Traffic Engineering in Case of Interconnected and Integrated Layers

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Introduction

Metro and Backbone networks

- Two or more layers
- Different network technologies at each layer
  - Lower Layer: Optical
  - Upper Layer: Electronic
- Interoperation of different Network Layers:
  - Vertical interconnection
    - Each layer is operated by its Control plane
    - A certain amount of information is shared
    - Overlay, augmented, peer
  - Vertical integration
    - A single control plane operating both layers

Introduction

Current Study

- Optical layer:
  - Wavelength Division Multiplexing technology
  - Fast lightpath reconfigurations (set up/tear down)
- Electronic layer:
  - MPLS capability
  - RSVP with TE extensions
- TE approaches:
  - TE with Adaptive WDM Topology
    - Suitable for the integrated model
    - Single provider operates both layers
  - TE on Fixed Topology using MPLS Functionalities
    - Overlay model
    - Layers share a small amount of information

TE With Adaptive WDM Topology

- Use dynamic optical layer
- Adapt the lightpath topology to the changing traffic demands
- 3 types of actions to route the demands
  1. Groom with the traffic on existing lightpaths
     ☹ detours increase resource usage
  2. Generate new lightpaths
     ☹ wastes resources
  3. Fragment existing lightpaths
     ☹ may cause trafic loss
- Combine these actions in the most efficient way
- Route the demands on the Wavelength Graph

TE With Adaptive WDM Topology

Wavelength Graph Model

- Nodes represented by sub-graphs
  - Sub-graph topology depends on node functionality
  - A node with optical and electronic interfaces is different from a simple OXC
- Physical links → as many graph edges as the number of wavelengths
- The lightpath set is exploited as far as possible
  - do not refuse demands if there’s available capacity
- Avoid too many lightpath fragmentations

TE With Adaptive WDM Topology

- Apply shortest path
  Link Weights:

Transition	Cost
Edges modeling a single λ in a fiber carrying traffic	1
Edges modeling a single λ in a fiber without traffic	25
Edges modeling transition between electronic and optical layer carrying traffic	50
Edges modeling transition between electronic and optical layer without traffic	250
Edges modeling fragmentation of existing λ-paths	500

- Existing lightpaths preferred first
- Avoid passing to electronic layer
- Avoid deploying opto-electronic devices
- Highest cost belongs to fragmentation of existing lightpaths

MPLS TE on Fixed WDM Topology

- Overlay model, separate control planes
  - Operated by separate providers
  - For network management purposes
- Upper layer designs the WDM topology and requests from the lower layer
  - Use previously available traffic information
- Traffic deviations and changes handled by MPLS layer actions
  - LSP tunnels set up with Resource Reservation

- Two phases:
  - Design of the fixed WDM topology (offline)
  - Rerouting and bandwidth update of the LSPs (online)

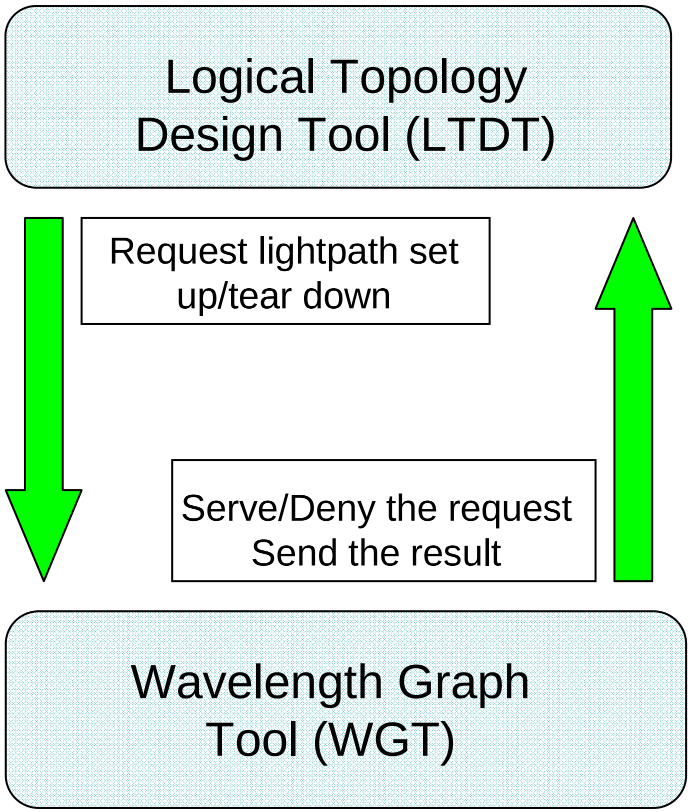
MPLS TE on Fixed WDM Topology

1st Phase: Design of the optimal WDM layer topology

- Available Information → Expected traffic for each time interval (an hour)
- Objective: Maximize the total routed traffic
- Constraints:
  - Fixed number of lightpaths (depends on the traffic parameters)
  - Maximum nodal degree
- Heuristic search algorithm
  - Utilizes Tabu Search metaheuristic
  - Starts from a randomly generated topology
  - Searches the solution space by consecutive moves
    - Tear down and existing lightpath and set up a new one

MPLS TE on Fixed WDM Topology

WDM topology design – Layer Interaction



- The upper (electronic) layer
- Designs the lightpath topology
- Requests lightpath actions from WGT

- Represents the lower (optical) layer
- Establishes the requested lightpaths
- Routes them on the physical topology

MPLS TE on Fixed WDM Topology

2nd Phase: Online traffic engineering

- Rerouting of the LSP flows
- Alternate path approach
  - Precalculated paths
- Use a dynamic path cost function
  - Both available capacity and length are considered in the cost function
    - When traffic is low, the length component dominates
    - When the traffic is high, the load component dominates

$$F_{\cos t}(p) = L_p + A^{u - \frac{C^p_{\text{Residual}}}{C}}$$

A,u: Cost Function Parameters (10, 0.5)
C: Lightpath capacity
L_p: Length of path *p*
C^p_{Residual}: Residual capacity on path *p*

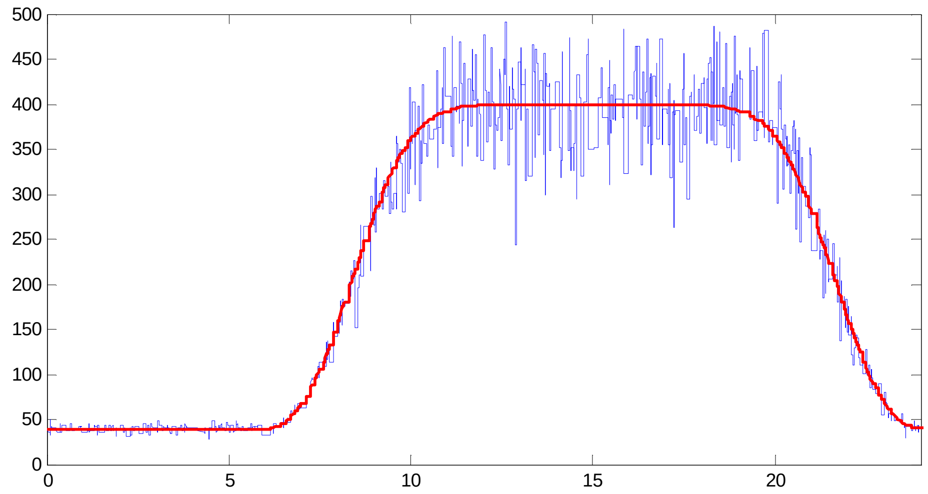
Traffic Model

- Flow based
- Two components:
  - Expected value
  - Zero mean Gaussian noise

    Std. Deviation=0.1 x Expected value

$$T_{act}(i, j, t) = T_{\exp}(i, j, t) + N(0, (0.1 \times T_{\exp}(i, j, t))^2)$$

- To generate expected traffic, a 24 hour continuous traffic pattern is used



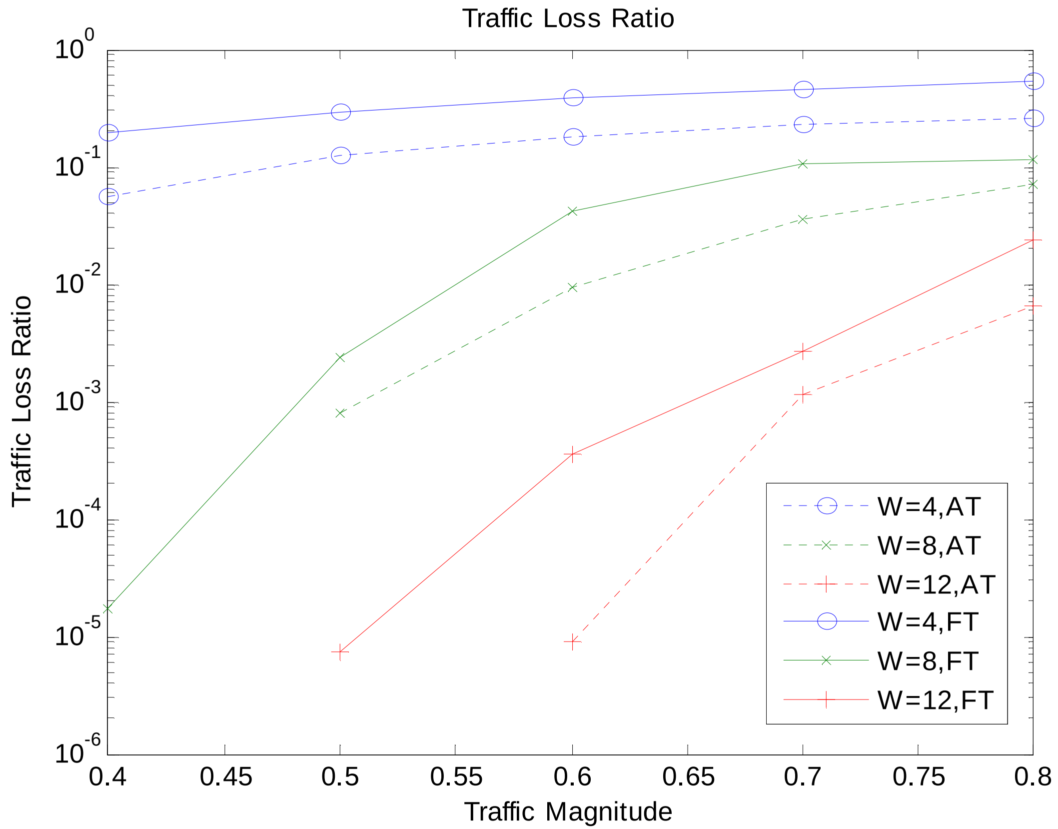
Simulations

Implementing the approaches

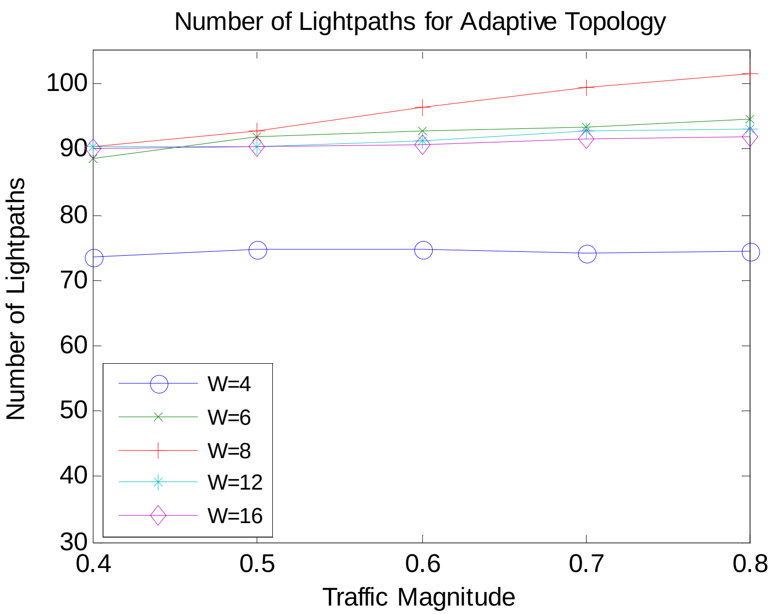
- Single LSP for each source-destination
- The bandwidth requirements of the LSPs are updated dynamically
  - Poisson process with rate 30/hour.
- When a bandwidth update arrives
  - 1st approach (adaptive WDM):
    - Tear down the old demand
    - Treat it as a newly arriving demand
    - Route it on the wavelength graph
  - 2nd approach (fixed topology):
    - Choose the best path according to the cost function
    - (Re)route the LSP with new bandwidth on the chosen path
- If no sufficient capacity
  - Do not update the bandwidth
  - Update amount is blocked

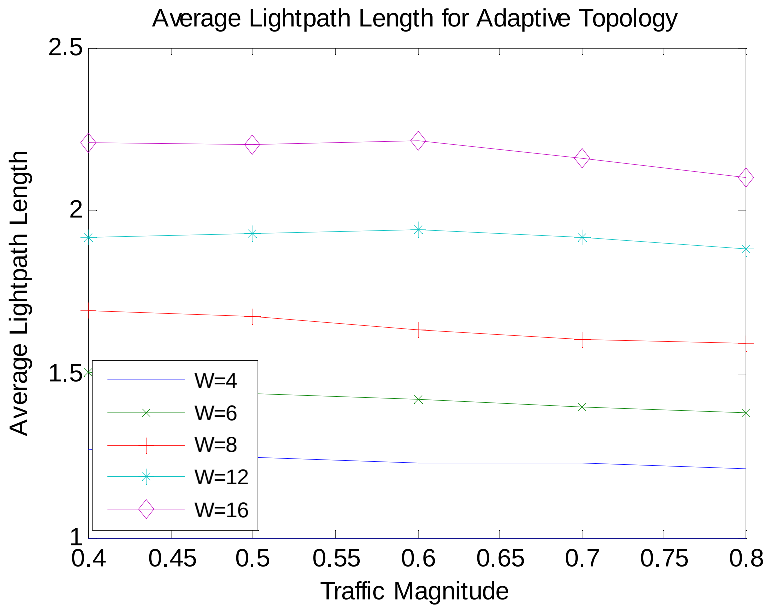
Simulation Results

Traffic pattern is scaled by a factor (Traffic magnitude)
Ratio of the maximum traffic flow to single wavelength capacity

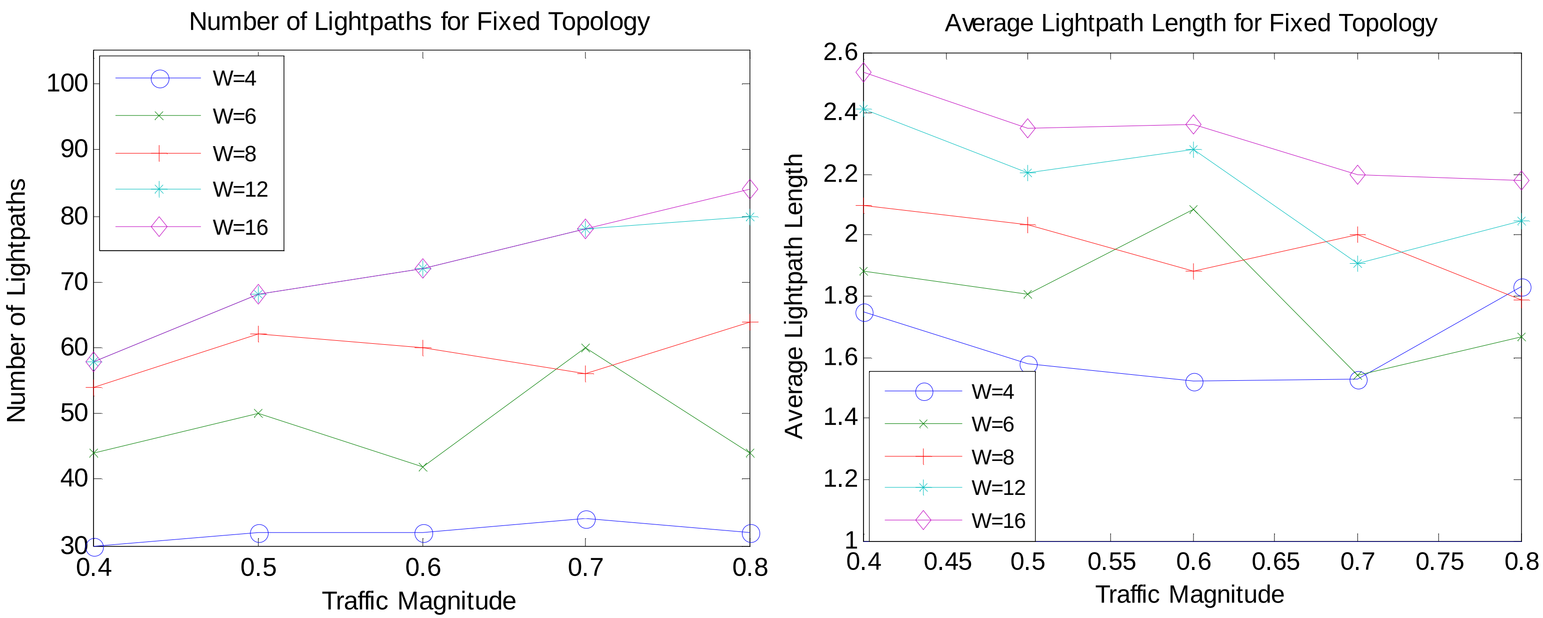


Simulation Results





Simulation Results



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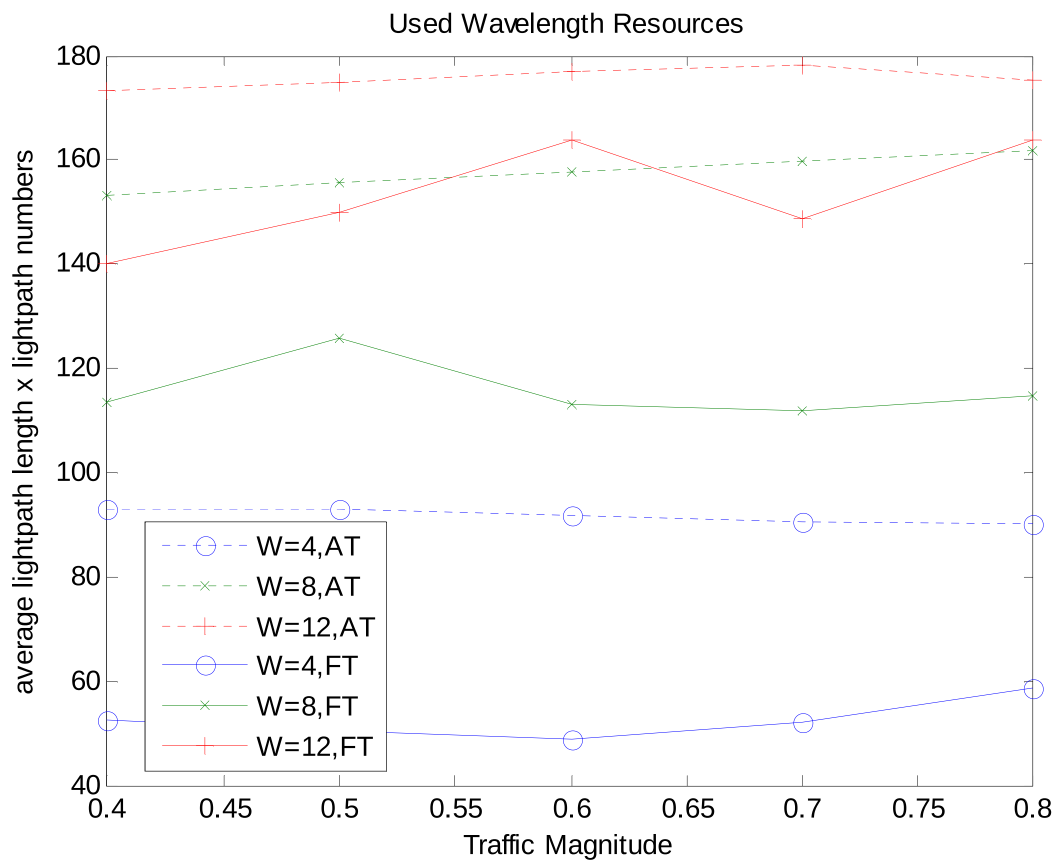

Conclusions

- TE approaches investigated for two interoperation models
- Adaptive Topology approach
  - ☺ Has better blocking performance
  - 😐 Utilizes more network resources
  - ☹ Frequent topology changes may delay/disrupt traffic (max. 40 per hour)
- Fixed Topology, MPLS TE
  - ☺ No fast lightpath reconfigurations, does not disrupt traffic
  - ☹ Requires traffic information
- Future Work:
  - Explore different models
    - More information sharing
    - Shared intelligence
      - Layers act collaboratively
  - Investigate the effect physical impairments