Reduction of Crosstalk in WDM Networks
With optional FEC Coding

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Overview

- Introduction
- RWA with optional FEC coding
- Validation by simulation
- Conclusions
Introduction

- All-optical networks with no wavelength conversion
- Physical layer effects impair the QoS of lightpaths
  - typically we want to keep \( BER \leq 10^{-9} \) at all times, for each lightpath
- Context: large networks where some paths are very long
  - some paths are so long no call can be established without breaking the QoS constraint
- Forward Error Correction coding trade-off
  - can improve BER and keep it below threshold
  - cost: bandwidth expansion
Metrics

- Average call blocking probability (BP): decrease
- Fairness: \( 0 \leq f(X) = \frac{E_S[X]^2}{E_S[X^2]} \leq 1 \)
  - here, \( S \) is the set of all (source, destination) pairs, \( X \) is BP
  - meaning: all clients should have equal access to the network
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Algorithm flow

Golay (23, 12) code, rate $\approx 1/2$: need 2 LPs per call

RWA: alternate routing (k-SPF), random wavelength assignment

Golay (23, 12) code, rate $\approx 1/2$: need 2 LPs per call

RWA: alternate routing (k-SPF), random wavelength assignment
Fast, dynamic estimation of BER: $BER = 0.5 \text{erfc}(Q/\sqrt{2})$

\[
Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1} = \frac{\mu_1 - \mu_0}{\sigma_0 + \sqrt{\sigma_i^2 + \sigma_n^2 + \sum_q \sigma_{nxp}^2 + \sum_p \sigma_{ixq}^2}}
\]

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

\[ Q = \frac{\mu_1 - \mu_0}{\sigma_0 + \sigma_1} = \frac{\mu_1 - \mu_0}{\sigma_0 + \sqrt{\sigma_i^2 + \sigma_n^2 + \sum_q \sigma_{nxp}^2 + \sum_p \sigma_{ixq}^2}} \]

- Further split \( \sigma_1^2 \) into ISI, ASE noise, node crosstalk, interchannel variances
- Sum crosstalk terms over all interfering paths
Impact of crosstalk

- Impact of crosstalk accumulation on the maximum transmission distance (70-km spans), for a typical optical network
  - node crosstalk
    | Crosstalks | 0, 1 | 2, 3 | 4 | 5, 6 | 7, 8 | 9 | 10 |
    | Spans      | 12   | 11   | 10 | 9    | 8    | 7 | 6  |
  - XPM
    | Crosstalks | 0 | 1 | 2-8 |
    | Spans      | 12 | 9 | 7   |
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Downscaled NSF topology; the weights are the number of spans.

<table>
<thead>
<tr>
<th><strong>Spans</strong></th>
<th>2-12</th>
<th>14+</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paths</strong></td>
<td>164</td>
<td>18</td>
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</tbody>
</table>

<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>Nonlinear parameter</td>
<td>$2.2 \text{ (W.m)}^{-1}$</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>NRZ</td>
</tr>
<tr>
<td>Fabric xtalk</td>
<td>$-40 \text{ dB}$</td>
</tr>
<tr>
<td>Adj. port xtalk</td>
<td>$-30 \text{ dB}$</td>
</tr>
<tr>
<td>Non adj. port xtalk</td>
<td>$-60 \text{ dB}$</td>
</tr>
<tr>
<td>Fiber type</td>
<td>SMF</td>
</tr>
<tr>
<td>Dispersion compensation</td>
<td>post-DC</td>
</tr>
<tr>
<td>Number of WL</td>
<td>8</td>
</tr>
<tr>
<td>Minimum Q factor</td>
<td>$Q_1 = 6$</td>
</tr>
<tr>
<td></td>
<td>$Q_2 = 3.6$</td>
</tr>
</tbody>
</table>
BP for 1-SPF

![Graph showing blocking probability vs. total offered load](image_url)

- Black line: noise, ISI, node and interchannel crosstalk
- Red line: noise, ISI, interchannel crosstalk
- Blue line: noise, ISI, node crosstalk
- Pink line: noise, ISI

Legend:
- Plain: no coding
- Dotted: with optional coding

- X-axis: Total offered load (Erlang)
- Y-axis: Blocking probability

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Fairness for 1-SPF

![Graph showing fairness vs. total offered load]

- Black line: noise, ISI, node and interchannel crosstalk
- Red line: noise, ISI, interchannel crosstalk
- Blue line: noise, ISI, node crosstalk
- Pink line: noise, ISI

Legend:
- Plain: no coding
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Total offered load (Erlang) vs. Fairness for different types of noise and crosstalk with and without optional FEC coding.
Fairness for 4-SPF

- noise, ISI, node and interchannel crosstalk
- noise, ISI, interchannel crosstalk
- noise, ISI, node crosstalk
- noise, ISI

plain: no coding
dotted: with optional coding

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Conclusions

- Compared to situations where no coding at all is available, optional coding ...
  - helps reducing blocking probabilities in large networks
  - mitigates physical layer impairments
  - improves fairness among users