Path Selection Methods with Multiple Constraints in Service-Guaranteed WDM Networks

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IEEE/ACM Trans. on Networking, Feb. 2004

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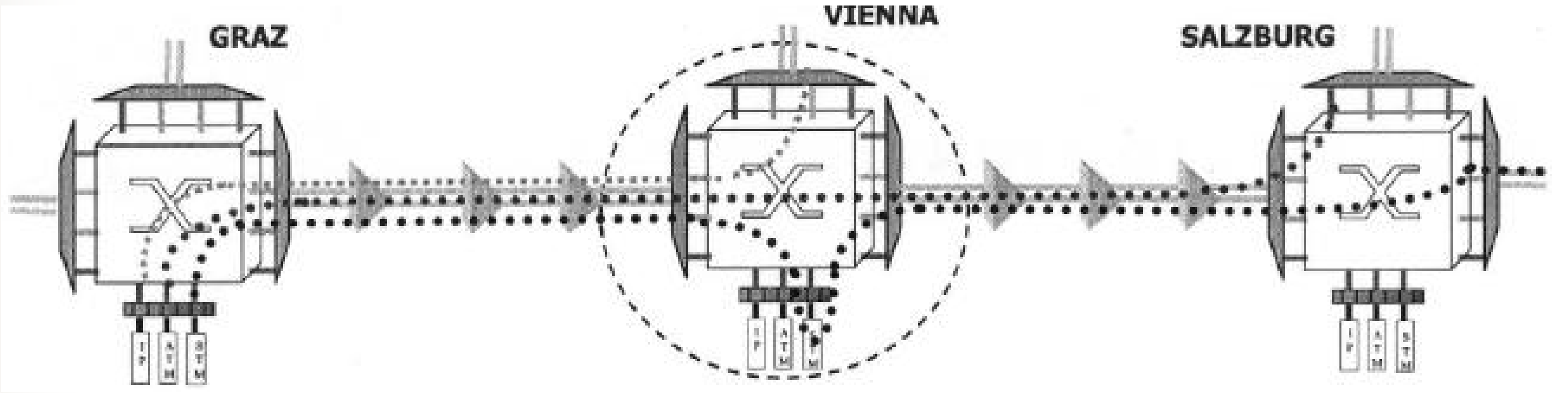
Outline

- Introduction
- Network model
- Distributed discovery of wavelength paths
- DWP implementation
- Performance study
- Conclusions

Introduction

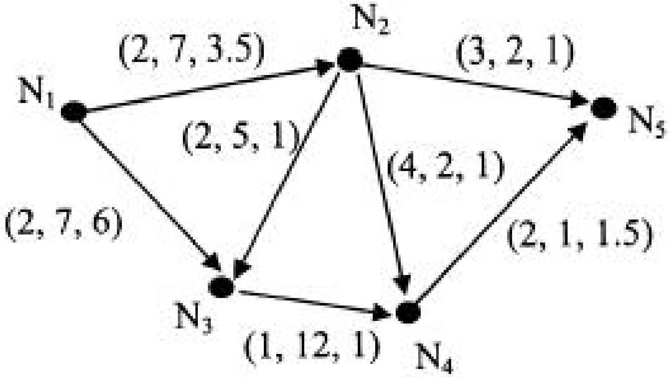
- All-optical networks
    - Transparent and cost-efficient operation
    - Signal degradation limit cascadeability of optical components and traffic-dependent signal quality
- Opaque optical networks
    - With electronic regenerators
    - Impose limitations on wavelength routing, such as delay accumulation, reliability reduction and operational cost increase

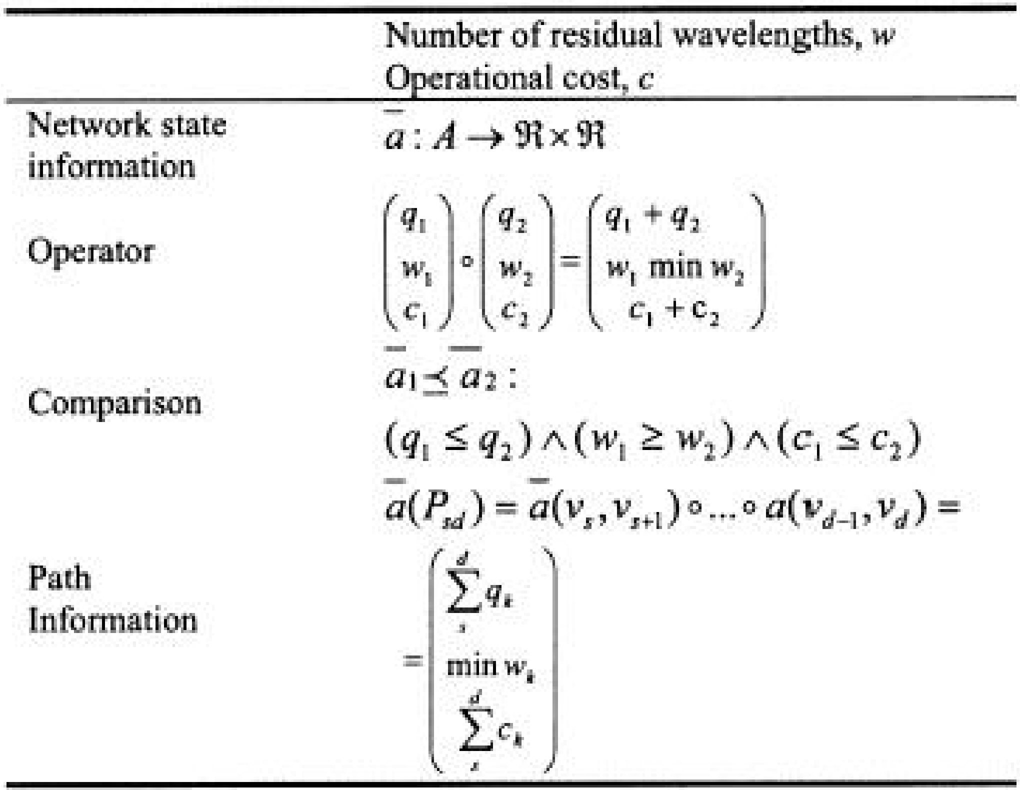


Network model

- WDM network is modeled as G(V, E)
  - $\Lambda=\{\lambda_1, \lambda_2, \ldots, \lambda_F\}$: a pool of wavelength per link
  - $S=\{S_1, S_2, \ldots, S_P\}$: optical network service set
  - $h_k^{N,L}$: network element associated with a node or link
- *Definition 1*: Service-Specific Wavelength Set (SWS)
  - $\Lambda_{SWS}[S_r, h_k^{N,L}]$: only $\lambda \in \Lambda_{SWS}$ is considered for allocation
- *Definition 2*: Local Network State Information $\bar{a}$
  - Usually several components (metrics) related to $h_k^{N,L}$ and λ_i
- *Definition 3*: Path Information
- *Definition 4*: Feasible Path
- *Definition 5*: Optimal Path

Example





	Number of residual wavelengths, w Operational cost, c
Network state information	$\bar{a}: A \to \Re \times \Re$
Operator	$\begin{pmatrix} q_1 \\ w_1 \\ c_1 \end{pmatrix} \circ \begin{pmatrix} q_2 \\ w_2 \\ c_2 \end{pmatrix} = \begin{pmatrix} q_1 + q_2 \\ w_1 \min w_2 \\ c_1 + c_2 \end{pmatrix}$
Comparison	$\bar{a}_1 \preceq \bar{a}_2 :$ $(q_1 \le q_2) \wedge (w_1 \ge w_2) \wedge (c_1 \le c_2)$
Path Information	$\bar{a}(P_{sd}) = \bar{a}(v_s, v_{s+1}) \circ \ldots \circ a(v_{d-1}, v_d) =$ $= \begin{pmatrix} \sum_s^d q_k \\ \min w_k \\ \sum_s^d c_k \end{pmatrix}$

$$P_1(N_1, N_2, N_4) = \begin{pmatrix} 6 \\ 2 \\ 4.5 \end{pmatrix}$$

$$P_2(N_1, N_3, N_4) = \begin{pmatrix} 3 \\ 7 \\ 7 \end{pmatrix}$$

$$P_3(N_1, N_2, N_3, N_4) = \begin{pmatrix} 5 \\ 5 \\ 5.5 \end{pmatrix}$$

$$\bar{a}(P_1) = \bar{a}(N_1, N_2) \circ \bar{a}(N_2, N_4) = \begin{pmatrix} 2 + 4 \\ \min(7, 2) \\ 3.5 + 1 \end{pmatrix}$$

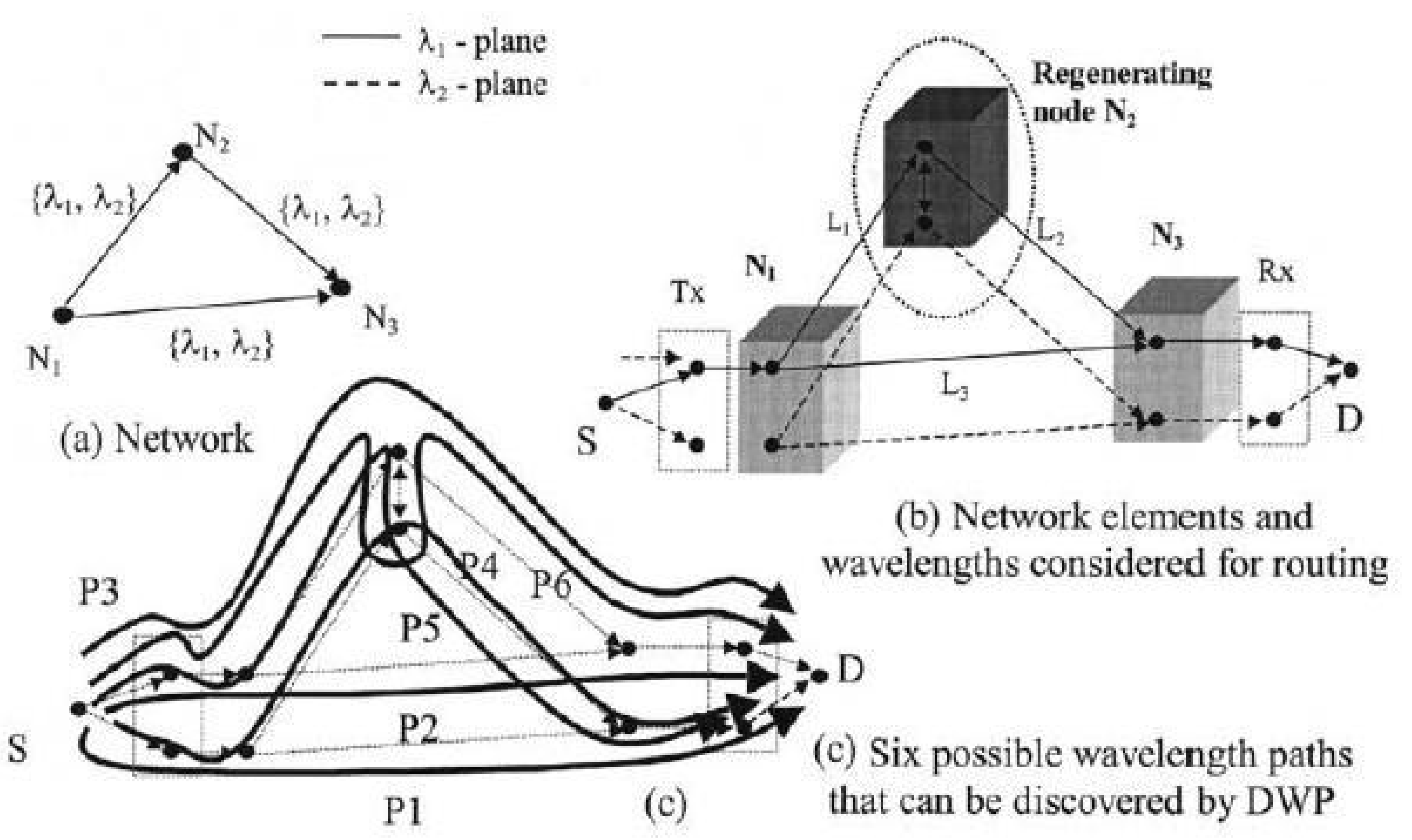
DWP
(Distributed Discovery of Wavelength Paths)

- Step 1: Initialization
  - Set a service specific vector of routing constraints $\mathbf{d}(S)=[a_{MAX}, m_{MIN}, r_{MIN}]$, a additive, m multiplicative, r restrictive; initialize path state $\bar{a}[a_a=0, a_m=1, a_r=W]$
- Step 2: Path information update by flooding
  - Forward received path information message with updated parameters to all neighbors not in visited NEs until ***dest*** is reach
- Step 3: Path selection
  - ***dest*** selects the best path according to operational criteria from all feasible paths
- Step 4: Signaling of path setup

DWP implementation

<table>
<tr><td>Node Architecture</td><td colspan="2">DWP-R (fully regenerative)</td><td colspan="2">DWP-NR (no regeneration)</td><td>DWP-S (Selective)</td></tr>
<tr><td>Network Deployment</td><td colspan="2">DWP-R-ALL</td><td colspan="2">DWP-NR-ALL</td><td>DWP-SPAR</td></tr>
<tr><td>Service Type</td><td colspan="3">SRT (constrained by optical reach and delay)</td><td colspan="2">SDT (constrained by optical reach only)</td></tr>
<tr><td>Path Selection Criteria</td><td colspan="3">DWP-MIN-HOP (minimum number of hops)</td><td colspan="2">DWP-LB (maximum number of residual wavelengths)</td></tr>
</table>

Example network



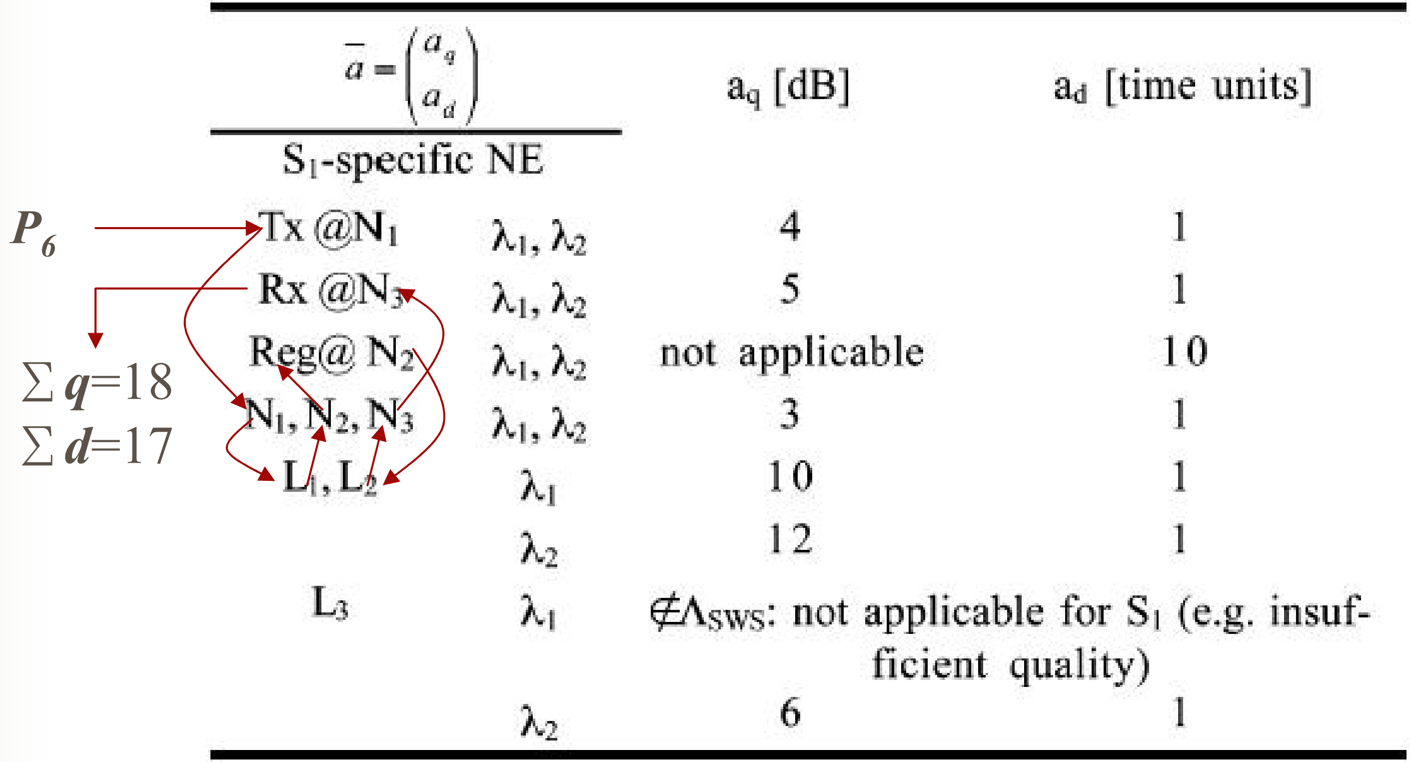
(a) Network

(b) Network elements and wavelengths considered for routing

(c) Six possible wavelength paths that can be discovered by DWP

Example network states

- Maximum transmission quality degradation $q_{max}(S_1) \leq 30$
- S_1-specific network states



$\bar{a} = \begin{pmatrix} a_q \\ a_d \end{pmatrix}$ S_1-specific NE		a_q [dB]	a_d [time units]
Tx @N_1	λ_1, λ_2	4	1
Rx @N_3	λ_1, λ_2	5	1
Reg@ N_2	λ_1, λ_2	not applicable	10
N_1, N_2, N_3	λ_1, λ_2	3	1
L_1, L_2	λ_1	10	1
	λ_2	12	1
L_3	λ_1	$\notin \Lambda_{SWS}$: not applicable for S_1 (e.g. insufficient quality)	
	λ_2	6	1

P_6

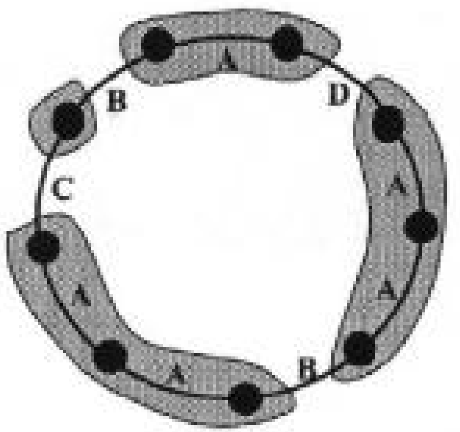
$\sum q = 18$

$\sum d = 17$

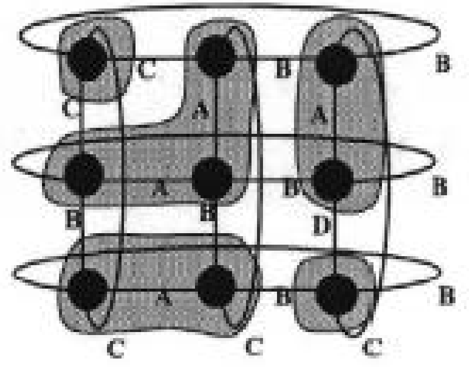
Reducing the flooding

- Complexity
  - Number of messages arriving at destination: $O(n!m^h)$, n, h, m denote number of nodes, hops, wavelengths
  - Number of message updates: $O(n!m^h \log n)$
- Reducing number of message updates
  - Apply DWP on pre-defined routes
  - Limit the number of wavelength conversion
  - Add additional constraints to the message discarding policy in Step 2

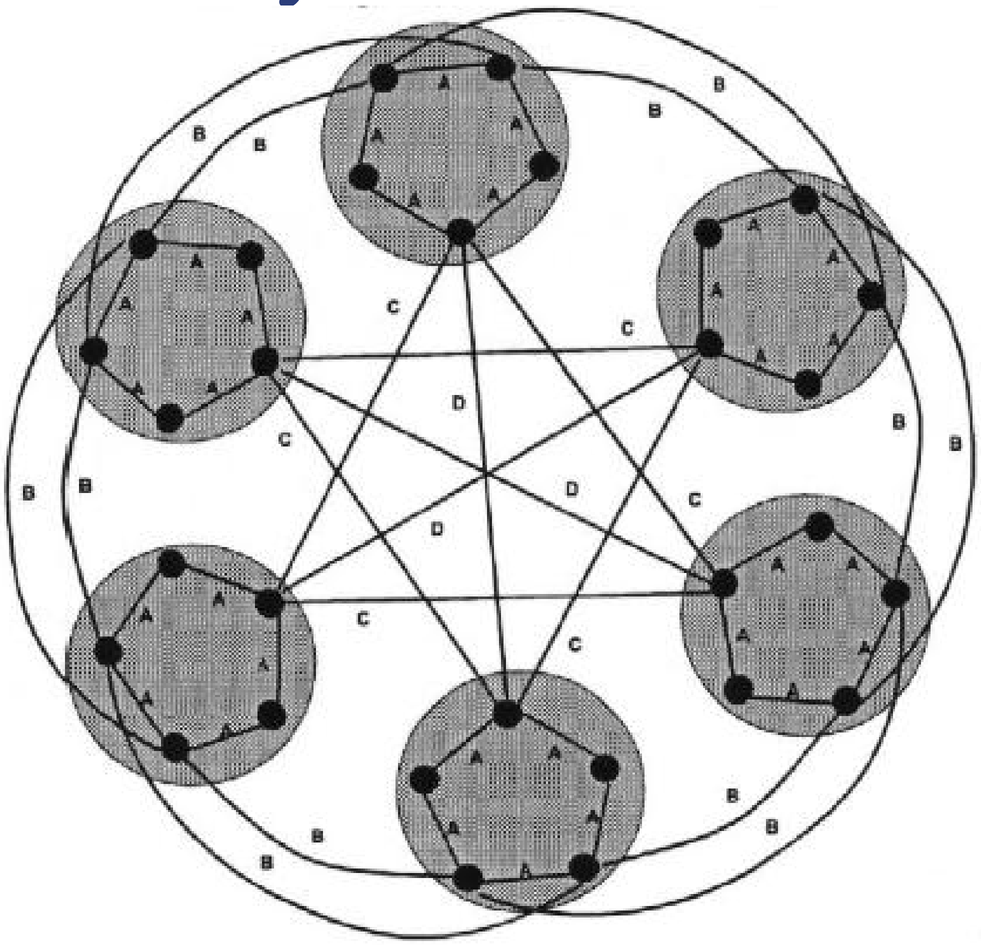
Topologies for study



(1) 9-nodes ring



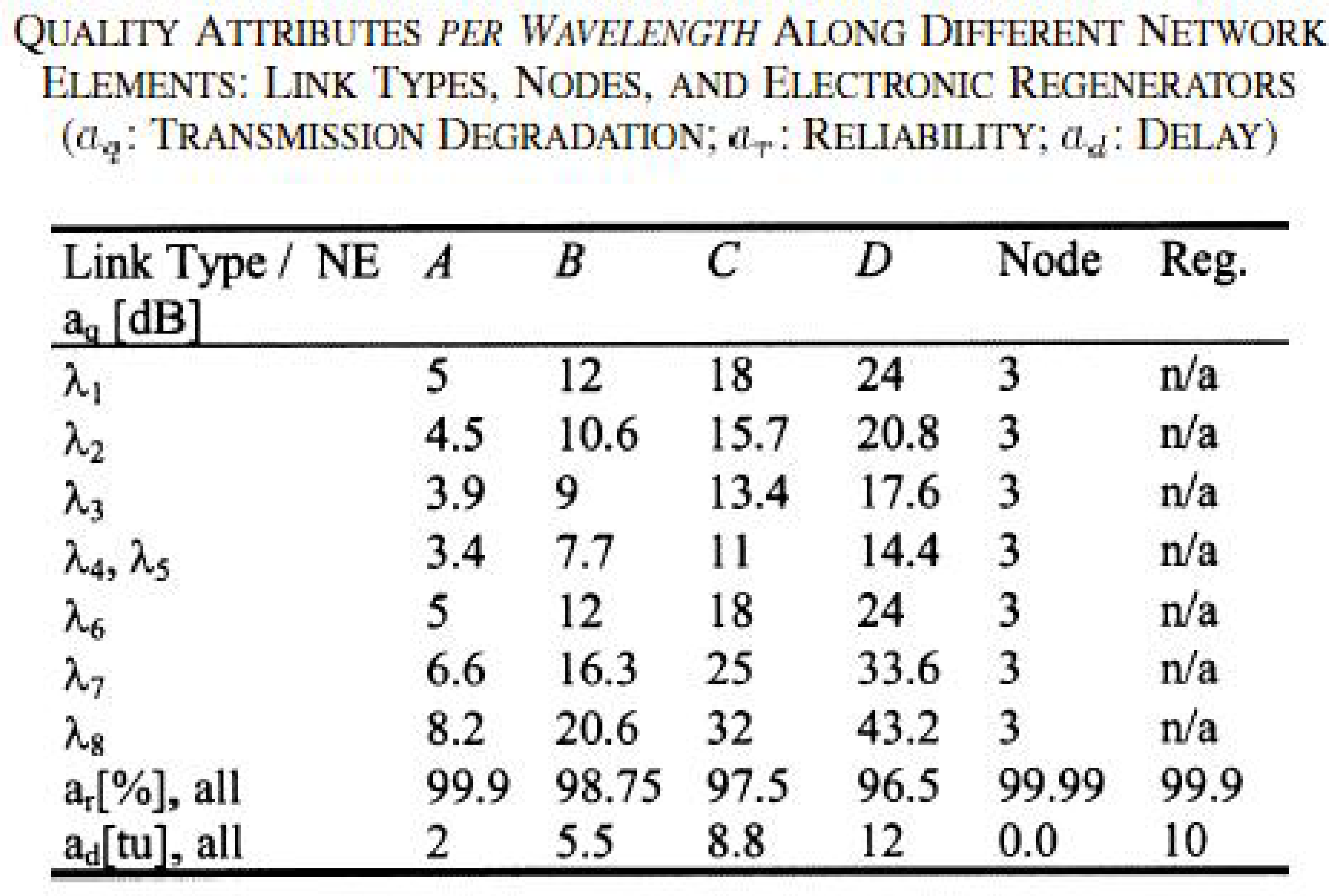
(2) 9-nodes mesh-torus



(3) 6x5-nodes interconnected ring

(4) full-mesh

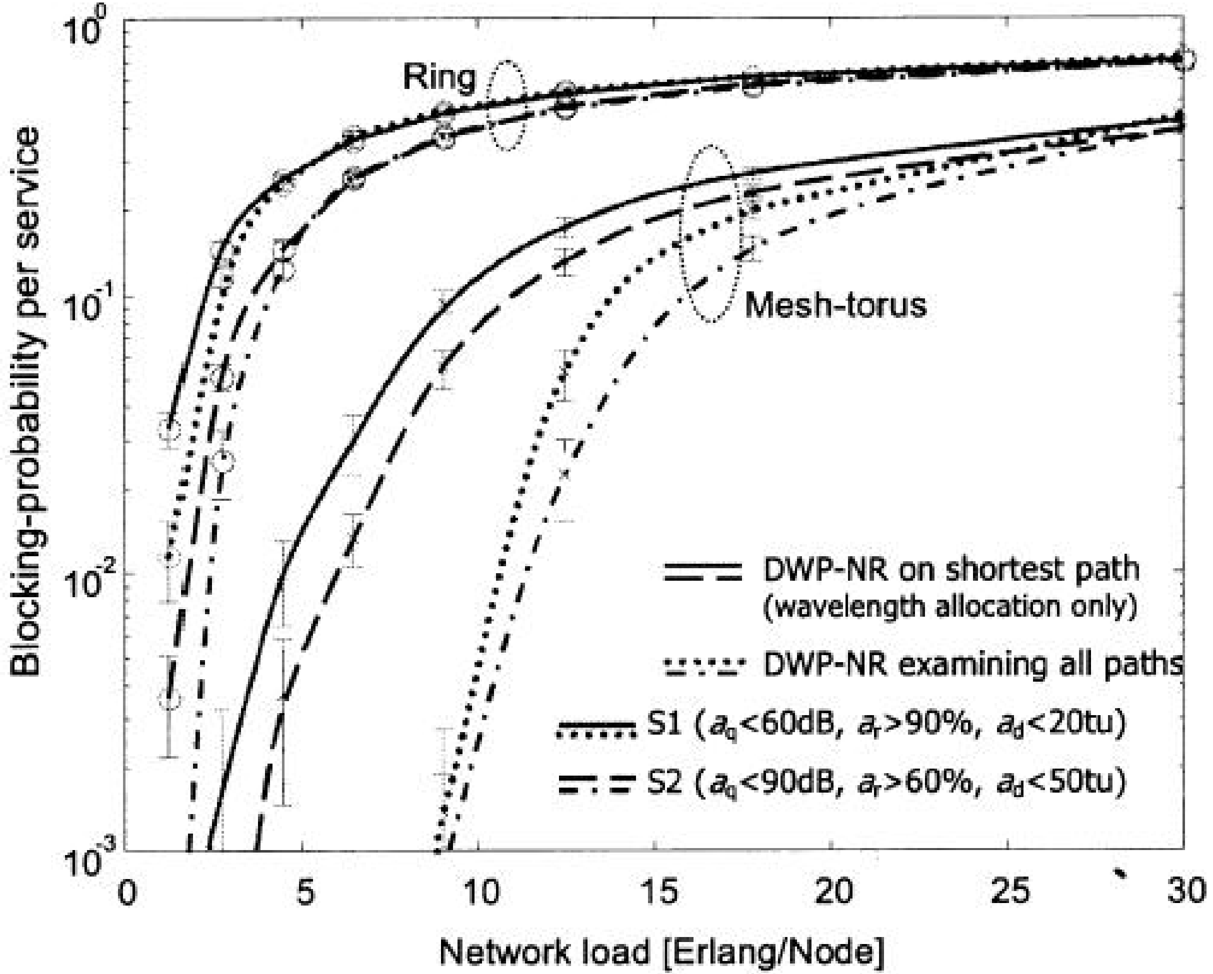
Quality attributes



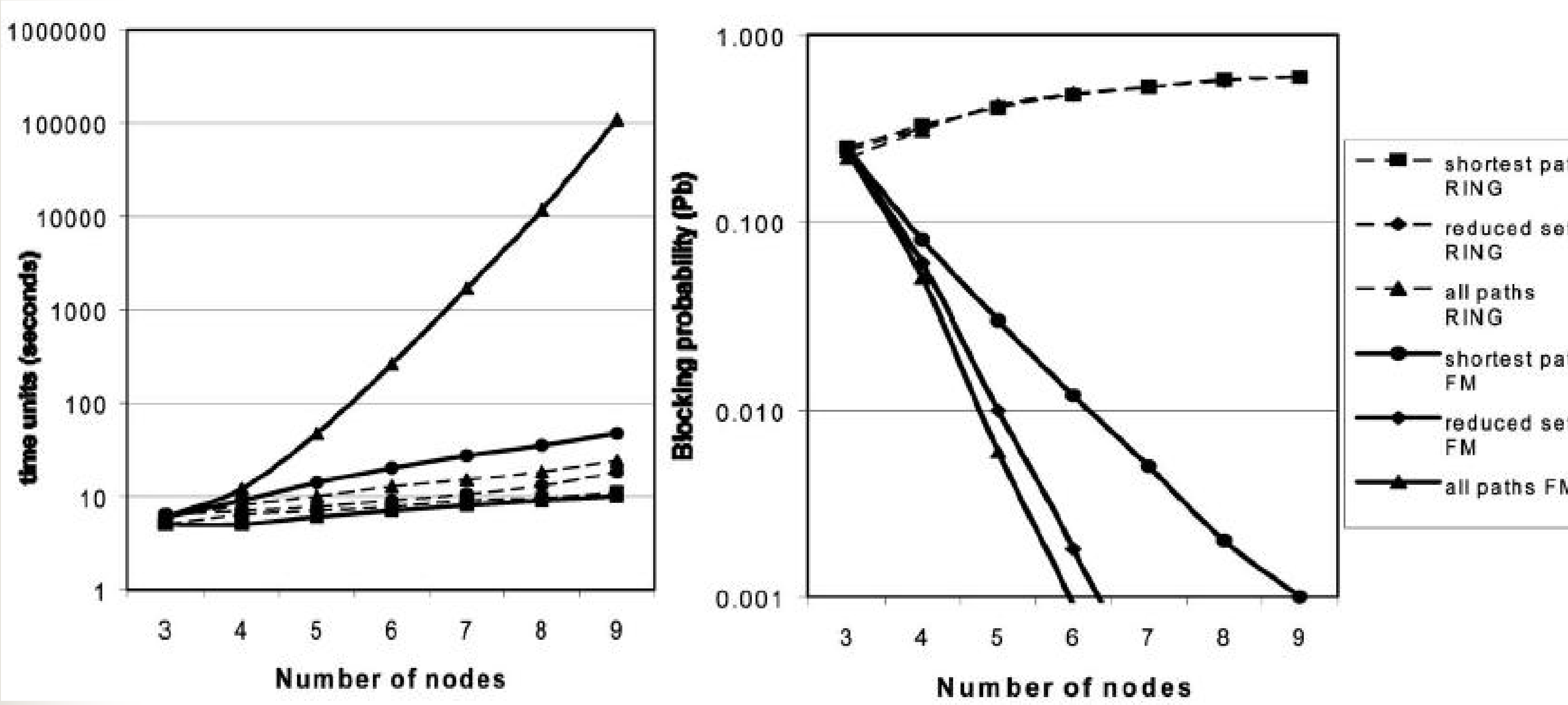
QUALITY ATTRIBUTES *PER WAVELENGTH* ALONG DIFFERENT NETWORK ELEMENTS: LINK TYPES, NODES, AND ELECTRONIC REGENERATORS (a_q: TRANSMISSION DEGRADATION; a_r: RELIABILITY; a_d: DELAY)

Link Type / NE a_q [dB]	*A*	*B*	*C*	*D*	Node	Reg.
λ_1	5	12	18	24	3	n/a
λ_2	4.5	10.6	15.7	20.8	3	n/a
λ_3	3.9	9	13.4	17.6	3	n/a
λ_4, λ_5	3.4	7.7	11	14.4	3	n/a
λ_6	5	12	18	24	3	n/a
λ_7	6.6	16.3	25	33.6	3	n/a
λ_8	8.2	20.6	32	43.2	3	n/a
a_r[%], all	99.9	98.75	97.5	96.5	99.99	99.9
a_d[tu], all	2	5.5	8.8	12	0.0	10

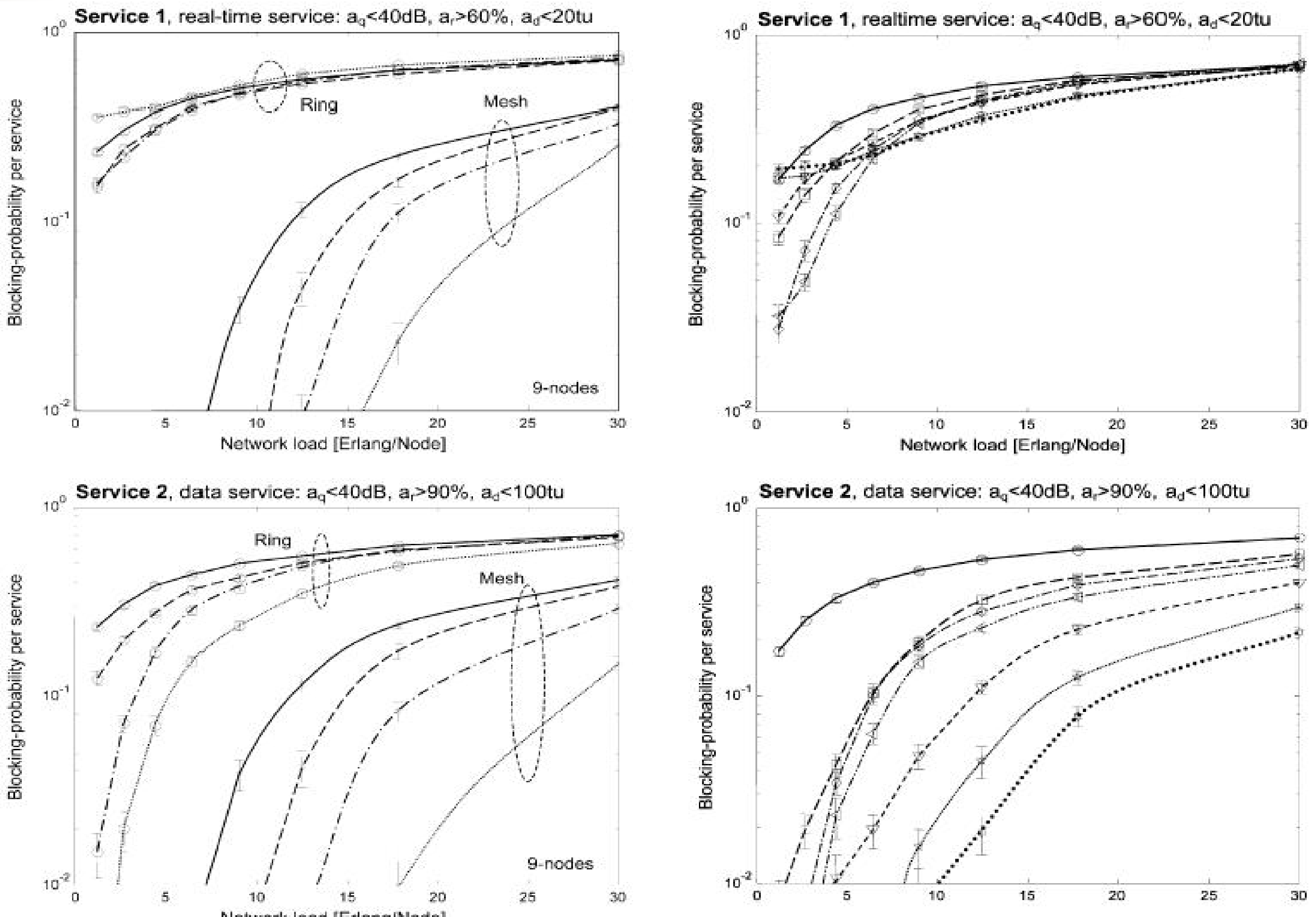
Simulation results for ring and mesh-torus networks



Convergence time and blocking prob.



Impact of electronic regenerator



Conclusions

- A new approach to constraint-based path selection for dynamic routing and wavelength allocation in WDM networks is proposed
- The use of regeneration decreases blocking when wavelength services have limited optical reach
- For end-to-end service guarantees, the electronic regeneration on gateway, the constraints on their usage, location, and design, will be critical to enable interconnections of all-optical networks.