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

Péter Babarczi
babarczi@tmit.bme.hu
Budapest University of Technology and Economics
Department of Telecommunications and Media Informatics

Authors: Péter Babarczi, János Tapolcai, Pin-Han Ho
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

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

\[
\begin{pmatrix}
(1,2) & 1 & 0 & 0 & 0 & 0 \\
(0,3) & 0 & 1 & 0 & 0 & 0 \\
(2,3) & 0 & 0 & 1 & 0 & 0 \\
(0,1) & 0 & 0 & 0 & 1 & 0 \\
(1,3) & 0 & 0 & 0 & 0 & 1 \\
\end{pmatrix}
\]

\[
\begin{pmatrix}
(0,1) & 1 & 0 & 0 & 0 \\
(1,3) & 1 & 1 & 0 & 0 \\
(2,3) & 0 & 1 & 0 & 0 \\
(0,3) & 0 & 0 & 1 & 0 \\
(1,2) & 0 & 0 & 0 & 1 \\
\end{pmatrix}
\]
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)

\[
\begin{pmatrix}
    1 & 0 & 0 & 0 \\
    1 & 1 & 0 & 0 \\
    0 & 1 & 0 & 0 \\
    0 & 0 & 1 & 0 \\
    0 & 0 & 0 & 1 \\
\end{pmatrix} = A
\]

\[
\begin{pmatrix}
    1 & 1 & 0 & 0 \\
    1 & 1 & 1 & 0 \\
\end{pmatrix}
\]

ACT

failures are disjoint sets (single link)
all failures up to \( d \) (dense SRLG)
all single and a few adjacent failure (sparse SRLG)
Proposed approaches

<table>
<thead>
<tr>
<th></th>
<th>single link</th>
<th>dense SRLG</th>
<th>sparse SRLG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal</td>
<td>ILP</td>
<td>ILP</td>
<td>ILP [4]</td>
</tr>
</tbody>
</table>

- **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.

Computational complexity

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

\[
x \xrightarrow{f(x)} Y \\
N \xrightarrow{Y} MAP \xrightarrow{Y} N
\]

**HS \ll MAP**

- **bm-trail** (arbitrary connected subgraph)
- **m-trail** (Euler property)
Necessary and sufficient conditions

SRLG = \{e,f\}
\begin{array}{c}
  e \\
  f \\
  g \\
  h \\
\end{array}
\begin{array}{c}
  0 \\
  1 \\
  1 \\
  0 \\
\end{array}

SRLG = \{g,h\}
\begin{array}{c}
  e \\
  f \\
  g \\
  h \\
\end{array}
\begin{array}{c}
  1 \\
  0 \\
  1 \\
  0 \\
\end{array}

\{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.

\[
\begin{array}{c}
  e \\
  g \\
  h \\
\end{array}
\begin{array}{c}
  1 \\
  1 \\
  0 \\
\end{array}
\]
\[j\]

\[
\begin{array}{c}
  \{g,h\} \\
\end{array}
\begin{array}{c}
  1 \\
\end{array}
\]

- **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

\[ G = (V, E) \]
\[ L(G) = (V_{L(G)} = E, E_{L(G)}) \]

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

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

- Within the partitions: single link approach
- direct sum of matrices

(\textbf{Theorem}: ACT is unique.)

### Link Code Construction Heuristic

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

<table>
<thead>
<tr>
<th>SRLG Pair</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0,1)</td>
<td>1 0 0 0 0</td>
</tr>
<tr>
<td>(1,3)</td>
<td>1 1 0 0</td>
</tr>
<tr>
<td>(2,3)</td>
<td>0 1 0 0</td>
</tr>
<tr>
<td>(0,3)</td>
<td>0 0 1 0</td>
</tr>
<tr>
<td>(1,2)</td>
<td>0 0 0 1</td>
</tr>
</tbody>
</table>

(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: \(O(|SRLG|^2)\) complexity, increased running time
Simulation results

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

GCS – greedy code swapping – designed for dense SRLG

Fig. 5. The number of m-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 o, +, and Δ, respectively.

Fig. 6. Number of AAs versus the number of nodes with different SRLG levels, with girth parameter \( g = 5 \), where AFL, CA, and GCS⁹ are denoted by □, ○, and ◊, respectively. (a) Single-link failures. (b) Low SRLG level. (c) Medium SRLG level. (d) High SRLG level.

Fig. 7. The number of m-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 o, +, and Δ, respectively.
Thank you!