Motivation

- Layer-1 VPN
  - Attractive solution for enterprises, ISPs, large institutional users of bandwidth
  - To create their own private networks among a subset of nodes over a physical optical WDM network.
  - Constructed as a client network over a physical infrastructure of a provider network.
- With emerging technologies like GMPLS, IP/MPLS, ASON, multi-layer optimization of packet over circuit networks raises as a problem.
- Resilient design of such a multi-layer network

"Multi Layer Resilient Design for Layer-1 VPNs": Ç. Cavdar, A. Gençata & B. Mukherjee
University of California-Davis & Istanbul Technical University
Multi layer network model

Layer-1 VPN

Physical Topology

"Multi Layer Resilient Design for Layer-1 VPNs", C. Cavdar, A. Gencata & B. Mukherjee
University of California-Davis & Istanbul Technical University

Multi layer network model

Non-resilient design

Layer-1 VPN

Physical Topology

"Multi Layer Resilient Design for Layer-1 VPNs", C. Cavdar, A. Gencata & B. Mukherjee
University of California-Davis & Istanbul Technical University
Previous work: Survivable Lightpath Routing

- **Given:**
  - Physical Topology
  - Number of Transceivers
  - Virtual connectivity

- **Find:**
  - Survivable mapping
  - Routing of each lightpath (RWA)

- **Goal:**
  - Route the VT on a PT such that the VT remains connected even in the event of a physical link failure.

---

Our study: Multilayer Design

- **Given:**
  - Traffic Demands,
  - Physical Topology
  - Number of Transceivers
  - Capacity of each channel
  - Set of nodes \( N_i \) in the client network

- **Find:**
  - Routing of traffic demands
  - Virtual connectivity
  - Survivable mapping
    - Routing of each lightpath (RWA)

- **Goal:**
  - Find a minimum set of lightpaths in VPN and route the VPN topology on a PT such that the VT remains connected even in the event of a physical link failure.
ILP for Survivable Layer-1 VPN Design

Objective functions

Minimize \( \sum_{(i,j)} V_{ij} \) \( i,j \) : end nodes of a lightpath

Minimize \( \sum_{(m,n)} \sum_{(i,j)} P_{mn}^{ij} \) \( m,n \) : end nodes of a physical link

Constraints

VT constraints due to number of transceivers

\[ \sum_j V_{ij} \leq T_i \quad \forall i \]

\[ \sum_i V_{ij} \leq R_j \quad \forall j \]

Routing of lightpaths

\[ p_{mn}^{ij} \leq P_{mn} \]

\[ p_{nm}^{ij} \leq V_{ij} \]

\[ \sum_m p_{mk}^{ij} = \sum_n p_{kn}^{ij} \quad \text{if} \ k \neq i,j \]

\[ \sum_n p_{in}^{ij} = V_{ij} \]

\[ \sum_v p_{vj}^{ij} = V_{ij} \]
ILP for Survivable Layer-1 VPN Design

Constraints

Routing of traffic demands

\[ \lambda_{ij}^{sd} \geq 0 \]
\[ \sum_j \lambda_{ij}^{sd} = \lambda_{id} \]
\[ \sum_i \lambda_{ij}^{sd} = \lambda_{ij} \]
\[ \sum_s \lambda_{ij}^{sd} = \sum_j \lambda_{ij}^{ks} \quad \text{if} \quad k \neq s, d \]
\[ \sum_{s,d} \lambda_{ij}^{sd} \leq V_{ij} * C * \alpha \]

Survivability Constraints

\( X_{mn}^{k,l} = 1 \) if lightpath \( (i,j) \) is an element of cut \( k \) and routed through fiber \( (m,n) \)
\( K_{ij}^{s} = 1 \) if lightpath \( (i,j) \) is an element of cut \( k \)
\( C_{k} = 1 \) if cut \( k \) exists

\( (m,n) \neq (1,6) \)

\[ \forall (i,j) \in E \sum_{(i,j) \in CS(S,N_L-S)} P_{mn}^{ij} \leq |CS(S,N_L-S)| \]

\[ \sum_{i,j \in N_L} X_{mn}^{k,l} + C_{k} \leq \sum_{i,j \in N_L} K_{ij}^{s} \quad k = 1..K \]

\[ \forall m,n \in N \]
Survivability Constraints

\[ \sum_{i,j} T_{ij} \leq V_{ij}, \quad \forall i, j \in N_L \]  

(1)

\[ \sum_{j} T_{ij} = \sum_{j} T_{ji}, \quad \forall i \in N_L \]  

(2)

\[ \sum_{i,j} K^k_{ij} p^{m}_{ij} + C_i \leq \sum_{i,j} K^j_{ij}, \quad k = 1..K \]  

\( \forall m, n \in N \)  

(3)

Let \( T_{ij} = T_{ji} \)  

(4)

\[ U_{ij} = 0, \quad (i, j) \neq (x, y) \]  

\( \forall i, j, x, y \in N_L \)  

(5)

\[ U_{ij} = 0 \]  

(6)

\[ \forall k, i, j \in N_L, \quad U_{ij}^{k,xy} = \sum_{l} U_{il}^{k-1,xy} + U_{lj}^{k-1,xy} \]  

(7)

\[ \forall i, j, q, r \in N_L, \quad C^q_{ij} = \sum_{a} C_{ij} - \sum_{a} K_{ij} \sum_{a} p_{ij}^{m} - \sum_{a} Y_{ij}^{m, p_{ij}^{m}} = 0 \]  

(8)

Illustrative numerical examples

Input: Set of nodes in the VPN \( \{1, 6, 5, 3\} \), and traffic intensities

Output: VPN connectivity and routing

1 Minimizing # of lightpaths  

(4, 14)

VPN topology #1

Resilient VPN routes #1

2 Minimizing # of wavelength links  

(4, 12)

VPN topology #2

Resilient VPN routes #2
Illustrative numerical examples

Input: Provider network topology

1. VPN topology is given

Output: Resilient VPN routes do not exist

2. Traffic between \{1,2,3,5\} is given

Output1: VPN Topology

Output2: Resilient VPN routes with the multilayer approach

---

Conclusion and Future work

- We defined a mathematical model for multi-layer resilient design of Layer-1 VPNs.
- We linearized the survivability constraint -> ILP.
- Our approach is multi layer survivable design which does not take the VT as a given. We optimized the VPN connectivity and routing together considering traffic demands as input.
- Future Work: Investigate sub-optimal relaxation techniques to solve this model for the resilient Layer-1 VPN design problem and develop heuristic algorithms.
... THANK YOU

“Multi-Layer Resilient Design in Optical WDM Networks”

Çiçek Çavdar, ccavdar@ucdavis.edu
University of California-Davis

Ayşegül Gençata Yayimli, gencata@itu.edu.tr
Istanbul Technical University

Biswanath Mukherjee, mukherje@ucdavis.edu
University of California-Davis