IP over WDM Path Routing and Restoration

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Outline

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Introduction

- **IP over WDM network**
  - Optical-layer protection can provide fast recovery and high scalability
  - Higher-layer recovery provide finer granularity of recovery
- **Routing and wavelength assignment (RWA)** in WDM network contains
  - Route establishment
  - Wavelength assignment
Problem formulation

• IP over WDM network is modeled as
  – A graph $G(V, E, W)$ where
    • $V$: set of all nodes
    • $E$: set of optical links
    • $W$: set of wavelengths per link
  – Given a request $R(s, d, b)$ from ingress router $s$ to egress router $d$ requiring bandwidth $b$
    • Find a path and the wavelengths on the links along the path to meet the request requirement
Categories of solutions

- RWA problems can be solved in either
  - Two-stage: wavelength assignment after path routing
  - Joint RWA: consider both in the same time
- Routing problems can be divided into
  - Active/single path routing
  - Backup path routing
  - Disjoint paths routing
- Three generic approaches
  - Integer Linear Programming (ILP) optimization
  - Link-weight based Dijkstra’s algorithm
  - Flooding based path searching
Active/single path routing

• Focus on maximizing network efficiency: to accommodate as many requests as possible
  – IWG [1]
  – MOCA [2]: based on MIRA
  – BI [3]
  – MCPS [4]
IWG

• IWG: IP over WDM Grooming

• Routing is based on cost function
  
  – Path\_Cost = \( N\_\text{links} + P \times N\_\text{FA-LSP\_Links} + Q \times N\_\text{hops} \), where

  • \( N\_\text{links} \) is the number of new optical links
  • \( N\_\text{FA-LSP\_Links} \): number of optical links already active
  • \( N\_\text{hops} \): number of O/E/O conversions
  • \( P \) and \( Q \): coefficients to adjust performance
    
    \( P < 1 \) implies fostering reuse of established path
    \( Q > 1 \) means paths with many O/E/O will be avoided
MOCA

- MOCA: Maximum Open Capacity Routing Algorithm
- Idea:
  - Model IP/WDM network with logical links
  - Find the shortest path in a modified network where the link weights are proportional to the criticality of the links
  - Define all links that belong to the minimum cut for an ingress-egress pair to be critical
MOCA network model

Two wavelength per link

After request (4, 3, 0.2)

Link weight after 4→3
BI

- **BI: Blocking Island paradigm**
- **Routing is based on**
  - Construction of BI hierarchy
  - Route existence check
  - K different weighted shortest routes using path cost function
    - **Path_Cost = N_links + P * Active_Lightpaths**
  - Pick the route with minimum splitting cost
MCPS

- MCPS: Multiple Constraints Path Selection
- Idea:
  - Each node maintains local network state info.
  - Routing is based on path information update by flooding
  - Select the best path at destination according to networks’ operational criteria
Backup path routing

• Active path is assumed to be established first based on Dijkstra’s algorithm
• Focus on minimizing reserved bandwidth for all backup paths
  – SPR (Shortest Path Restoration)
  – PIR [6]
  – FIR [5]: enhance PIR
  – DLB [7]
Backup path routing

- **PIR: Partial Information Restoration**
  - Idea: weight each link using an estimate of additional bandwidth that needs to be reserved if a particular restoration path is selected
  - After service path $Ps$ is selected, the source node calculate maximum service bandwidth $M$ over all links along the service path
  - Assign a weight to each link in the network

$$w[i] = \begin{cases} 
\min(b, M+b-R[i]) \\ 
\cdot W[i], & \text{if } M+b-R[i] > 0 \text{ and } i \notin Ps \\
\varepsilon, & \text{if } M+b-R[i] \leq 0 \text{ and } i \notin Ps \\
\infty, & \text{if } i \in Ps 
\end{cases}$$
Backup path routing

- **FIR**: Full Information Restoration
  - Idea: after selecting service path $Ps$, the source node collects the array $T[i]$, the maximum bandwidth needed on link $i$ if any of the links along $Ps$ fails
  - Assign a weight to each link in the network

$$w[i] = \begin{cases} \min (b, T[i] + b - R[i]) \cdot W[i] & \text{if } T[i] + b - R[i] > 0 \\
& \text{and } i \notin Ps \\
\varepsilon & \text{if } T[i] + b - R[i] \leq 0 \\
& \text{and } i \notin Ps \\
\infty & \text{if } i \in Ps. \end{cases}$$
Backup path routing

- **DLB:** Decentralized Local Backup LSP calculation
  - Given the primary path \( P = \{ N_{X_0}, N_{X_1}, \ldots, N_{X_n} \} \)
  - For each node along the primary path, each link is assigned a cost \( K_{ij} \)

- if we protect against node failure
  - \( Inc_{ij}(F, bw) \) if \( i \neq F \land j \neq F \land Inc_{ij}(F, bw) \neq 0 \)
  - \( \varepsilon \) if \( i \neq F \land j \neq F \land Inc_{ij}(F, bw) = 0 \)
  - \( \infty \) if \( i = F \lor j = F \)

- if we protect against link failure
  - \( Inc_{ij}(F, bw) \) if \( (i \neq N_{x_k} \lor j \neq F) \land Inc_{ij}(F, bw) \neq 0 \)
  - \( \varepsilon \) if \( (i \neq N_{x_k} \lor j \neq F) \land Inc_{ij}(F, bw) = 0 \)
  - \( \infty \) if \( i = N_{x_k} \land j = F \)

- \( Inc_{ij}(F, bw) = R_{ij}' - R_{ij} \) increased reserved bandwidth
Trap problem

- Active path first (APF) heuristic may lead to the so-called “trap problem”
  - Fail to find link-disjoint paths when such a pair exists
Disjoint path routing

- Find link/node-disjoint paths
  - SPP [8]: min-weight disjoint path
  - MIRR [9]: based on MIRA
  - APFE [10]: enhanced APF
  - COLE [11]
MIRR

- MIRR: Minimum Interference Restorable Routing algorithm
- Idea
  - Compute the maximum 2-route flows
  - Compute the 2-critical link sets $C_{sd}$
  - Compute the criticality indices $w(I)$ as link weight of link $I$
  - Use SPP to find shortest disjoint paths based on link weight $w(I)$
  - Choose one as active path, the other as backup path
APFE

- **APFE: enhanced Active Path First**
- **Idea:**
  - Find AP (Active Path) using minimum number of links
  - Assign a cost of infinity for every active or reserved channel, assign a cost of M (very big number) for every free channel on a link of AP, assign a cost of 1 for every other free channel
  - Find a minimum cost BP (Backup Path)
  - If AP and BP are not link-disjoint, use the BP as active path and repeat until AP and BP are link disjoint
COLE

- COLE: Conflicting Link Exclusion
- Idea
  - Minimize the cost of AP (Active Path)
  - Find the shortest AP in the network
  - Identify the conflicting link set T
  - Divide the problem P into sub-problems in the form of P(I, O) based on T; the sub-problem without link-disjoint path pairs is further divided
  - Compare link-disjoint path pairs found in each sub-problem, choose the one with shortest AP
Discussion

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- Active/single path routing considers WDM wavelengths and logical network thus better utilize network resource, but doesn’t consider backup path simultaneously.
- Backup path routing after active path minimizes reserved bandwidth but may encounter trap problem.
- Disjoint path routing considers optimized disjoint path for restoration, but doesn’t consider WDM layer multi-wavelength effect.

Ref [11]
Discussion

• **Design goal of IP/WDM routing**
  – WDM physical path disjointness
  – With minimum interference to maximize the acceptable requests
  – Consider both dedicated and shared bandwidth among all backup paths

• **Bandwidth sharing may not be allowed**
  – Link-state information for backup paths not available
  – 1+1 redundancy
  – After failure is fixed, traffic will not switched back to the primary path
Reference

Reference


