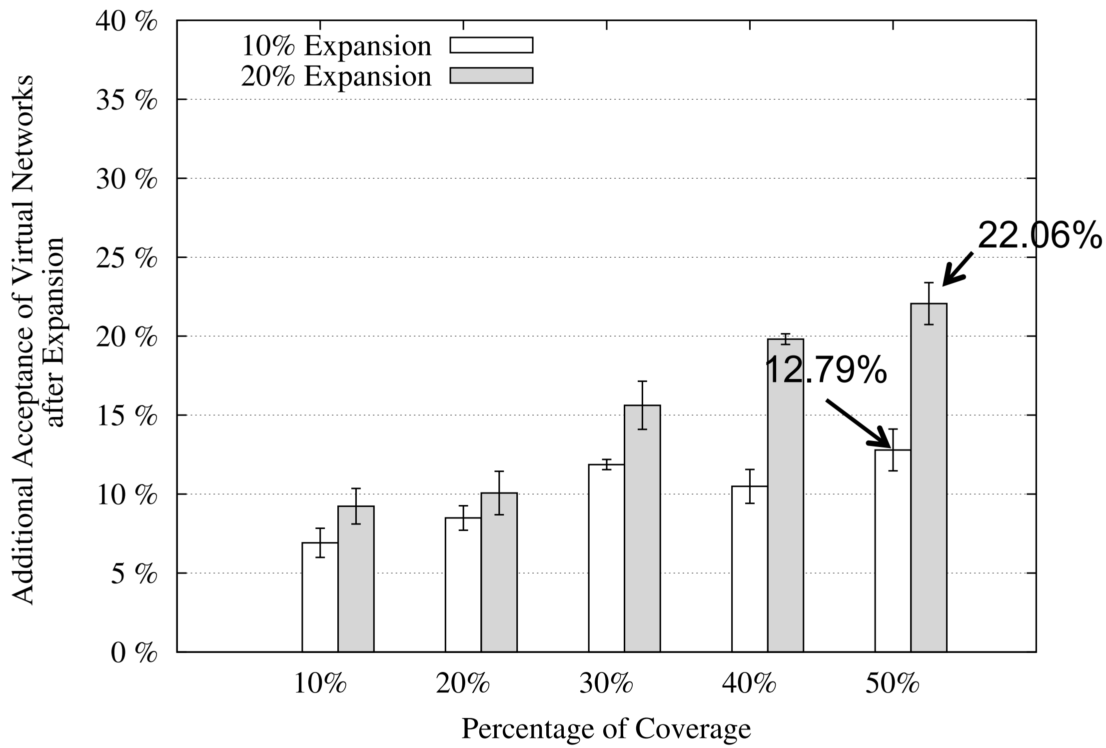
Overall physical bandwidth usage after the expansion, considering virtual networks with random topology.

Evaluation
Results



Average increase in virtual network acceptance after consecutive employments of the expansion strategy.

Evaluation
Results



Average increase in virtual network acceptance after consecutive employments of the expansion strategy.

Conclusion and Future Work

- The expansion strategy performed by our solution leads to:
  - A **a sustained increase of up 30%** in virtual network acceptance
  - As well as up to **52% in resource utilization** compared to the original network
- Extending the evaluation
  - Apply it to other backbones topologies
  - Evaluate and propose novel strategies for resource distribution among infrastructure devices
  - Conduct and in-depth analysis of the inter-relationship between its parameters

Thanks!

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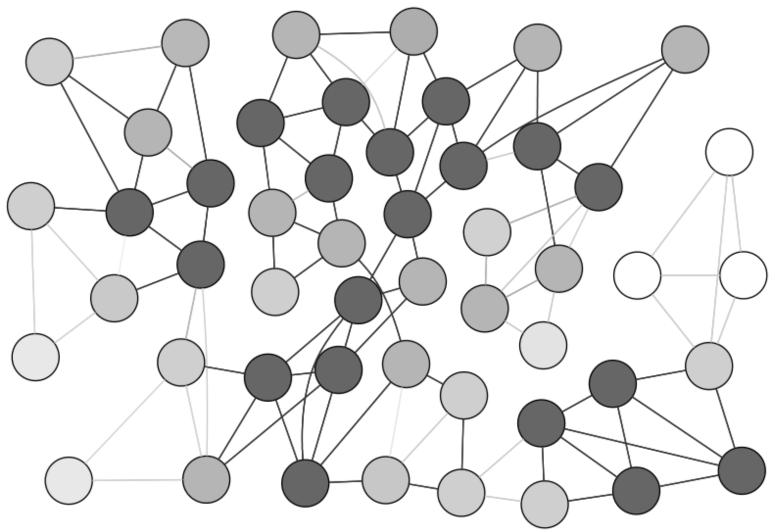
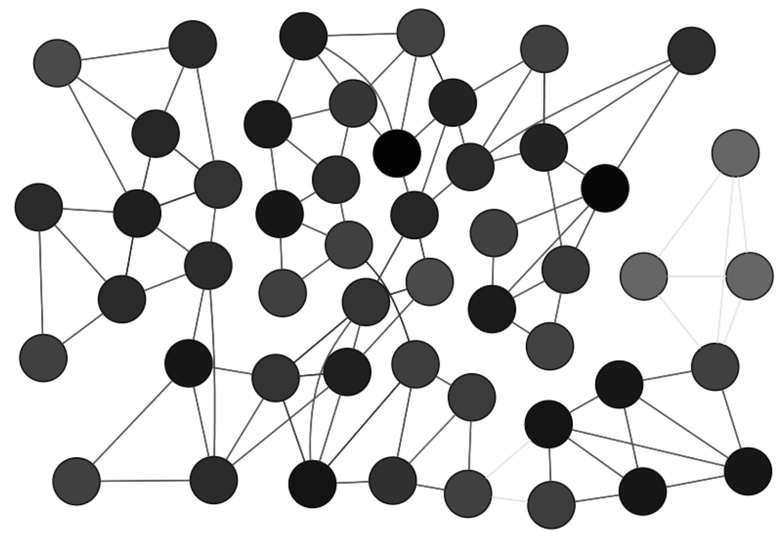
Evaluation

Results



(a) Resource usage before expansion.

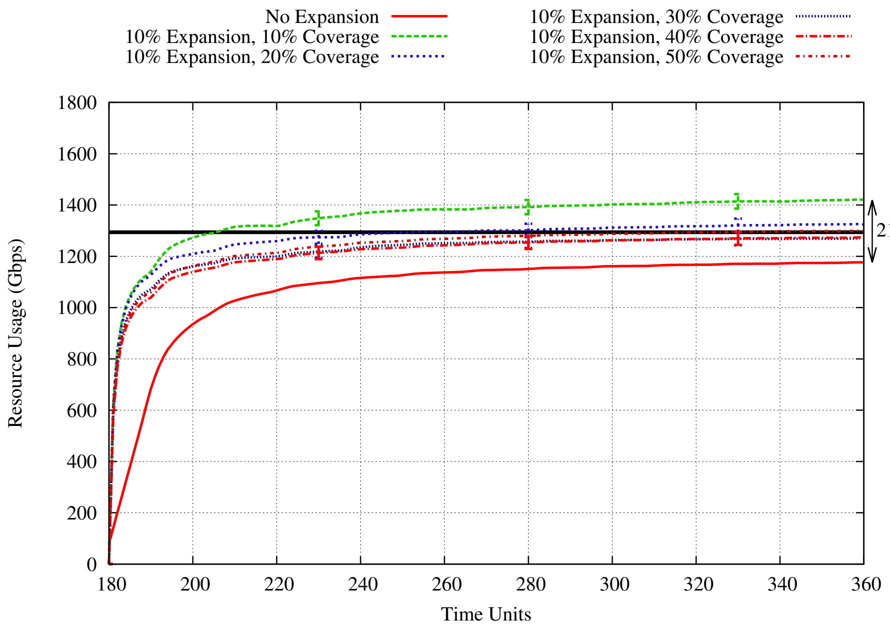


(b) Resource usage after expansion.

Graphical representation of average infrastructure resource usage before (a) and after (b) an expansion of 20% of resources with coverage of 20%. Darker shades represent higher resource usage.

Evaluation

Results – Resource Consumption / Ring Topology



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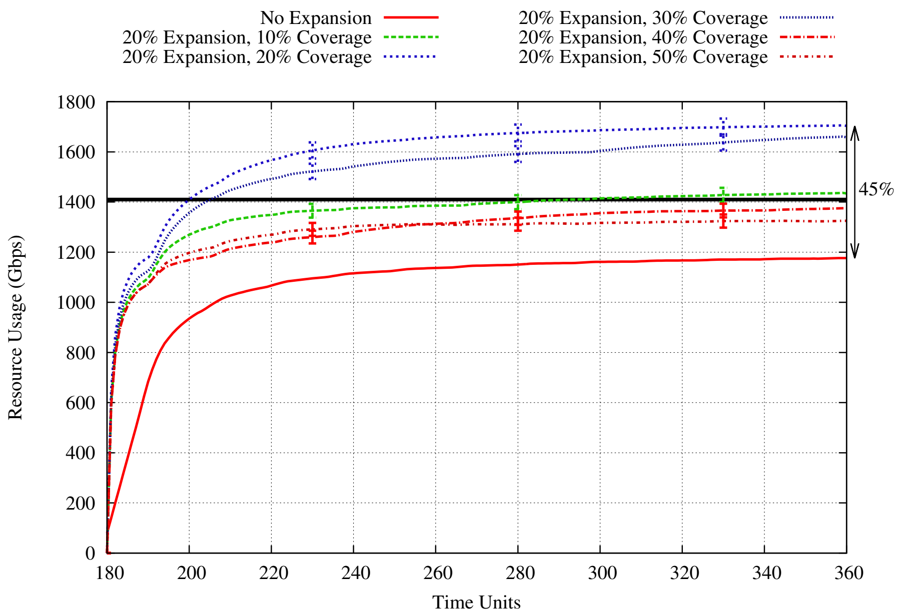

(b) Experiments considering an expansion of 20%.

Overall physical bandwidth usage after the expansion, considering virtual networks with ring topology.

Optimal Model for Virtual Network

Objective function:

$$min \sum_{(i,j)\in L^P} \sum_{r\in N^V,(k,l)\in L^V} A^L_{i,j,r,k,l} B^V_{r,k,l}$$

Subject to:

$$\sum_{r\in N^V, j\in R^V} C^V_{r,j} A^R_{i,r,j} \leq C^P_i \qquad \forall i \in R^P \quad \text{(R1)}$$

$$\sum_{r\in N^V, j\in R^V} M^V_{r,j} A^R_{i,r,j} \leq M^P_i \qquad \forall i \in R^P \quad \text{(R2)}$$

Optimal Model for Virtual Network

$$\sum_{r \in N^V, (k,l) \in L^V} B^V_{r,k,l} A^L_{i,j,r,k,l} \leq B^P_{i,j} \qquad \forall (i,j) \in L^P \quad \text{(R3)}$$

$$\sum_{i \in R^P} A^R_{i,r,j} = 1 \qquad \forall r \in N^V, j \in R^V \quad \text{(R4)}$$

$$\sum_{j \in R^V} A^R_{i,r,j} \leq 1 \qquad \forall i \in R^P, r \in N^V \quad \text{(R5)}$$

Optimal Model for Virtual Network

$$\sum_{j \in R^P} A^L_{i,j,r,k,l} - \sum_{j \in R^P} A^L_{j,i,r,k,l} = A^R_{i,r,k} - A^R_{i,r,l} \qquad \forall r \in N^V, (k,l) \in L^V, i \in R^P \quad \text{(R6)}$$

$$jA^R_{i,r,k} = lA^R_{i,r,k} \qquad \forall (i,j) \in S^P, r \in N^V, (k,l) \in S^V \quad \text{(R7)}$$

$$A^R_{i,r,j} = E^R_{i,r,j} \qquad \forall (i,r,j) \in E^R \quad \text{(R8)}$$

$$A^L_{i,j,r,k,l} = E^L_{i,j,r,k,l} \qquad \forall (i,j,r,k,l) \in E^L \quad \text{(R9)}$$

InP Expansion Model

$$CustoExp = \sum_{e \in L^P} xb_e \cdot costBw^P e + \sum_{i \in R^P} (xc_i \cdot costCPU^P i + xm_i \cdot costMem^P i) \quad (5.1)$$

$$x_e \cdot (B^P_{i,j} + \frac{CapitalDisp \cdot Cobertura}{costBw^P_{i,j}}) \leq EB^P_{i,j} \qquad \forall e \in L^P \quad (5.2)$$

$$x_{i,j} \cdot (C^P_i + \frac{CapitalDisp \cdot Cobertura}{costCpu^P_i}) \leq EC^P_i \qquad \forall (i,j) \in L^P \quad (5.3)$$

$$x_{i,j} \cdot (M^P_i + \frac{CapitalDisp \cdot Cobertura}{costMem^P_i}) \leq EM^P_i \qquad \forall (i,j) \in L^P \quad (5.4)$$

InP Expansion Model

$$CustoExp \leq CapitalDisp \tag{5.5}$$

$$\sum_{a \in \delta^+(u)} x_a^k - \sum_{a \in \delta^-(u)} x_a^k = \begin{cases} 1 \cdot q_u & \text{se } u = s \\ -1 \cdot q_u & \text{se } u = k \\ 0 & u \in R^P / \{s, k\} \end{cases} \quad \forall u \in R^P, \forall k \in R^C \tag{5.6}$$

$$q_u \geq \frac{\sum_{a \in \delta^+(u)} z_a}{|\delta^+(u)|} \quad \forall u \in R^P \tag{5.7}$$

$$\frac{\sum_{\forall e \in L^P} x_e}{|L^P|} \leq Cobertura \tag{5.8}$$

$$Maximize \sum_{e \in X} I_e \cdot z_e \tag{5.9}$$

HIPER: Detailed Algorithm

Input: Capital disponível, Percentual de cobertura, Periodicidade da expansão, Infraestrutura física do InP N, Mapeamento das redes virtuais $A^R_{i,r,j}$ and $A^L_{i,j,r,k,l}$
Output: Conjunto de dispositivos físicos a serem expandidos

$X \leftarrow \emptyset$
$F \leftarrow \emptyset$
$C \leftarrow \emptyset$
foreach $UnidadeTempo$ **do**
  $particoes \leftarrow obterConjuntoParticoes(N, E^R, E^L)$
  $X \leftarrow atualizarEnlacesCorte(particoes)$
  $F \leftarrow atualizarFrequencia(X)$
  $C \leftarrow atualizarCobertura(X, particoes)$
  if $PeriodicidadeDaExpansao$ **then**
    foreach $(i,j) \in X$ **do**
      $I_{i,j} \leftarrow \frac{F_{i,j}}{\sum_{\forall(i,j)} F_{i,j}} \cdot C_{i,j}$
    end
    while $true$ **do**
      $ordenaDesc(X, I)$
      $list \leftarrow$ seleciona % dos enlaces de X (% igual ao percentual de cobertura)
      $R^c \leftarrow$ roteadores de $list$
      $L^c \leftarrow$ enlaces dos caminhos de custo mínimo entre cada par de roteador $(a,b) \in R^c$
      $N^c = (R^c, L^c)$
      $sol^c \leftarrow mst(N^c)$
      if $numeroRoteadores(sol^c) > Cobertura$ *ou* $numeroEnlaces(sol^c) > Cobertura$ **then**
        $X.removeItem()$
      else
        $parar$
      end
    end
    $sugiraExpansaoEnlaces(CapitalDisponivel)$
    $sugiraExpansaoRoteadores(CapitalDisponivel)$
    $X \leftarrow \emptyset$

end

Algoritmo 1: Visão geral da solução proposta para o problema de expansão de redes de InPs.