Waveband Switching Efficiency in WDM Networks: Analysis and Case Study

Payam Torab, Virginia Hutcheon, David Walters and Abdella Battou

Lambda Optical Systems Corporation, 12100 Sunset Hills Rd, Suite 100, Reston, VA 20190, USA
Phone: +1-703-689-9500, Fax: +1-703-689-3795, E-mail: {ptorab, vhutcheon, dwalters, abattou}@lopsys.com

Abstract: We study the optical port saving under uniform waveband switching, and derive the network and traffic conditions that make waveband switching more efficient than wavelength switching. In particular, we study a combined waveband/wavelength switching scheme that allows wavelength circuits to share waveband circuits, and results in better waveband utilization. Using a model of a typical carrier core network, we demonstrate that waveband switching provides close to 25% port saving under an aggressive growth scenario.

©2006 Optical Society of America

OCIS codes: (060.4510) Optical communications; (060.4250) Networks

1. Introduction

Waveband switching is regarded as an efficient transparent switching solution that has the potential to keep up with the rapidly increasing demand for transparent wavelength circuits [1, 2]. A waveband refers to a group of contiguous or separate wavelengths, and waveband switching refers to a switching scheme where a group of transit wavelength circuits are switched using a single optical cross-connection, or two optical ports, as opposed to wavelength switching, where each transit wavelength circuit is switched individually.

As in any other aggregated switching scheme, the efficiency of waveband switching depends in part on waveband utilization, i.e., the percentage of wavelengths that are utilized in the waveband. One approach to increasing the utilization is to use variable-sized or nonuniform wavebands, i.e., to define the waveband size according to the number of wavelength circuits between the two endpoints [2]. More precisely, in this approach, a single waveband circuit, or bandpath, is set up between two endpoints with as many wavelength channels as required, and wavelength circuits, or lightpaths are routed on the single bandpath connecting the endpoints. This is shown in Fig. 1(a), where two lightpaths $lp_1$ and $lp_2$ with the same endpoints are sharing the bandpath $bp_1$.

Although nonuniform wavebands result in the best waveband utilization, in practice they have to be realized through several intermediate filtering or switching stages with variable optical paths and different losses, which adds to system complexity and necessitates power equalization after each switching node. Furthermore, network studies in [2] do not show a significant cost saving for nonuniform wavebands compared to the much simpler case of uniform wavebands of appropriate size. A simpler yet less studied approach is to employ uniform wavebands and to increase the waveband utilization by sharing bandpaths among lightpaths with partially overlapping routes and different endpoints. This is illustrated in Fig. 1(b), where two lightpaths $lp_1$ and $lp_2$ with different endpoints and overlapping routes are sharing the bandpath $bp_1$.

In this paper, we quantify the optical port savings under waveband switching for both dedicated and shared bandpath cases. We identify the network and traffic conditions that need to be met for waveband switching to be more efficient than wavelength switching. Finally, we summarize our findings from a study of waveband switching efficiency for a model of a typical carrier core network.

2. Waveband Switching Efficiency

Waveband switching efficiency (or efficiency for short) is defined as the savings in the total number of optical ports in a network when its lightpaths are switched at the waveband level instead of wavelength level. To be able to compare port usage under these two switching schemes, we assume that lightpaths take the same route in both cases. This is a valid assumption when each lightpaths is routed on the shortest path, or the shortest disjoint paths for protected lightpaths, and only lightpaths with common endpoints share bandpaths. However, the assumption is typically an approximation when lightpaths with different endpoints share bandpaths.

In the remaining of the paper, $n_b$ and $n_o$ denote the total number of optical ports required under waveband and wavelength switching respectively, $h$ is the average number of physical hops for each bandpath, $b$ is the number of wavelengths in each waveband, which is assumed to be fixed, and $u$ is the average bandpath utilization. Thus, the product $bu$ is the average number of lightpaths that are switched as a waveband.
2.1 Dedicated Bandpaths

This case has been studied in a slightly simpler form in [1] and [2]. Here we assume each node is equipped with a wavelength cross-connect in addition to the waveband cross-connect, and also assume that adding or dropping a lightpath requires two additional ports on the wavelength cross-connect at each endpoint. Referring to Fig. 1(a), the number of ports needed for switching \( bu \) lightpaths over one logical hop (bandpath), with \( h \) physical hops in each bandpath, is calculated as follows for wavelength and waveband switching,

\[
\begin{align*}
    n_w &= 2bu + 2bu(h - 1) + 2bu = 2bu(h + 1) \\
    n_b &= 2(bu + 1) + 2(h - 1) + 2(bu + 1) = 2bu + 2h + 2
\end{align*}
\]

The waveband switching efficiency is given by

\[
e = \frac{n_w - n_b}{n_w} = \frac{h - 1}{h + 1} \frac{1}{bu}
\]

![Diagram showing dedicated bandpaths with lightpaths same routes](a)

![Diagram showing shared bandpaths with lightpaths have different endpoints and partially overlapping routes](b)

Fig. 1. Waveband switching with (a) dedicated bandpaths, and (b) shared bandpaths.

2.2 Shared Bandpaths

Each bandpath defines a logical hop in this case, and lightpaths are routed over one or more (average of \( l \)) logical hops. The number of ports needed at the bandpath-hopping node (where a lightpath moves from one bandpath to another) is different, depending on whether the lightpath needs wavelength conversion at this node or not. For example, switching the lightpath \( lp2 \) from bandpath \( bp3 \) to bandpath \( bp4 \) in Fig. 1(b) requires six optical ports at Node B if \( lp2 \) can stay on the same wavelength (four ports on the waveband cross-connect and two ports on the wavelength cross-connect, as shown in the figure). If \( lp2 \) needs to go through wavelength conversion at Node B however, two more ports are needed on the wavelength cross-connect.

Let \( 0 < p < 1 \) be the average wavelength conversion ratio, i.e., the percentage of times that a wavelength circuit has to go through wavelength conversion when transferring from one bandpath to another. The number of optical ports needed to switch \( bu \) lightpaths over \( l \) logical hops (bandpaths), and with \( h \) physical hops in each bandpath, is calculated as follows for wavelength and waveband switching,

\[
\begin{align*}
    n_w &= 2bu + 2bu(h - 1) + 2bu = 2bu(h + 1) \\
    n_b &= [2(bu + 1) + 2(h - 1) + 2(bu + 1)] + (l - 1)[2(bu + p) + 2(h - 1) + 2(bu + 1)] = 2l(2bu + h + p) + 2(l - p)
\end{align*}
\]

The waveband switching efficiency, which is a generalization of (2) to \( l > 1 \) in this case, is given by

\[
e = \frac{n_w - n_b}{n_w} = \frac{lh + 1 - 2l}{lh + 1} - \frac{(l - 1)p}{bu(h + 1)}
\]

2.3 Analysis

Both efficiency equations (2) and (4) confirm that 1- Waveband switching efficiency improves as more lightpaths are carried through longer bandpaths, i.e., it improves with larger utilization \( u \) or more physical hops in each bandpath \( h \), and 2- Switching efficiency is a function of the product of waveband size and utilization \( bh \), i.e., the saving in optical ports is the same for wavebands of size 8 at 50% utilization, and wavebands of size 4 at 100% utilization. The efficiency condition \( n_b < n_w \) (or \( e > 0 \)) defines a waveband switching efficiency region in the two-dimensional \( bu-h \) plane, as shown in Fig. 2. Note that in the shared bandpath case the efficiency region is also a function of the average number of logical hops \( l \) and conversion ratio \( p \).
3. Case Study: Typical Carrier Core Network Model

To see the waveband switching efficiency in optical core networks, we studied a model of a typical carrier core network. The network has 79 nodes, 137 links, and a mixture of STM-1/4/16/64 traffic. At least 50% of the STM-1 traffic and 100% of the remaining traffic are 1+1-protected. All STM-1/4 and most of the STM-16 traffic with common endpoints are groomed into STM-64 lightpaths. The working and protection paths for all protected traffic are disjoint at every multiplexing layer. We considered both dedicated and shared-bandpath designs. The physical network, as well as the bandpaths for the dedicated bandpath design are shown in Fig. 3.

Table 1 lists the key design parameters for the nominal traffic volume, as well as x2 and x5 growth scenarios. As seen from the table, waveband switching is more efficient than wavelength switching in both dedicated and shared bandpath cases, and for at most getting close to 25% when traffic is uniformly increased by a factor of 5. For each traffic scenario, the design “operating point” in terms of average bandpath length and utilization is marked on the efficiency region shown in Fig. 2.

Table 1: Waveband Switching Efficiency for a Typical Carrier Core Network Model

<table>
<thead>
<tr>
<th>design approach</th>
<th>traffic growth</th>
<th>STM-64 circuits</th>
<th>throughput (Tbps)</th>
<th>b</th>
<th>u</th>
<th>h</th>
<th>l</th>
<th>p</th>
<th>n_w</th>
<th>n_b</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>shared bandpaths</td>
<td>x1</td>
<td>188</td>
<td>178</td>
<td>5.540</td>
<td>4</td>
<td>0.923</td>
<td>2.820</td>
<td>1.986</td>
<td>0.836</td>
<td>48.738</td>
<td>44.179</td>
</tr>
<tr>
<td></td>
<td>x2</td>
<td>341</td>
<td>246</td>
<td>9.280</td>
<td>4</td>
<td>0.951</td>
<td>2.945</td>
<td>1.700</td>
<td>0.753</td>
<td>45.698</td>
<td>38.934</td>
</tr>
<tr>
<td></td>
<td>x3</td>
<td>890</td>
<td>239</td>
<td>20.190</td>
<td>4</td>
<td>0.975</td>
<td>3.457</td>
<td>1.641</td>
<td>0.739</td>
<td>51.240</td>
<td>39.173</td>
</tr>
<tr>
<td>dedicated bandpaths</td>
<td>x1</td>
<td>188</td>
<td>239</td>
<td>6.150</td>
<td>4</td>
<td>0.523</td>
<td>3.820</td>
<td>1.000</td>
<td>0.000</td>
<td>20.167</td>
<td>18.008</td>
</tr>
<tr>
<td></td>
<td>x2</td>
<td>341</td>
<td>316</td>
<td>9.980</td>
<td>4</td>
<td>0.604</td>
<td>3.890</td>
<td>1.000</td>
<td>0.000</td>
<td>23.628</td>
<td>19.444</td>
</tr>
<tr>
<td></td>
<td>x3</td>
<td>890</td>
<td>305</td>
<td>20.850</td>
<td>4</td>
<td>0.608</td>
<td>4.600</td>
<td>1.000</td>
<td>0.000</td>
<td>27.238</td>
<td>20.928</td>
</tr>
</tbody>
</table>

4. Conclusions

Waveband switching is the natural solution to meet up with the rapidly increasing demand for transparent lightpaths. When WDM and fiber resources are scarce, sharing waveband circuits (bandpaths) through combined wavelength/waveband switching can improve the waveband and as a result the fiber utilization. Blocking performance of shared bandpaths needs more study however. Switching efficiency can only improve under realistic traffic growth scenarios, for at least two reasons: 1- More lightpaths between two endpoints improve the waveband utilization, and 2- The sub-rate traffic, which normally requires grooming, will grow enough to fill up a whole lightpath, which reduces the need for grooming and results in longer bandpaths. Finally, adding another level of transparent switching on top of wavelength switching enables the carriers to overlay arbitrary logical WDM topologies over their fixed fiber network and expose only the logical topology to wavelength customers.

References