An Analytical Study of an All-Optical Packet Switch with QoS Support

J. S. Vardakas*, I. D. Moscholios**, and M. D. Logothetis*

* Wire Communications Laboratory, Department of Electrical & Computer Engineering, University of Patras, 265 04 Patras, Greece.

**Dept. of Telecommunications Science and Technology, University of Peloponnese, 22 100, Tripoli, Greece
Contents

- Purpose
- All-Optical Packet Switch with Wavelength Conversion Capability
- All-Optical Packet Switch without Wavelength Conversion Capability
- Evaluation
- Conclusion
Purpose of the Paper (1)

Device under study:
All-Optical Packet Switch

Target of the Analysis

To examine several QoS differentiation schemes, including wavelength conversion, packet dropping and wavelength reservation
Absence of QoS Policy

The Wavelength Reservation Policy

The Pre-Emptive Drop Policy

The Intentional Packet Dropping Policy

All-Optical Switch

A, B, C: with Wavelength Conversion
D, E: without Wavelength Conversion
All-Optical Switch with W-C Capability (1)

- The All-Optical switch has $F$ input/output fibers
- Each fiber supports $W$ wavelengths
- Total number of input/output wavelengths: $R_f = FW$
- The capacity of each wavelength is $C$ bits/sec
- The OPS network supports $K$ service-classes
- The arrival rate of service-class $k$ packets is $\lambda_k$.
- The length of the packets is exponentially distributed with mean $l$, same for all service-classes
- Time that a wavelength is occupied: $\mu^{-1} = l/C$
All-Optical Switch with W-C Capability (2)

Absence of QoS Differentiation Policy

\[ P(i - 1) [(R_f - (i - 1)) \lambda] + P(i + 1) [(i + 1) \mu] = P(i) [(R_f - i) \lambda + i \mu] \]

\[ P(i) = \left( \frac{\lambda}{\mu} \right)^i \cdot \prod_{j=1}^{i} \left[ R_f - (j - 1) \right] \cdot P(0) \]

\[ P(0) = \left[ \sum_{n=0}^{W} \left( \frac{\lambda}{\mu} \right)^n \prod_{j=1}^{n} \left[ R_f - (j - 1) \right] \right]^{-1} \]

The PBP is given by \( P(W) \)
All-Optical Switch with W-C Capability (3)

The Intentional Packet Dropping Policy

- A service-class \( k \) packet is dropped with a constant probability \( p_k \), before reaching the output fiber.
- \( p_1 > p_2 > \ldots > p_K \)
- We use the same transition diagram of the previous case, with the substitution:

\[
\lambda = \sum_{k=1}^{K} \lambda_k (1 - p_k)
\]

The PBP of service-class \( k \) packet is given by

\[
B_k = p_k + (1 - p_k) P(W)
\]
The Wavelength Reservation Policy

- A number of output wavelengths is reserved exclusively for each service-class
- A service-class $k$ packet is accepted for service when more than $t_k$ wavelengths are available in the fiber
- $t_1 > t_2 > \ldots > t_K$
- The new arrival rate is: $\lambda(i) = \sum_{k=1}^{K} \lambda_k D_k(i)$

$P(i) = \frac{(R_f - (i - 1))}{\mu \cdot i} \sum_{k=1}^{K} \lambda_k D_k(i - 1) \cdot P(i - 1)$

$D_k(i - 1) = \begin{cases} 
1, & \text{for } i \leq W - t_k \\
0, & \text{for } i > W - t_k 
\end{cases}$

The PBP of service-class $k$ packet is given by

$B_k = \sum_{j=W-t_k}^{W} P(j)$
The Intentional Packet Dropping Policy

- We focus on the determination of the occupancy distribution of one output wavelength.
- A service-class $k$ packet is dropped with a constant probability $p_k$ before reaching the output fiber.
- The total arrival rate is: $\lambda = \sum_{k=1}^{K} \lambda_k (1 - p_k)$

$$P(0) = \frac{\mu}{R_{f,w} \lambda + \mu}$$

$$P(1) = \frac{R_{f,w} \lambda}{R_{f,w} \lambda + \mu}$$

The PBP of service-class k packet is given by

$$B_k = p_k + (1 - p_k) P(1)$$
All-Optical Switch without W-C Capability (2)

The Pre-Emptive Drop Policy

- High priority packets pre-empt low priority packets currently in transmission in the case of contention
- The OPS network supports 3 service-classes
- Packets that belong to service-class 3 could be pre-empted by the 1\textsuperscript{st} and the 2\textsuperscript{nd} service-class, with $p_2$ and $p_1$, respectively. $p_2 < p_1$

\[ P(0,0) = \frac{\mu}{R_{f,w} (\lambda_1 + \lambda_2 + \lambda_3) + \mu} \]
\[ P(1,1) = \frac{\lambda_1 R_{f,w} ((\lambda_1 + \lambda_3) R_{f,w} p_1 + \lambda_2 R_{f,w} p_2 + \mu)}{(R_{f,w} (\lambda_1 + \lambda_2 + \lambda_3) + \mu) (\lambda_1 R_{f,w} p_1 + \lambda_2 R_{f,w} p_2 + \mu)} \]
\[ P(1,2) = \frac{\lambda_2 R_{f,w} (\lambda_1 R_{f,w} p_1 + p_2 R_{f,w} (\lambda_1 + \lambda_2) + \mu)}{(R_{f,w} (\lambda_1 + \lambda_2 + \lambda_3) + \mu) (\lambda_1 R_{f,w} p_1 + \lambda_2 R_{f,w} p_2 + \mu)} \]
\[ P(1,3) = \frac{\lambda_3 R_{f,w} \mu}{(R_{f,w} (\lambda_1 + \lambda_2 + \lambda_3) + \mu) (\lambda_1 R_{f,w} p_1 + \lambda_2 R_{f,w} p_2 + \mu)} \]

The PBP of service-class $k$ packet is given by

\[ B_1 = P(1,1) + P(1,2) + (1 - p_1) P(1,3) \]
\[ B_2 = P(1,1) + P(1,2) + (1 - p_2) P(1,3) \]
\[ B_3 = P(1,1) + P(1,2) + P(1,3)(1 + p_1 \frac{\lambda_1}{\lambda_3} + p_2 \frac{\lambda_2}{\lambda_3}) \]
Evaluation (1)

We compare analytical to simulation results

1\textsuperscript{st} example: an all-optical switch with W-C capability:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of fibers $F$</td>
<td>10</td>
</tr>
<tr>
<td># of wavelengths $W$</td>
<td>8</td>
</tr>
<tr>
<td>Wavelength capacity $C$</td>
<td>1 Gbps</td>
</tr>
<tr>
<td># of service-classes $K$</td>
<td>2</td>
</tr>
<tr>
<td>Mean packet length $l$</td>
<td>1250 bits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arrival rate (packets/sec) per idle wavelength</th>
<th>Packet Blocking Probability (RFP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analysis (%)</td>
</tr>
<tr>
<td></td>
<td>Mean (%)</td>
</tr>
<tr>
<td>1\textsuperscript{st} serv.</td>
<td>2\textsuperscript{nd} serv.</td>
</tr>
<tr>
<td>500</td>
<td>1500</td>
</tr>
<tr>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>1500</td>
<td>2500</td>
</tr>
<tr>
<td>2000</td>
<td>3000</td>
</tr>
<tr>
<td>2500</td>
<td>3500</td>
</tr>
<tr>
<td>3000</td>
<td>4000</td>
</tr>
</tbody>
</table>
### Evaluation (2)

<table>
<thead>
<tr>
<th>Arrival rate (packets/sec)</th>
<th>PBP 1&lt;sup&gt;st&lt;/sup&gt; service-class</th>
<th>PBP 2&lt;sup&gt;nd&lt;/sup&gt; service-class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulation</td>
<td>Simulation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1&lt;sup&gt;st&lt;/sup&gt; serv.</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; serv.</th>
<th>Analysis (%)</th>
<th>Mean (%)</th>
<th>95% Conf. Interval</th>
<th>Analysis (%)</th>
<th>Mean (%)</th>
<th>95% Conf. Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>1500</td>
<td>0.01189</td>
<td>0.0117</td>
<td>0.00612</td>
<td>5.01129</td>
<td>4.91725</td>
<td>0.00731</td>
</tr>
<tr>
<td>1000</td>
<td>2000</td>
<td>0.14735</td>
<td>0.1446</td>
<td>0.03121</td>
<td>5.13998</td>
<td>5.04352</td>
<td>0.01271</td>
</tr>
<tr>
<td>1500</td>
<td>2500</td>
<td>0.70598</td>
<td>0.6928</td>
<td>0.04133</td>
<td>5.67068</td>
<td>5.56426</td>
<td>0.01337</td>
</tr>
<tr>
<td>2000</td>
<td>3000</td>
<td>2.03114</td>
<td>1.9933</td>
<td>0.04193</td>
<td>6.92958</td>
<td>6.79954</td>
<td>0.02121</td>
</tr>
<tr>
<td>2500</td>
<td>3500</td>
<td>4.28049</td>
<td>4.2007</td>
<td>0.03867</td>
<td>9.06646</td>
<td>8.89632</td>
<td>0.01521</td>
</tr>
<tr>
<td>3000</td>
<td>4000</td>
<td>7.36336</td>
<td>7.2261</td>
<td>0.03657</td>
<td>11.9952</td>
<td>11.7761</td>
<td>0.02813</td>
</tr>
</tbody>
</table>

Packets of the 2<sup>nd</sup> service-class are dropped with a constant probability $p_2=0.05$.

One wavelength is reserved for the 1<sup>st</sup> service-class ($t_1=0$, $t_2=1$).

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Evaluation (1)

We compare analytical to simulation results

2nd example: an all-optical switch without W-C capability:

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The successful pre-emption
of a service-class 3 packet by
a packet that belongs to
the 2nd and 3rd service-
classes is $p_2=0.01$ and
realized with a probability
$p_3=0.02$, respectively.
$p_2=0.1$ and $p_1=0.2$,
respectively.
Conclusion

We propose analytical models for the calculations of the PBP in an all-optical packet switch, under several QoS differentiation schemes.

The PBP was derived by the steady-state equation of one-dimensional Markov chains.

The accuracy of the proposed calculations is quite satisfactory as was verified by simulations.

In our future work we shall extend this analysis, in order to study the effect of the implementation of FDLs and deflection routing to the blocking performance of the switch.
Thank You!