Fair QoS-Aware Routing and Wavelength Assignment in All-Optical Networks

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Overview

▻ Introduction

▻ Adaptive QoS-aware RWA

▻ Validation by simulation

▻ Conclusions
Introduction

▷ All-optical networks with no wavelength conversion

▷ Crosstalk impairs the QoS of lightpaths
  ■ typically we want to keep $BER \leq 10^{-9}$ at all times, for each lightpath

▷ Design Routing and Wavelength Assignment (RWA) algorithms to mitigate crosstalk effects
  ■ wavelength continuity constraint and QoS constraint
  ■ adaptive RWA is a class of RWA with low blocking probability due to the wavelength continuity constraint
Metrics

- Average call blocking probability (BP): keep low
- Bit-error rate (BER)
  - a margin allows for greater scalability, flexibility, robustness, fewer retransmissions at higher layers
- Fairness: $0 \leq f(X) = \frac{E_S[X]^2}{E_S[X^2]} = \frac{1}{1+(s/m)^2} \leq 1$
  - here, $S$ is the set of all (source, destination) pairs and $X$ is either BP or BER
- BP fairness: all clients should have equal access to the network
- BER fairness: more fair $\Rightarrow$ need FEC for fewer paths
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Generic QoS-aware adaptive RWA algorithm

- **Call Arrival**
  - $i = 1$
  - $SP(\lambda_i)$ exists?
  - yes
    - adaptive
    - $QoS$ and reservation conditions met?
      - yes
      - $QoS$-aware
      - add $SP(\lambda_i)$ to list of candidates
      - yes
      - $i < C$?
        - yes
        - call accepted
        - select path according to policy ($SP/SP2/HQ/MMQ$)
      - no
      - candidates list empty?
        - yes
        - call rejected
        - no
      - no
  - no
    - $i = i + 1$

- Loop on the set of wavelengths

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Fast, dynamic estimation of BER: \( BER = 0.5 \text{ erfc}(Q/\sqrt{2}) \)

\[
Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1} = \frac{\mu_1 - \mu_0}{\sigma_0 + \sqrt{\sigma_i^2 + \sigma_n^2 + \sum_k \sigma_{x_k}^2}}
\]

\( \mu_0, \mu_1, \sigma_0, \sigma_1 \): means, st.dev. for the received “0s” and “1s”

Further split \( \sigma_1^2 \) into ISI, ASE noise and crosstalk variances

Sum crosstalk terms over all interfering paths
Impact of crosstalk accumulation on the maximum transmission distance, for a typical optical network

- each span is 70 km long

<table>
<thead>
<tr>
<th>Crosstalks</th>
<th>0, 1</th>
<th>2, 3</th>
<th>4</th>
<th>5, 6</th>
<th>7, 8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spans</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>
Generic QoS-aware adaptive RWA algorithm

loop on the set of wavelengths

- call arrival
- $i=1$
- $\exists SP(\lambda_i)$
  - yes
    - $\text{QoS and reservation conditions met?}$
      - yes
        - add $SP(\lambda_i)$ to list of candidates
      - no
        - $i=i+1$
  - no
    - $i=i+1$

- call accepted
  - select path according to policy (SP/SP2/HQ/MMQ)
  - $\text{candidates list empty?}$
    - no
      - $i=C$?
    - yes
      - call rejected
Reference policy: SP, SP2

▫ Considered algorithms are as complex as traditional adaptive RWA with BER guarantee

▫ SP is the traditional Shortest Path policy

▫ SP2 is SP with protecting threshold – single-hop paths accepted only if 2 or more wavelengths are available

▫ Insight: put aside wavelengths for longer paths, which are more likely to be blocked due to both wavelength continuity and QoS constraints

▫ Reference for standard adaptive RWA/SP: Mokhtar/Azizoğlu’98
Our novel policies: HQ, MMQ

- HQ selects the lightpath with the highest Q factor

- MMQ: inserting a new lightpath “LP1” in the network changes the BER for all LPs that cross LP1; MMQ maximizes (over the set of wavelengths) the minimum Q (over the set of LPs that cross each candidate lightpath)

- Insight: optimize QoS by selecting the path that manages the largest QoS (HQ) or QoS margin (MMQ) in the network

- HQ/MMQ are QoS-enhanced but may waste resources compared with SP2
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### Topology and physical parameters

![Downscaled NSF topology; the weights are the number of spans.](image)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span length</td>
<td>70 km</td>
</tr>
<tr>
<td>Signal peak power</td>
<td>2 mW</td>
</tr>
<tr>
<td>Bit rate</td>
<td>10 Gbps</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>NRZ</td>
</tr>
<tr>
<td>Fabric crosstalk</td>
<td>−40 dB</td>
</tr>
<tr>
<td>Adj. port crosstalk</td>
<td>−30 dB</td>
</tr>
<tr>
<td>Non adj. port crosstalk</td>
<td>−60 dB</td>
</tr>
<tr>
<td>Fiber type</td>
<td>SMF</td>
</tr>
<tr>
<td>Dispersion compensation</td>
<td>100% post-DC</td>
</tr>
<tr>
<td>Noise factor</td>
<td>2</td>
</tr>
<tr>
<td>Receiver elec. BW</td>
<td>7 GHz</td>
</tr>
<tr>
<td>Number of WL</td>
<td>8</td>
</tr>
<tr>
<td>Maximum BER</td>
<td>$10^{-9}$</td>
</tr>
</tbody>
</table>

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BPs are equivalent for all algorithms
Our QoS-enhanced RWA algorithms perform better for BER than SP/SP2
MMQ, SP2 exhibit highest BP fairness
Fairness: BER

- MMQ exhibits highest BER fairness

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Recall: $f(X) = \frac{1}{1+(s/m)^2}$
Conclusions

- Presented two new QoS-enhanced RWA algorithms based on adaptive RWA: HQ, MMQ
- Introduced new metrics to evaluate RWA algorithms
- Perform well in terms of BP
- Perform better than others in terms of QoS and fairness