OFC/NFOEC 2006 Session OTuG - Optical Network Architectures I
March 7, 2006

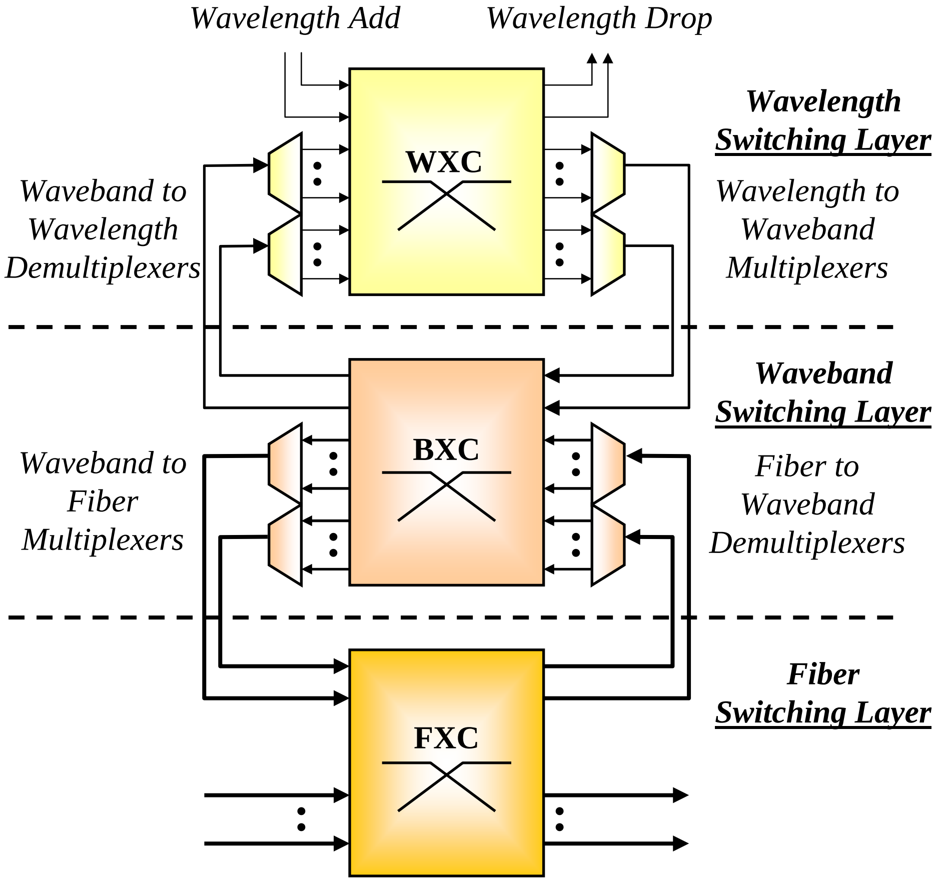
Waveband Switching Efficiency in WDM Networks: Analysis and Case Study

Payam Torab, Virginia Hutcheon,
David Walters and Abdella Battou

Lambda OpticalSystems 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

Introduction

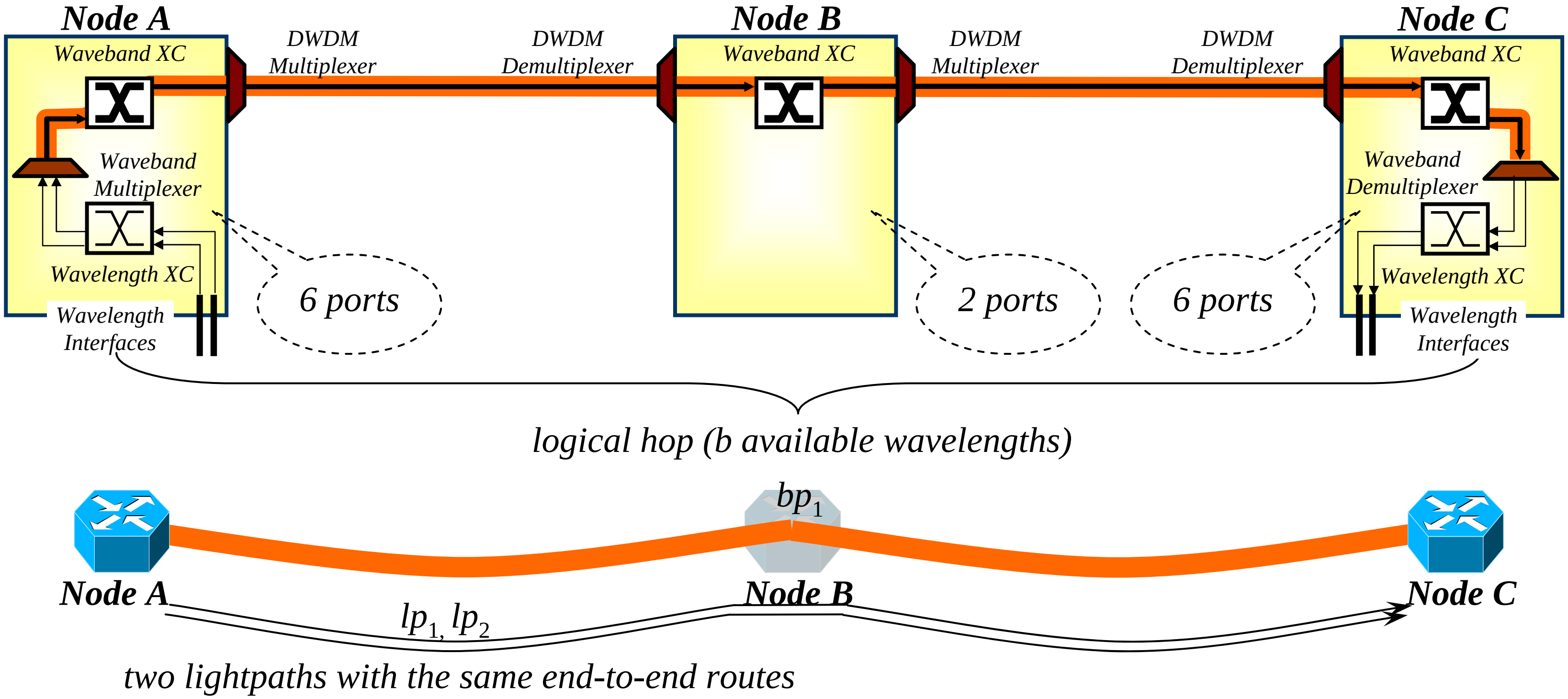
- Waveband switching has received a lot of attention due to its switching efficiency, i.e., saving in optical ports
- An ideal switch architecture should be able to provide wavelength, waveband and fiber switching (multigranular optical crossconnect (MG-OXC)
- Here we consider only waveband and wavelength switching layers
- Wavebanding assumptions
  - Uniform and fixed wavebands
  - General link sharing (no restriction such as same source or same destination for wavelength circuits)
- Intuitively, waveband switching is most efficient when several wavelength circuits share several common links
- We quantify this efficiency here



Xiaojun Cao; Anand, V.; Yizhi Xiong; Chunming Qiao, "A study of waveband switching with multilayer multigranular optical cross-connects," IEEE Journal on Selected Areas in Communications, volume 21, number 7, Sept. 2003, pp. 1081-1095

Wavebanding – Simple Case

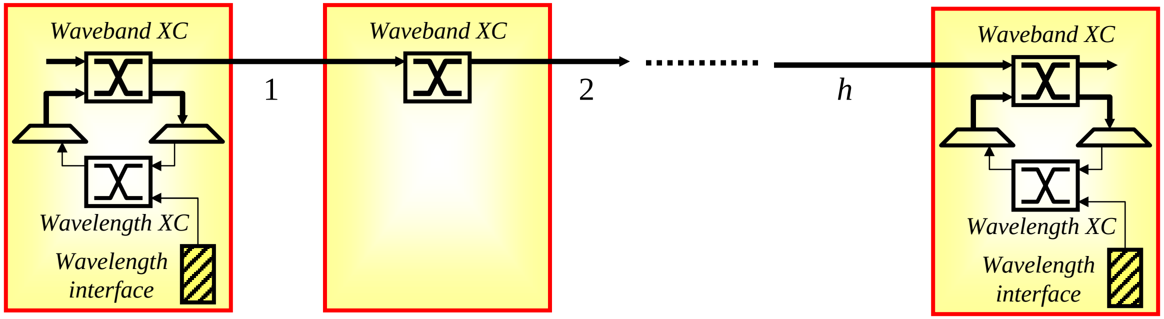
- In the simple case, wavelength circuits (lightpaths) with the same source and destination nodes are grouped together in a waveband
- Logically, these lightpaths can be thought of as being routed on a *logical link* made of one or more waveband circuits (bandpaths)
- Transit nodes switch the signal at waveband level and therefore take only two optical ports for each switched waveband
- End nodes have to terminate the waveband and therefore need more ports



P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Analysis - Single Logical Hop

- Variables: b : number of wavelengths in each waveband
  h : average number of physical hops
  u : average waveband utilization



- Number of optical ports (band + wavelength) if waveband-switched

$$n_b = 2(bu+1) + 2(h-1) + 2(bu+1) = 4bu + 2h + 2$$

- Number of optical ports (wavelength) if wavelength-switched

$$n_w = 2bu + 2bu(h-1) + 2bu = 2bu(h+1)$$

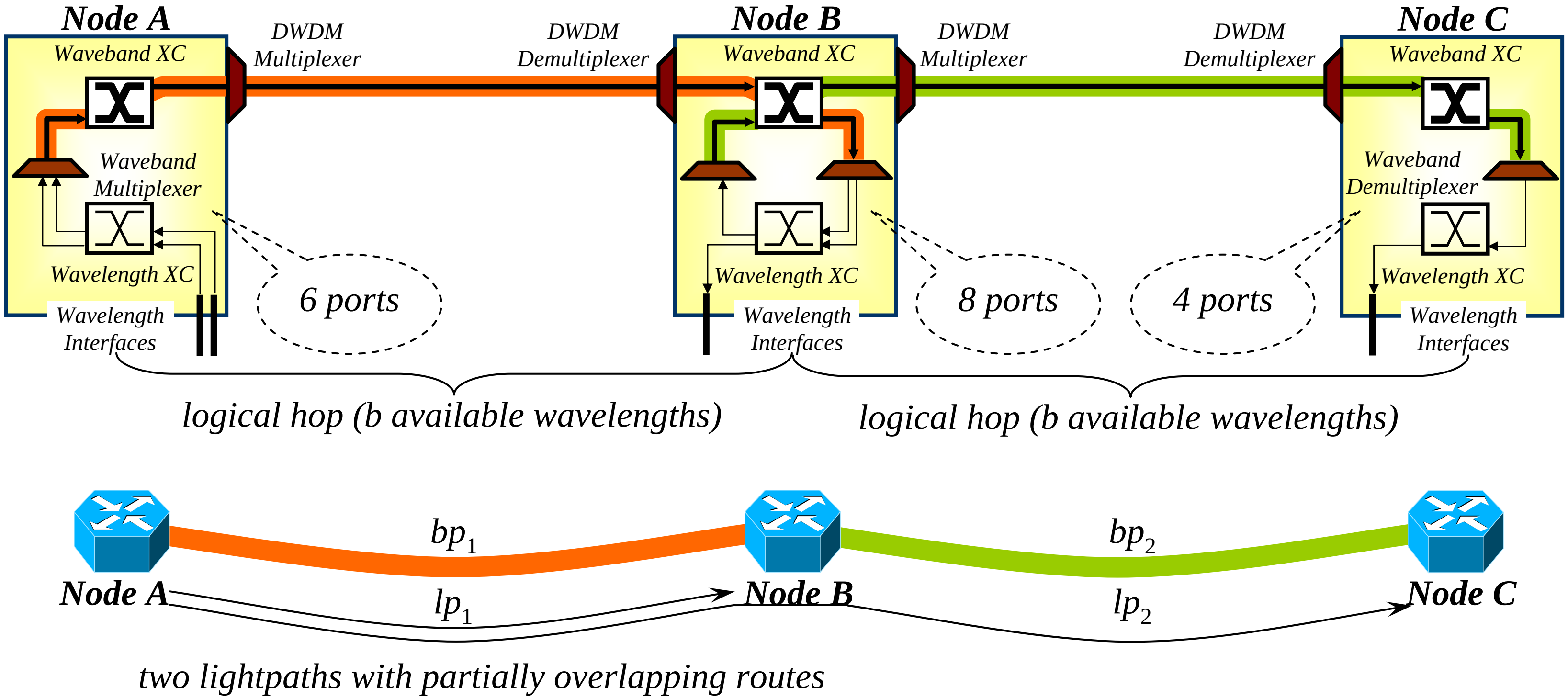
- Waveband switching uses fewer optical ports when

$$\boxed{n_b < n_w \Leftrightarrow bu > \frac{h+1}{h-1} \quad ; h > 1}$$

P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Wavebanding – More Complex Case

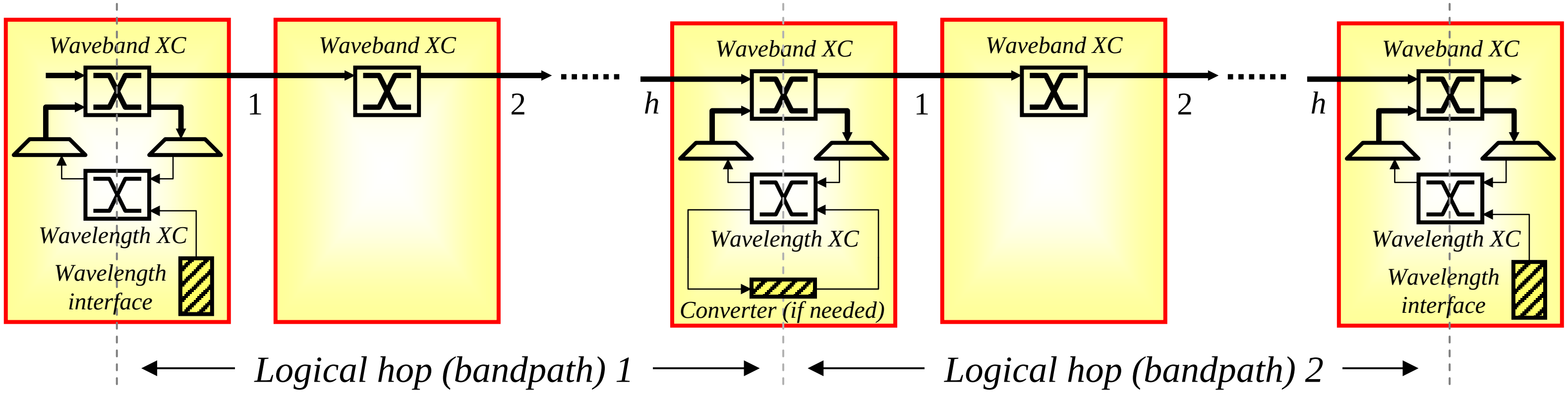
- In the simple case, wavelength circuits (lightpaths) with the same source and destination nodes are grouped together in a waveband
- Logically, these lightpaths can be thought of as being routed on a *logical link* made of one or more waveband circuits (bandpaths)
- Transit nodes switch the signal at waveband level and therefore take only two optical ports for each switched waveband
- End nodes have to terminate the waveband and therefore need more ports



P. Torab et al., *Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006*

Analysis - Multiple Logical Hops

- Variables: b, u and h same as in the single-hop case
  l : number of logical hops per circuit (figure shows l=2)
  p : probability of wavelength conversion when crossing logical hops



- Number of optical ports:

$$n_b = [2(bu+1)+2(h-1)+2(bu+1)]+(l-1)[2(bu+p)+2(h-1)+2(bu+1)]$$
$$= 2l(2bu+h+p)+2(1-p)$$
$$n_w = 2bu+2bu(lh-1)+2bu = 2bu(lh+1)$$

- Waveband switching uses fewer optical ports when

$$\boxed{n_b < n_w \Leftrightarrow bu > \frac{l(h+p)+(1-p)}{1+l(h-2)} \quad ; h > 2-\frac{1}{l}}$$

LAMBDA OpticalSystems

P. Torab et al., *Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006*

Waveband Switching Efficiency

- Waveband switching efficiency is the relative saving in number of optical ports when waveband switching is performed instead of wavelength switching:

$$e = \frac{n_w - n_b}{n_w} = 1 - \frac{n_b}{n_w}$$

- Waveband switching efficiency for single and multiple logical hops

Single logical hop→ $e = 1 - \frac{n_b}{n_w} = \frac{h-1}{h+1} - \frac{1}{bu} \quad ; h > 1$

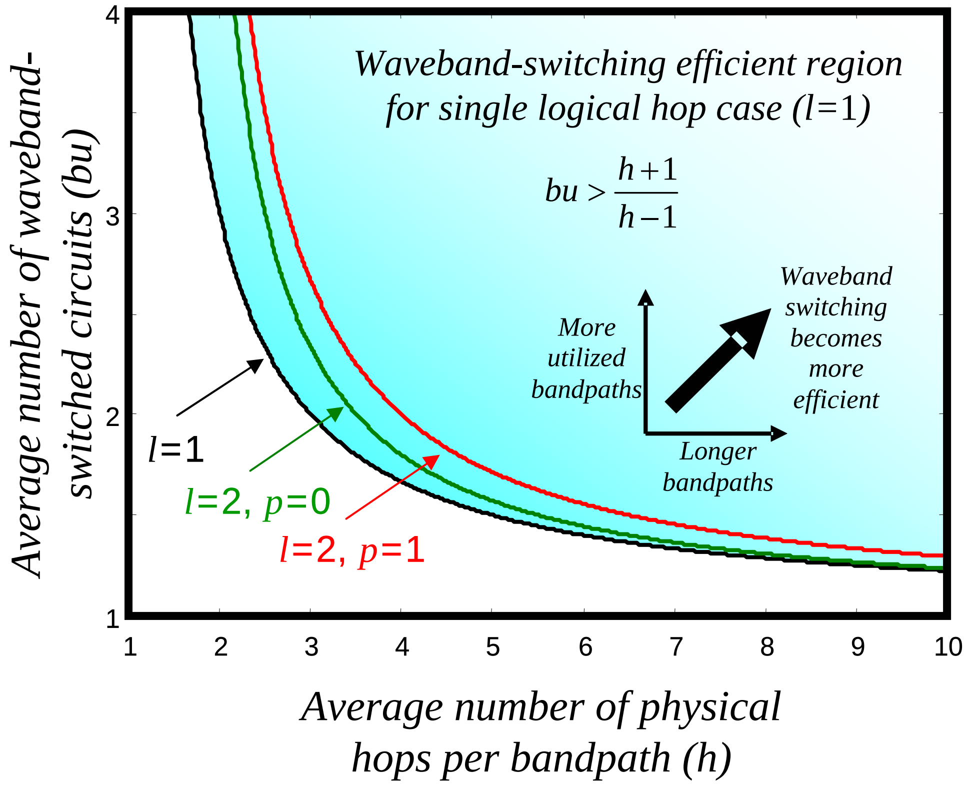
Multiple logical hops→ $e = 1 - \frac{n_b}{n_w} = \frac{lh+1-2l}{lh+1} - \frac{1}{bu} - \frac{(l-1)p}{bu(lh+1)} \quad ; h > 2 - \frac{1}{l}$

- Notes:
  - As expected, waveband switching efficiency improves as logical hops in each circuit get longer and fewer (larger h *and* smaller l); it also improves with higher band utilization (larger u), and fewer conversions (smaller p).
  - Efficiency is a function of the product of the waveband size and utilization (bu); for example, efficiency is the same for wavebands of size 8 at 50% utilization and wavebands of size 4 at 100% utilization.

P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Waveband Switching Efficiency Region

- The efficiency condition $n_b < n_w$ (or $e > 0$) defines a region in the two-dimensional bu-h plane where waveband switching is more efficient:



Other examples of breakeven points and port savings

$l=2$, $p=1$

$bu=3$, $h=3$ → $e=4.8\%$

$bu=4$, $h=3$ → $e=14.3\%$

$l=3$, $p=1$

$bu=3$, $h=3$ → $e=0.0\%$

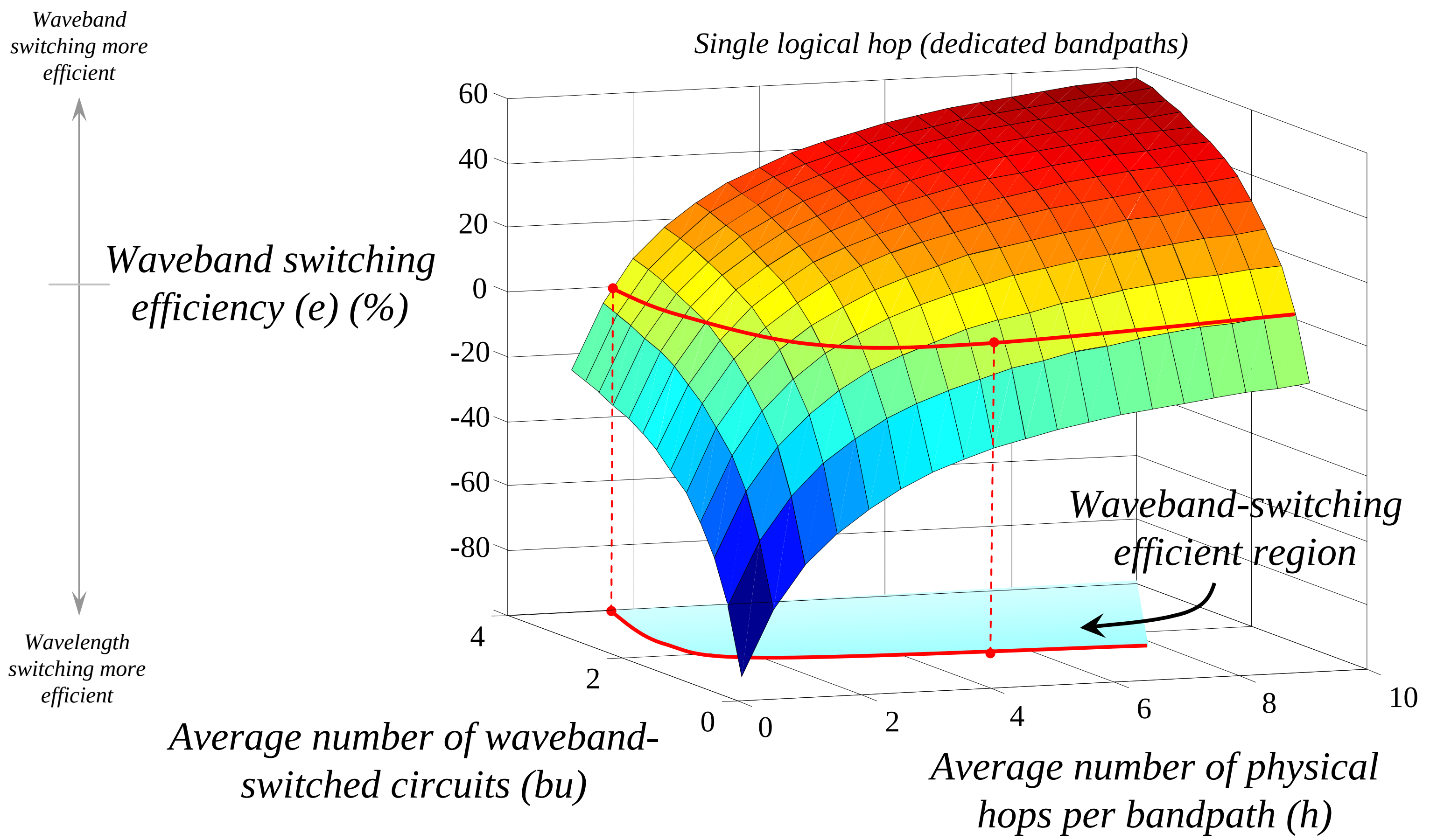
$bu=4$, $h=3$ → $e=10.0\%$

$bu=3$, $h=4$ → $e=15.4\%$

$bu=4$, $h=4$ → $e=25.0\%$

Waveband switching can still be efficient even with 100% wavelength conversion as long as bandpaths are sufficiently long and packed!

Another View of Switching Efficiency



P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Case Study: A Carrier Network Model

- Network : 79 nodes, 137 links, complex mix of STM-1/4/16/64 circuits, 1+1 protection on fiber-disjoint paths for almost the entire demand
- Assumptions
  - Base traffic, as well as x2 and x5 growth scenarios
  - 10G capacity per wavelength (no 40G wavelengths)
  - Single as well as multiple logical hop design (dedicated and shared bandpaths)
  - Growth rate equally applied across STM-1/4/16 and STM-64 demand
  - Scaled up STM-1/4/16 demands are aggregated into new STM-64 circuits, accelerating the STM-64 demand growth; for example, under x2 growth, 36 STM-1 and 2 STM-64 circuits between endpoints A and B will turn into 36*2-64=8 STM-1 and 2*2+1=5 STM-64 circuits, therefore STM-64 circuits have more than doubled

- The analysis is about switching efficiency in terms of optical port usage, and is not affected by change in transmission parameters (e.g., number of wavelengths/wavebands per fiber)
- The studies are sample studies to demonstrate the waveband switching efficiency – they do not necessarily represent optimal designs for each scenario

Dedicated Bandpaths - Base Demand

Results at x1

DWDM links: 215

Bandpaths: 294

2.5G/10G demand:

188 1+1 protected (external)

239 unprotected (internal)

615 total

Performance

$b=4$

$h=3.820$

$u=0.523$

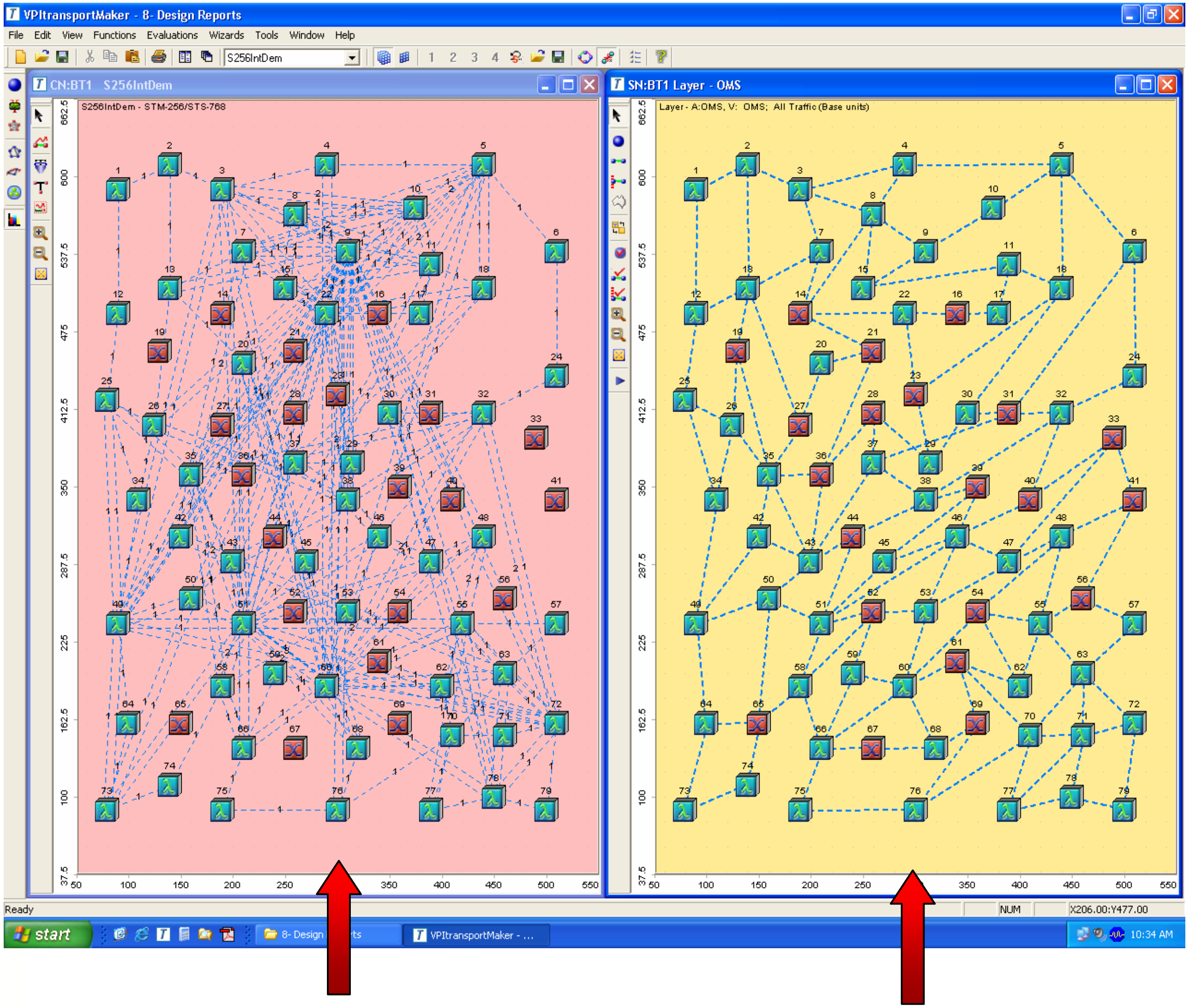
$l=1$ (single logical hop)

$n_b=9.004$

$n_w=10.083$

→ Switching efficiency

$e=10.7\%$



Bandpaths

Physical Links

Dedicated Bandpaths – X2 Growth

Results at x2

DWDM links: 271

Bandpaths: 413

2.5G/10G demand:

341 1+1 protected (external)

316 unprotected (internal)

998 total

Performance

$b=4$

$h=3.890$

$u=0.604$

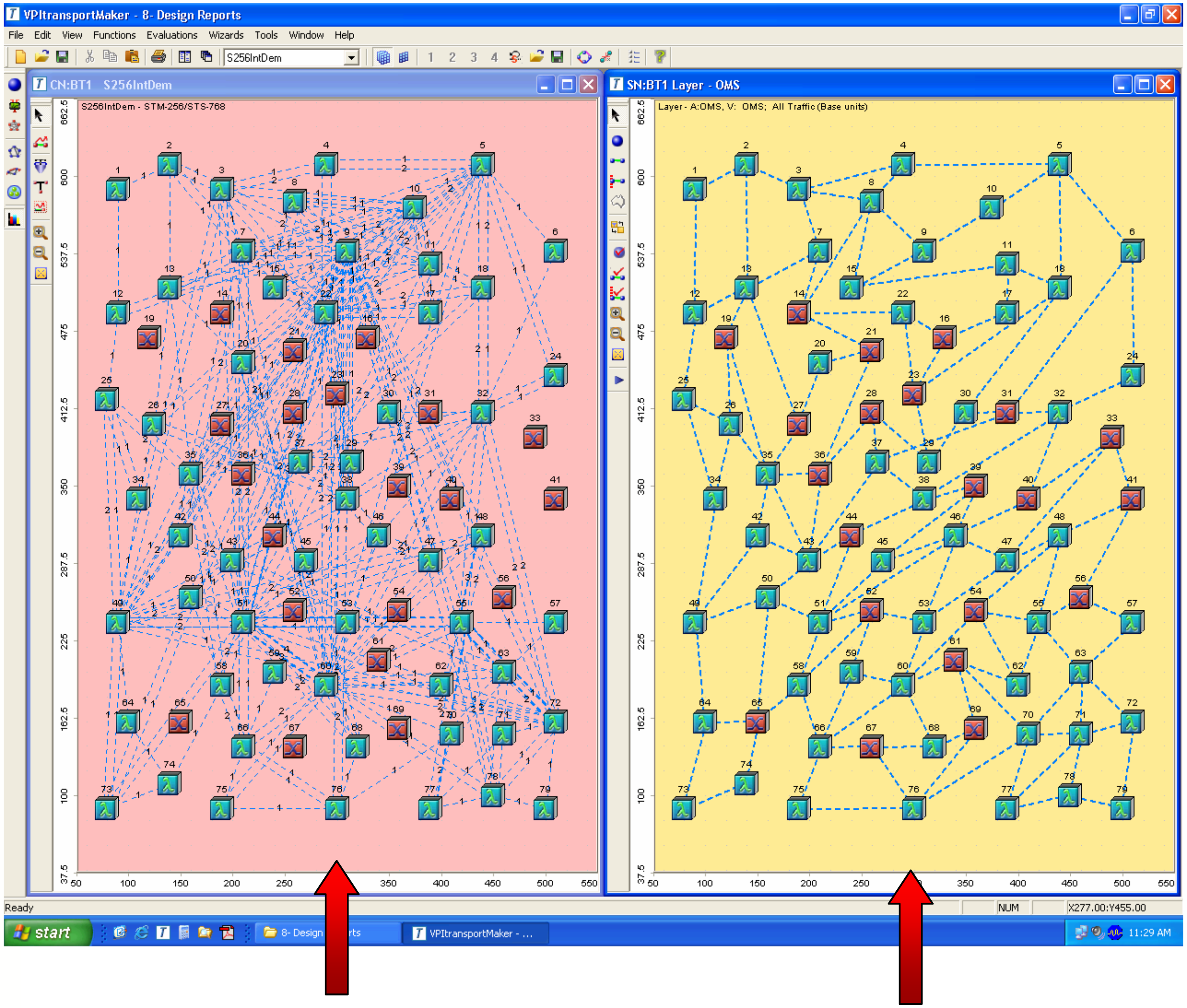
$l=1$ (single logical hop)

$n_b=9.723$

$n_w=11.816$

→ Switching efficiency

$e=17.7\%$



Bandpaths

Physical Links

P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Dedicated Bandpaths – X5 Growth

Results at x5

DWDM links: 563

Bandpaths: 857

2.5G/10G demand:

890 1+1 protected (external)

305 unprotected (internal)

2085 total

Performance

$b=4$

$h=4.600$

$u=0.608$

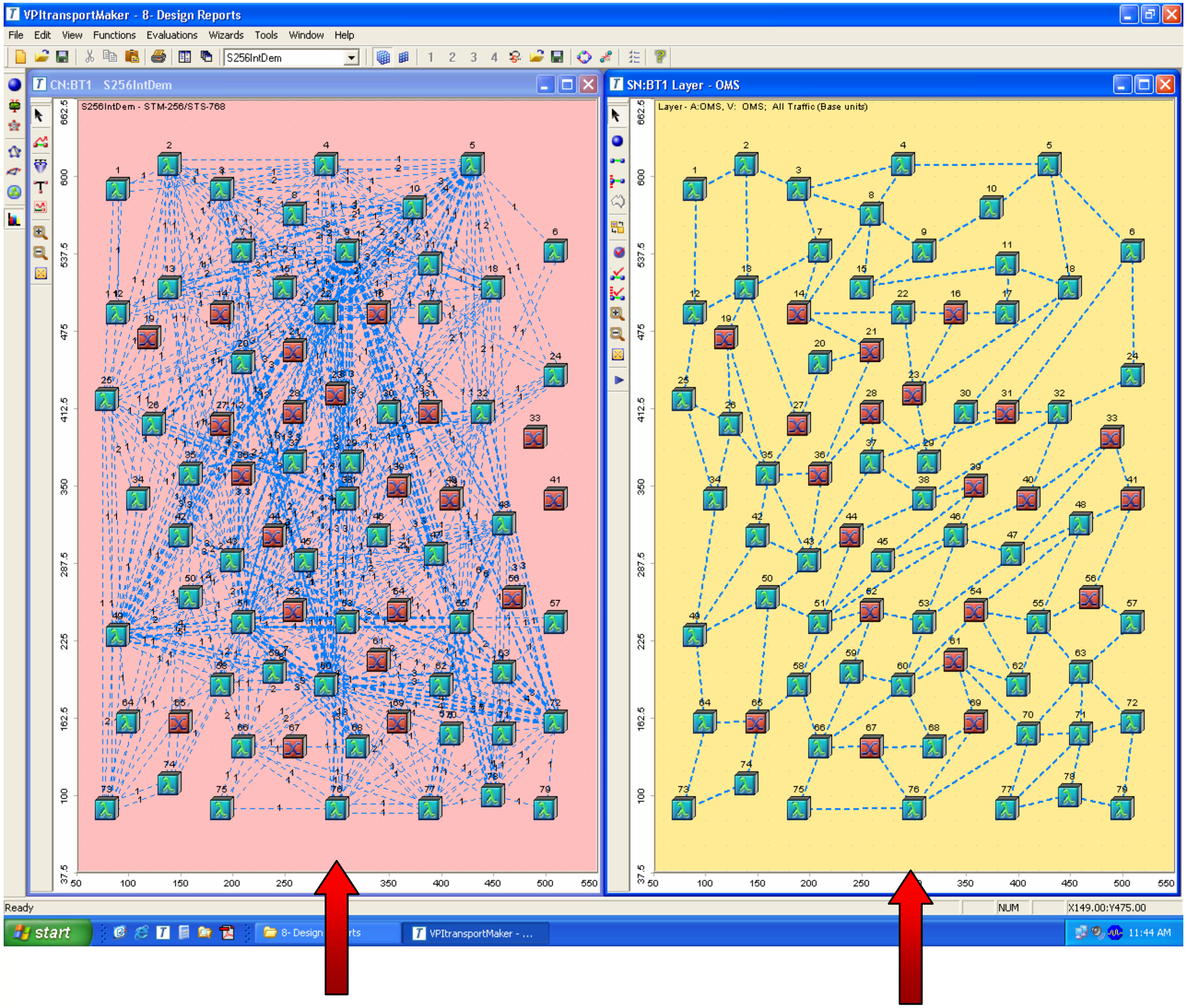
$l=1$ (single logical hop)

$n_b=10.464$

$n_w=13.619$

→ Switching efficiency

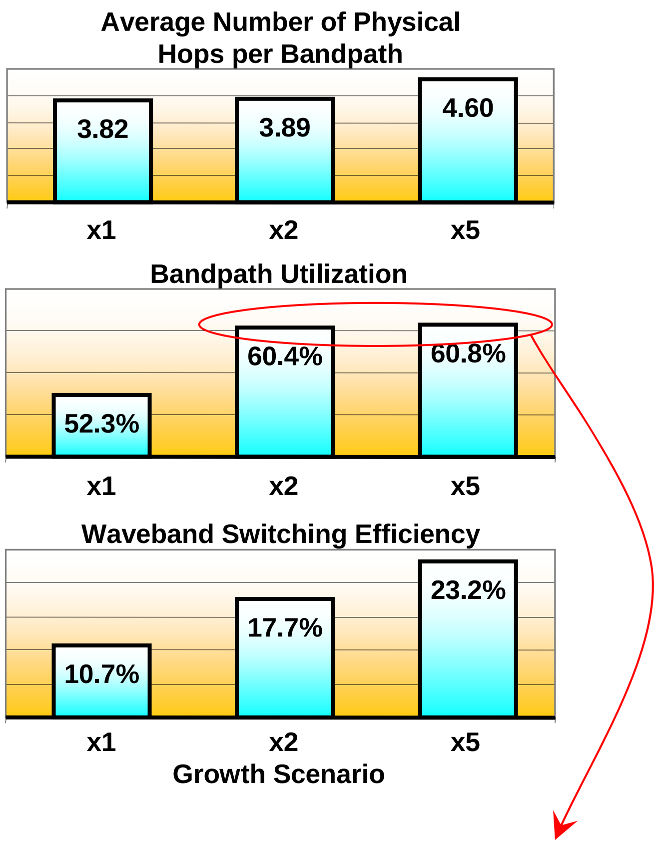
$e=23.2\%$

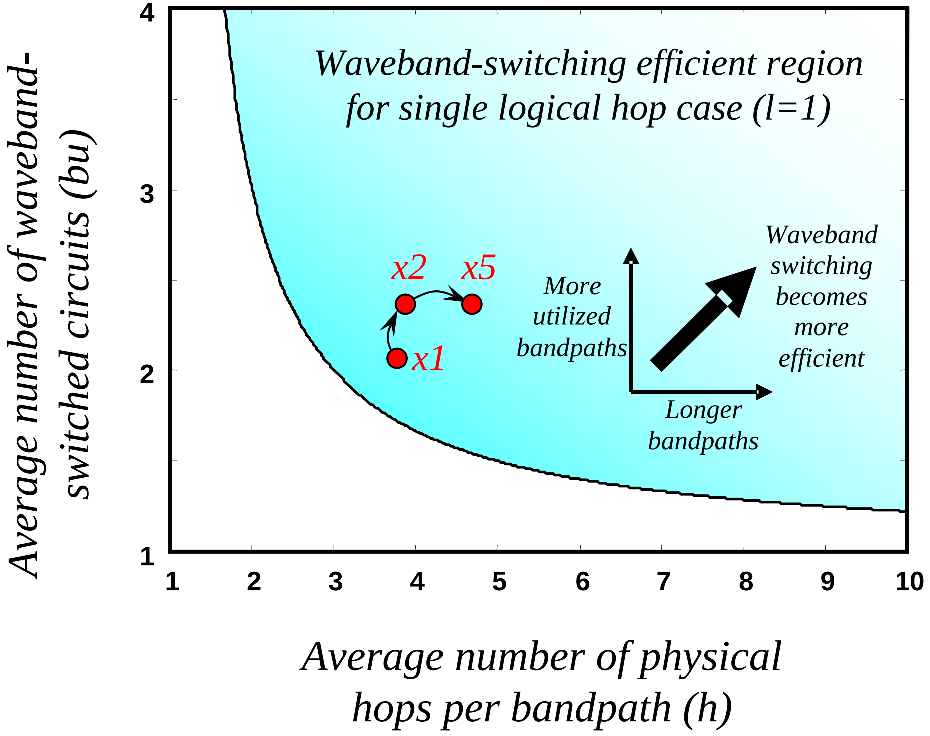


Bandpaths

Physical Links

Dedicated Bandpaths - Summary





Waveband modularity effect

P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Summary – Dedicated and Shared Bandpaths

- Same detailed design process was repeated assuming that bandpaths can be shared. Simple heuristics were used for waveband and wavelength assignment.

Probably can be improved through better waveband assignment

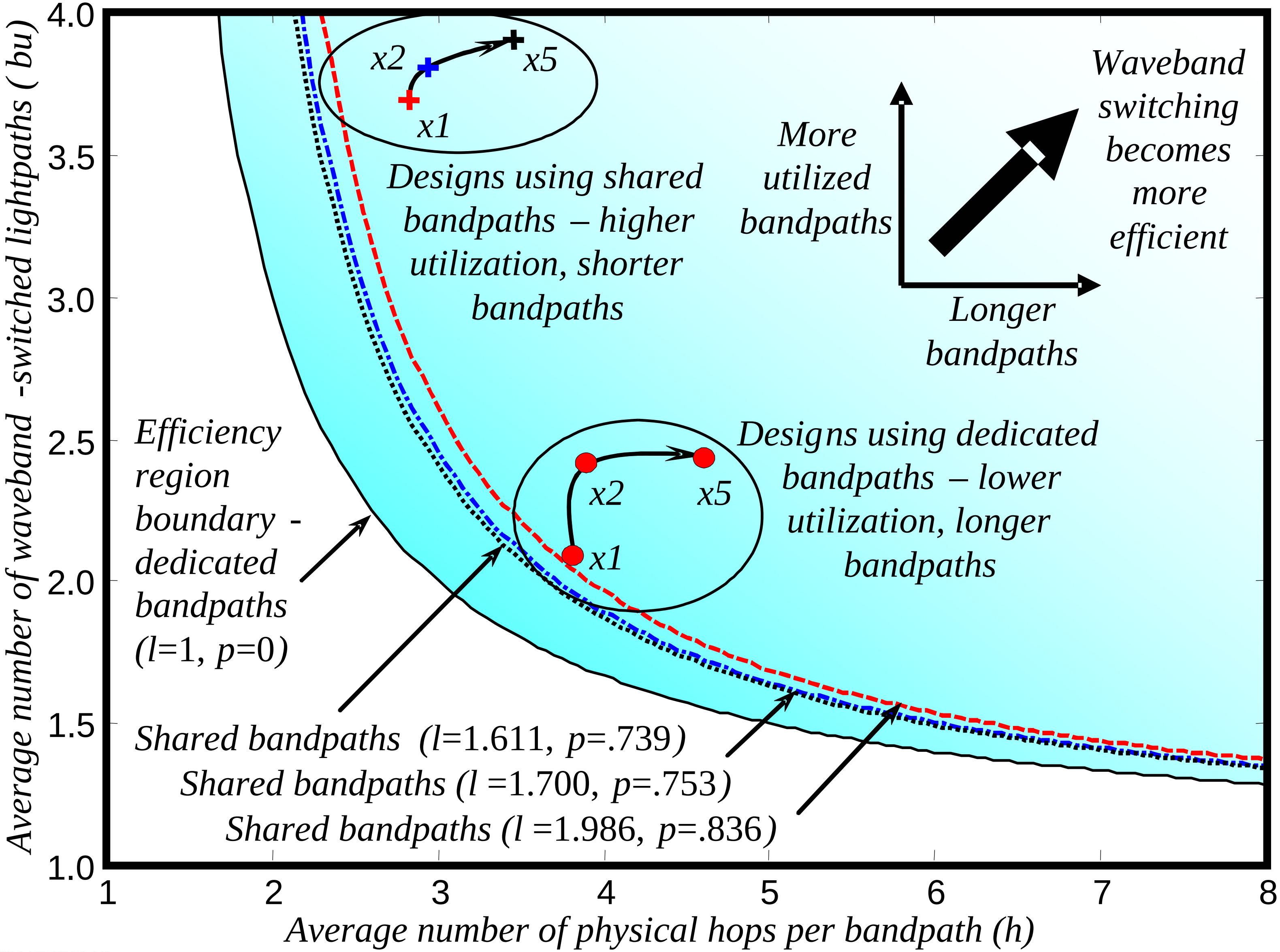
design approach	*traffic growth*	*STM-64 circuits*		*throughput (Tbps)*	***b***	***u***	***h***	***l***	***p***	n_w	n_b	***e***
		1+1	*unprotected*									
shared bandpaths	*x1*	188	178	5.540	4	0.923	2.820	1.986	0.836	48.738	44.179	**9.35%**
	x2	341	246	9.280	4	0.951	2.945	1.700	0.753	45.698	38.934	**14.8%**
	x5	890	239	20.190	4	0.975	3.457	1.611	0.739	51.240	39.173	**23.6%**
dedicated bandpaths	*x1*	188	239	6.150	4	0.523	3.820	1.000	0.000	20.167	18.008	**10.7%**
	x2	341	316	9.980	4	0.604	3.890	1.000	0.000	23.628	19.444	**17.7%**
	x5	890	305	20.850	4	0.608	4.600	1.000	0.000	27.238	20.928	**23.2%**

No need for wavelength conversion, always one logical hop with dedicated bandpaths

LAMBDA OpticalSystems

P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Design Summary – Alternate View



Designs using shared bandpaths – higher utilization, shorter bandpaths

More utilized bandpaths

Longer bandpaths

Waveband switching becomes more efficient

Designs using dedicated bandpaths – lower utilization, longer bandpaths

Efficiency region boundary - dedicated bandpaths (l=1, p=0)

Shared bandpaths (l=1.611, p=.739)

Shared bandpaths (l =1.700, p=.753)

Shared bandpaths (l =1.986, p=.836)

P. Torab et al., Waveband Switching Efficiency in WDM Networks: Analysis and Case Study, OFC/NFOEC 2006

Conclusion

- We analyzed waveband switching efficiency for the multigranular optical crossconnect architecture, unrestricted waveband sharing, and *considering the impact of need for wavelength conversion*

- We have done a comprehensive study of a realistic network, with lots of subrate traffic (which adversely affects switching efficiency), yet waveband switching was still found to be very effective

- Traditional observations hold that efficiency improves as bandpath utilization or number of hops in each bandpath increase, however, the effect of wavelength conversion on efficiency does not seem to be major, i.e., waveband switching can be still efficient when wavelength conversion ratio is high (80%+), as long as wavebands are well utilized

- Joint wavelength/waveband routing design is a nice research problem, but what is more practical at this point is wavebanding and waveband assignment (assuming wavelength routes are given), because wavelength routing is constrained by subrate traffic and diversity requirements

Thank You – Questions

- Visit our booth (**Booth No. 3503**) to learn about our multigranular optical crossconnect with integrated DWDM and waveband/wavelength switching, as well as our other products.

LAMBDA OpticalSystems

www.lambdaopticalsystems.com

Booth No. 3503