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

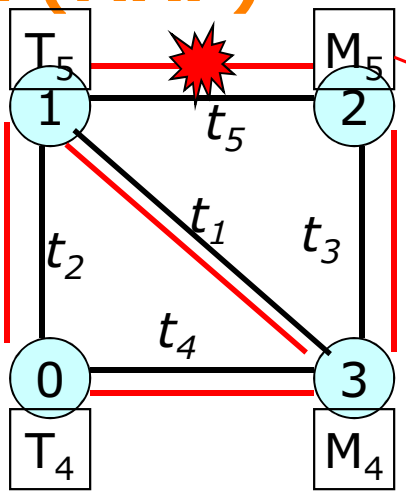
Downtime cost (per hour)

Brokerage operations	**$6,450,000**
Credit card authorization	**$2,600,000**
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."

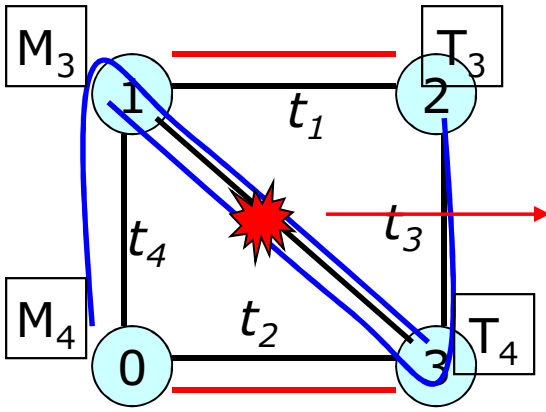
M-trail Allocation Problem (MAP)

- Link-based monitoring
  - Central network manager can unambiuously localize arbitrary failure by collecting alarms
  - Not scalable, |E| alarms
- Multi-hop mointoring lightpaths
  - Cycle, simple path
  - Non-simple path with Euler property (monitorig trails, **m-trails**)
  - Connected subgraph (bidirec-tional 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

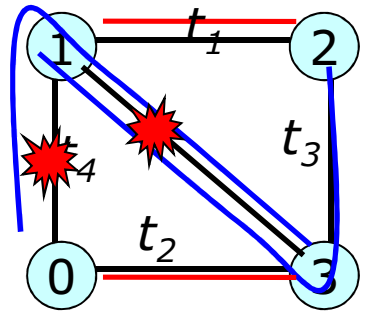
	t_5	t_4	t_3	t_2	t_1
(1,2)	1	0	0	0	0
(0,3)	0	1	0	0	0
(2,3)	0	0	1	0	0
(0,1)	0	0	0	1	0
(1,3)	0	0	0	0	1



	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

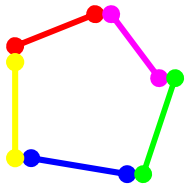
State-of-the-art

- 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) followd by (R1)**

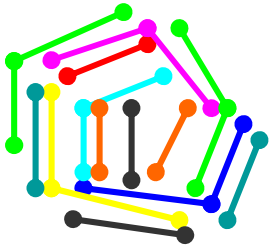


$$A = \begin{array}{c} \\ (0,1) \\ (1,3) \\ (2,3) \\ (0,3) \\ (1,2) \end{array} \begin{array}{c} \begin{array}{cccc} t_4 & t_3 & t_2 & t_1 \end{array} \\ \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{array}$$

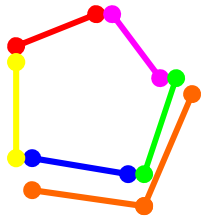
$$ACT = \begin{array}{c} \\ \{(0,1),(1,3)\} \\ \{(0,3),(1,3)\} \end{array} \begin{array}{c} \begin{array}{cccc} t_4 & t_3 & t_2 & t_1 \end{array} \\ \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \end{pmatrix} \end{array}$$



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



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



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

Proposed approaches

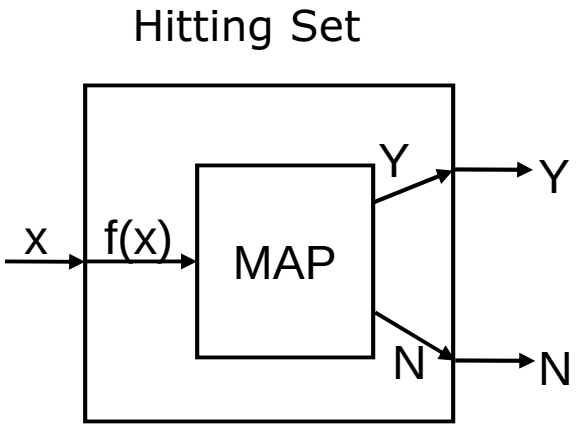
	single link	dense SRLG	sparse SRLG
Optimal	ILP	ILP	ILP [4]
Heuristic	Random Code Swapping [1]	Greedy Code Swapping [2]	Adjacent-link Failure Localization [3], **Link Code Construction**

- 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.

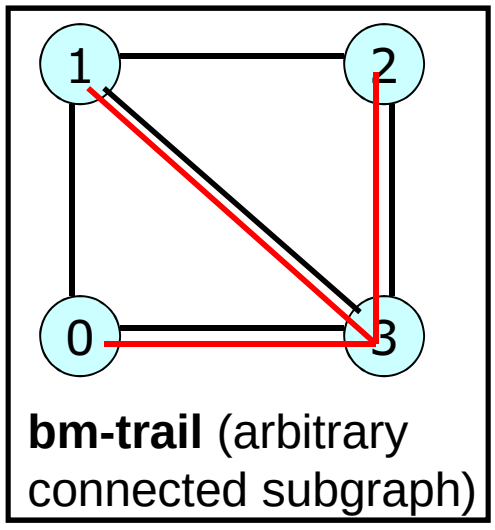
- [1] J. Tapolcai, B. Wu, and P.-H. Ho. On monitoring and failure localization in mesh all-optical networks. In Proc. **IEEE INFOCOM**, pages 1008–1016, Rio de Janero, Brasil, 2009.
- [2] J. Tapolcai, Pin-Han Ho, L. Rónyai, P. Babarczi, Bin Wu, Failure Localization for Shared Risk Link Groups in All-Optical 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

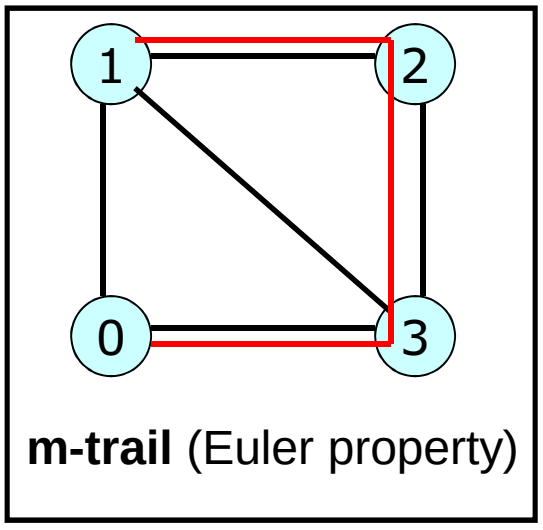
- *M-trail allocation problem (MAP) for SRLGs is NP-complete*



$HS \prec MAP$



bm-trail (arbitrary connected subgraph)



m-trail (Euler property)

Necessary and sufficient conditions

SRLG = {e,f}

SRLG = {g,h}

e	0	1	0	1
f	1	0	1	0
g	1	1	0	0
h	0	0	1	1
$\{e, f\}$	1	1	1	1
$\{g, h\}$	1	1	1	1

- Strict sufficient condition (**on link codes!**)
- **Substance**: Arbitrary link *e* can have ‘1’ bit with at most one link from an arbitrary *F* SRLG.

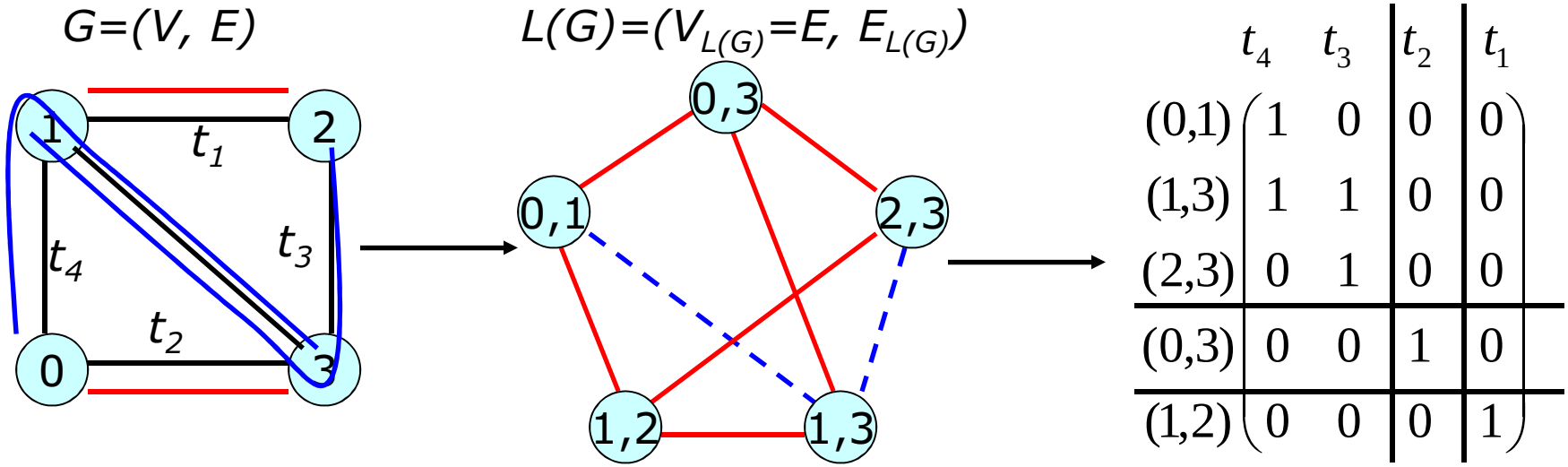
SRLG = {e}

SRLG = {g,h}

e	1	1	1	0
g	1	0	0	1
h	0	1	0	0
			j	
$\{g, h\}$	1	1	0	1

- Permissive necessary and sufficient condition (**on link codes!**)
- **Substance**: Two SRLG codes are different iff exists a link *e* and a bit position *j* with ‘1’ in $SRLG_1$, which is ‘0’ for all links in $SRLG_2$.

Adjacent-Link Failure Localization Heuristic



$$\begin{array}{c|cccc} & t_4 & t_3 & t_2 & t_1 \\ \hline (0,1) & 1 & 0 & 0 & 0 \\ (1,3) & 1 & 1 & 0 & 0 \\ (2,3) & 0 & 1 & 0 & 0 \\ \hline (0,3) & 0 & 0 & 1 & 0 \\ \hline (1,2) & 0 & 0 & 0 & 1 \end{array}$$

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

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

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

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

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

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

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

!

(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(|SRLG|^2) complexity, increased running time

Simulation results

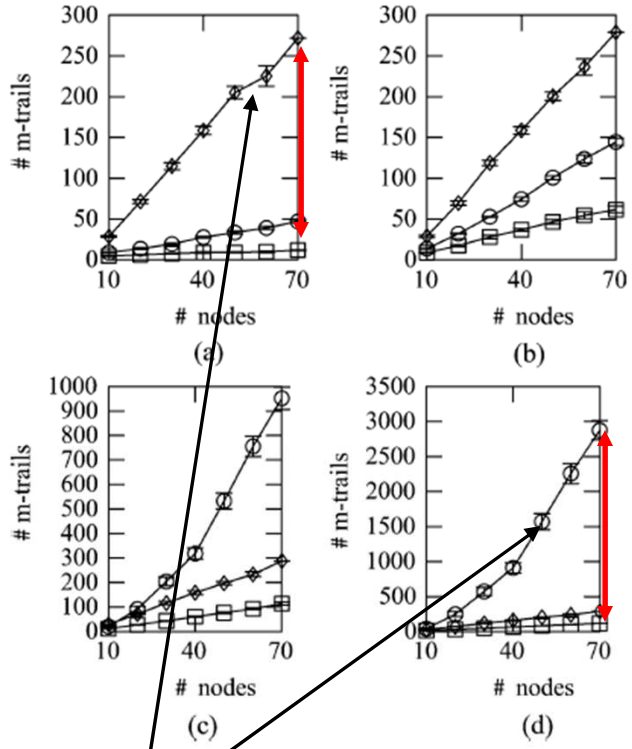


Fig. 6. Number of AAs versus the number of nodes with different SRLG levels, with girth parameter $g = 5$, where AFL, CA, and GCS[3] are denoted by □, ○, and ◇, respectively. (a) Single-link failures. (b) Low SRLG level. (c) Medium SRLG level. (d) High SRLG level.

CA – Cycle accumulation ((R2) first (R1) second)

GCS – greedy code swapping – designed for dense SRLG

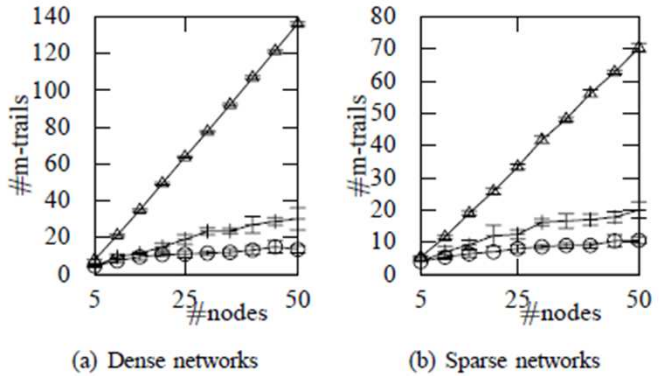


Fig. 5. The number of bm-trails versus the number of nodes with different girth parameters $g = 3$ and 7, with **10% of adjacent dual SRLGs**, where LCC, AFL, and link-based monitoring is denoted by ○, +, and △, respectively.

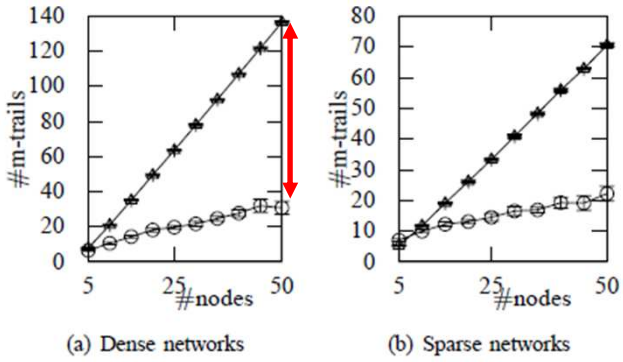


Fig. 7. The number of bm-trails versus the number of nodes with different girth parameters $g = 3$ and 7, with **all single link and node** failure, where LCC, AFL, and link-based monitoring is denoted by ○, +, and △, respectively.

Thank you!