



# SRLG Failure Localization with Monitoring Trails in All-Optical Mesh Networks

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## Survivable optical networks – Failure management

- Protection approaches
  - Pre-planned
  - **Capacity efficiency, simplicity**
- Restoration approaches
  - Reactive
  - **Rapid failure localization** is crucial
- Failure scenarios
  - Assumption of independent failures could be inaccurate
  - Consider dependent failures in the survivable network design (**Shared Risk Link Groups**)
- Shared Risk Link Groups (SRLGs)
  - Physical hierarchy (multi-layer networks, duct topology, etc.)
  - Logical hierarchy (geographical)
    - Adjacent-link failures
    - Node failures



### Downtime cost (per hour)

• <b>Brokerage operations</b>	<b>\$6,450,000</b>
• <b>Credit card authorization</b>	<b>\$2,600,000</b>
• Ebay(1 outage 22 hours)	\$225,000
• Amazon.com	\$180,000
• Package shipping services	\$150,000
• Home shopping channel	\$113,000
• Catalog sales center	\$90,000
• Airline reservation center	\$89,000
• Cellular service activation	\$41,000
• On-line network fees	\$25,000
• ATM service fees	\$14,000

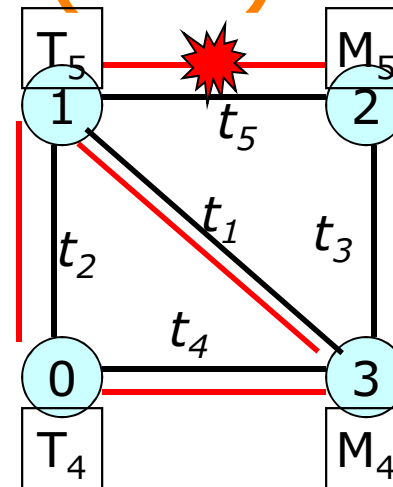
Sources: InternetWeek4/3/2000+FibreChannel: A Comprehensive Introduction, R.Kembel2000, p.8. "...based on a survey done by Contingency Planning Research."





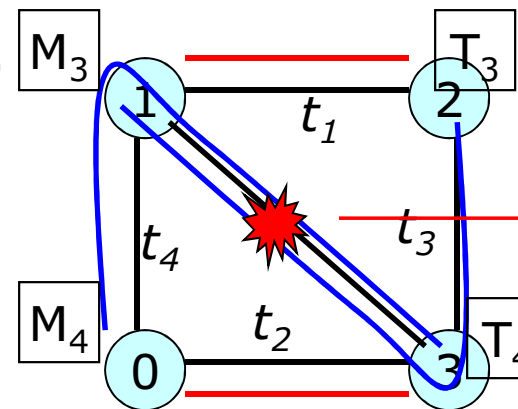
## M-trail Allocation Problem (MAP)

- Link-based monitoring
  - Central network manager can unambiguously localize arbitrary failure by collecting alarms
  - Not scalable,  $|E|$  alarms
- Multi-hop monitoring lightpaths
  - Cycle, simple path
  - Non-simple path with Euler property (monitoring trails, **m-trails**)
  - Connected subgraph (bidirectional m-trails, **bm-trails**)
- **Input:**  $I = \{G=(V,E), F\}$
- **Output:** set of m-trails (or equivalent **link code matrix A**) for unambiguous failure localization for all SRLGs in  $F$ .



Central Network Manager

	$t_5$	$t_4$	$t_3$	$t_2$	$t_1$
$(1,2)$	1	0	0	0	0
$(0,3)$	0	1	0	0	0
$(2,3)$	0	0	1	0	0
$(0,1)$	0	0	0	1	0
$(1,3)$	0	0	0	0	1

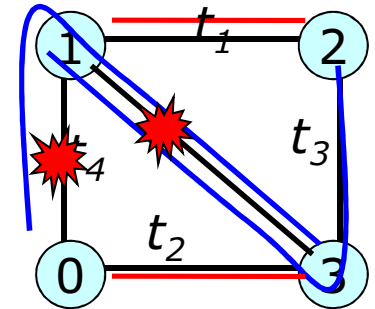


	$t_4$	$t_3$	$t_2$	$t_1$
$(0,1)$	1	0	0	0
$(1,3)$	1	1	0	0
$(2,3)$	0	1	0	0
$(0,3)$	0	0	1	0
$(1,2)$	0	0	0	1



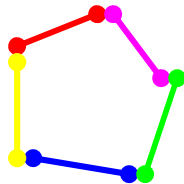
## State-of-the-art

- Single link failure case is well investigated
  - M-trails are on physical links
- SRLGs (logical entity)
  - Codes are the **bitwise OR** of the link codes contained
  - Alarm code table (**ACT**) is formed from the SRLG codes
- Two subtasks have to be solved (on different matrices!)
  - (R1) each SRLG has unique code (rows of the **ACT** matrix) and
  - (R2) each bit position contains a single trail (columns of the **A** matrix)
- **Most heuristics perform first (R2) followed by (R1)**

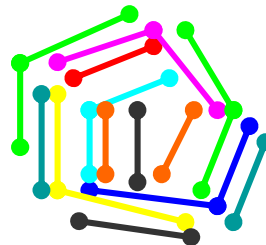


$$\begin{matrix}
 & t_4 & t_3 & t_2 & t_1 \\
 (0,1) & \begin{pmatrix} 1 & 0 & 0 & 0 \end{pmatrix} \\
 (1,3) & \begin{pmatrix} 1 & 1 & 0 & 0 \end{pmatrix} \\
 (2,3) & \begin{pmatrix} 0 & 1 & 0 & 0 \end{pmatrix} \\
 (0,3) & \begin{pmatrix} 0 & 0 & 1 & 0 \end{pmatrix} \\
 (1,2) & \begin{pmatrix} 0 & 0 & 0 & 1 \end{pmatrix}
 \end{matrix} = \underline{\underline{\mathbf{A}}}$$
  

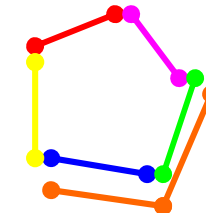
$$\underbrace{\begin{matrix} \{(0,1), (1,3)\} \\ \{(0,3), (1,3)\} \end{matrix}}_{\underline{\underline{\mathbf{ACT}}}} \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$



failures are disjoint sets (**single link**)



all failures up to  $d$  (**dense SRLG**)



all single and a few adjacent failure (**sparse SRLG**)



## Proposed approaches

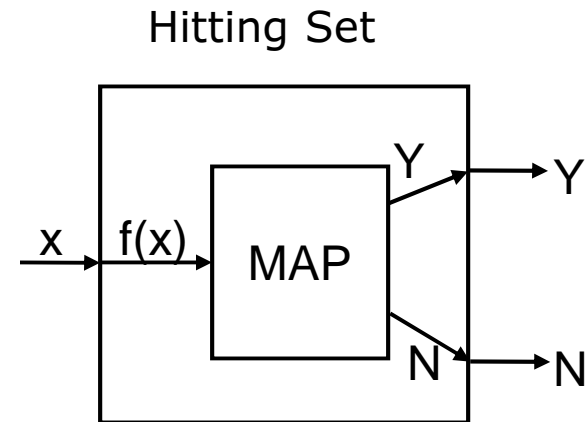
	single link	dense SRLG	sparse SRLG
Optimal	ILP	ILP	ILP [4]
Heuristic	Random Code Swapping [1]	Greedy Code Swapping [2]	Adjacent-link Failure Localization [3], <b>Link Code Construction</b>

- Goals:
  - propose methods for the **sparse SRLG case** (realistic scenario)
  - minimize the number of m-trails (failure localization complexity)
  - **Perform (R1) first followed by (R2)**, i.e. the problem design space can be better explored.
- [1] J. Tapolcai, B. Wu, and P.-H. Ho. On monitoring and failure localization in mesh all-optical networks. In Proc. **IEEE INFOCOM**, pages 1008–1016, Rio de Janeiro, Brasil, 2009.
- [2] J. Tapolcai, Pin-Han Ho, L. Rónyai, P. Babarczi, Bin Wu, Failure Localization for Shared Risk Link Groups in All-Optical Mesh Networks using Monitoring Trails, **IEEE/OSA Journal of Lightwave Technology (JLT)**, vol. 29, no. 10, pp. 1597-1606, impact factor (in 2010) 2.255
- [3] P. Babarczi, J. Tapolcai, Pin-Han Ho, Adjacent Link Failure Localization with Monitoring Trails in All-Optical Mesh Networks, **IEEE/ACM Transactions on Networking (ToN)**, vol. 19, no. 3, pp. 907-920, impact factor (in 2010) 2.284
- [4] B. Wu, Pin-Han Ho, J. Tapolcai, and P. Babarczi, Optimal Allocation of Monitoring Trails for Fast SRLG Failure Localization in All-Optical Networks, in Proceedings of the **IEEE Global Communications Conference (GLOBECOM)**, Miami, Florida, pp. 1-5, 2010

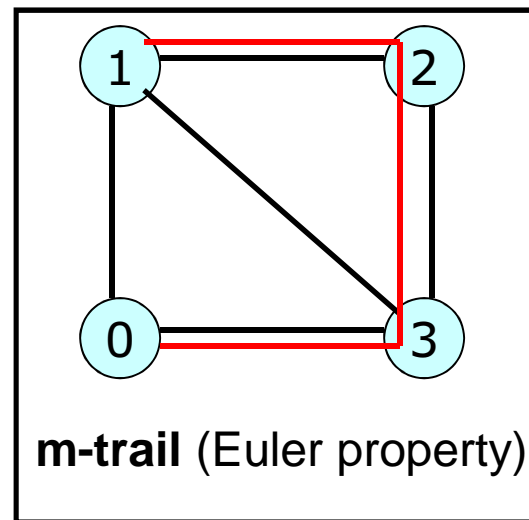
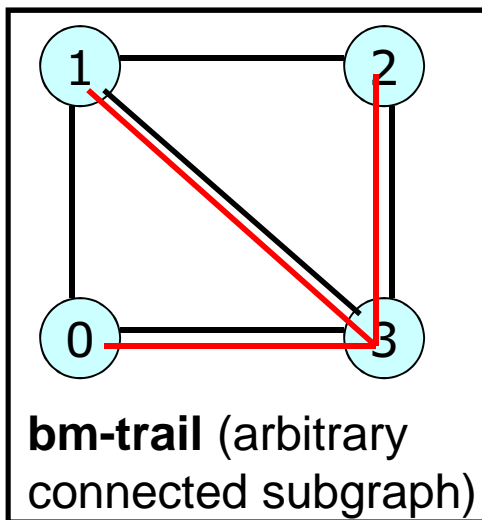


## Computational complexity

- *M-trail allocation problem (MAP) for SRLGs is NP-complete*



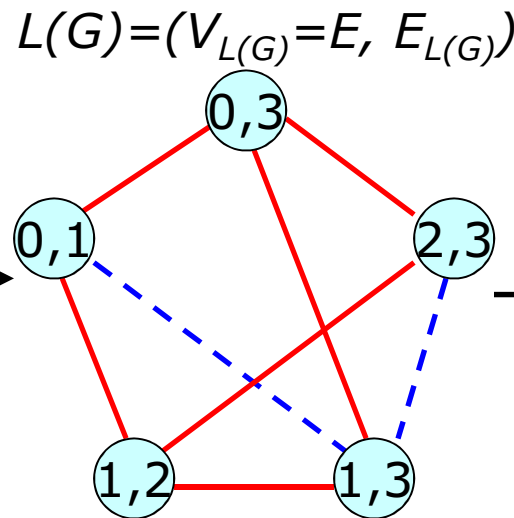
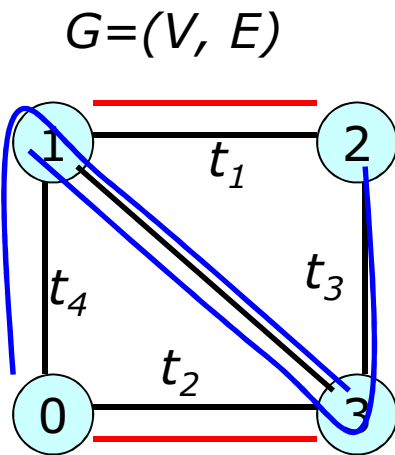
$$HS \prec MAP$$







# Adjacent-Link Failure Localization Heuristic



	$t_4$	$t_3$	$t_2$	$t_1$
(0,1)	1	0	0	0
(1,3)	1	1	0	0
(2,3)	0	1	0	0
(0,3)	0	0	1	0
(1,2)	0	0	0	1

$F = \{\text{single}, \{(0,1), (1,2)\},$   
 $\{(0,1), (0,3)\}, \{(0,3), (2,3)\},$   
 $\{(2,3), (1,2)\}, \{(1,3), (1,2)\}\}$

Find maximal blue vertex-induced subgraph (without red edge!)

- Within the partitions: single link approach
- direct sum of matrices (**Theorem:** ACT is unique.)

- P. Babarczi, J. Tapolcai, Pin-Han Ho, Adjacent Link Failure Localization with Monitoring Trails in All-Optical Mesh Networks, **IEEE/ACM Transactions on Networking (ToN)**, vol. 19, no. 3, pp. 907-920, impact factor (in 2010) 2.284



## Link Code Construction Heuristic

$$\begin{matrix} (0,1) \\ (1,3) \\ (2,3) \\ (0,3) \\ (1,2) \end{matrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\begin{matrix} (0,1) \\ (1,3) \\ (2,3) \\ (0,3) \\ (1,2) \\ \{(0,1), (1,3)\} \\ \{(0,3), (1,3)\} \\ \{(0,1), (0,3)\} \end{matrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 \end{pmatrix}$$

$$\begin{matrix} (0,1) \\ (1,3) \\ (2,3) \\ (0,3) \\ (1,2) \\ \{(0,1), (1,3)\} \\ \{(0,3), (1,3)\} \\ \{(0,1), (0,3)\} \end{matrix} \begin{pmatrix} 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & x \\ 0 & 0 & 1 & 0 & x \\ 0 & 0 & 0 & 1 & x \\ 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 & x \\ 1 & 0 & 1 & 0 & 1 \end{pmatrix} !$$

(1) Start from a single link-failure solution (e.g. RCS)

(2) Check the code of each SRLG pair **once**

(3) Make them different in a position

- Pros: Efficient against node failures owing to the use of bm-trails (backup monitoring node required)
- Cons:  $O(|\text{SRLG}|^2)$  complexity, increased running time



# Simulation results

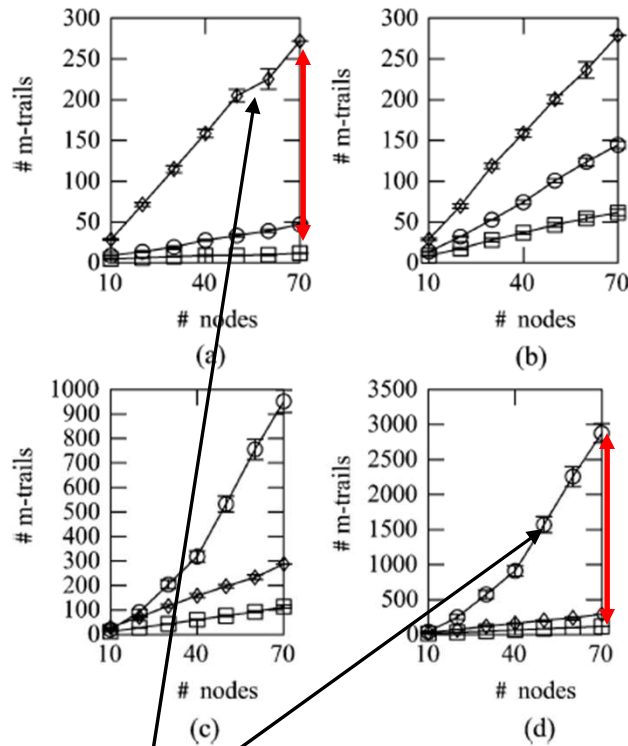


Fig. 6. Number of AAs versus the number of nodes with different SRLG levels, with girth parameter  $g = 5$ , where AFL, CA, and GCS<sup>3</sup> are denoted by  $\square$ ,  $\circ$ , and  $\diamond$ , respectively. (a) Single-link failures. (b) Low SRLG level. (c) Medium SRLG level. (d) High SRLG level.

**CA – Cycle accumulation ((R2) first (R1) second)**  
**GCS – greedy code swapping – designed for dense SRLG**

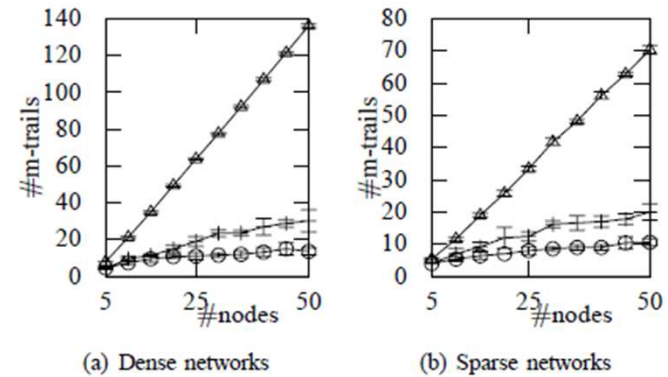


Fig. 5. The number of bm-trails versus the number of nodes with different girth parameters  $g = 3$  and  $7$ , with 10% of adjacent dual SRLGs, where LCC, AFL, and link-based monitoring is denoted by  $\circ$ ,  $+$ , and  $\triangle$ , respectively.

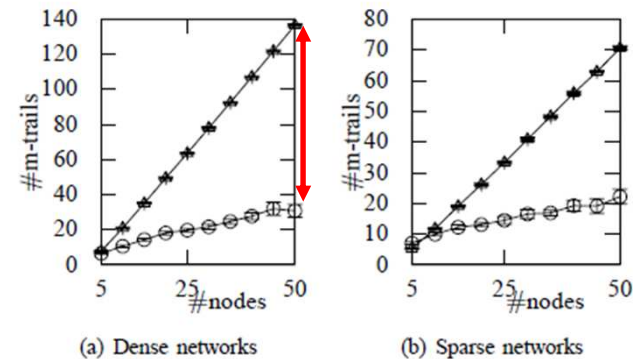


Fig. 7. The number of bm-trails versus the number of nodes with different girth parameters  $g = 3$  and  $7$ , with all single link and node failure, where LCC, AFL, and link-based monitoring is denoted by  $\circ$ ,  $+$ , and  $\triangle$ , respectively.



**Thank you!**

