Integrated Logical Topology Design and LSP Configuration for MPLS/WDM Networks

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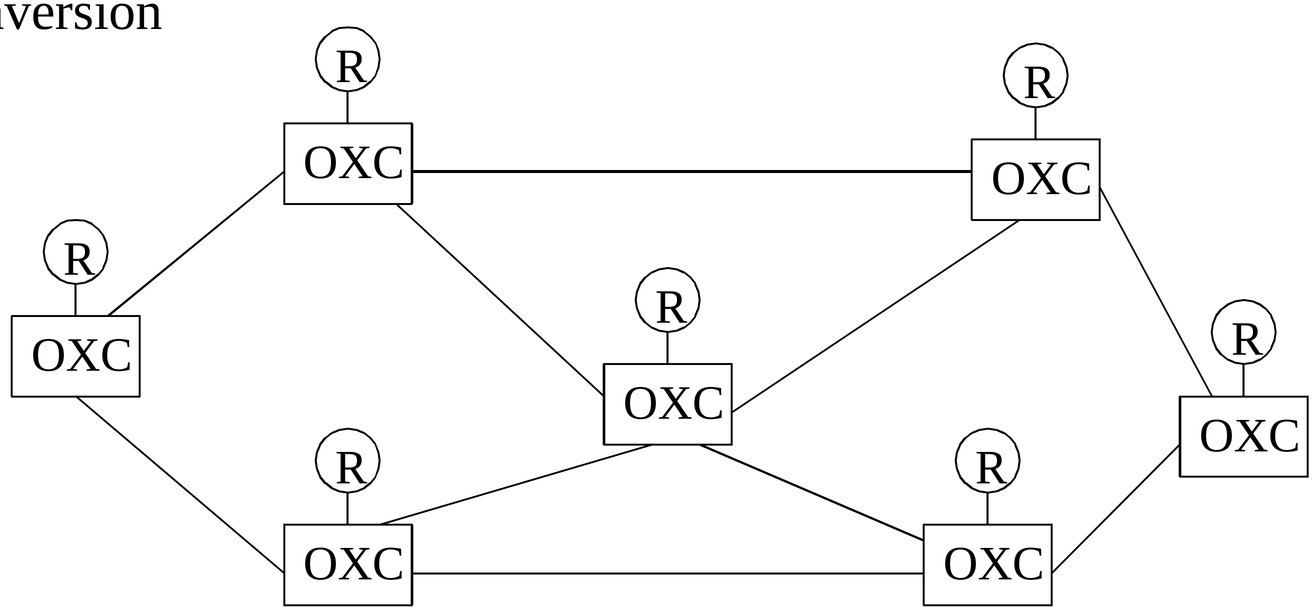
Overview

- If IP is implemented over a reconfigurable WDM network, the logical links between routers can be changed in response to changes in traffic demands
- Traffic engineering in an MPLS/WDM network requires both logical topology design and LSP routing and provisioning
  - can be formulated as Mixed Integer Linear Program (MILP) (NP−complete)
- Standard approach
  - use heuristic for logical topology design
  - apply routing algorithm to map traffic demands onto logical topology
- New approach: Integrate LSP routing and provisioning into logical topology design

Reconfigurable Optical Network

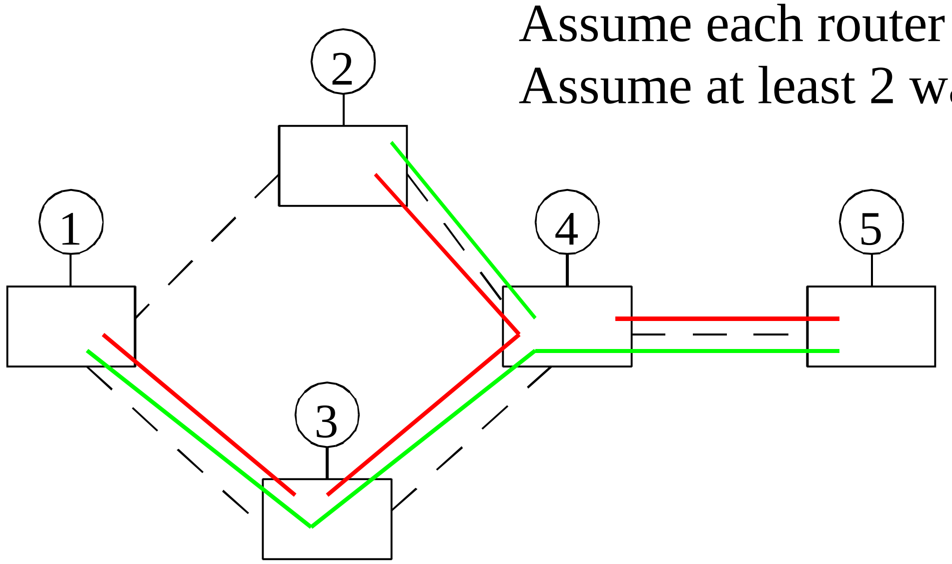
- Each node consists of router (LSR) together with optical crossconnect
- LSR has interfaces (transmitters and receivers) that each terminate one wavelength
- OXCs are interconnected by optical fibers that carry multiple wavelengths
- OXC can be configured to switch a wavelength on an input port to a wavelength on any output port, possibly with wavelength conversion



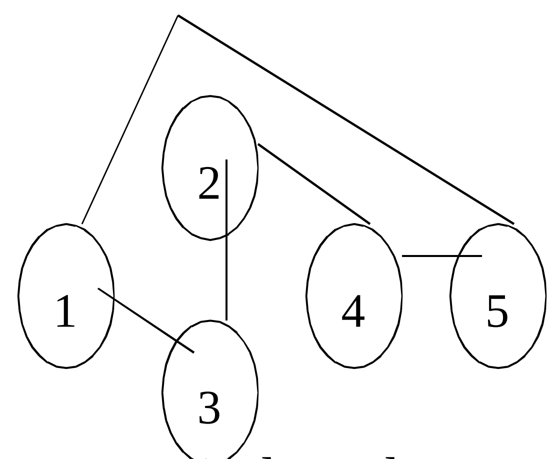
Logical Topology Design

- Logical link between a pair of routers is formed by creating a lightpath between the nodes
  - Consists of sequence of fiber links together with selection of a wavelength in each fiber (RWA problem)
  - If no wavelength conversion, then RWA problem is subject to wavelength continuity constraint

Assume each router has 2 pairs of interfaces
Assume at least 2 wavelengths per fiber



Lightpaths



Logical topology

Timescales

- Slowest: optical network reconfiguration
- Moderate: LSP reconfiguration (routing and bandwidth provisioning)
- Fast: balancing traffic among parallel LSPs
- Dynamic traffic engineering problem for MPLS/WDM can be formulated as Multi−timescale Markov Decision Process
- Reference
  - H.S. Chang, P. Fard, S.I. Marcus and M.A. Shayman, "Multi−timescale Markov Decision Processes," to appear in *IEEE Transactions on Automatic Control.*
- Observation: each optical network reconfiguration must be accompanied by LSP reconfiguration

Traffic Engineering Issues

- Optical network reconfiguration includes
  - Logical topology design
    - Selection of logical neighbors and links
  - RWA (Routing and Wavelength Assignment)
    - Allocation of optical (physical) resources
  - Traffic Grooming for multi−hop traffic
    - Integrating low traffic into high traffic streams
    - Mapping of traffic demand onto logical topology
    - Equivalent to routing of LSPs and mapping of traffic demand onto LSPs (if multiple LSPs for ingress−egress pair)

LTD and TG Problem

- Given traffic demand matrix, physical topology and router interface constraints, construct the logical topology and route each traffic demand in order to minimize the average weighted delay

$$\frac{\sum T_{s,d} \times d_{s,d}}{\sum T_{s,d}}$$

- Contribution: new algorithm for integrated LTD & TG that outperforms existing algorithms
- <u>Reference</u>: K.I. Lee, L. Sudarsan and M.A. Shayman, Integrated Logical Topology Design and Traffic Grooming in Reconfigurable WDM Networks, submitted.

LTD Algorithms − HLDA

- Heuristic Logical Topology Design
- Multiple lightpaths for same s−d pair
- Algorithm

```
Procedure HLDA (void)
    While (not done)
        Find s and d such that t_sd = MAX t_ij for all i,j
        If ((free transmitter available at s) AND (free receiver available at d) AND
                (free wavelength available in any optical path from s to d))
                Establish lightpath between s and d
                    t_sd = t_sd − C
     Endif
    Endwhile
```

LTD Algorithms – MRU

- Maximizing Resource Utilization
- Use <u>physical</u> (optical) hop distance H_{sd}
- Algorithm

Procedure MRU(void)

  Compute H_{sd} $\forall s,d$

  While (not done)

    Find s and d such that $[t_{sd} / H_{sd}] = MAX [t_{ij} / H_{ij}]$ for all i,j

    If ((free transmitter available at s) AND (free receiver available at d) AND

        (free wavelength available in any optical path from s to d))

      establish lightpath between s and d

    Endif

  Endwhile

LTD Algorithms − MMHA

- Maximizing Multi−Hop Algorithm
- Use logical hop distance H_{sd}
- Algorithm

```
Procedure MMHA(void)
    While (not done)
        Compute H_sd ∀s,d
        Find s and d such that t_sd (H_sd−1)= MAX t_ij (H_ij −1) for all i,j
        If ((free transmitter available at s) AND (free receiver available at d) AND
                (free wavelength available in any optical path from s to d))
                        establish lightpath between s and d
            endif
    endwhile
```

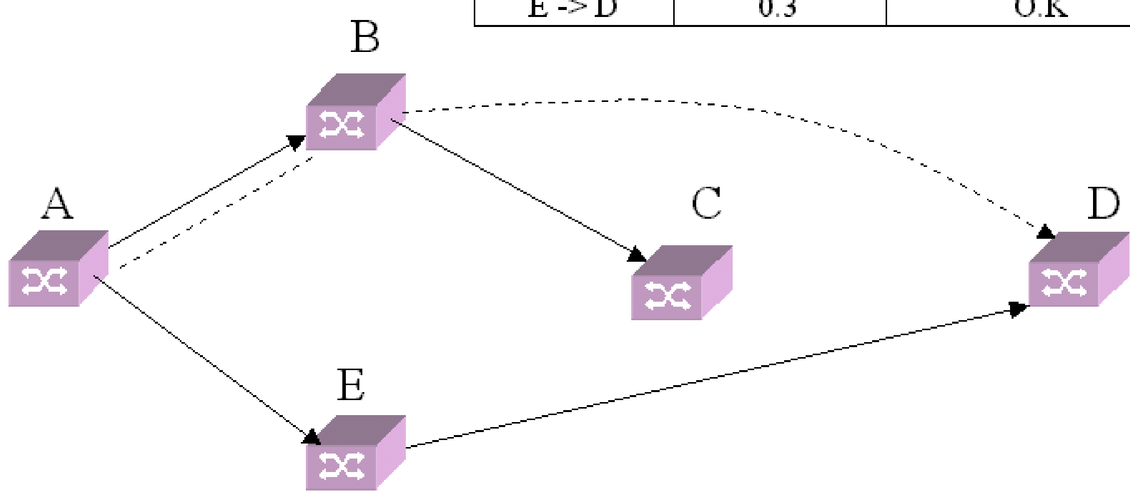
Note: If i and j are in different connected components, set H_{ij} to infinity and rank such pairs based on t_{ij}

Integrated LTD & Traffic Grooming

- Motivation
  - Provide Multi−hop lightpath setup mechanism for multi−hop traffic
    - Typical algorithms only consider multihop traffic for routing, not for logical topology design
- Goals
  - Minimize the average weighted delay (Hop Count)
  - Maximize network throughput
- Approach
  - Integrate LTD + Traffic Grooming (LSP routing)
  - Always give high priority to high traffic demands when setting up logical links, even if single hop path is not possible

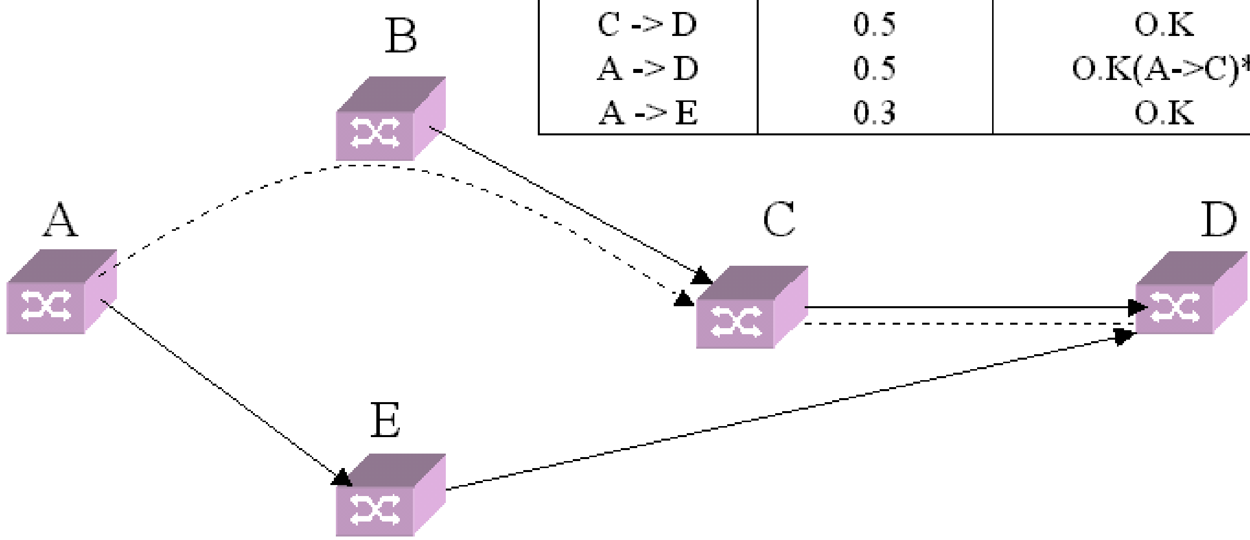
Forward Multihop Lightpath Setup

Traffic Matrix		Lightpath setup
A-> E	0.7	O.K
B -> C	0.6	O.K
A -> B	0.5	O.K
A -> D	0.5	O.K(B->D)*
E -> D	0.3	O.K



Each router has 2 pairs of interfaces
No interface available at source

Backward Multihop Lightpath Setup



Traffic Matrix		Lightpath setup
E-> D	0.7	O.K
B -> C	0.6	O.K
C -> D	0.5	O.K
A -> D	0.5	O.K(A->C)*
A -> E	0.3	O.K

No interface available at destination

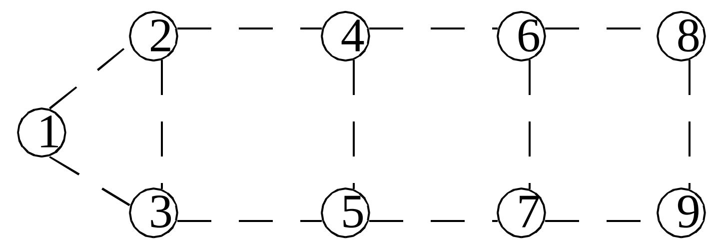
Sketch of Algorithm

- Consider traffic demands t_{ik} in decreasing order.
- When t_{sd} is considered, if s has an available transmitter and d an available receiver, and if there is a physical path from s to d with an available wavelength, create a lightpath from s to d and set up 1−hop LSP.
- If s has available transmitter but d has no available receiver, and if d has a logical neighbor d' such that available BW on link d'd is at least t_{sd} create lightpath from s to d' and set up 2−hop LSP.
  - Consider multihop neighbors of d if necessary.
- If d has available receiver but s has no available transmitter, and if s has a logical neighbor s' such that available BW on link ss' is at least t_{sd} create lightpath from s' to d and set up 2−hop LSP.
  - Consider multihop neighbors of s if necessary.
- Use constrained shortest path routing to route LSPs for remaining traffic demands in decreasing order of demands.

Example

	1	2	3	4	5	6	7	8	9
1	*	6	5	0	0	0	0	0	4
2		*	0	2	0	1	0	1	0
3			*	0	1	0	1	0	1
4				*	0	2	0	1	0
5					*	0	2	1	1
6						*	1	2	1
7							*	1	2
8								*	2
9									*

Traffic Matrix (symmetric)

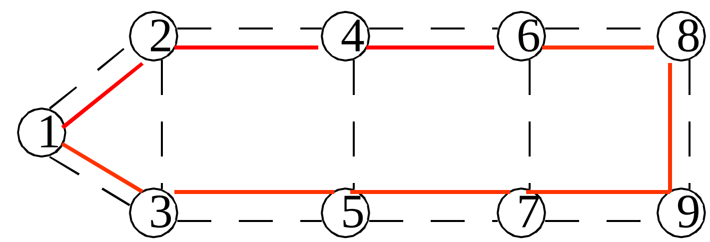


Physical Topology

Assume each lightpath has capacity 9 units.
Assume each router has 2 pairs of interfaces.

Logical Topology: HLDA & MRU

	1	2	3	4	5	6	7	8	9
1	*	6	5	0	0	0	0	0	4
2		*	0	2	0	1	0	1	0
3			*	0	1	0	1	0	1
4				*	0	2	0	1	0
5					*	0	2	1	1
6						*	1	2	1
7							*	1	2
8								*	2
9									*

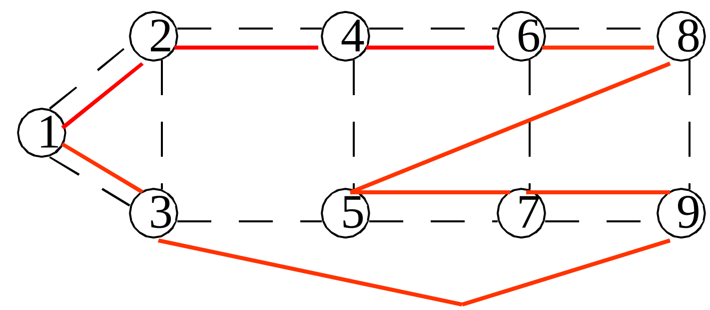


Large demand t_{19} is not considered in logical topology design since no interfaces are available. Resulting hop distance for 1−9 is 4.

Shortest path routing places 10 units on link (5,7) and 11 units on link (7,9), exceeding link capacities. No choice of routing is consistent with the link capacity constraint of 9.

Logical Topology: Integrated LTD & TG

	1	2	3	4	5	6	7	8	9
1	*	6	5	0	0	0	0	0	4
2		*	0	2	0	1	0	1	0
3			*	0	1	0	1	0	1
4				*	0	2	0	1	0
5					*	0	2	1	1
6						*	1	2	1
7							*	1	2
8								*	2
9									*

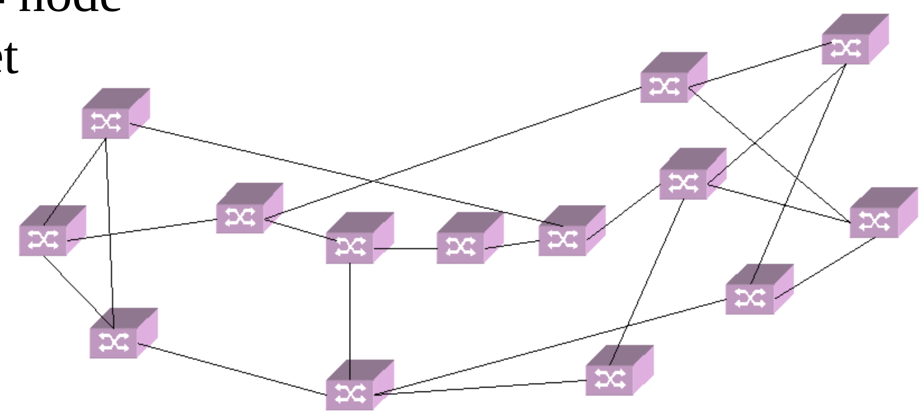


Large demand t_{19} is considered to create multihop path in logical topology design since no interfaces are available. Resulting hop distance for 1−9 is 2.

Maximum load of 9 occurs on links (1,3) and (5,7) which does not exceed capacity.

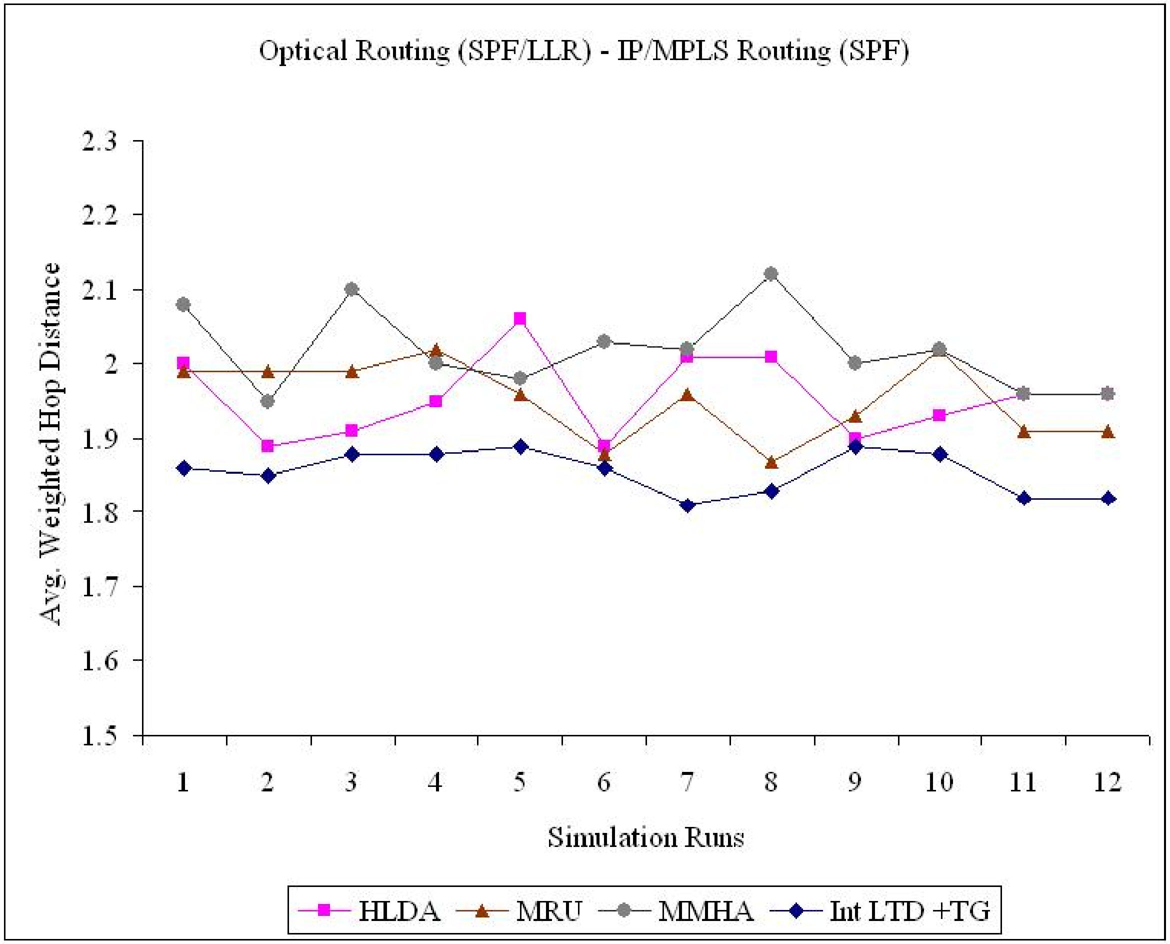
Experimental Analysis

- Topology
  - Use 14 node NSFnet

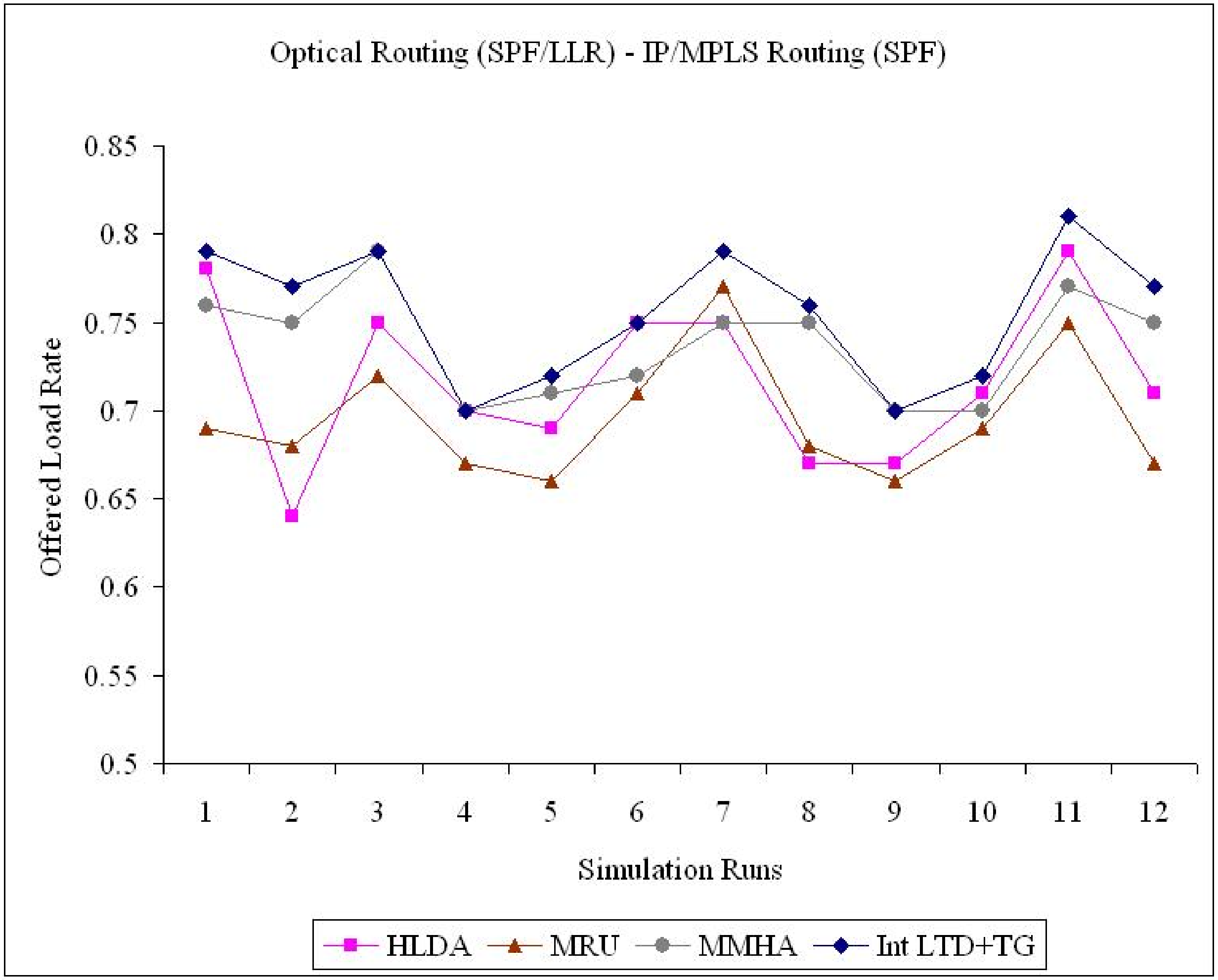


- Performance Metric
  - Avg. weighted delay or hop count
  - Avg. # of wavelength used = total wavelength / # of lightpaths setup
  - Throughput = total traffic rate accommodated in the network

Average Weighted Hop Distance

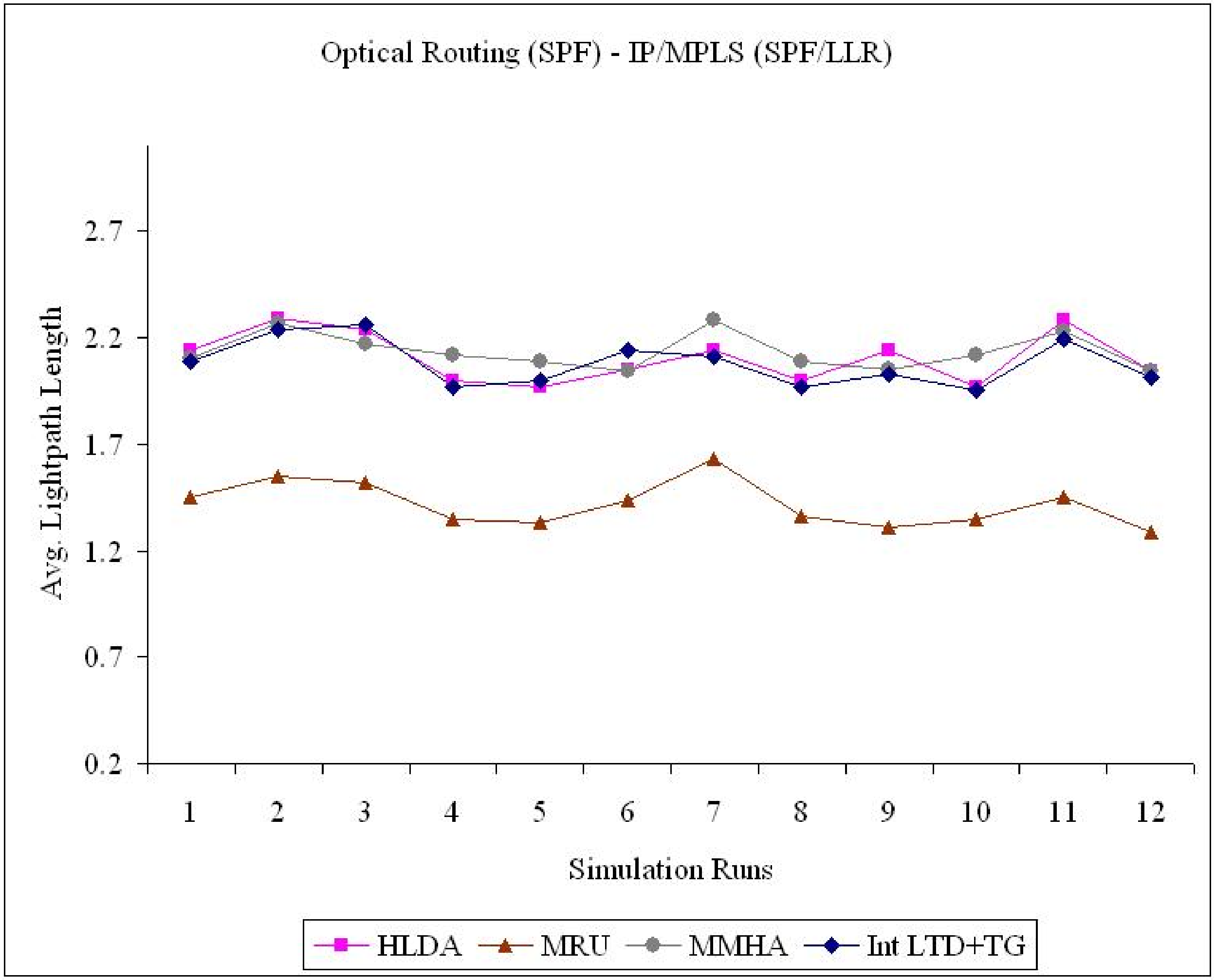


Throughput



Optical Routing (SPF/LLR) - IP/MPLS Routing (SPF)
Offered Load Rate
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
1
2
3
4
5
6
7
8
9
10
11
12
Simulation Runs
HLDA
MRU
MMHA
Int LTD+TG

Average Lightpath Length



Conclusions

- Integrated LTD & TG provides
  - Low delay (Avg. weighted hop distance)
  - High network throughput (Offered load rate)
- Current & Future Works
  - Integration of LTD algorithm with GLASS/SSF
    - Integrated with GLASS signaling protocol
  - Routing policy effects on Integrated TE
  - Multi−path routing
  - Dynamically varying traffic demands
  - QoS considerations