Dual-Failure Restorability of Meta-Mesh Networks

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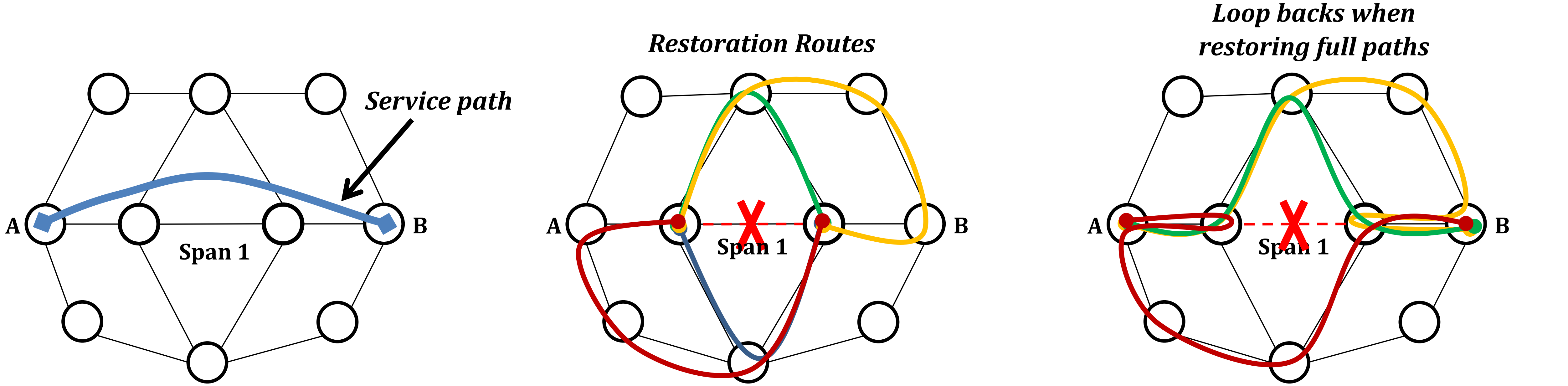
UNIVERSITY OF ALBERTA

Outline

- Introduction
  - ✓ Background
  - ✓ Introduction to span-restorable meta-mesh network
- Experimental Setup
  - ✓ Network family
  - ✓ Experimental networks and tools
- Studies Performed
  - ✓ High restorability meta-mesh capacity design
- Conclusions
  - ✓ Experimental Results and Discussion
  - ✓ Final Remarks

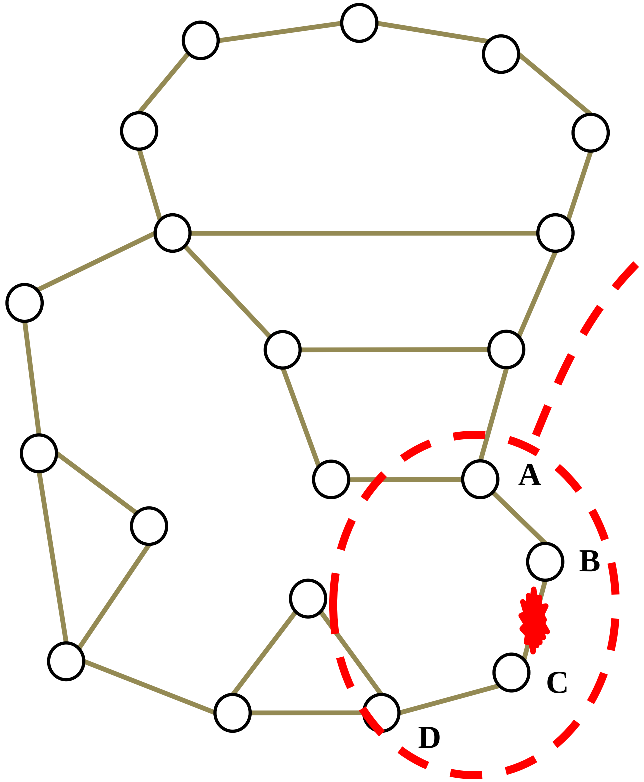
Background: Span Restoration Principle

- **Alternative path segments restore all working channels of the failed span.**
  - Local restoration between the end nodes of the failed span
  - Multiple restoration routes are possible per span
  - Restoration path segments for different spans can share spare capacity

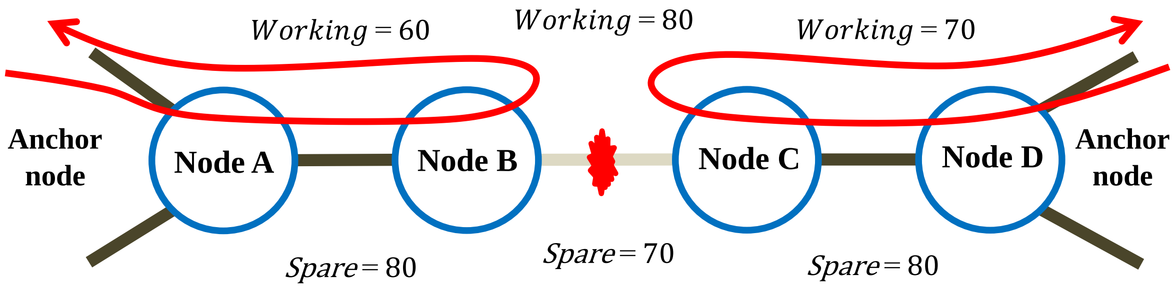


Introduction to Span-Restorable Meta-Mesh Network

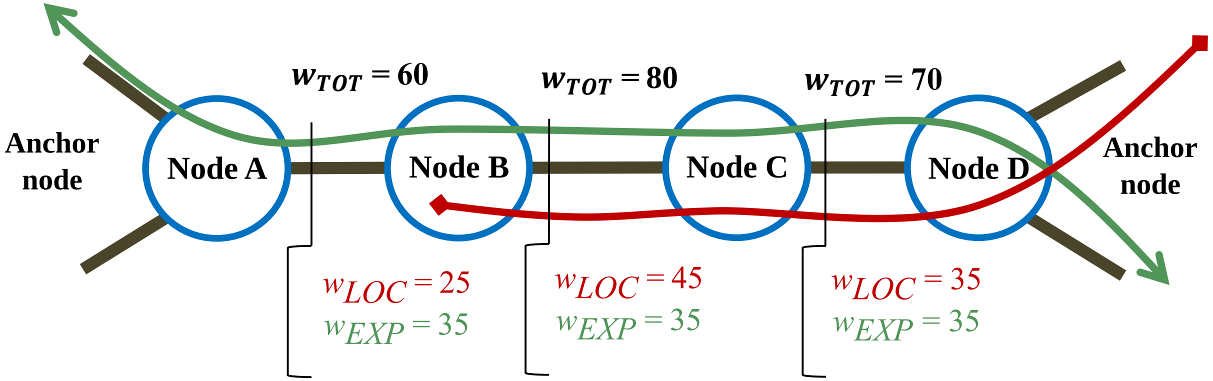
- **Special interest on chains of degree-2 nodes.**



- Inefficient spare capacity allocation in span restoration due to loopback in chains



- Meta-mesh breakdown of working capacity: **local** (LOC) and **express** (EXP) flow



Introduction to Span-Restorable Meta-Mesh Network (2)

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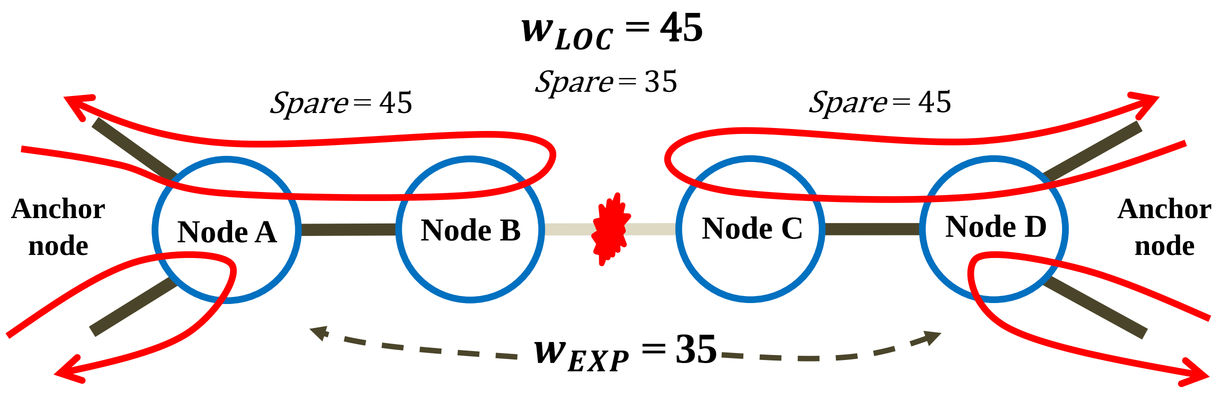
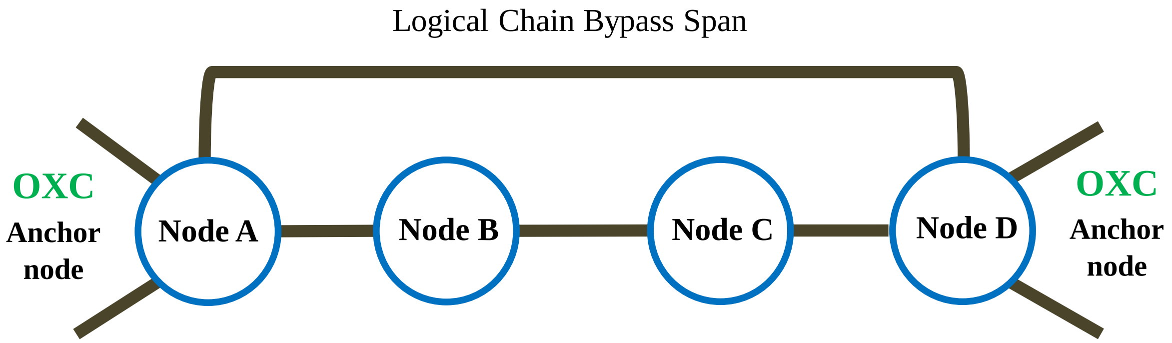
- Spare capacity requirements in a chain using the meta-mesh restoration model



- Logical bypass span in the meta-mesh design



Meta-mesh benefits:

1. Improved spare capacity in sparse network topologies
2. Up to 35% reduction in spare capacity in prior work[1]
3. Only meta-mesh nodes require full OXC functionality

[1] W. D. Grover, J. Doucette "Design of a Meta-Mesh of Chain Subnetworks: Enhancing the Attractiveness of Mesh-Restorable WDM Networking on Low Connectivity Graphs," IEEE Journal on Selected Areas in Communications, vol. 20, no. 1, pp. January 2002 .

Introduction to Span-Restorable Meta-Mesh Network (3)

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Original network

Sprint Communications' USA backbone network[2]-[3] (used with permission)

Meta-mesh network

The meta-mesh of the Sprint Communications' USA backbone network[4]

Original network
257 nodes, 305 spans $\bar{d}$ = 2.37
Lower bound redundancy = 73%

Meta-Mesh network
77 nodes, 123 spans $\bar{d}$ = 3.21
Lower bound redundancy = 45%

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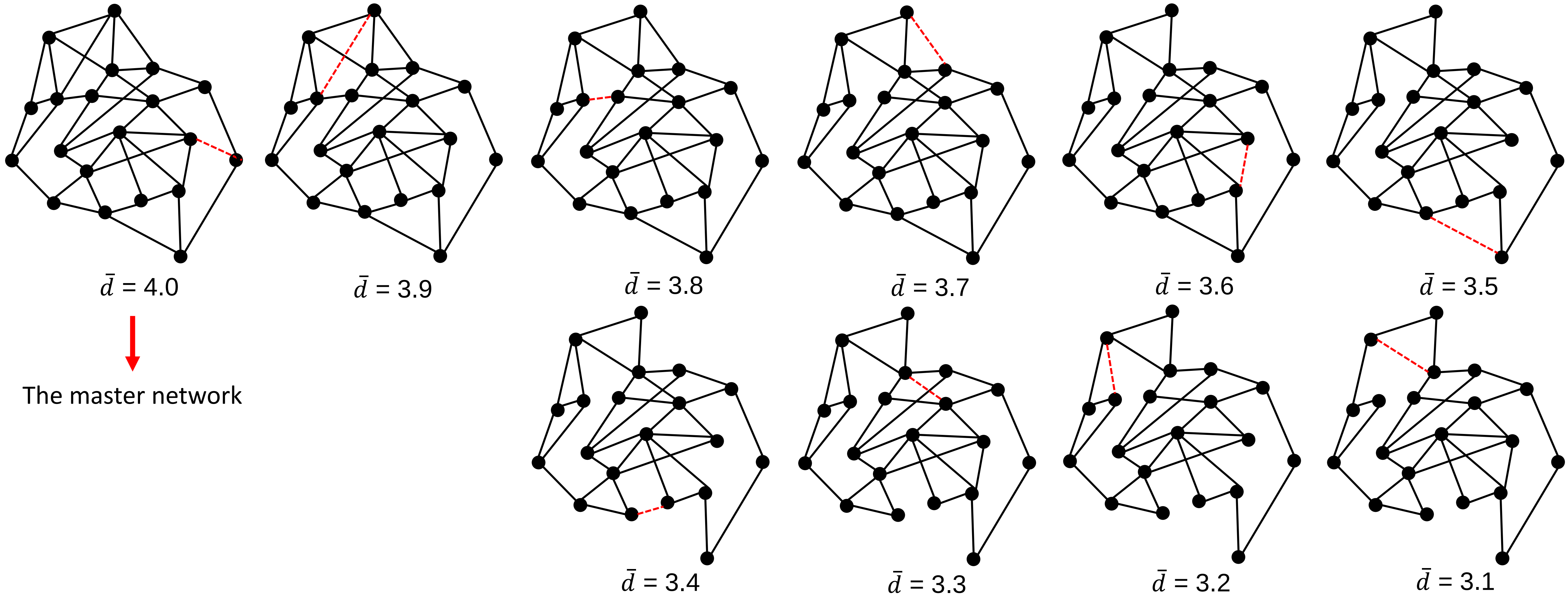
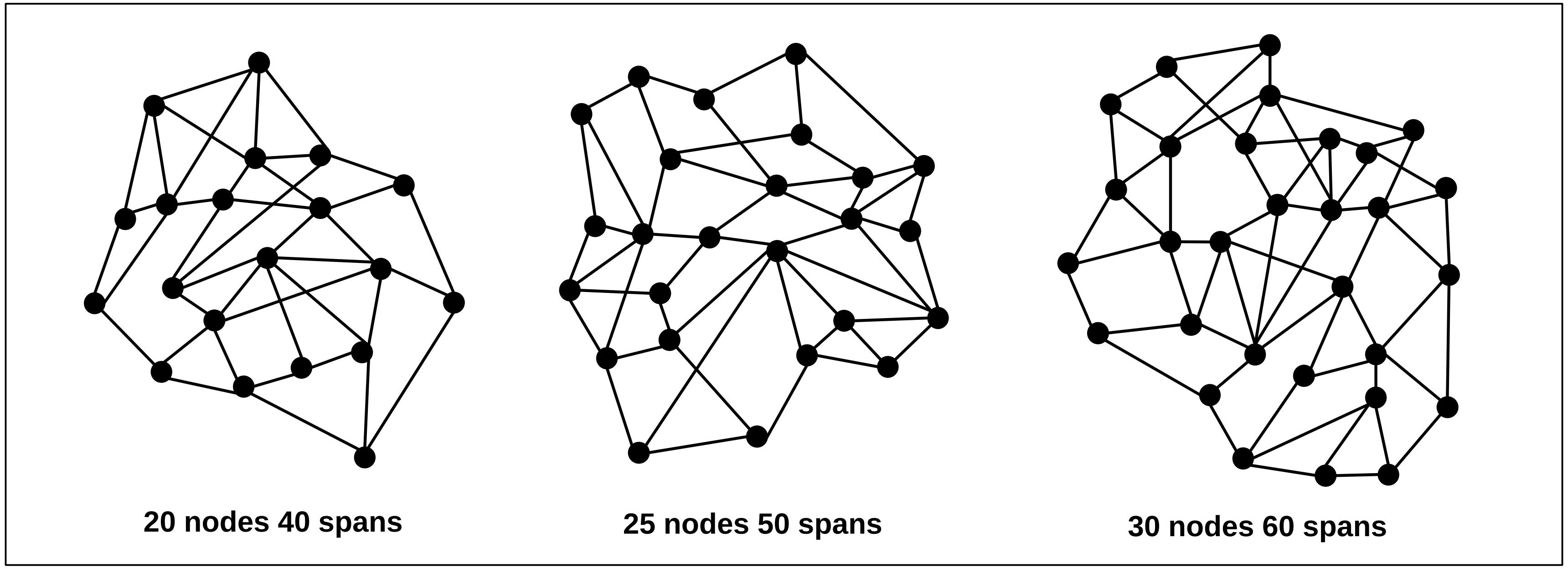
Network Family

- Each network family is created from an initial master network (e.g., 20-node network family).



Experimental Networks and Tools

- Topology of master networks in the 3 network families



58 experimental networks

Computational aspects

Mathematical modeling software

- ***AMPL v2.9***

Optimization solver

- ***Gurobi v6.5***

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Meta-Mesh ILP model

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Original single-failure meta-mesh ILP model[1]

Minimize $\sum_{j \in \mathbf{S}} C_j \cdot (s_j + w_j)$ (1) → Minimizing total cost

Subject to: $\sum_{q \in \mathbf{Q}^r} g^{r,q} = d^r \quad \forall r \in \mathbf{D}$ (2) → Satisfying demand requirement

$$w_j = \sum_{r \in \mathbf{D}} \sum_{q \in \mathbf{Q}^r} \zeta_j^{r,q} \cdot g^{r,q} \quad \forall j \in \mathbf{S} \quad (3)$$

→ Ensuring enough working capacity

$$\sum_{p \in \mathbf{P}_i} f_i^p = w_i \quad \forall i \in \mathbf{S} \quad (4)$$

→ Ensuring single-failure restorability

$$s_j \geq \sum_{p \in \mathbf{P}_i} \delta_{i,j}^p \cdot f_i^p \quad \forall i \in \mathbf{S}_d \quad \forall j \in \mathbf{S} | i \neq j \quad (5)$$

→ Ensuring enough amount of spare capacity in direct spans

$$s_j \geq \sum_{p \in \mathbf{P}_i} \delta_{i,j}^p \cdot f_i^p + \sum_{p \in \mathbf{P}_{k_i}} \delta_{k_i,j}^p \cdot f_{k_i}^p \quad \forall i \in \mathbf{S}_c \quad \forall j \in \mathbf{S} | i \neq j \neq k_i \quad (6)$$

→ Ensuring enough amount of spare capacity in chain spans

Average Dual-Failure Restorability

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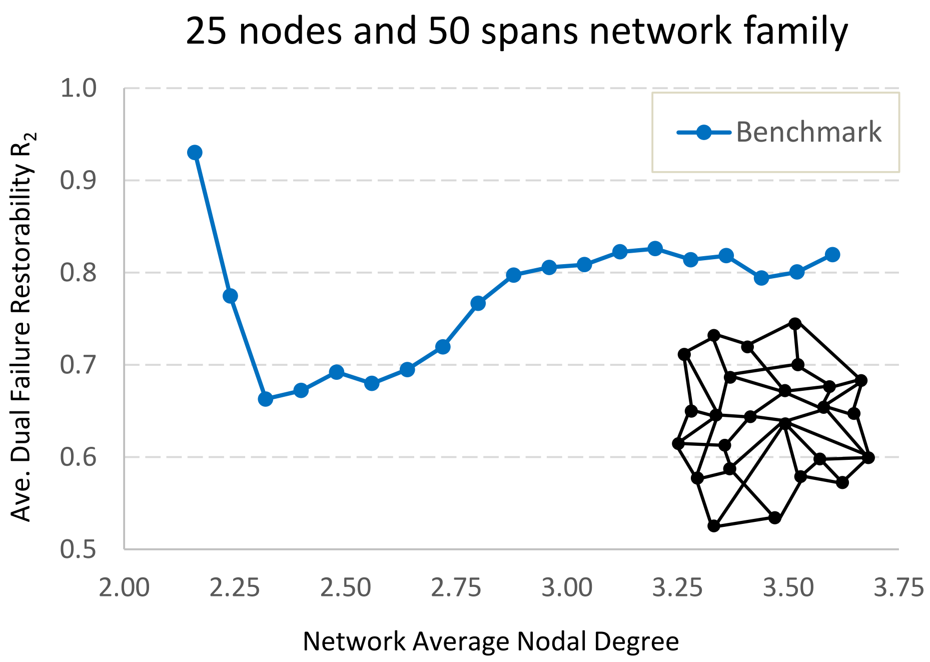
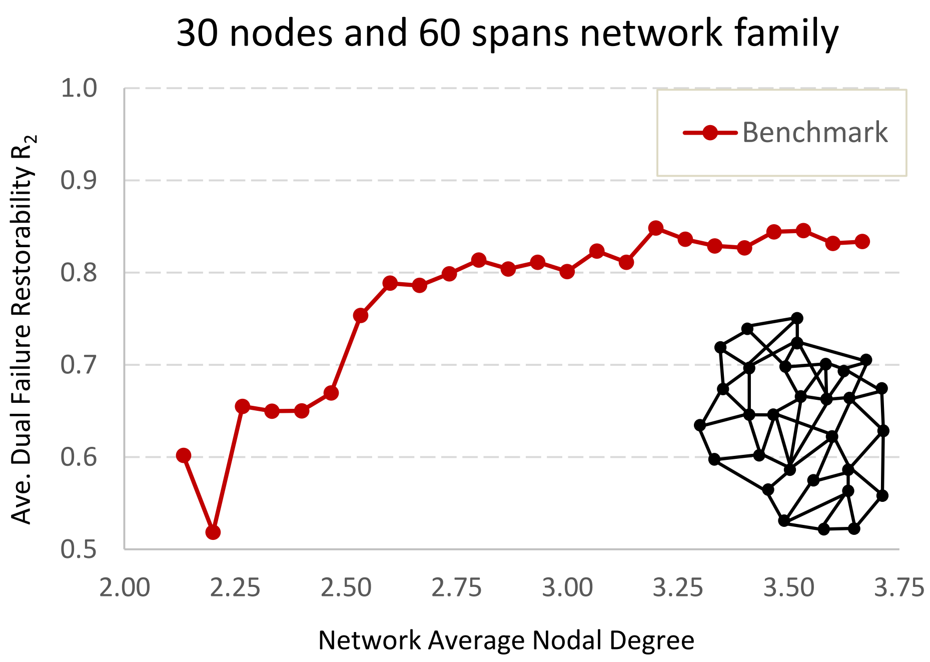
The original single-failure meta-mesh ILP model[1] responds to a dual-span failure scenario with the exception of dual-failure scenarios in degree-2 nodes.

- These results demonstrate how the redistribution of spare capacity in meta-mesh networks enhance the achievable dual-failure restorability.





Castillo-Lugo, A., Nakashima-Paniagua, T., Doucette, J.
"Dual-Failure Restorability of Meta-Mesh Networks"
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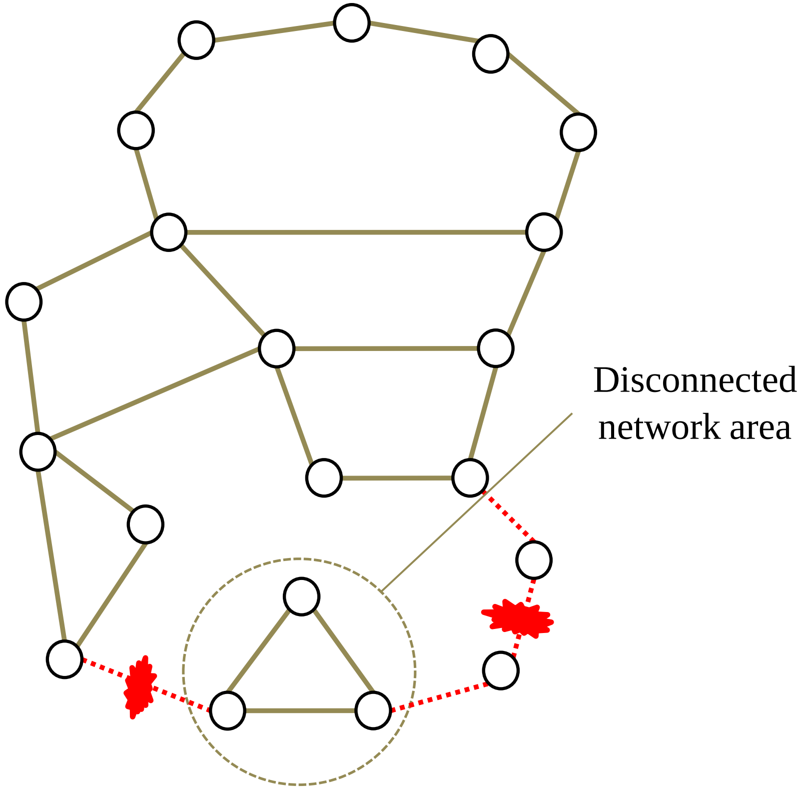
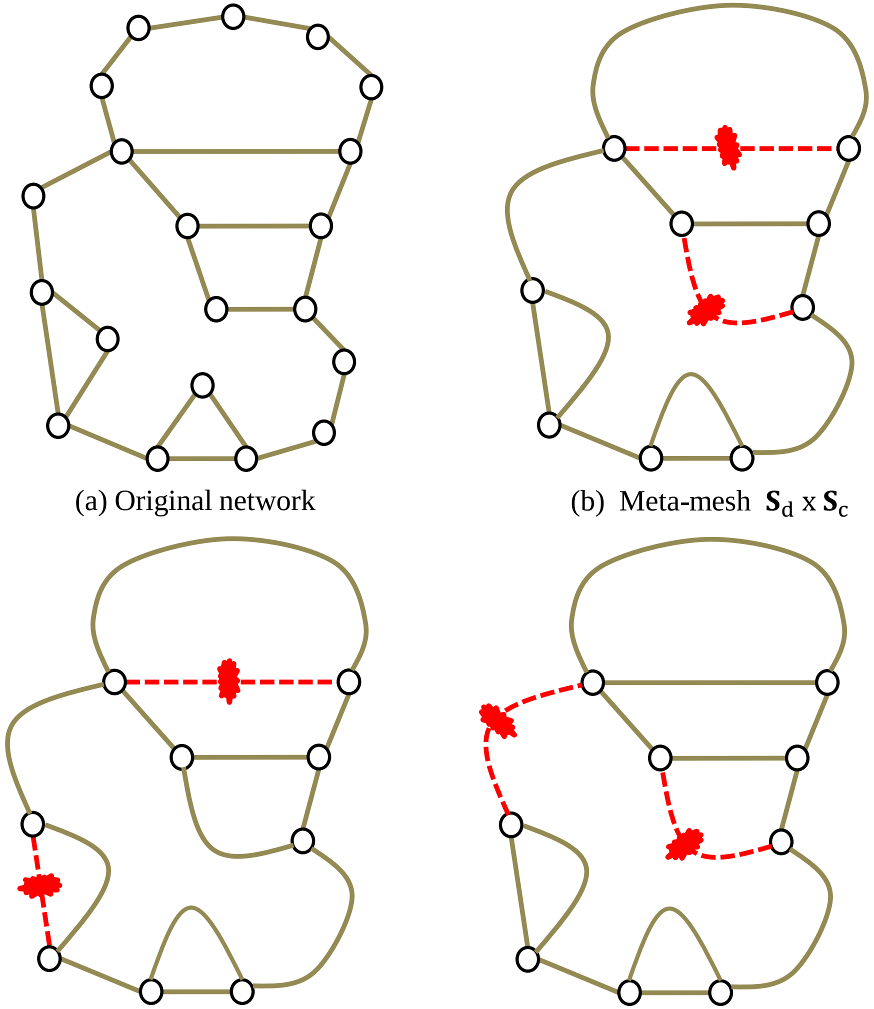
Topology Considerations

Eliminating infeasible solutions





(a) Original network

(b) Meta-mesh $\boldsymbol{S}_{\mathrm{d}}$ x $\boldsymbol{S}_{\mathrm{c}}$

(d) Meta-mesh $\boldsymbol{S}_{\mathrm{d}}$ x $\boldsymbol{S}_{\mathrm{d}}$

(d) Meta-mesh $\boldsymbol{S}_{\mathrm{c}}$ x $\boldsymbol{S}_{\mathrm{c}}$

Meta-Mesh Dual-Failure Minimum Capacity Model

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Our proposed DFMC ILP design model follows from the meta-mesh ILP design model, and carries forward the objective function and all of the constraints from that prior model. Added constraints are:

Subject to:

$$\sum_{p\in \mathbf{P}_i} f_{i,j}^{\;p} = w_i \qquad \forall (i,j) \in \mathbf{S_d^2} \mid i \neq j \qquad (1)$$

$$\sum_{p\in \mathbf{P}_i \mid \delta_{i,k}^p=0} f_{i,j}^{\;p} = w_i \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} \mid i \neq j, k = k(i) \qquad (2)$$

$$\sum_{p\in \mathbf{P}_j \mid \delta_{j,k}^p=0} f_{j,i}^{\;p} = w_j \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} \mid i \neq j, k = k(i) \qquad (3)$$

$$\sum_{p\in \mathbf{P}_k \mid \delta_{k,i}^p=0} f_{k,j}^{\;p} = w_k \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} \mid i \neq j, k = k(i) \qquad (4)$$

$$\sum_{p\in \mathbf{P}_i \mid \delta_{i,k}^p=0, \delta_{i,l}^p=0} f_{i,j}^{\;p} = w_i \qquad \forall (i,j) \in \mathbf{S_c^2} \mid i \neq j, k = k(i), \quad l = l(j) \qquad (5)$$

$$\sum_{p\in \mathbf{P}_k \mid \delta_{k,i}^p=0, \delta_{k,l}^p=0} f_{k,j}^{\;p} = w_k \qquad \forall (i,j) \in \mathbf{S_c^2} \mid i \neq j, k = k(i), \quad l = l(j) \qquad (6)$$

$$\sum_{p\in \mathbf{P}_l \mid \delta_{l,j}^p=0, \delta_{l,k}^p=0} f_{l,i}^{\;p} = w_l \qquad \forall (i,j) \in \mathbf{S_c^2} \mid i \neq j, k = k(i), \quad l = l(j) \qquad (7)$$

$$\sum_{p\in \mathbf{P}_i \mid \delta_{i,j}^p=1} f_{i,j}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_d^2} \mid i \neq j \qquad (8)$$

$$\sum_{p\in \mathbf{P}_i \mid \delta_{i,j}^p=1} f_{i,j}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} \mid i \neq j, k = k(i) \qquad (9)$$

$$\sum_{p\in \mathbf{P}_j \mid \delta_{j,i}^p=1} f_{j,i}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} \mid i \neq j, k = k(i) \qquad (10)$$

$$\sum_{p\in \mathbf{P}_k \mid \delta_{k,j}^p=1} f_{k,j}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} \mid i \neq j, k = k(i) \qquad (11)$$

$$\sum_{p\in \mathbf{P}_i \mid \delta_{i,j}^p=1} f_{i,j}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_c^2} \mid i \neq j, k = k(i), \quad l = l(j) \qquad (12)$$

$$\sum_{p\in \mathbf{P}_k \mid \delta_{k,j}^p=1} f_{k,j}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_c^2} \mid i \neq j, k = k(i), \quad l = l(j) \qquad (13)$$

$$\sum_{p\in \mathbf{P}_l \mid \delta_{l,i}^p=1} f_{l,i}^{\;p} = 0 \qquad \forall (i,j) \in \mathbf{S_c^2} \mid i \neq j, k = k(i), \quad l = l(j) \qquad (14)$$

$$s_w \geq \sum_{p\in \mathbf{P}_i} \delta_{i,w}^{\;p} \cdot f_{i,j}^{\;p} + \sum_{p\in \mathbf{P}_j} \delta_{j,w}^{\;p} \cdot f_{j,i}^{\;p} \qquad \forall (i,j) \in \mathbf{S_d^2} \; x \; \mathbf{S} \mid i \neq j \qquad (15)$$

$$s_w \geq \sum_{p\in \mathbf{P}_i} \delta_{i,w}^{\;p} \cdot f_{i,j}^{\;p} + \sum_{p\in \mathbf{P}_j} \delta_{j,w}^{\;p} \cdot f_{j,i}^{\;p} + \sum_{p\in \mathbf{P}_k} \delta_{k,w}^{\;p} \cdot f_{k,j}^{\;p} \qquad \forall (i,j) \in \mathbf{S_c} x \mathbf{S_d} x \mathbf{S} \mid i \neq j, k = k(i) \qquad (16)$$

$$s_w \geq \sum_{p\in \mathbf{P}_i} \delta_{i,w}^{\;p} \cdot f_{i,j}^{\;p} + \sum_{p\in \mathbf{P}_j} \delta_{j,w}^{\;p} \cdot f_{j,i}^{\;p} + \sum_{p\in \mathbf{P}_k} \delta_{k,w}^{\;p} \cdot f_{k,j}^{\;p} + \sum_{p\in \mathbf{P}_l} \delta_{l,w}^{\;p} \cdot f_{l,i}^{\;p} \qquad \forall (i,j) \in \mathbf{S_c^2} x \mathbf{S} \mid k = k(i), l = l(j) \qquad (17)$$

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Experimental Results and Discussion: MM-DFMC

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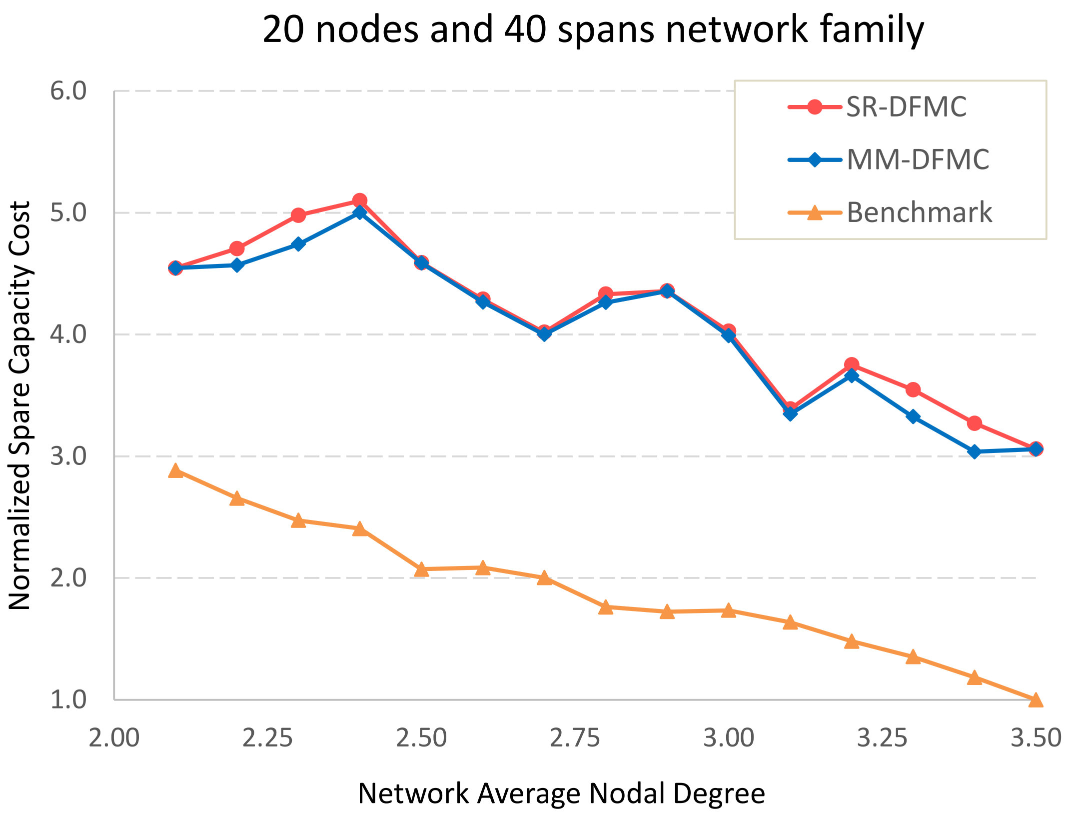
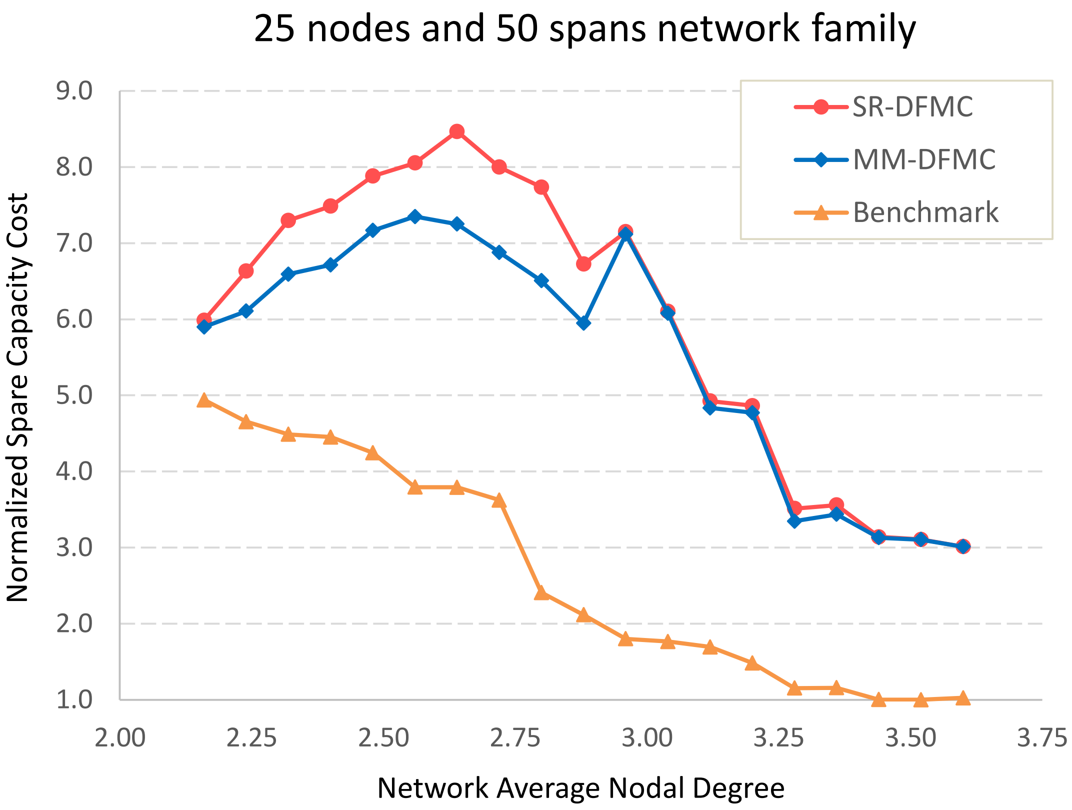
- Results demonstrate that the price of assuring dual-failure restorability in meta-mesh is moderately high.
- **The meta-mesh dual-failure design considerably improves the spare capacity requirements relative to the span-restorable dual-failure design.**





Experimental Results and Discussion: MM-DFMC (2)

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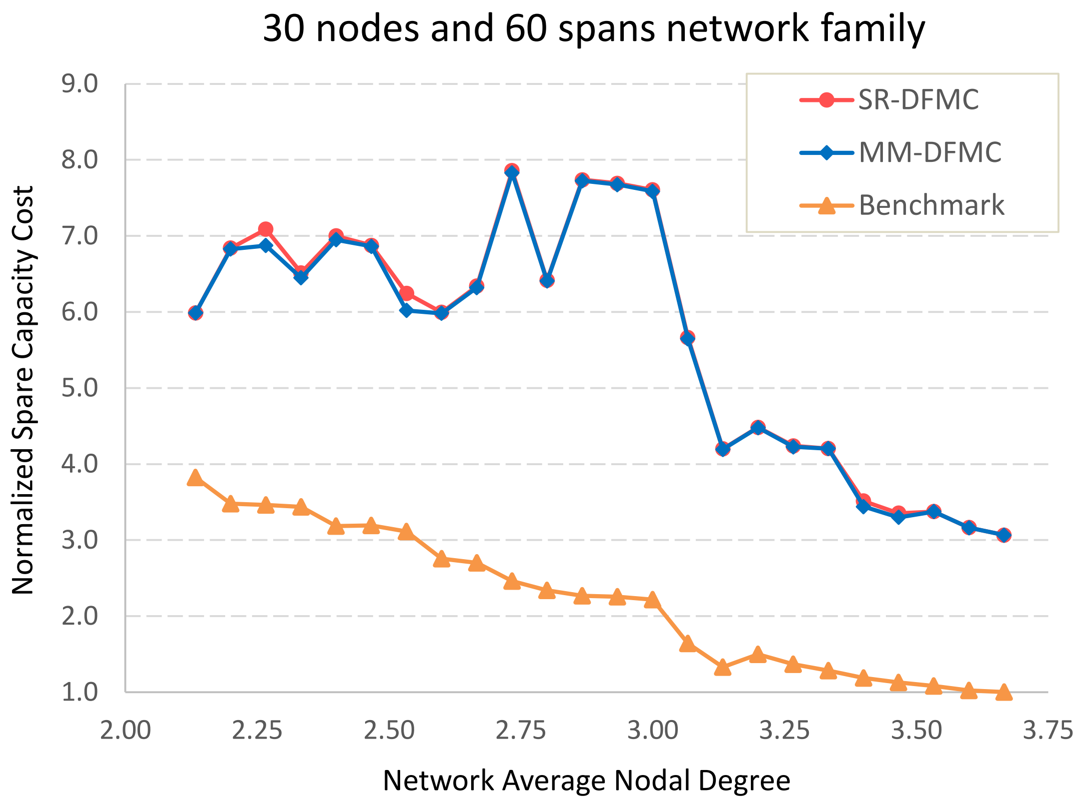
- However, in some network families (large network families) the improvement relative to span-restoration dual-failure was not significant.



Final Remarks

- **We have designed and implemented a new ILP model capable of providing dual-failure restoration in a meta-mesh design model.**
  - Results show that providing dual-failure in a meta-mesh design is quite expensive and in some cases exceedingly difficult (e.g., spare capacity required, design considerations).
  - Unfeasibility issues: network disconnection, as well as increasing the number of working and restoration routes is required.
  - However, the dual-failure meta-mesh model outperformed the dual-failure span-restorable model providing an attractive reduction in spare capacity in some test networks.
  - In addition, meta-mesh network designed to be only single failure restorable will exhibit a sizeable inherent degree of dual-failure restorability.

References

[1] W. D. Grover, J. Doucette *"Design of a Meta-Mesh of Chain Subnetworks: Enhancing the Attractiveness of Mesh-Restorable WDM Networking on Low Connectivity Graphs,"* IEEE Journal on Selected Areas in Communications, vol. 20, no. 1, pp. January 2002 .

[2] University of Kansas, *"ResiliNets Topology Map Viewer",* 2010. [Online]. Available: http://www.ittc.ku.edu/resilinets/maps/#. [Accessed: 10-Aug-2017].

[3] United States Map, Google maps. [Accessed: 20-Dec-2017].

[4] N. Spring, R. Mahajan, D. Wetherall, *"Measuring ISP Topologies with Rocketfuel",* SIGCOMM, Pittsburgh, Pennsylvania, USA 2002.

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