Joint Backup Capacity Allocation and Embedding for Survivable Virtual Networks

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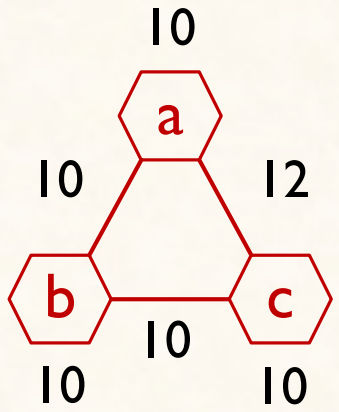
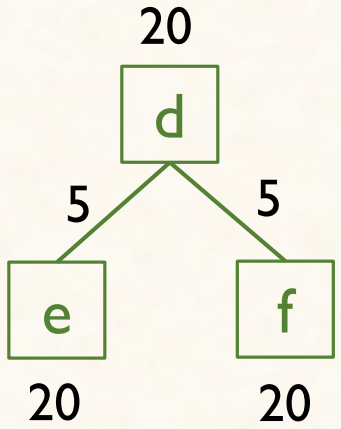
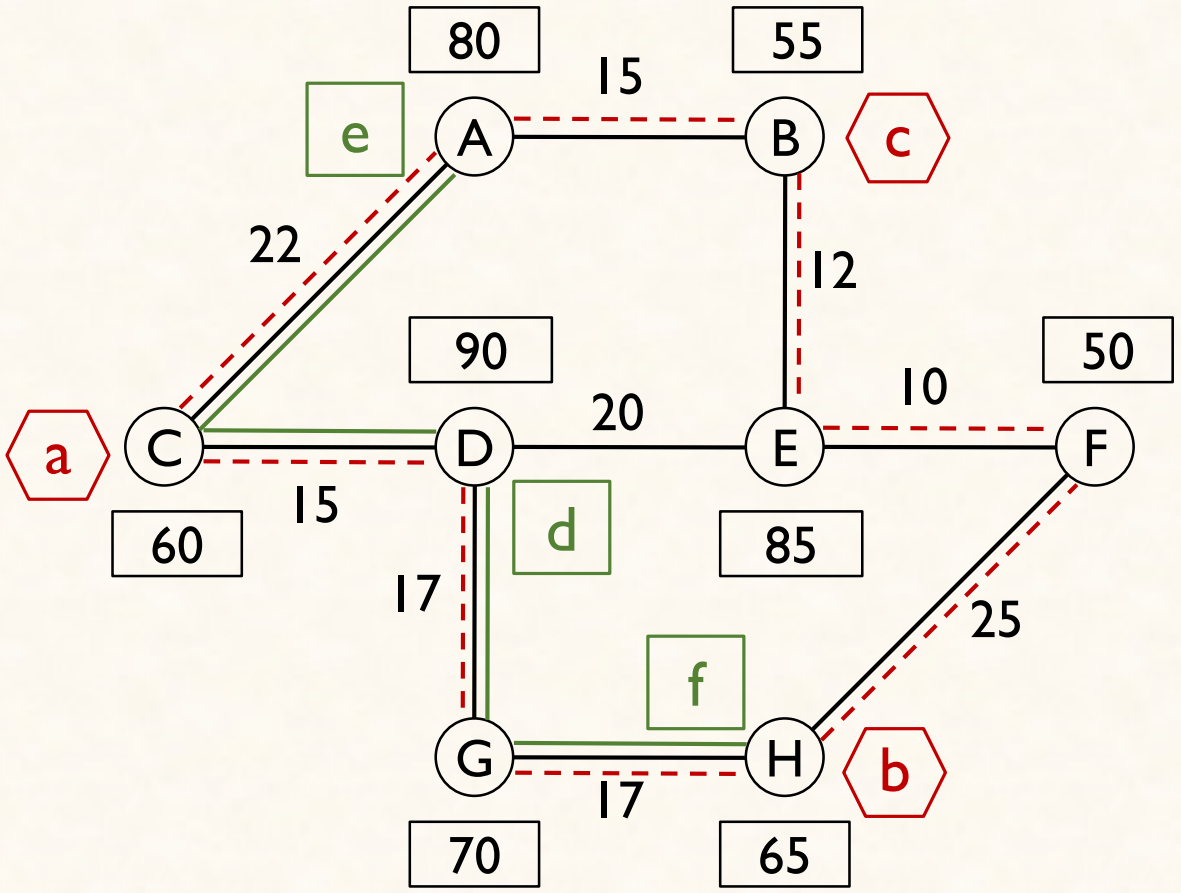
Virtual Network Embedding (VNE)







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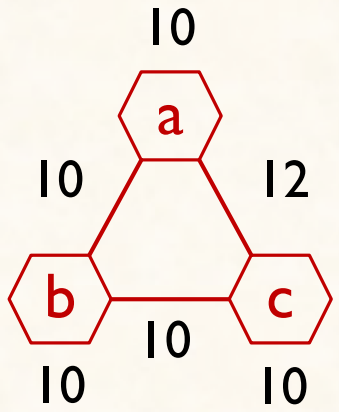

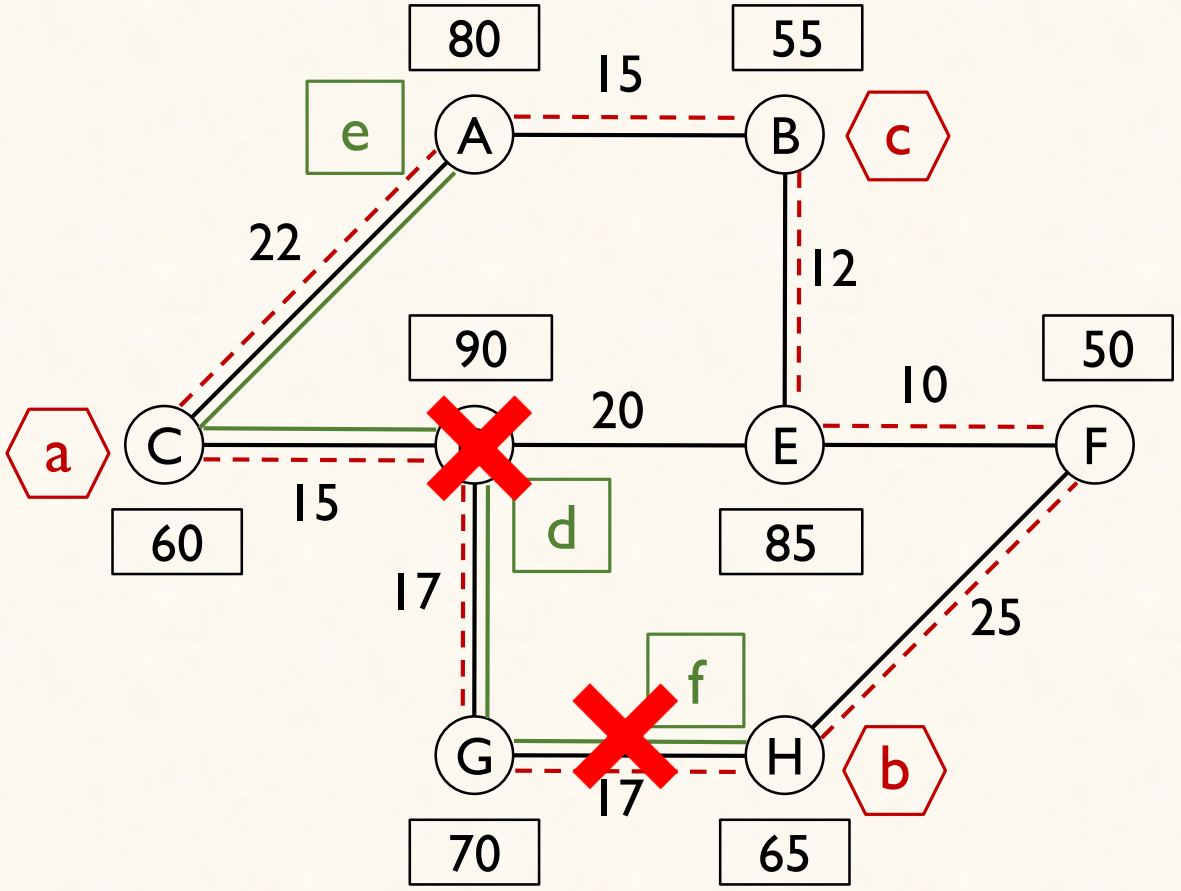

SVNE*: State-of-the-art

Proactive	Reactive
Pre-allocate backup resources in the substrate to guarantee VN QoS	*Reallocate* VNs completely or partially *after* a substrate failure

In general, SVNE approaches *keep the VN as is* and provision primary and backup resource in the substrate, possibly disjoint from each other.

* Survivable Virtual Network Embedding

Question:

How can we modify a VN to equip it with sufficient *spare capacity* and *embed* it so that the VN can *survive substrate link failures*?

The Problem

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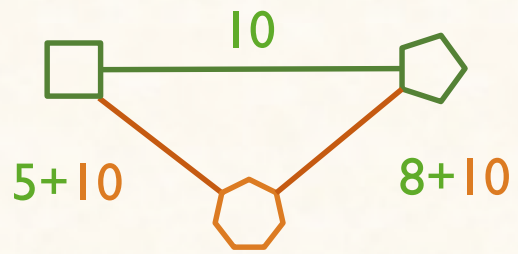
Allocate spare capacity on VLinks to act as backup of other VLinks



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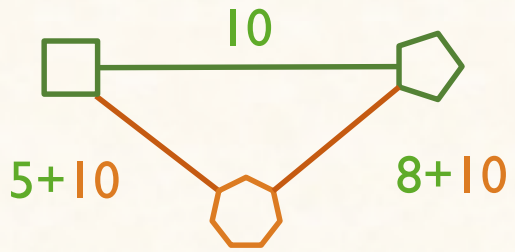
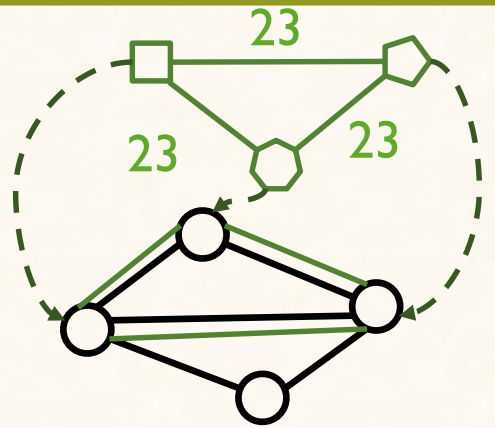


Embed VLinks disjointedly from their backup VPaths



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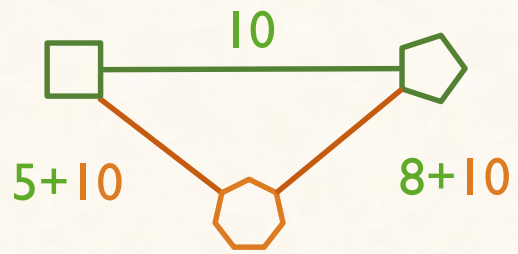

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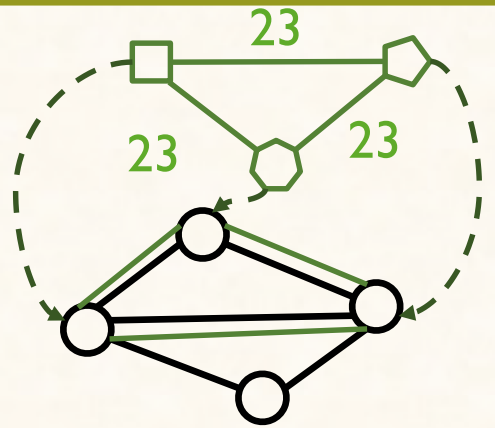
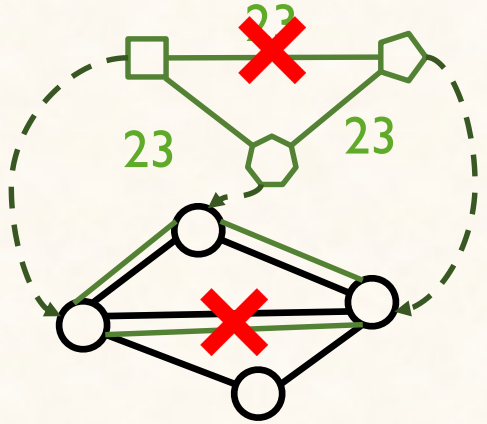


Guaranteed bandwidth under single substrate link failure



Why Allocate Backup at the Level of VN?

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Shift responsibility from infrastructure provider to service provider

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Lesser cost of leasing compared to 1+1 backup (typical for operator networks)

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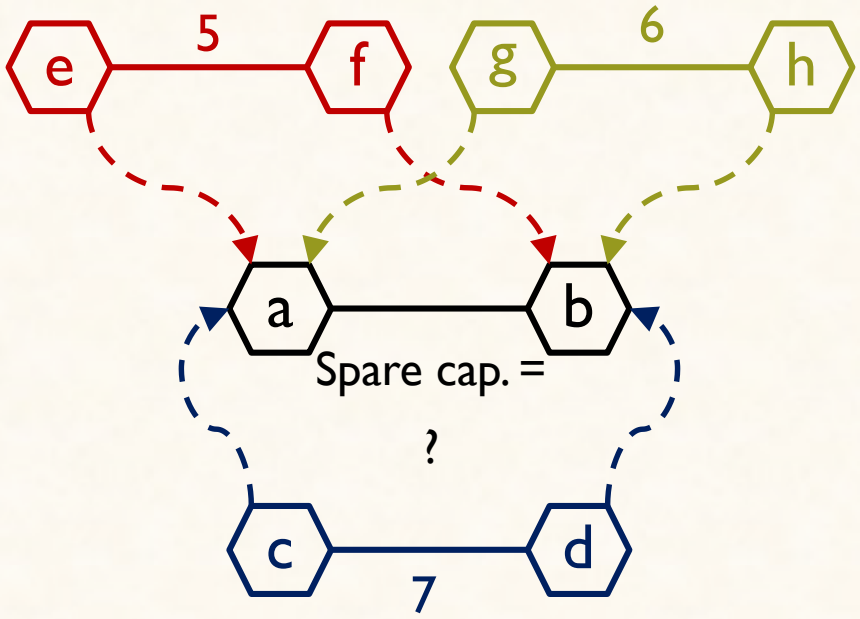
Potential for new service offerings

How to Assign Spare Capacity?



VLink (a, b) on backup paths for VLinks (e, f), (g, h), and (c, d)

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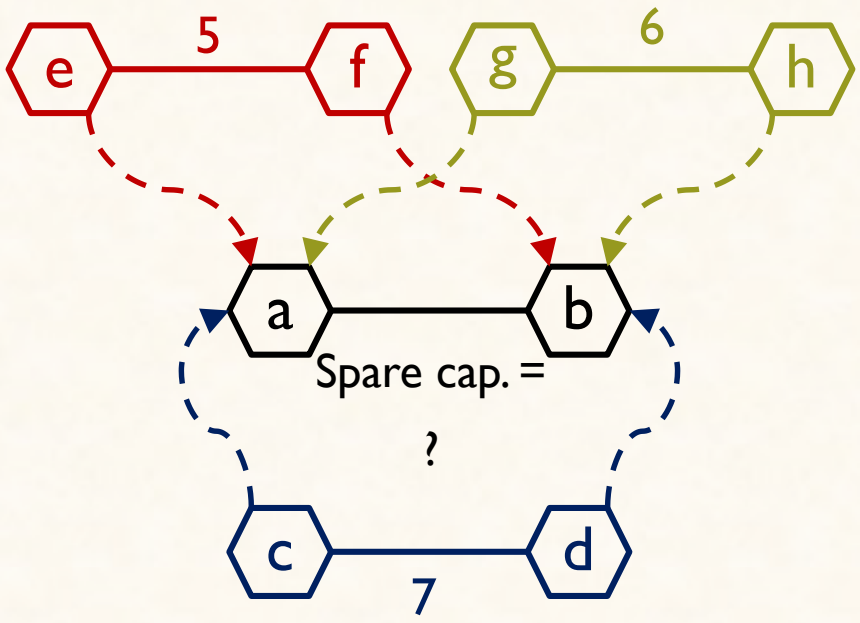

VLink (a, b) on backup paths for VLinks (e, f), (g, h), and (c, d)

Depends on how the VLinks are embedded !

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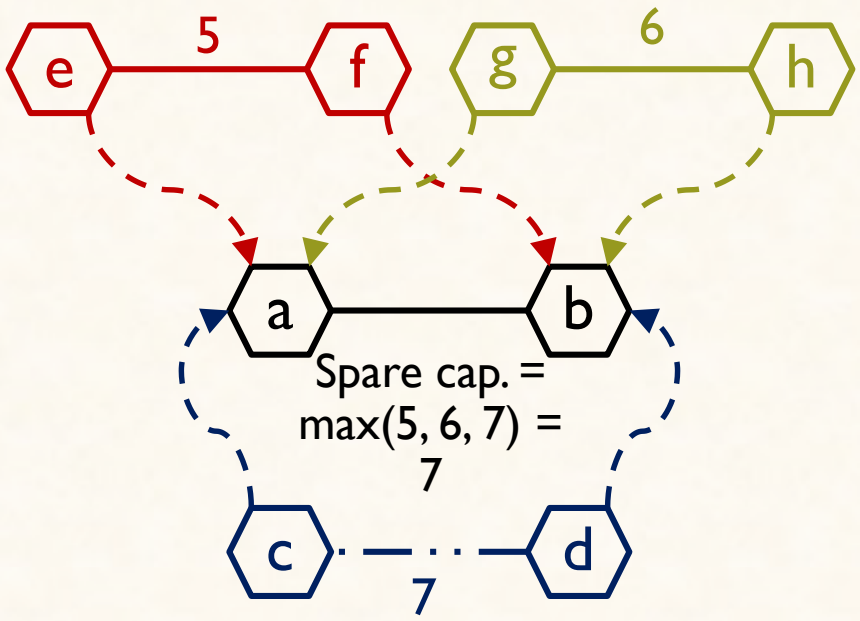

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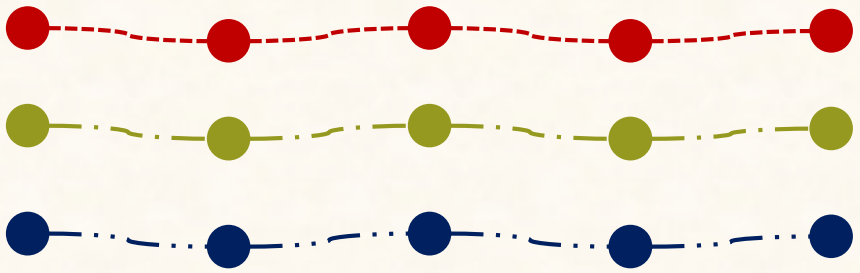
Embedding Case – I:
All three are disojoint



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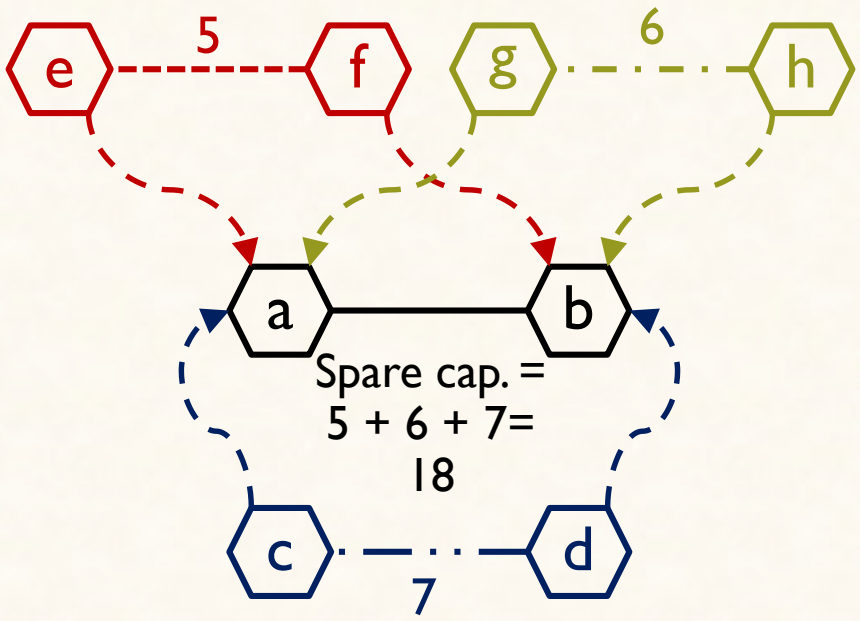

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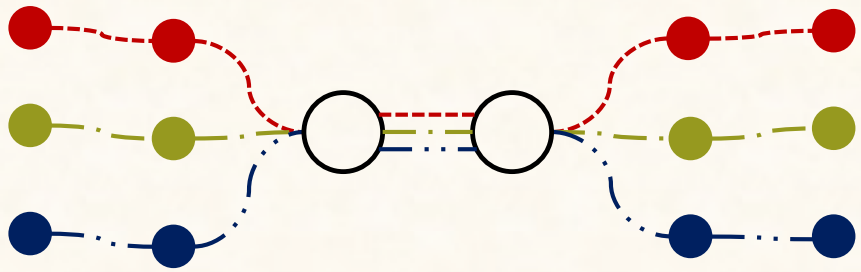
Embedding Case – II:
None of them are disjoint



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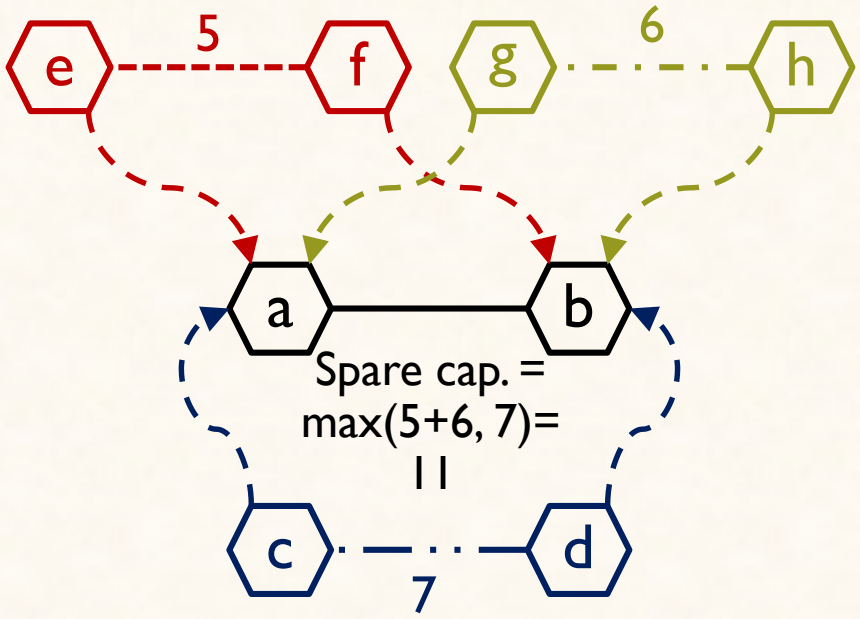
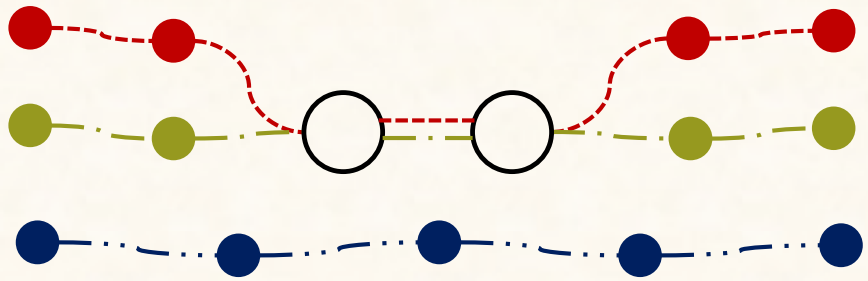


VLink (a, b) on backup paths for VLinks (e, f), (g, h), and (c, d)

Embedding Case – II:
Two disjoint groups



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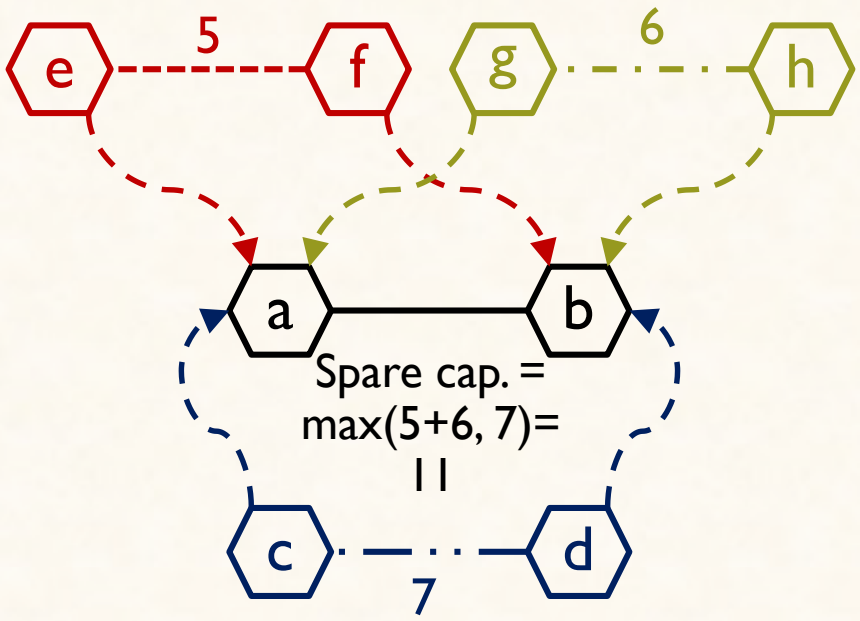

VLink (a, b) on backup paths for VLinks (e, f), (g, h), and (c, d)

Take-away

- Between different disjoint embedding groups *aka Shared Risk Group (SRG)*, spare capacity can be shared.
- Within an SRG, spare capacity is the *sum of all requirements*
- Total spare capacity is *maximum of required capacity of the SRGs*

Our Contribution

A suit of solutions

Optimal Solution

Formulated as an IQP and then transformed to an ILP* (NP-hard)

Heuristic

Three Step Heuristic: Estimate, Embed, Reconfigure

* Details is in the paper

Optimal Solution

Decision Variables

Assign *VLink to SRGs*, Assign *backup VPath to VLinks*, Allocate *spare capacity on VLinks*, Assign *VLink to SPath* and *VNode to SNode*

Quadratic Constraints

- SRG selection determines Spare capacity allocation.
- Spare capacity allocation determines bandwidth required on Slinks
- Together they yield quadratic constraint

IQP transformed to ILP*

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Cannot embed VLinks without knowing total bandwidth requirement

Heuristic Design: A Chicken and Egg Problem

Spare capacity allocation depends on how VLinks are embedded

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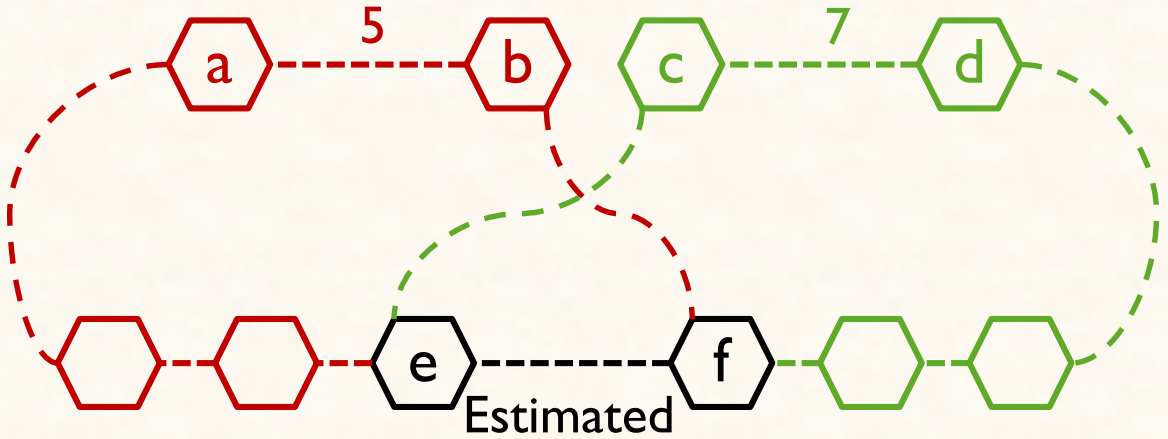
The Chicken and Egg Problem: Solution

Estimate, Embed, and Reconfigure

- Estimate backup VPaths by running weighted shortest path.
  - Adjust weights to reduce *spare capacity fragmentation*



Spare Cap. = 5 + 7 = 12

The Chicken and Egg Problem: Solution

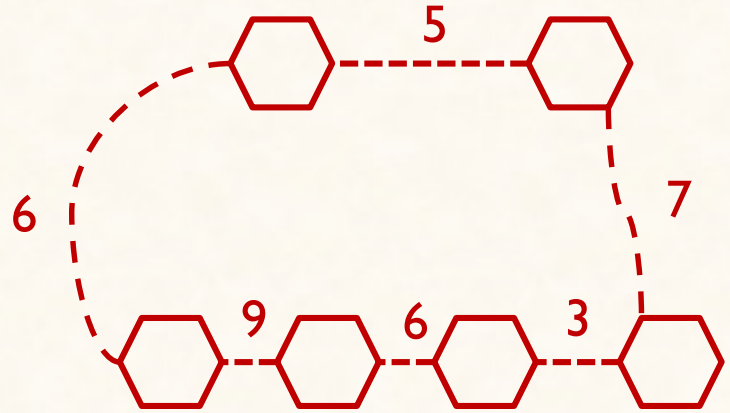
Estimate, Embed, and Reconfigure

- Embed VLinks with *estimated spare capacity*
  - Start embedding from most constrained (maximum degree) to least constrained VNode (minimum degree)
  - Use Dijkstra's shortest path algorithm with constraints to compute edge disjoint shortest paths for link embedding.

The Chicken and Egg Problem: Solution

Estimate, Embed, and Reconfigure

- Identify cycles in VN *s.t. no Vlink pair* on the cycle *shares an SLink in their embedding*.
  - Use the VLinks on such cycle as backup of each other



Required Spare Capacity:
max(5, 6, 9, 6, 3) = 9

Evaluation: Setup

- Heuristic compared with optimal solution
- Parameters
  - Substrate network
    - 20 – 90 nodes (small scale for comparison with optimal)
    - 500 and 1000 nodes (large scale)
    - Avg. node degree between 2 – 5
  - Virtual Network
    - 3 – 11 nodes (small scale)
    - 10 – 100 nodes (large scale)
    - Bandwidth demand = ~10% of substrate link bandwidth

Performance Highlights

Heuristic is within ***~1.2x*** *of optimal* on avg.

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Heuristic struggled to find solution for sparse substrate network (Node degree ~2)

Summary

We address a different form of survivability for VNs where the VN is equipped with the backup

We jointly optimize spare capacity allocation and VN embedding to obtain optimal solution

Our heuristic performs within **~1.2x** of the optimal (*empirically evaluated; not a theoretical bound*)

Questions?