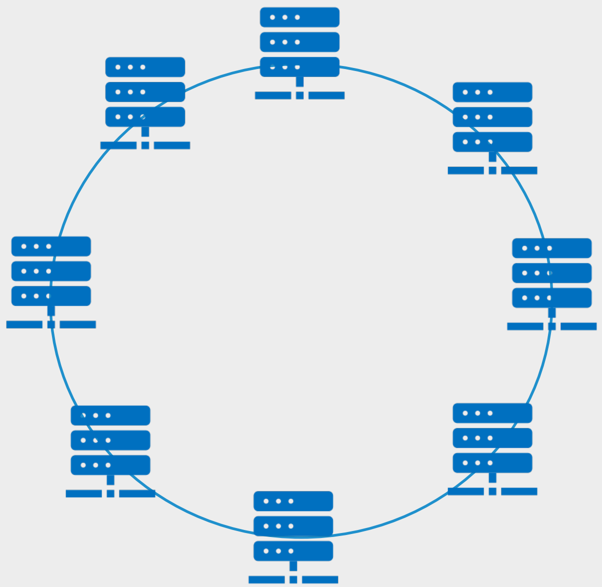
Minimizing the Weighted Average Shortest Path Length in Demand-Aware Networks via Matching Augmentation

Aleksander Figiel, Darya Melnyk, André Nichterlein, **Arash Pourdamghani** and Stefan Schmid

SPAA 2024

INET
Technische Universität Berlin

The Problem



Nodes (e.g., servers in datacenters) want to communicate along shortest paths.

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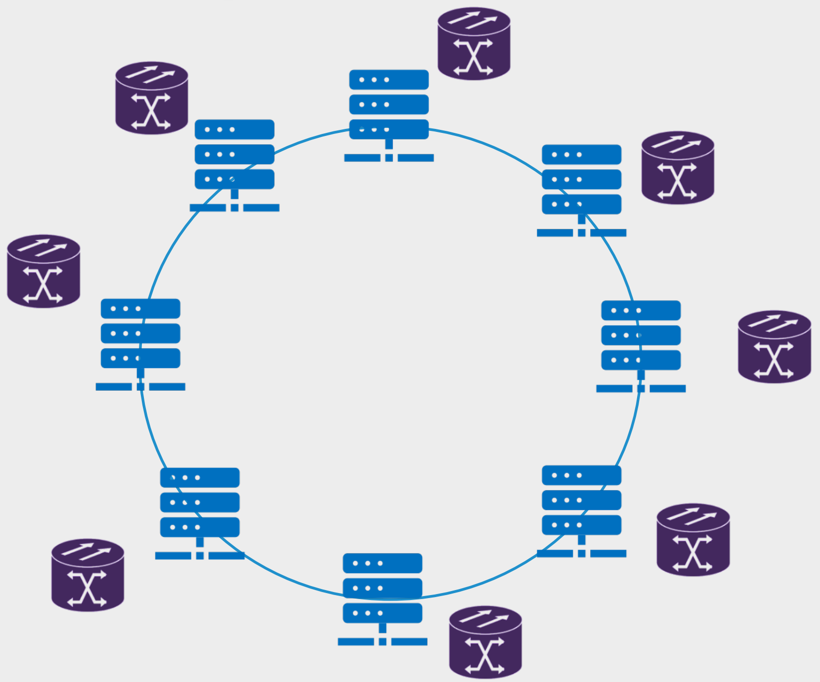

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Hybrid topology: a given fixed topology (here: ring) can be enhanced with a matching (realized with an optical switch).

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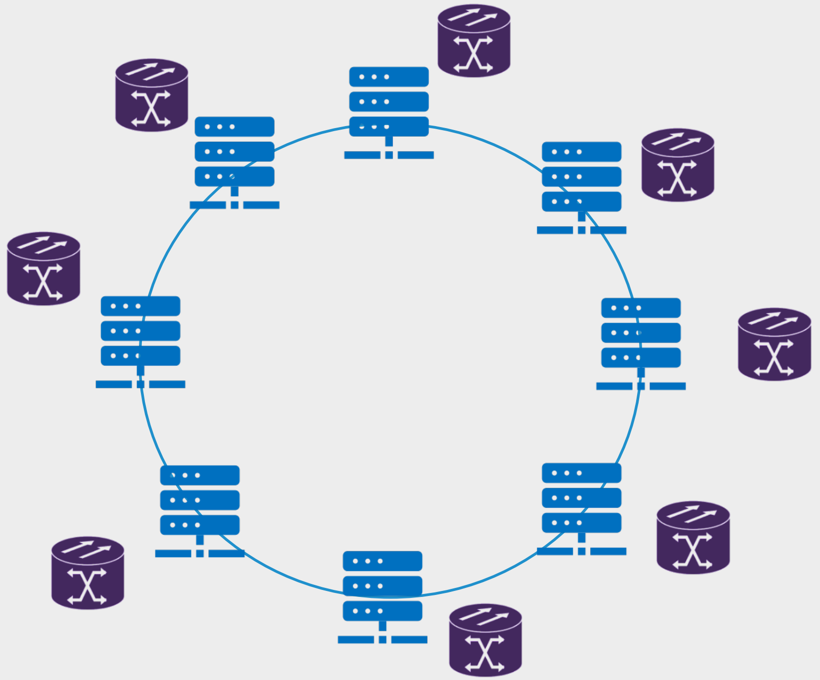

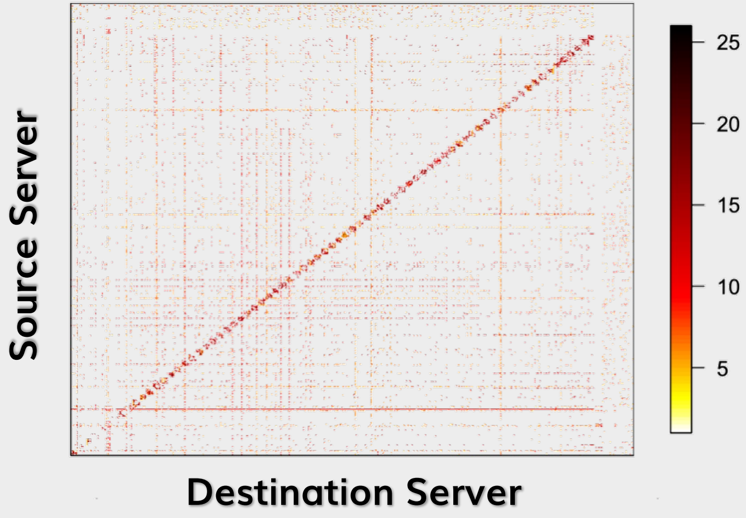

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The Nature of Datacenter Traffic: Measurements & Analysis
Microsoft Research

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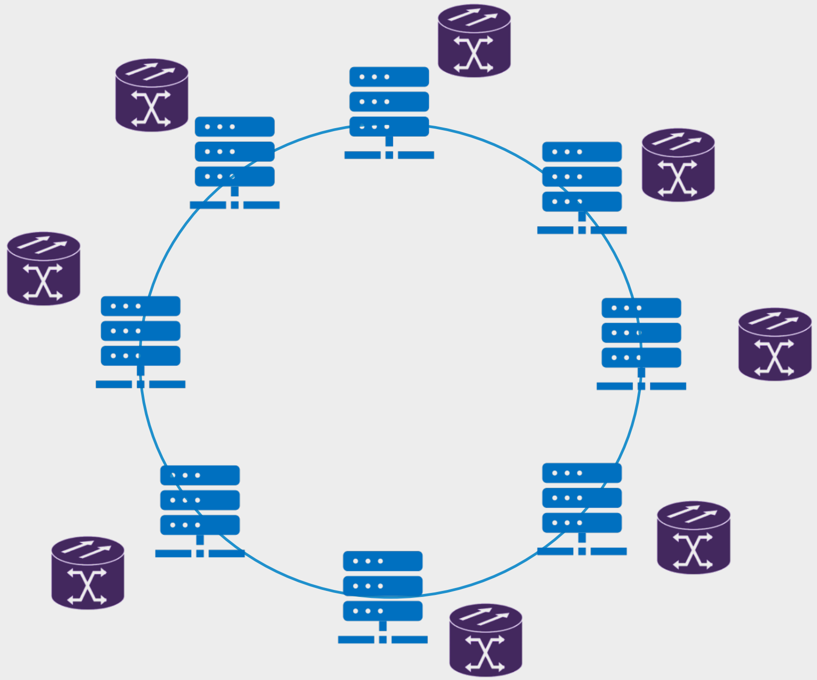

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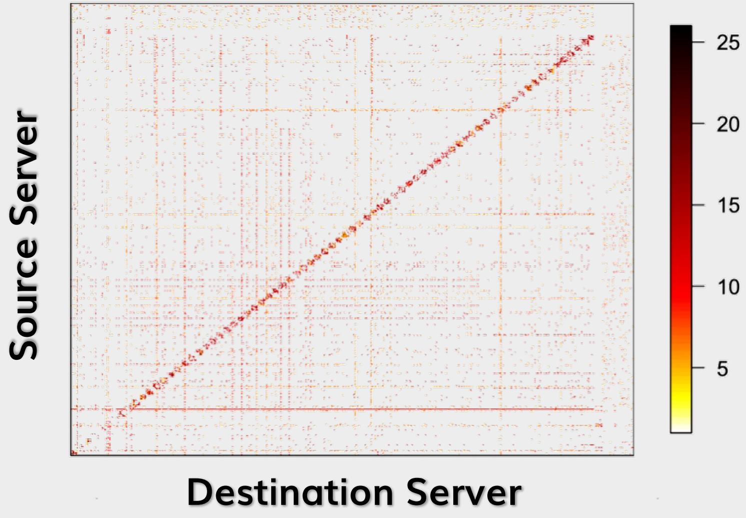

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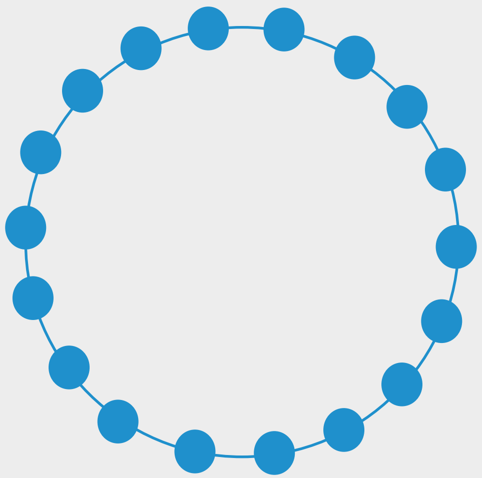
Finding the best static matching on top of the network.

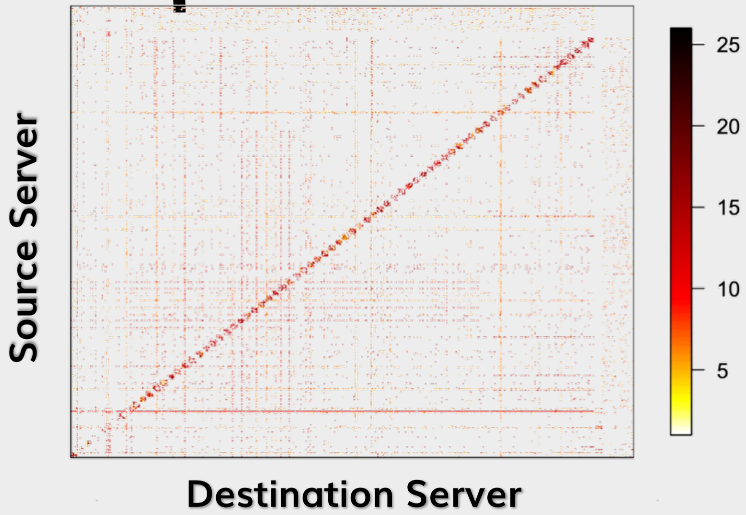
Goal is minimizing weighted shortest path lengths (known to be related to throughput)

Formal Model

Inputs

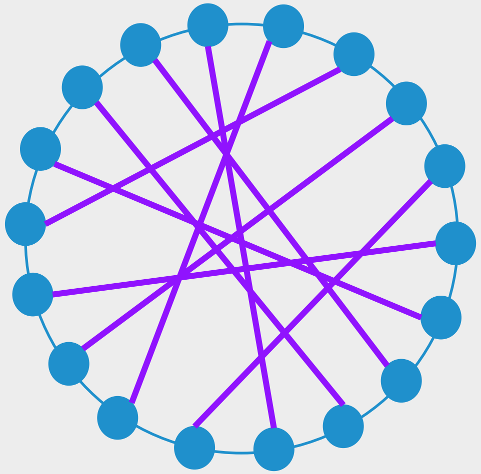


Ring, as a connected underlying network
(no capacity constraint!)



A weighted demand matrix
(indicating communication frequency)

Output



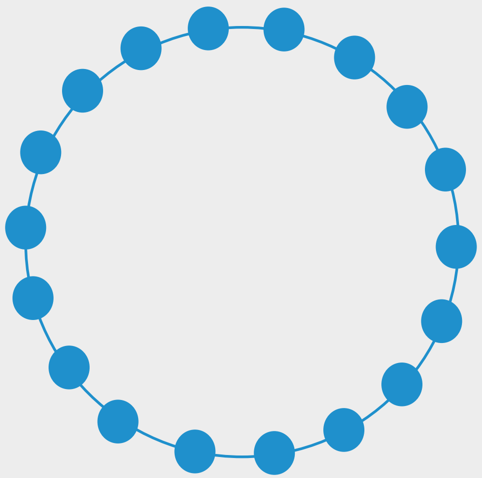
A static matching on top of the underlying network

Cost:

Average distance, weighted by frequency of communications between peers
(Links in underlying network and matching behave the same)

Formal Model

Inputs



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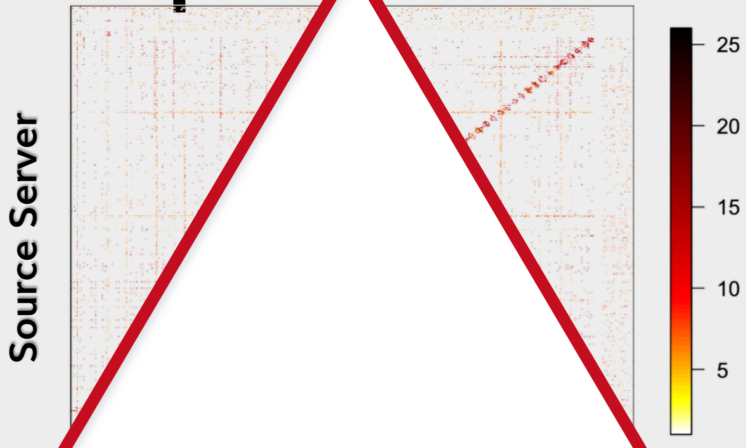
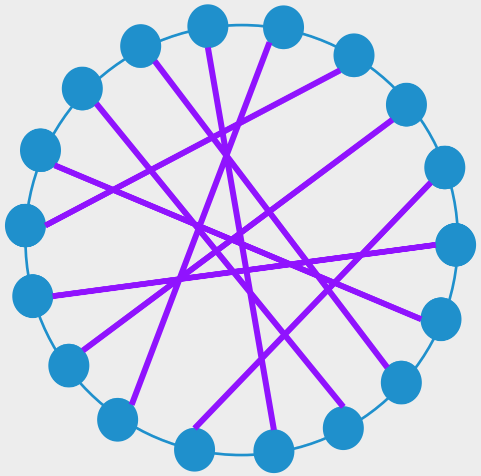


NP-Hard
(Reduction from vertex cover)

Output



A static matching on top of the underlying network

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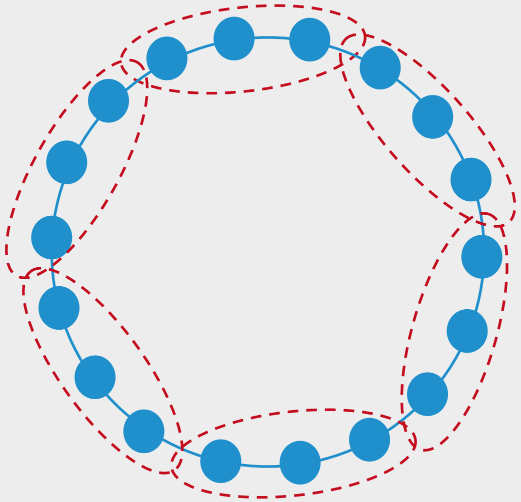
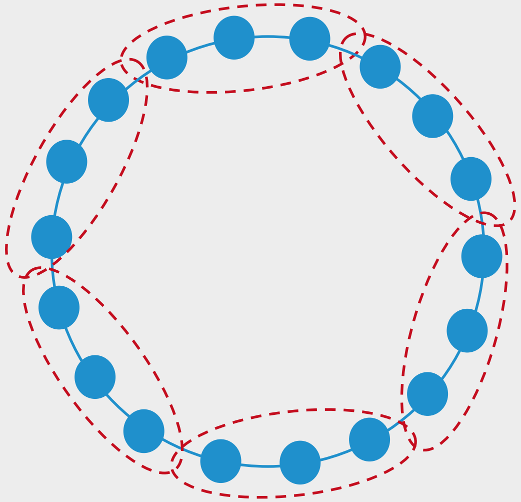
Constant Approximation Algorithm for Sparse* Demands



Decomposing into
super nodes of constant size

*Low average demand. Sparse demand are motivated by practical use cases.

Constant Approximation Algorithm for Sparse* Demands



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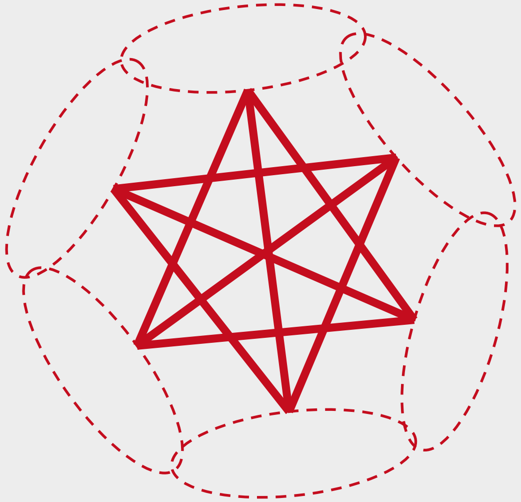

Creating a demand-aware
constant degree network#
on top of super nodes

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#Chen Avin, Kaushik Mondal, and Stefan Schmid. 2020. Demand-aware network designs of bounded degree. Distributed Computing (2020).

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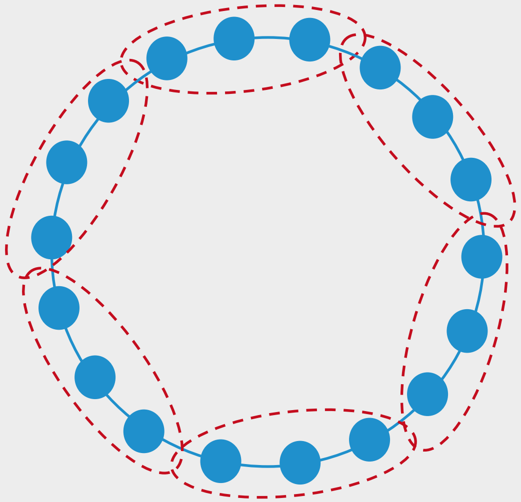

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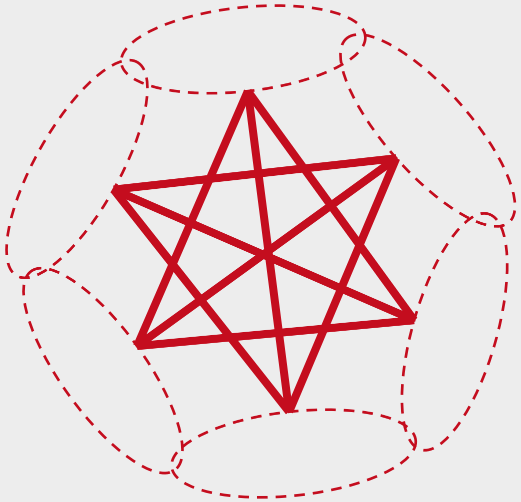

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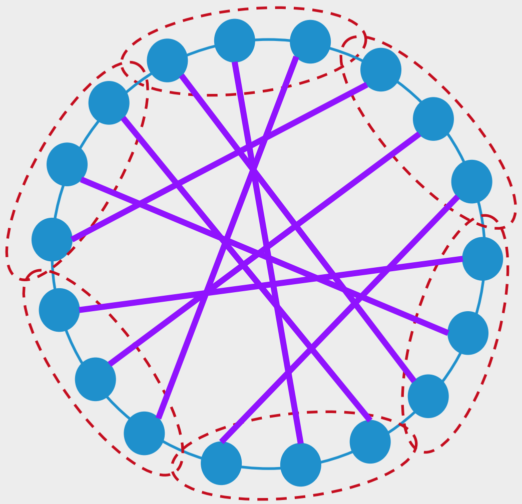

Transforming the
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to a matching

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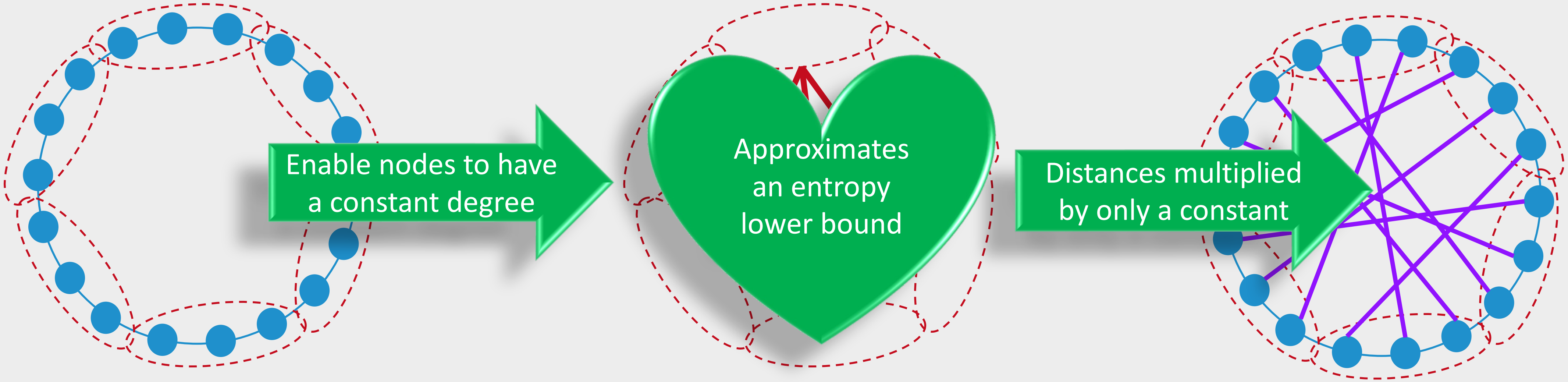

Decomposing into super nodes of constant size

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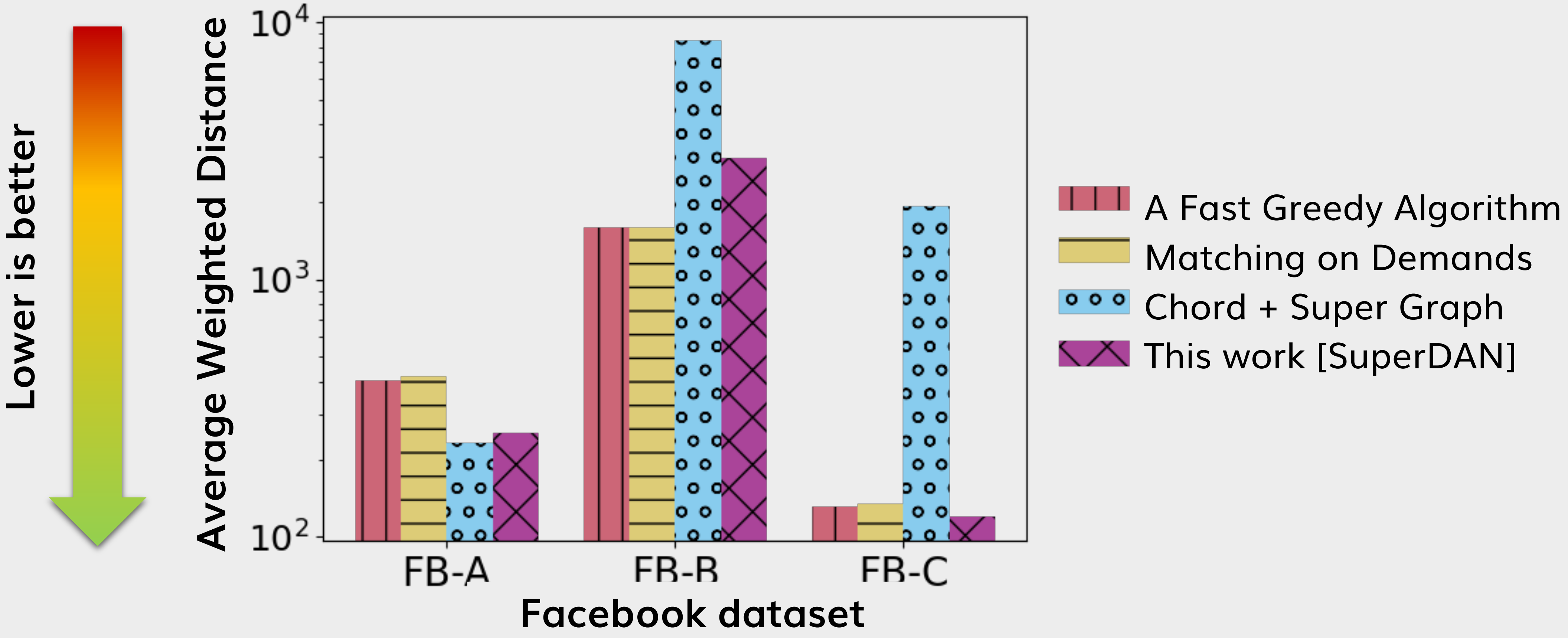
Empirical Results on Facebook Dataset



Thank you!

Theorem 1: Minimizing Weighted Average Shortest Path Length via Matching Addition is NP-hard, even if the underlying graph is a cycle and every row and column of demand matrix has at most two non-zero elements.

Theorem 2 [simplified]: Given a ring graph with n nodes and a sparse demand matrix, then **SuperDAN** computes in $O(n^2 \cdot \log n)$ time a matching that is a constant approximation of cost of any other solution.

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