Towards Min-Cost Virtual Infrastructure Embedding

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Introduction

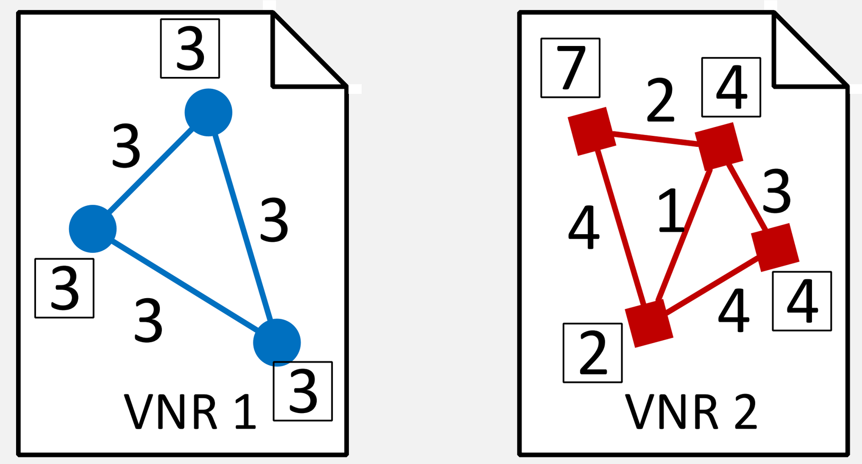
Embedding virtual networked infrastructure is a significant problem in network virtualization, data center networks, etc.

Two related problems:

- ***Virtual Network Embedding (VNE)***
- ***Virtual Infrastructure Embedding (VIE)***

Extensive efforts have been devoted to the VNE problem, but VIE only receives attention from recently.

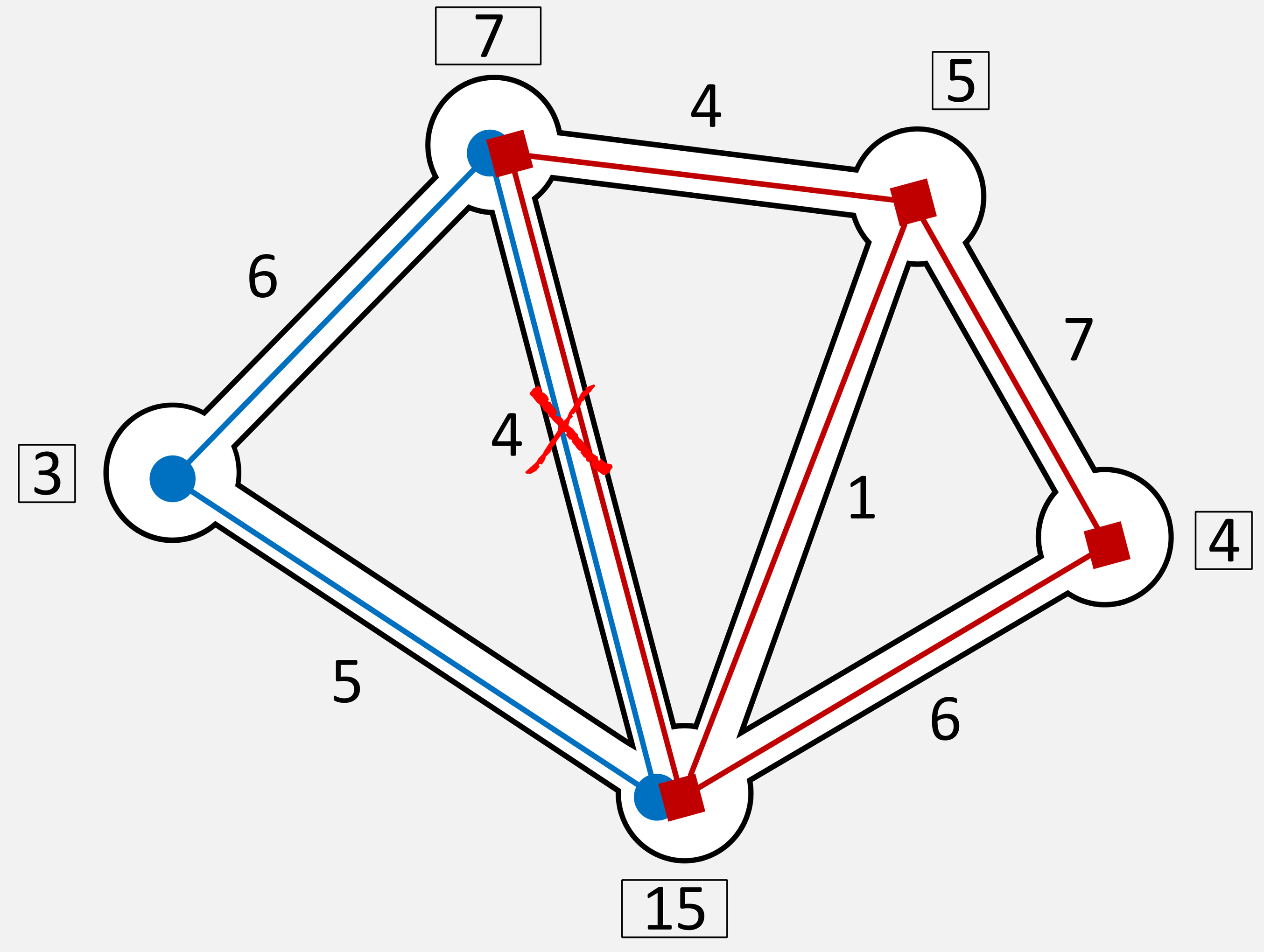
In this work we study how to extend a famous algorithm for VNE to be also applied to the VIE problem.



- Virtual nodes
- Virtual links
- Physical node
- Physical node
- Virtual network request
- Node capacity/demand
- 3 Link capacity/demand

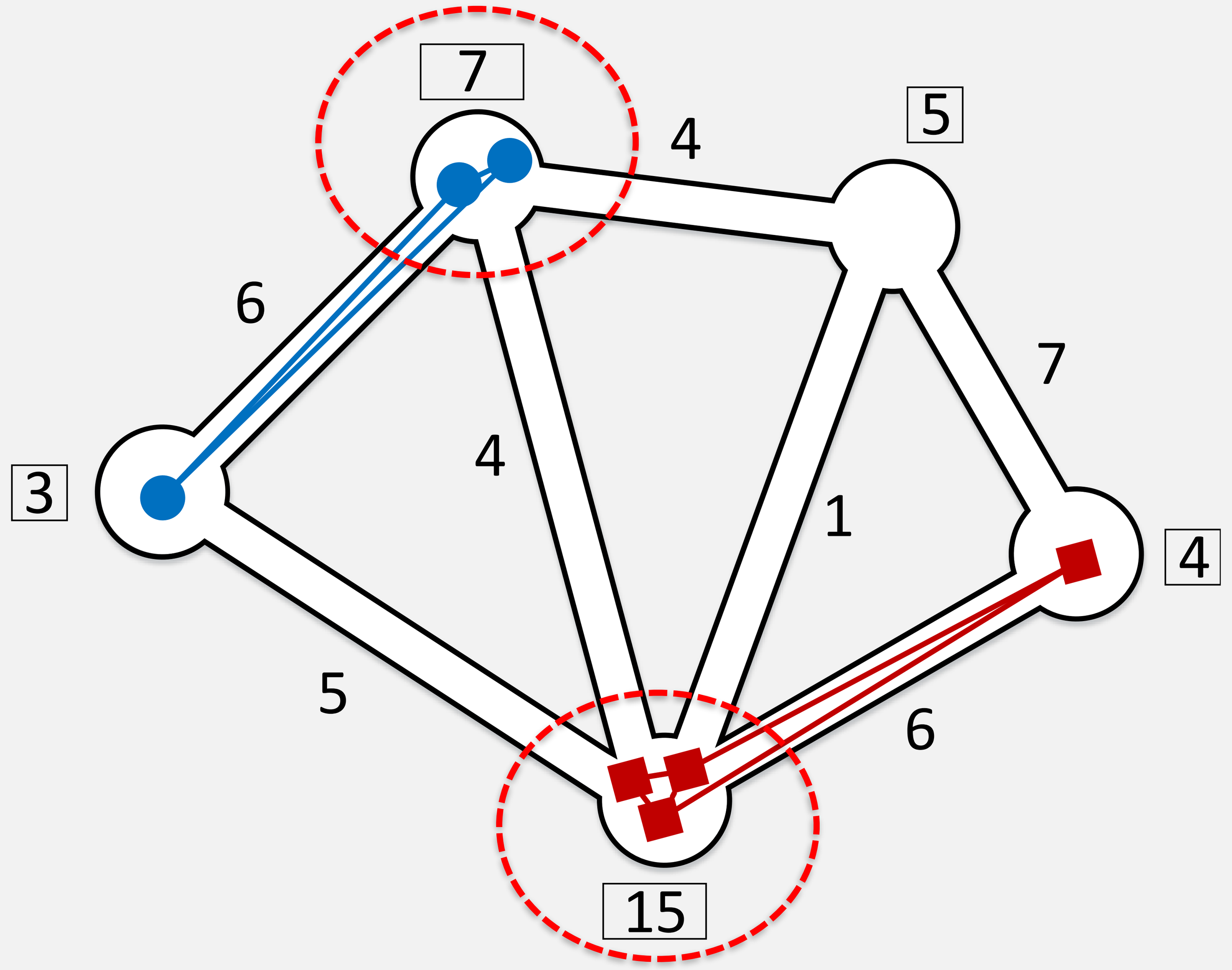
Server consolidation increases success probability and reduces bandwidth

Virtual Network Embedding (VNE)



- One-to-one virtual-physical node mapping for each VNR
- Virtual links can only map to physical paths

Virtual Infrastructure Embedding (VIE)



- **Server consolidation**: *many-to-one* node mapping
- Virtual link can map to physical path or *intra-server* communication links

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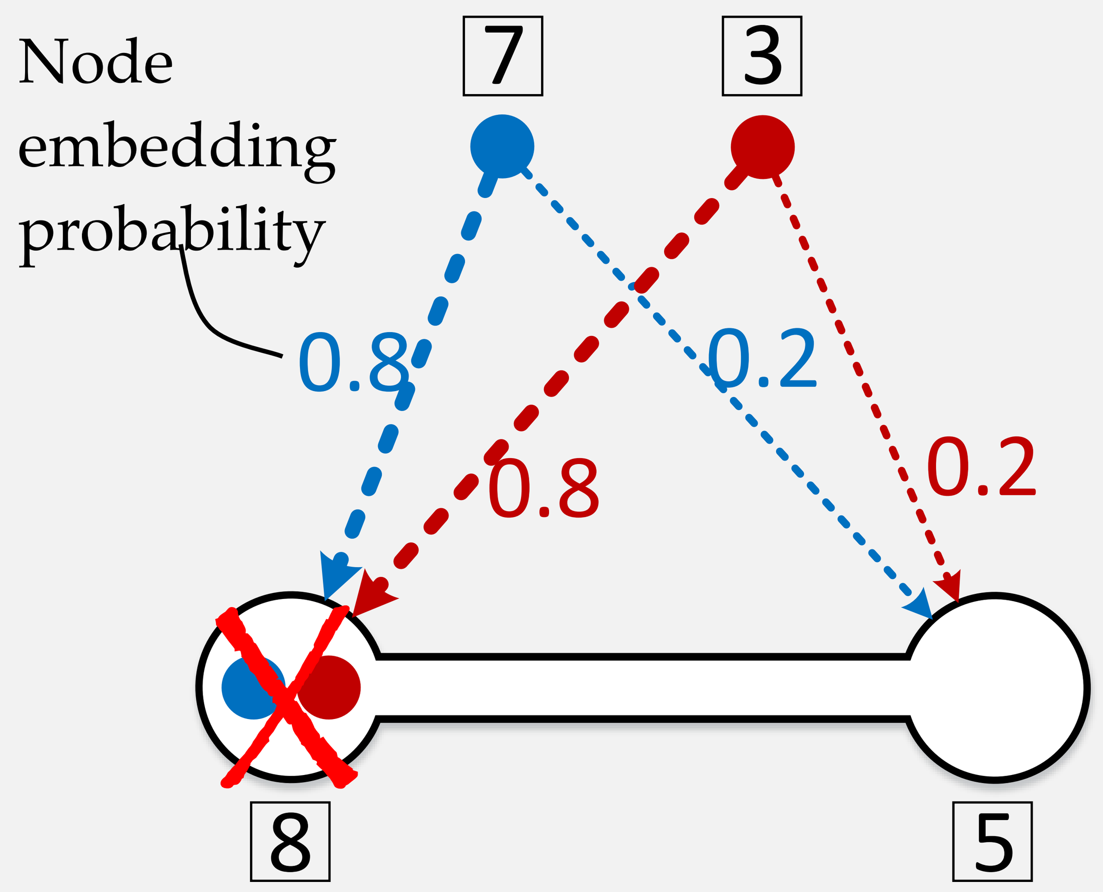
Existing algorithm: ViNE

Virtual Node Mapping:

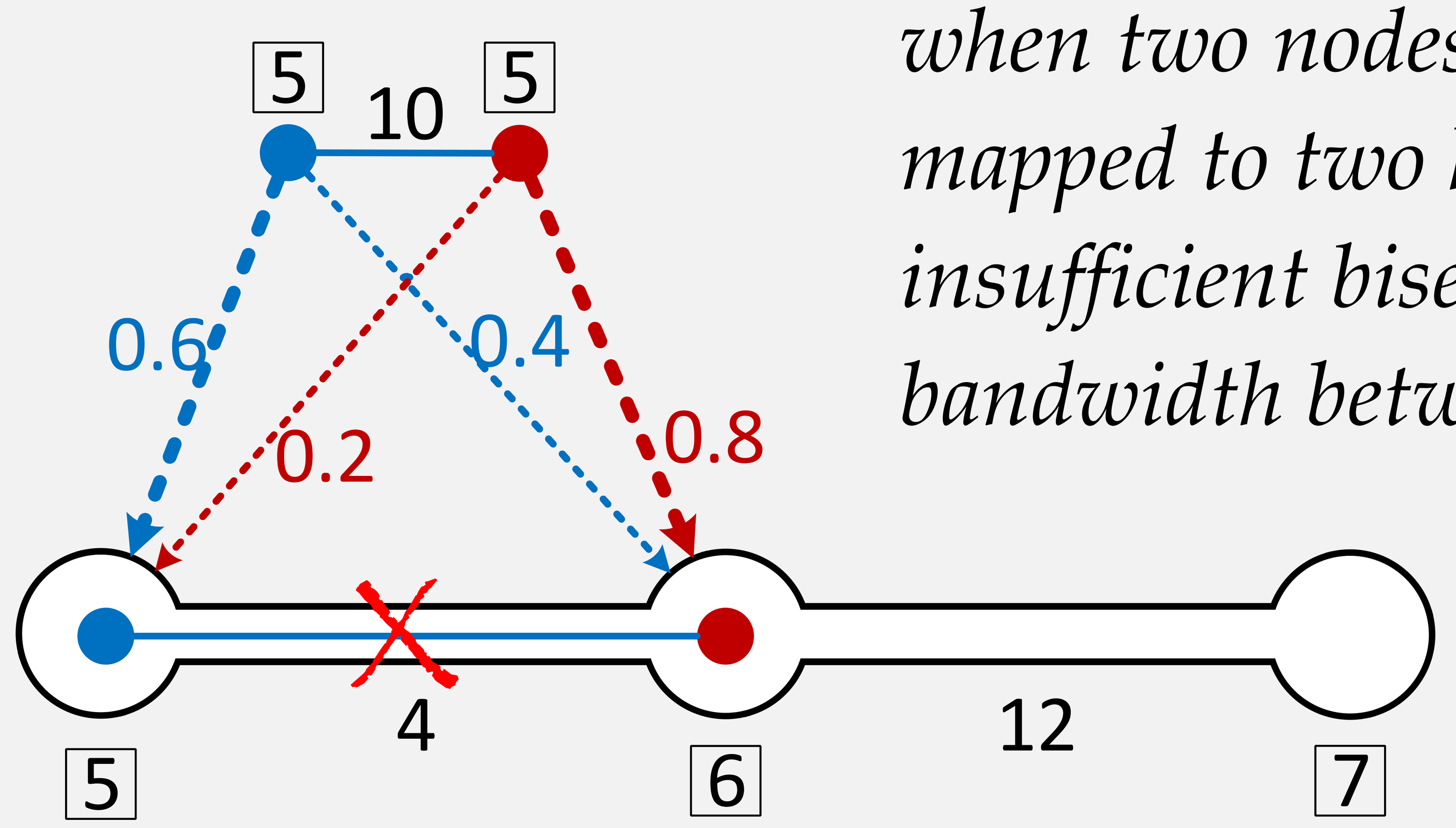
1. Form relaxed integer program formulation $\mathcal{L}$;
2. Solve $\mathcal{L}$ and sort all variables;
3. For *each node mapping variable* do
   a) Round the variable based on its value;

Virtual Link Mapping:

4. Solve Multi-Commodity-Flow for link mapping.



Case 1: *node conflict happens when two nodes are both partially mapped to one host that has insufficient capacity.*



Case 2: *link conflict happens when two nodes are partially mapped to two host that has insufficient bisectional bandwidth between them.*

ViNE[1] Algorithm

ViNE is a rounding-based algorithm for the VNE problem, proposed in 2009 by Chowdhury et. al.

The algorithm achieves *joint node and link mapping* via solving a relaxed LP of the problem formulation, and then apply variable rounding to maintain integrality.

However, in the VIE problem, since server consolidation is enabled, the ViNE algorithm may encounter two types of conflicts during rounding:

1. **Node embedding conflict**, and
2. **Link embedding conflict**.

[1] N. M. M. K. Chowdhury, M. R. Rahman, and R. Boutaba. *Virtual Network Embedding with Coordinated Node and Link Mapping*. In *IEEE INFOCOM*, pp. 783–791, 2009.

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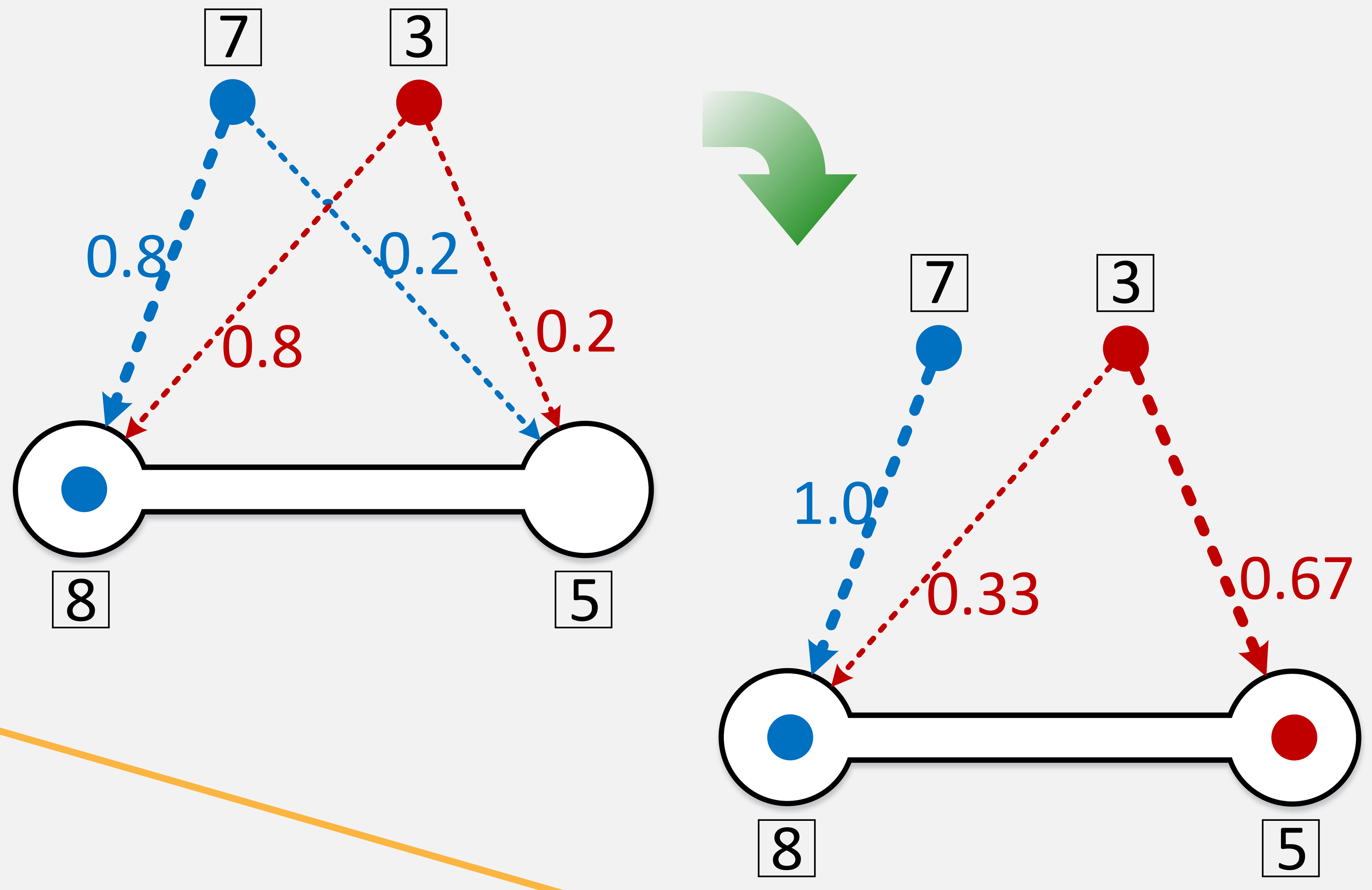
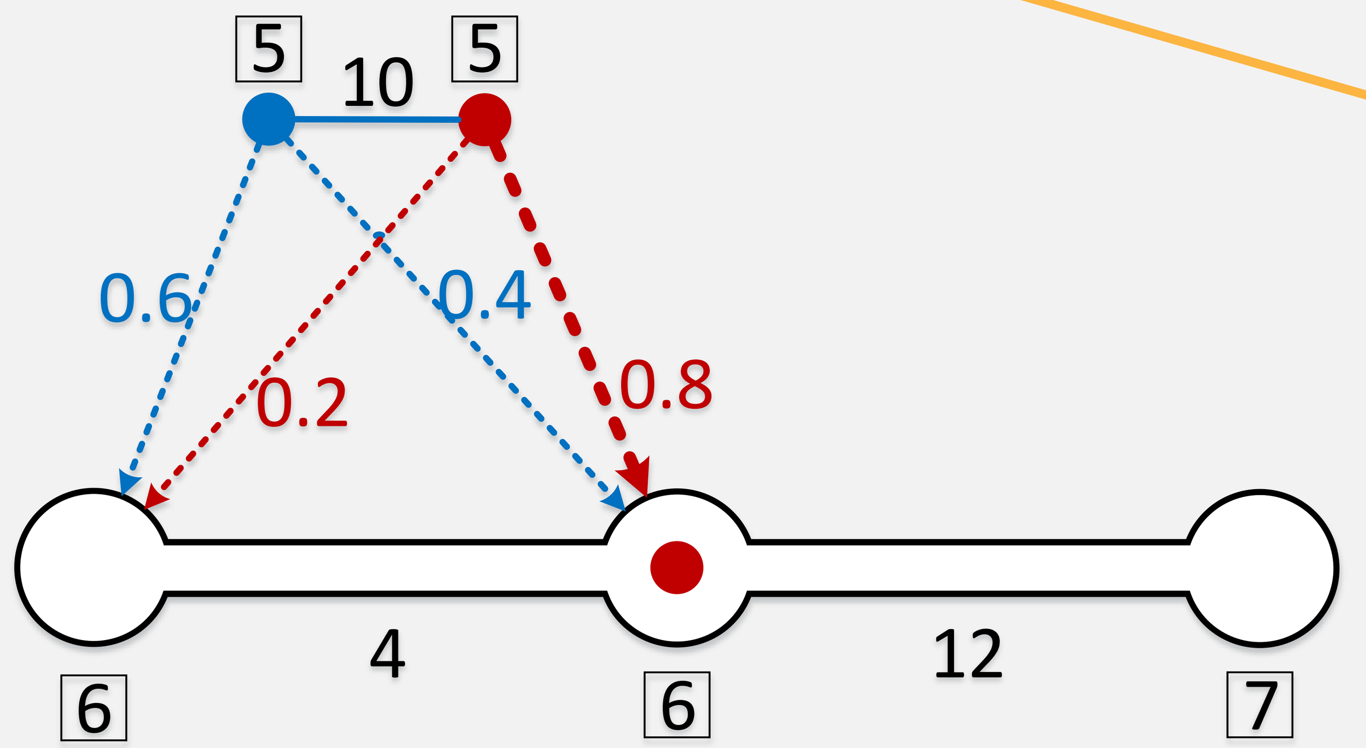
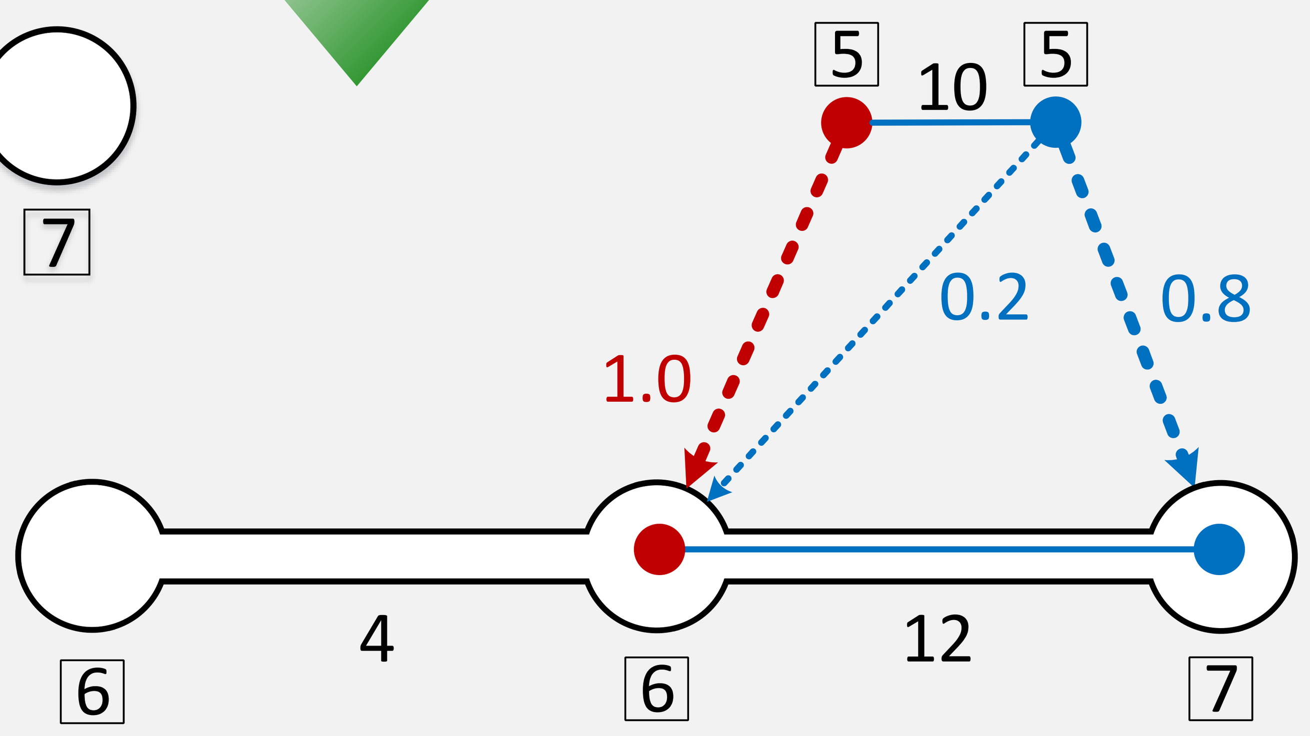
Case 1: *node conflict solved via re-solving the program and rounding*







Case 2: *link conflict solved via re-solving the program and rounding*

VIE Sequential Rounding

Virtual Node Mapping:

1. Form relaxed integer program formulation $\mathcal{L}$;
2. While *some node not mapped* do
   a) Solve $\mathcal{L}$ and sort fractional variables;
   b) Round the first variable based on its value;
   c) **Update $\mathcal{L}$ based on the rounded variable;**

Virtual Link Mapping:

4. Solve Multi-Commodity-Flow for link mapping.

VIE-SR trades linear time to achieve better embedding.

To address the conflicts, we propose a new algorithm.

Instead of rounding all fractional variables based on the initial program, we *update the program after each variable is rounded*, and *re-solve the updated program* which is used to round other fractional variables.

We call this iterative program solving and rounding process the **Sequential Rounding (VIE-SR)** algorithm.

Sequential Rounding

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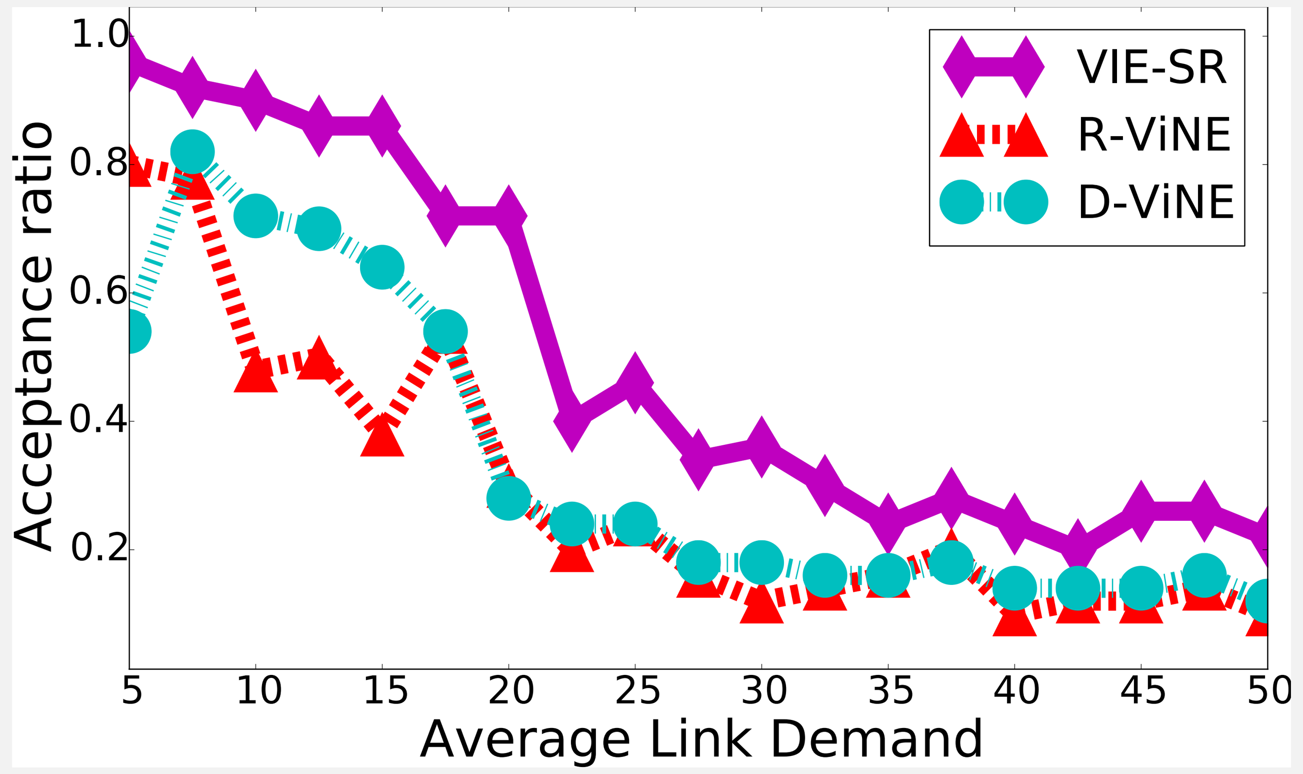
Evaluation & Results

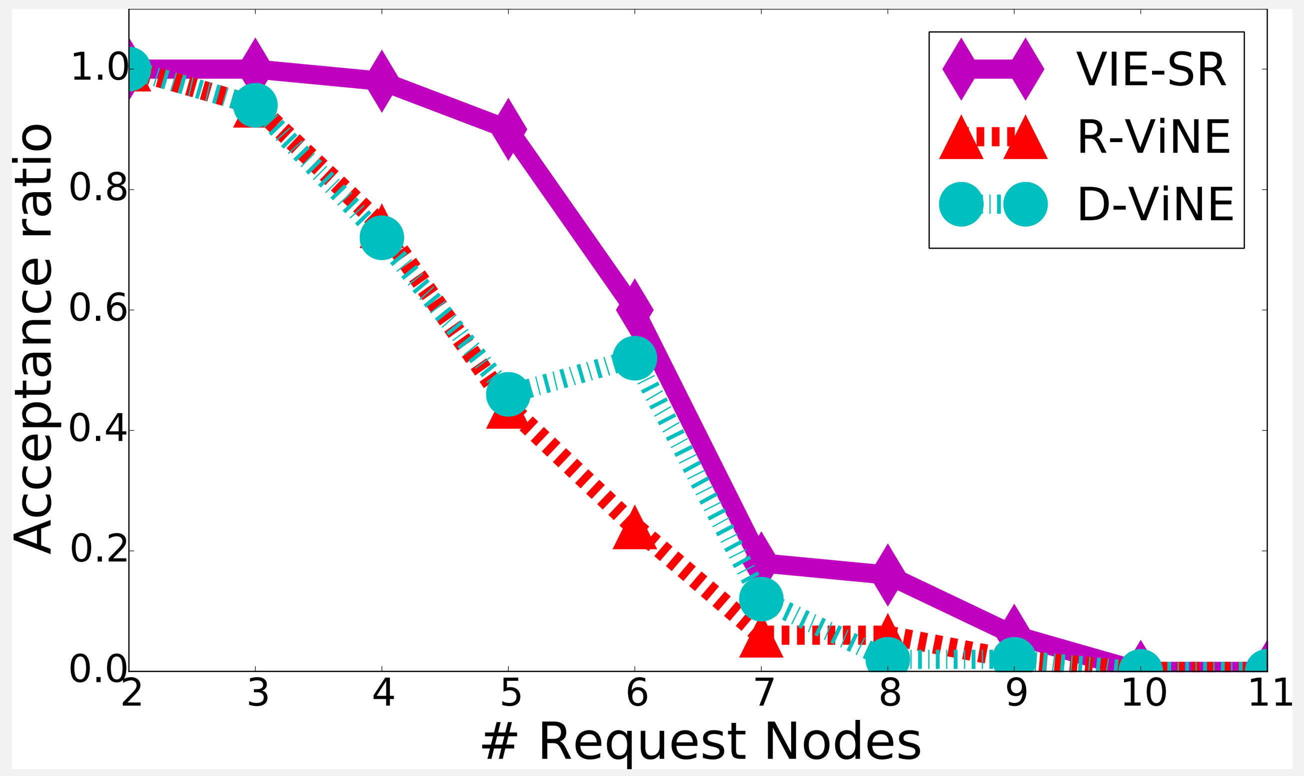
We conducted simulations to evaluate the VIE-SR algorithm, which was compared to the ViNE algorithm with both deterministic (D-ViNE) and randomized (R-ViNE) rounding.

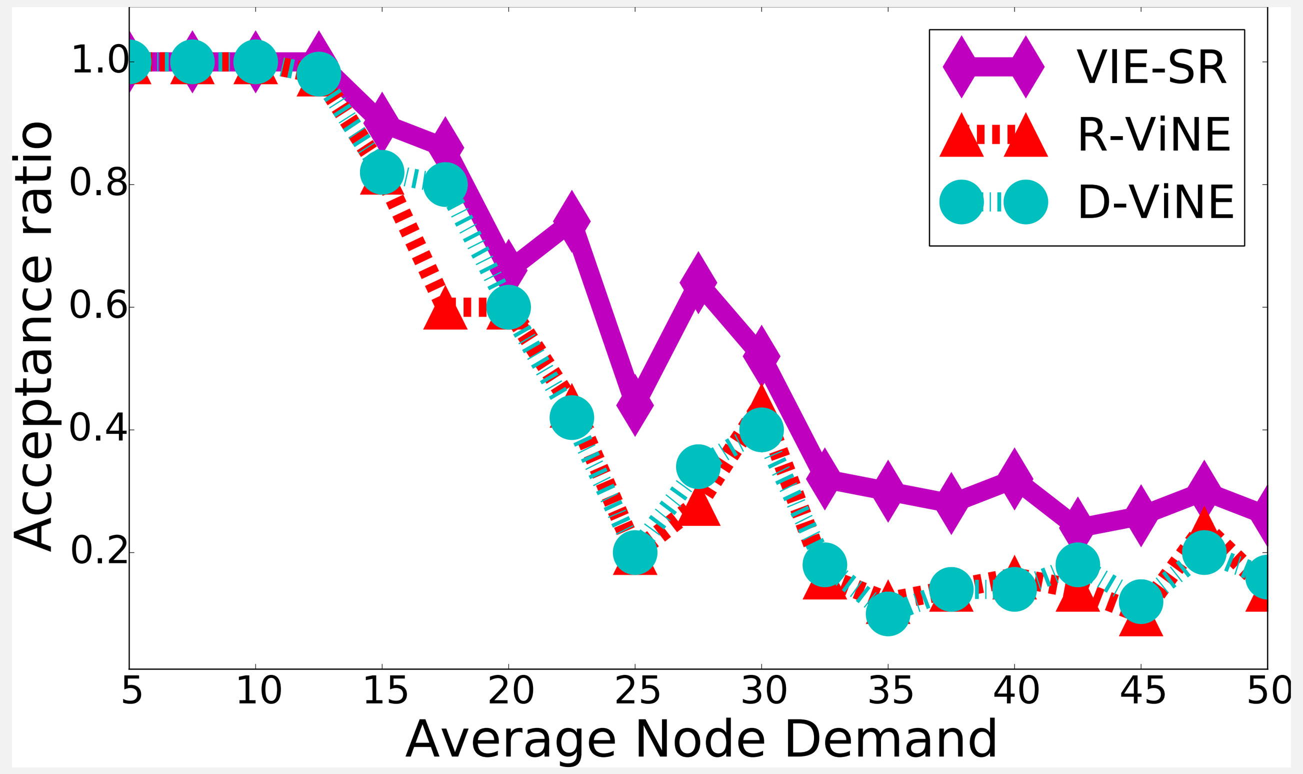
Experiment results show that the VIE-SR achieves better acceptance ratio than both ViNE implementations.

This validates that VIE-SR is capable of reducing conflicts between before and after rounding decisions, with the cost of an additional linear factor in its time complexity.

For details of the program formulation and the experiments, please refer to the original paper.







In all scenarios, VIE-SR achieves better acceptance ratio than both R-ViNE and D-ViNE. The average cost shows similar results, which can be found in our paper.

Discussions

Time Complexity

The linear factor induced by sequential rounding can be reduced by constraining the *amount of program re-solving* in the algorithm. In practice, the max amount of program re-solving can be selected as a constant that achieves the best trade-off between performance and running time.

Generality

Since the proposed algorithm is based on the program formulation of the problem, *various objectives and constraints* can be adopted to achieve different goals.

Optimal Solution

The optimal solution can be achieved by combining VIE-SR with *backtracking*. In fact, VIE-SR can be viewed as a good trade-off between the optimality of backtracking, and the polynomial time of a simple rounding algorithm.

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