OPS/OBS Scheduling Algorithms: Incorporating a Wavelength Conversion Cost in the Performance Analysis

Kurt Van Hautegem, Wouter Rogiest & Herwig Bruneel
{kurt.vanhautegem, wouter.rogiest, herwig.bruneel}@telin.UGent.be

Ghent University, Belgium (UGent)
Department of Telecommunications and Information Processing (TELIN)
Stochastic Modelling and Analysis of Communication Systems (SMACS)
Overview presentation

- The optical backbone
- Contention resolution & scheduling basics
- Scheduling algorithms
- Performance results
- Energy consumption results
- Conclusions
Overview presentation

• **The optical backbone**

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
The optical backbone

technological developments &
internet-based business models

demand for bandwidth

connections
links
optical fibers
‘unlimited’ capacity

intersections
nodes
switches
bottleneck


Introduction: the optical backbone

**Currently:** circuit switching

- dedicated communication channel
- guaranteed packet arrival
- fixed delay
- inefficient use of available fiber capacity (bandwidth)

**Future:** packet-based switching

- shared links
- improved usage of capacity
- contention possible
- potentially, packet loss
- no fixed delay
- potentially, substantial delay

---

main motivation of this work: improving contention resolution
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
Contestation & resolution

contention:

node 1

node 2

node 2, now!

node 2, now!

straightforward solution: electronic buffering (RAM)

- cannot keep up with optical speeds
- energy consuming O/E/O conversions

optical contention resolution
Optical contention resolution: two means

1. **wavelength converters (WCs)**
   - $c$ wavelengths
   - unlimited wavelength conversion capacity
   - energy consuming

2. **Fiber Delay Lines (FDLs)**
   - set of fibers, $\#=N+1$
   - lengths $j\cdot D$, $j=0...N$
   - $N$ = buffer size
   - $D$ = granularity
Provisional schedule

wavelength conversion + Fiber Delay Lines

- shows already scheduled packets
- updated at every arrival
- horizontal lines (dotted): outgoing wavelengths (c=4)
- vertical lines: delays of FDLs (N=5, D=1)
Schedule for minimal loss

SCHEDULING

choose:
- outgoing wavelength i (i=1...c)
- delay line j (j=0...N)

constraints:
- no overlap
- type of algorithm
  - non-void-filling (NVF) •
  - void-filling (VF)  • + ▲

satisfied: Scheduling Points (SPs)

goal:
minimize loss probability (LP)

choose SP “wisely”
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• **Scheduling algorithms**

• Performance results

• Energy consumption results

• Conclusions
Scheduling algorithms: current

- **JSQ(-NVF)**  
  join the shortest queue  
  =wavelength with shortest horizon

- **D-G(-NVF)**  
  first priority: minimum delay  
  second priority: minimum gap

- **G-D(-NVF)**  
  first priority: minimum gap  
  second priority: minimum delay

- **D-G-VF**  
  packet length ≤ 0.4
  0.4 < packet length ≤ 0.6
  packet length > 0.6

- **G-D-VF**  
  packet length ≤ 0.4
  packet length > 0.4
Scheduling algorithms: new

- assign cost to each SP
- choose SP with lowest cost

2 cost functions

**C**: cost of SP taking into account gap and delay:

\[ C = \alpha \cdot gap + (1 - \alpha) \cdot delay \]

**cw**: cost of SP taking into account gap, delay and wavelength conversion:

\[ CW = \left( \frac{1}{1 + \beta} \right)^{1 - \delta_{wi}} \cdot [\alpha \cdot gap + (1 - \alpha) \cdot delay] + \frac{\beta}{1 + \beta} \cdot D \cdot [1 - \delta_{wi}] \]
Scheduling algorithms: $C$

$C$: cost of SP (gap and delay, not wavelength conversion):

$$C = \alpha \cdot \text{gap} + (1 - \alpha) \cdot \text{delay}$$

- $\alpha$: algorithm parameter to optimise for minimal loss probability
- weighted average of gap and delay
- MOTIVATION: propose algorithms with better performance

→ algorithms $C$(-NVF) and $C$-VF
Scheduling algorithms: \(CW\)

\(CW\): cost of SP (gap, delay and wavelength conversion):

\[
CW = \left(\frac{1}{1 + \beta}\right)^{1-\delta_{wi}} \cdot [\alpha \cdot \text{gap} + (1 - \alpha) \cdot \text{delay}] + \frac{\beta}{1 + \beta} \cdot D \cdot [1 - \delta_{wi}]
\]

- \(\alpha\): algorithm parameter to optimise for minimal LP
- \(\beta\): algorithm parameter to reduce wavelength conversion (~ energy consumption)
- \(i\): outgoing wavelength, \(w\): incoming wavelength, \(\delta_{wi}\): Kronecker’s delta
- \(\neq C\), due to extra summand to penalise use of wavelength converter
- MOTIVATION: propose algorithms with reduced energy consumption

\(\rightarrow\) algorithms \(CW\)-(NVF) and \(CW\)-VF
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
Overview presentation

- The optical backbone
- Contention resolution & scheduling basics
- Scheduling algorithms

- **Performance results**
- Energy consumption results
- Conclusions
Performance results: assumptions

- $c = \# \text{incoming wavelengths} = \# \text{outgoing wavelengths} = 4$
- $N+1 = \# \text{Fiber Delay Lines} = 10$
- \text{inter-arrival time packets} = \text{exponentially distributed}, E[T]
- \text{packet size} = \text{exponentially distributed}, E[B]=100$
- \text{arriving wavelength} = \text{uniformly distributed}$
- \text{load} = \rho = \frac{E[B]}{c \cdot E[T]} = 80 \%$
- $D = \text{granularity} = 10, 20, ..., 200$
- Monte Carlo simulation
Performance results: current algorithms

Loss probability

- JSQ
- D-G
- G-D
- D-G-VF
- G-D-VF

$D_L$ $o$ $s$ $p$ $r$ $o$ $b$ $a$ $b$ $i$ $l$ $y$
Performance results: C

\[ C = \alpha \cdot \text{gap} + (1 - \alpha) \cdot \text{delay} \]

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>0.9</th>
<th>0.9</th>
<th>0.9</th>
<th>0.9</th>
<th>0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>D = 50 LP reduction (%)</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D = 70 LP reduction (%)</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D = 100 LP reduction (%)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>D = 150 LP reduction (%)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>D = 200 LP reduction (%)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Loss probability (LP)

- D = 50
- D = 70
- D = 100
- D = 150
- D = 200

\( \alpha \) ranges from 0 to 1.

\( \text{LP} \) varies from 0% to 15%.
Performance results: C-VF

\[ C = \alpha \cdot gap + (1 - \alpha) \cdot delay \]
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
Overview presentation

- The optical backbone
- Contention resolution & scheduling basics
- Scheduling algorithms
- Performance results
- **Energy consumption results**
- Conclusions
Energy consumption results

wavelength converters assumed only switched on when converting

\[
\Downarrow
\]

energy consumption \sim \text{payload converted packages}

\[
\Downarrow
\]

energy consumption measure = \frac{\text{payload converted packages}}{\text{payload packages not lost}}
Energy consumption results

Energy consumption measure

- JSQ
- D-G
- G-D
- C, \( \alpha = 0.9 \)
- D-G-VF
- G-D-VF
- C-VF, \( \alpha = 0.9 \)
Energy consumption results: $CW$

$$CW = \left(\frac{1}{1 + \beta}\right)^{1-\delta_{wi}} \cdot [\alpha \cdot gap + (1 - \alpha) \cdot delay] + \frac{\beta}{1 + \beta} \cdot D \cdot [1 - \delta_{wi}]$$

- $\alpha = 0,9$
Energy consumption results: CW-VF

\[ CW = \left( \frac{1}{1 + \beta} \right)^{1 - \delta_{wi}} \cdot [\alpha \cdot gap + (1 - \alpha) \cdot delay] + \frac{\beta}{1 + \beta} \cdot D \cdot [1 - \delta_{wi}] \]

- \( \alpha = 0.9 \)
Overview presentation

• The optical backbone

• Contention resolution & scheduling basics

• Scheduling algorithms

• Performance results

• Energy consumption results

• Conclusions
Overview presentation

- The optical backbone
- Contention resolution & scheduling basics
- Scheduling algorithms
- Performance results
- Energy consumption results

• Conclusions
Conclusions

- cost based approach
- 2 cost functions
- $C$ and $CW$

- weighted average delay & gap
- $\alpha$ optimised
- C and C-VF algorithms
- improved performance

- weighted average delay & gap + penalty cost for using WC
- fixed optimal $\alpha$, varying $\beta$
- CW and CW-VF algorithms
- improved performance tradeable for energy consumption reduction
Questions?