Energy Limitations on Optical Data Transport and Switching

Rod Tucker
University of Melbourne

ceet centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

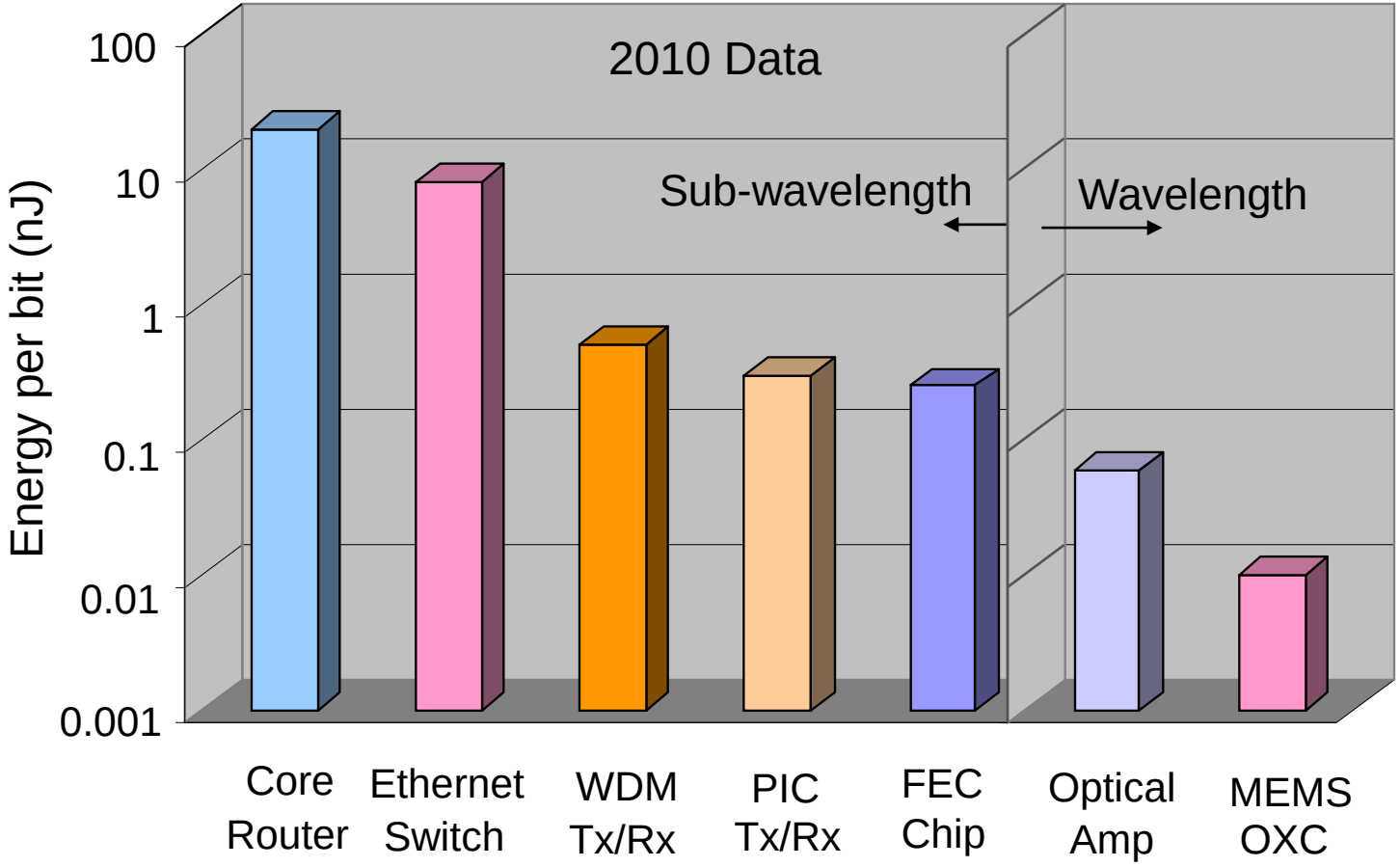
Summary

- Top-down estimate of energy consumption of the Internet
  - Projections of current trends (BAU)
    - Switches and routers
    - Optical transport

- Bottom-up estimate
  - Based on theoretical and practical lower bounds
    - Transport energy
    - Switching energy
    - Network energy

- Putting the GreenTouch factor of 1000 into context

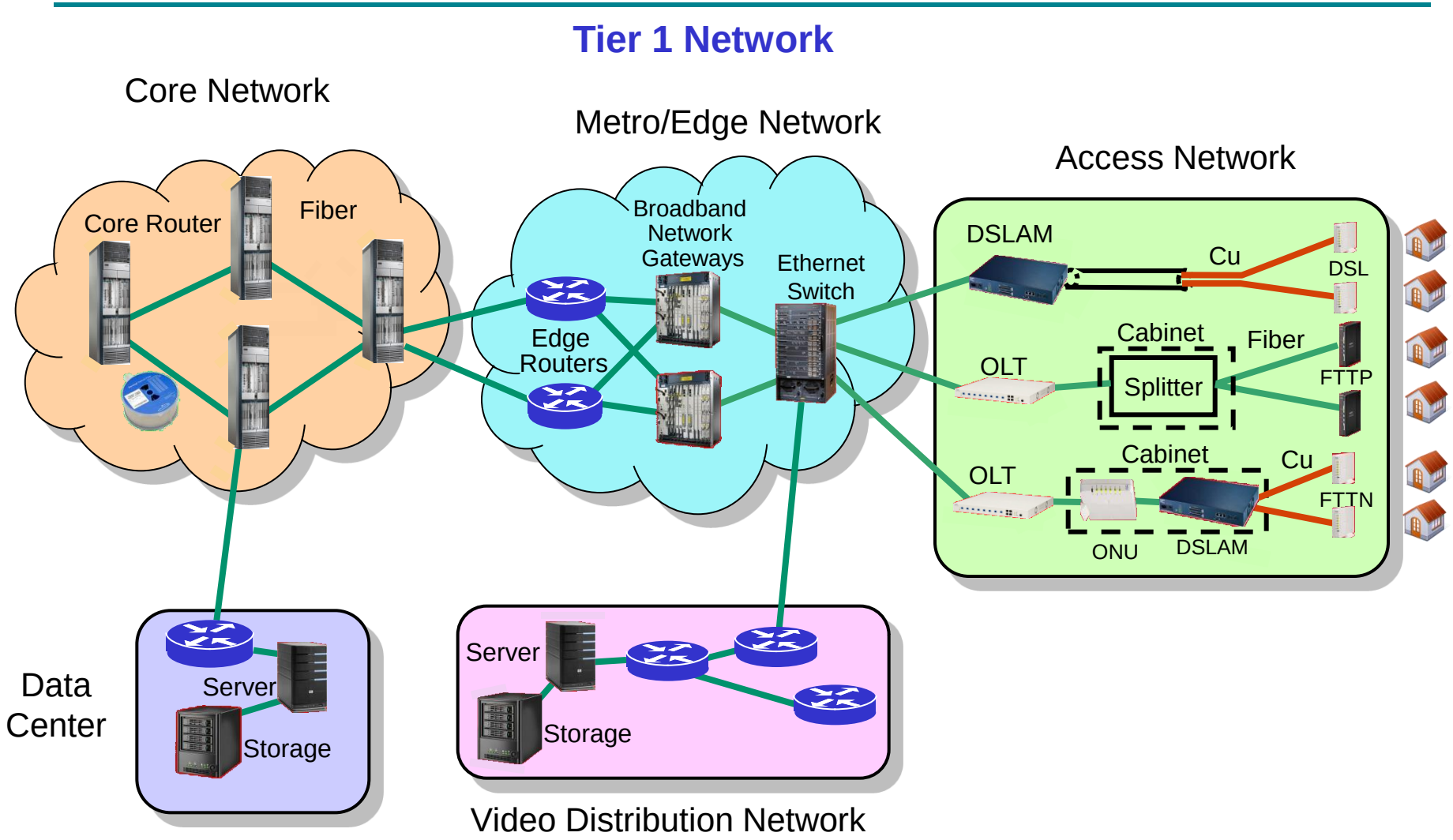
Top-Down Analysis



OLT:	50 nJ/b
DSL Modem:	500 nJ/b
Set-top Box:	1000 nJ/b
HD IPTV:	10,000 nJ/b

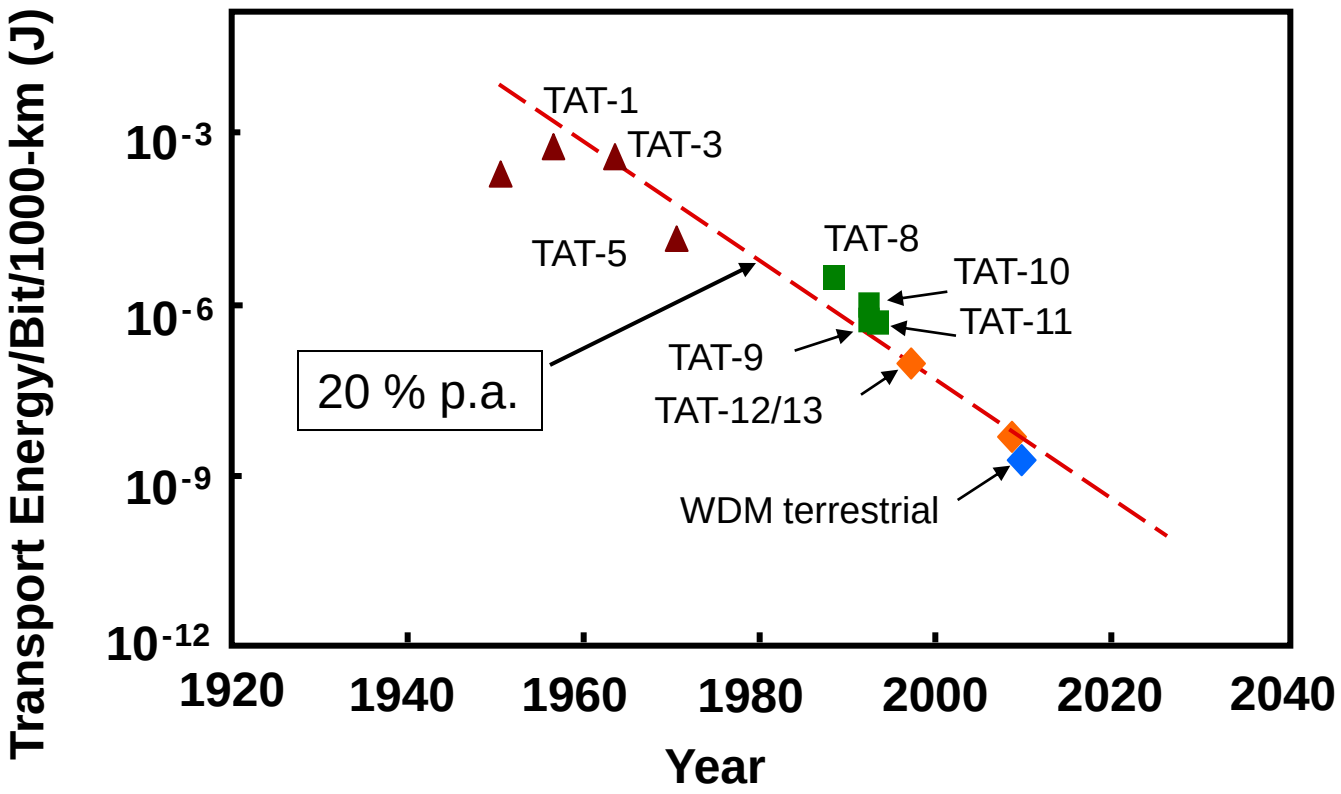
ceet centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Network Energy Model



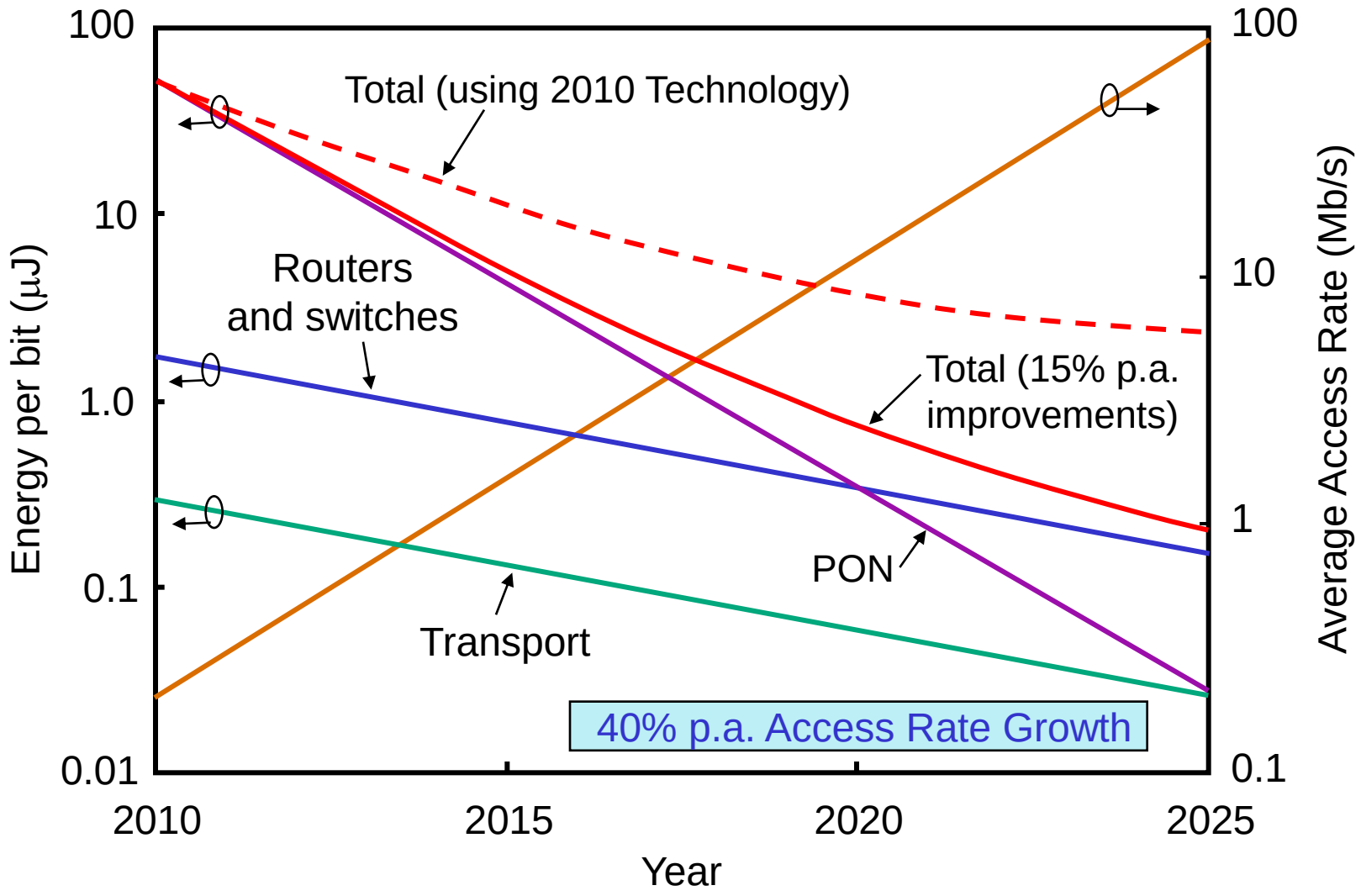
ceet centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Efficiency Trends – Transport Systems



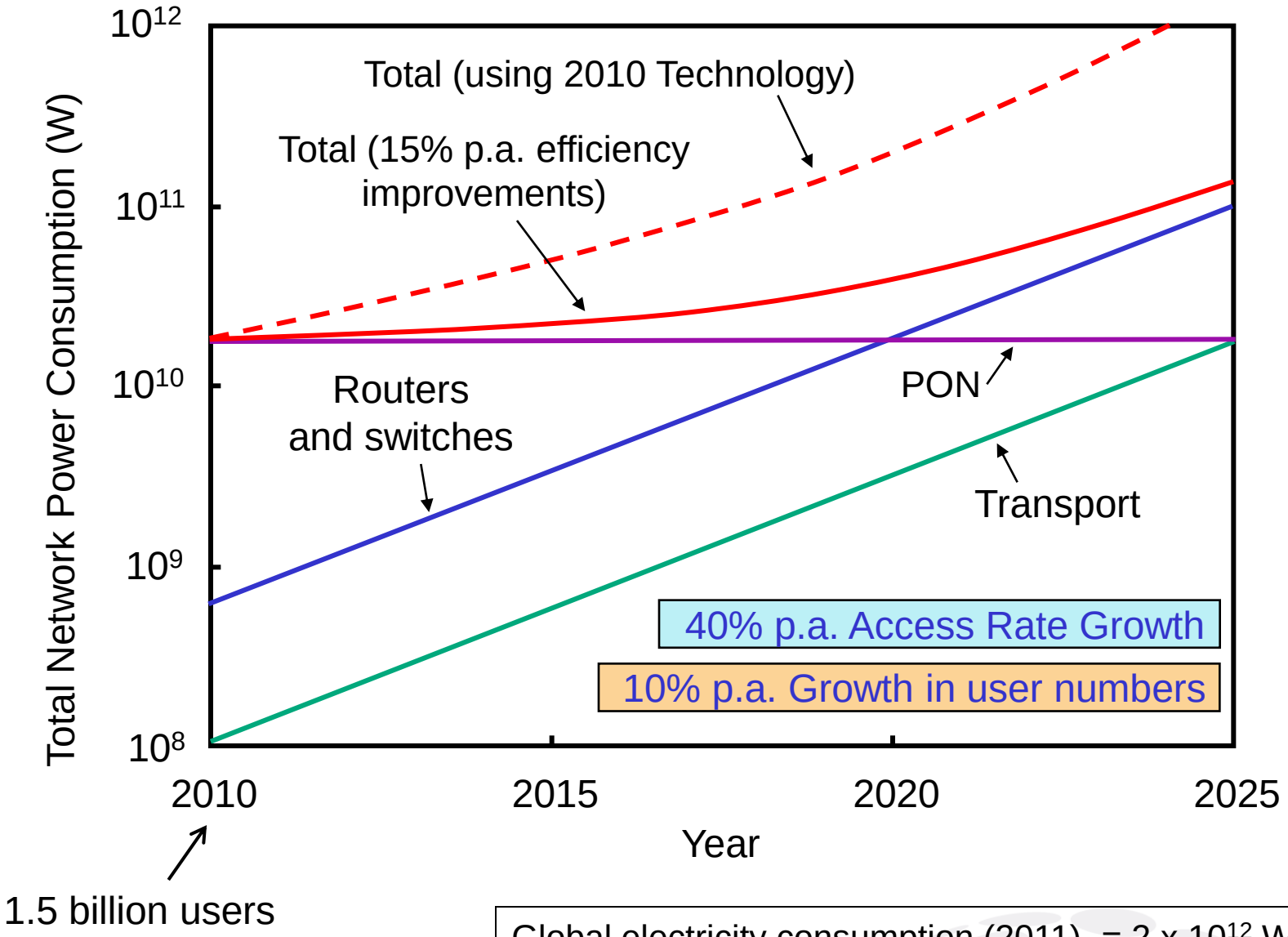
20% p.a. efficiency improvement in routers	(Neilson, JSTQE, 2006)
13% p.a. efficiency improvement in routers	(Tamm, BLTJ, 2010)
15% p.a. efficiency improvements in transport	(Han, IEEE Comms. Mag. 2010)

Top-Down Analysis



ceet centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Global Network Energy Consumption



Global electricity consumption (2011) = 2×10^{12} W

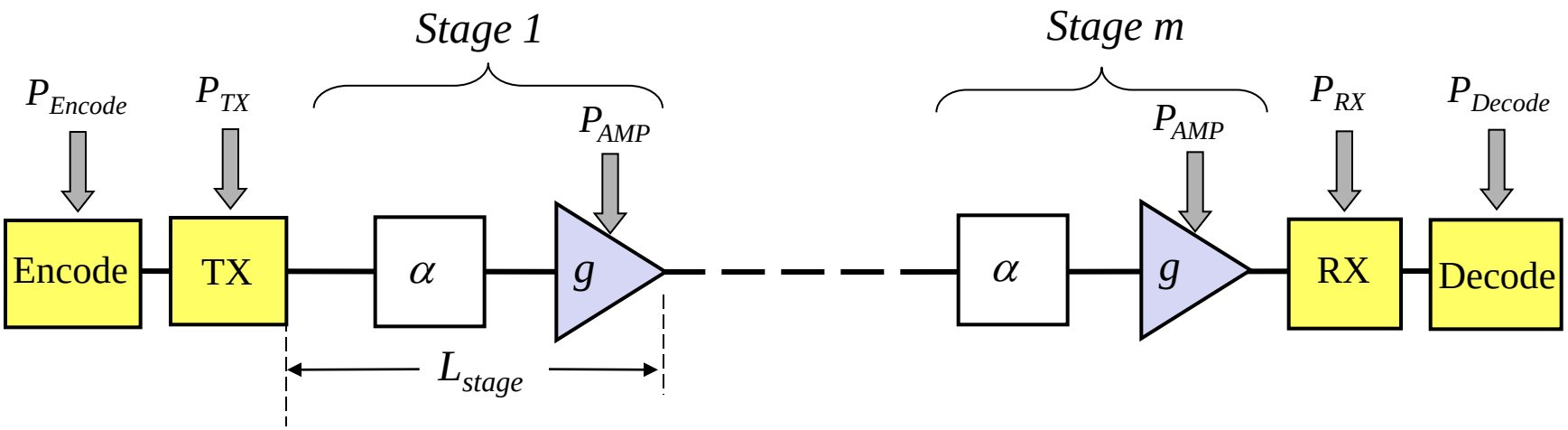
Summary

- Top-down estimate of energy consumption of the Internet
  - Projections of current trends
    - Switches and routers
    - Optical transport

- Bottom-up estimate
  - Based on theoretical and practical lower bounds
    - Transport energy
    - Switching energy
    - Network energy

- Putting the GreenTouch factor of 1000 into context

Lower Limit on Optical Transport Energy



Total Amplifier Energy per Bit

$$E_{AMP} = \sum \frac{P_{AMP}}{B_r} \cdot \frac{SNR_{bit}\, m^2 e^{\alpha L_{stage}} h\nu}{\eta_{AMP}}$$

Amplifier Efficiency

Total TX/RX Energy per Bit

$$E_{TX/RX} = \frac{P_{Encode} + P_{TX} + P_{RX} + P_{Decode}}{B_r}$$

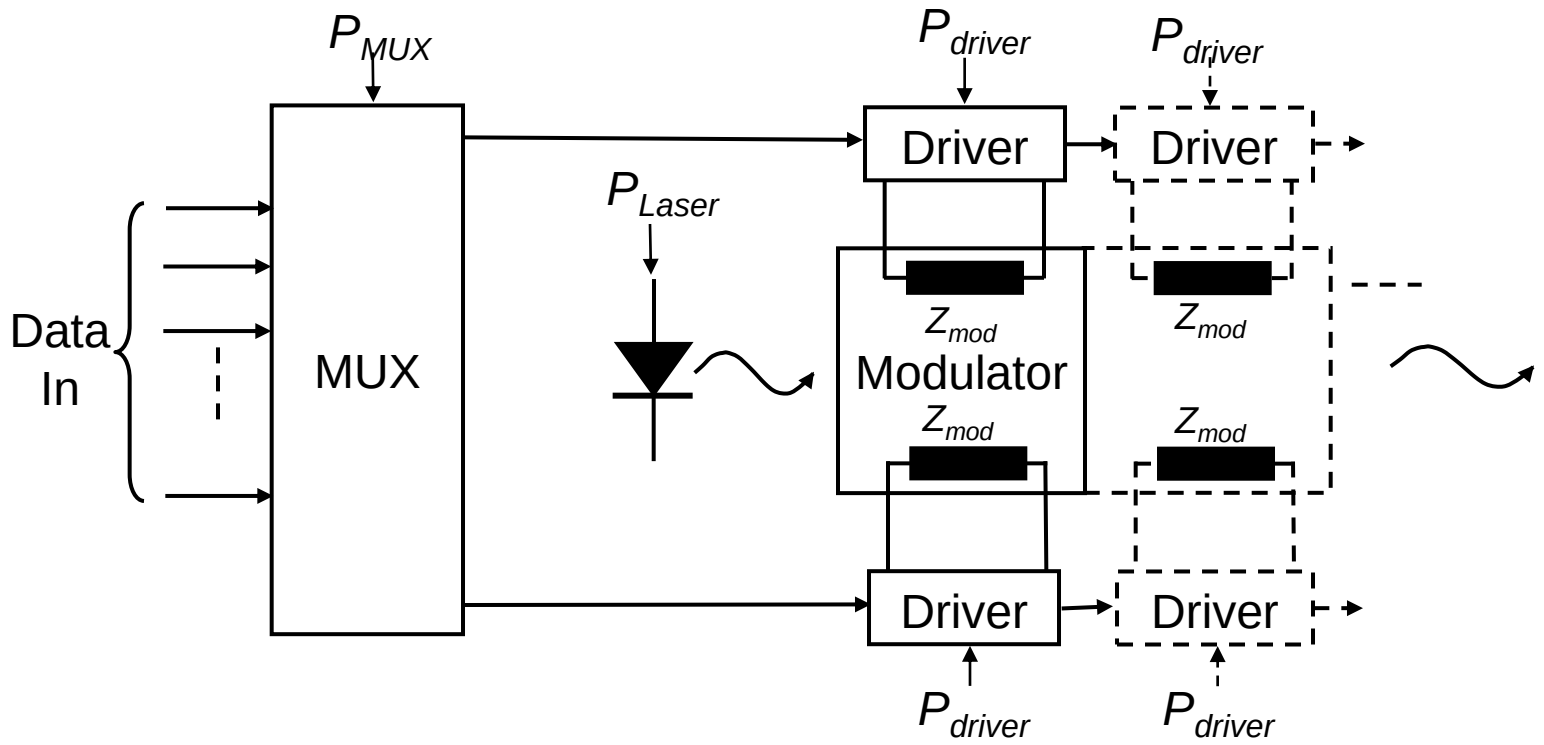
Dominates

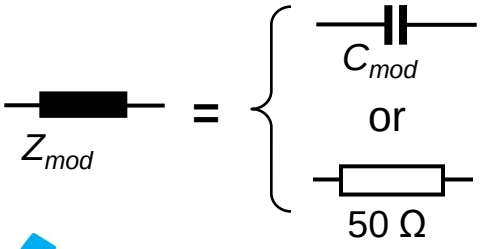
Bit Rate

centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

R. S. Tucker, "Green optical communications - Part I: Energy limitations in transport," *JSTQE,* March/April 2011.

Optical Transmitter





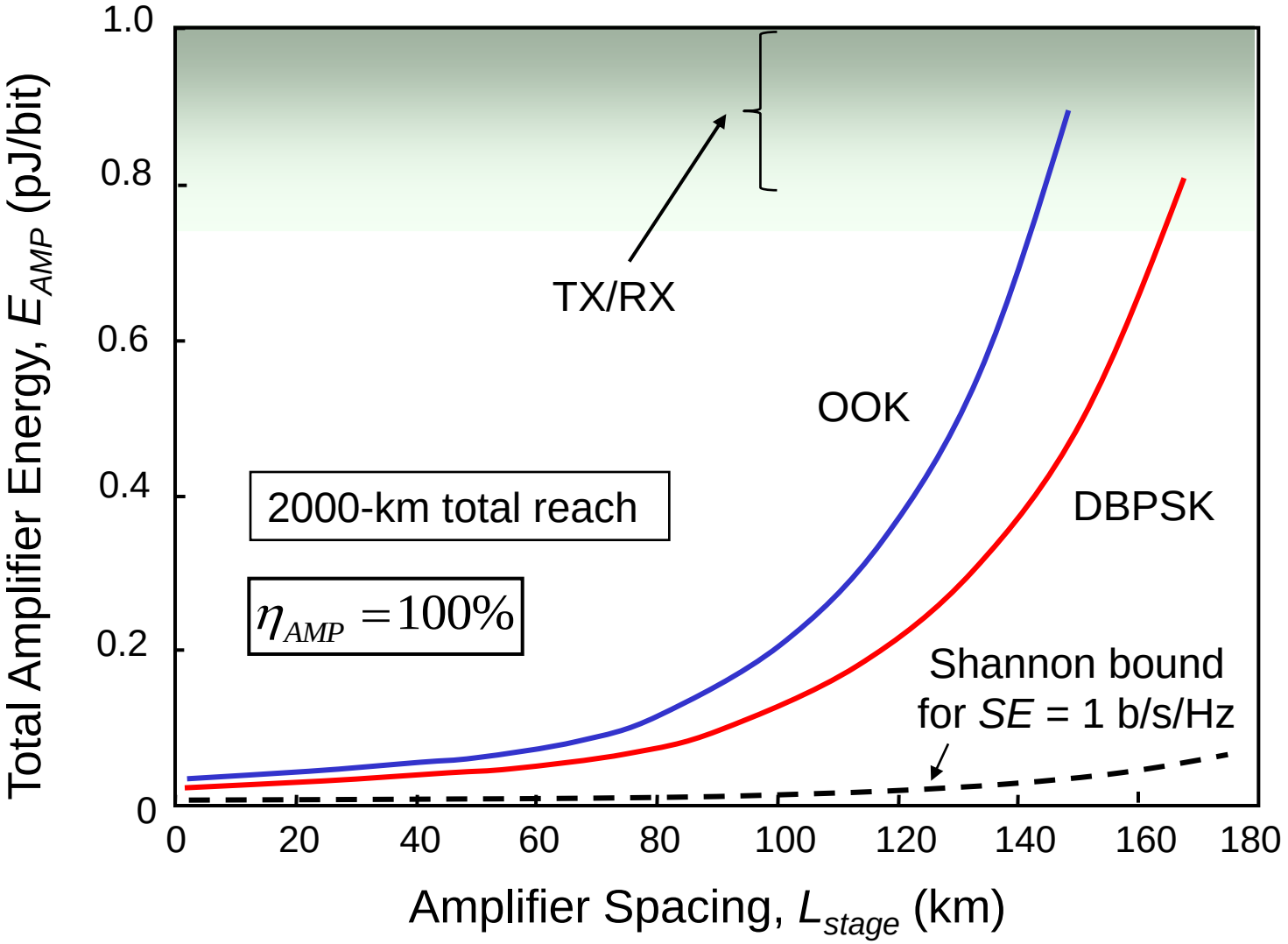
Lumped modulator $E = \frac{1}{2} C_{mod} V_{mod}^2$

Distributed modulator $E = \frac{V_{mod}^2}{50 B_r}$

~ 1 pJ

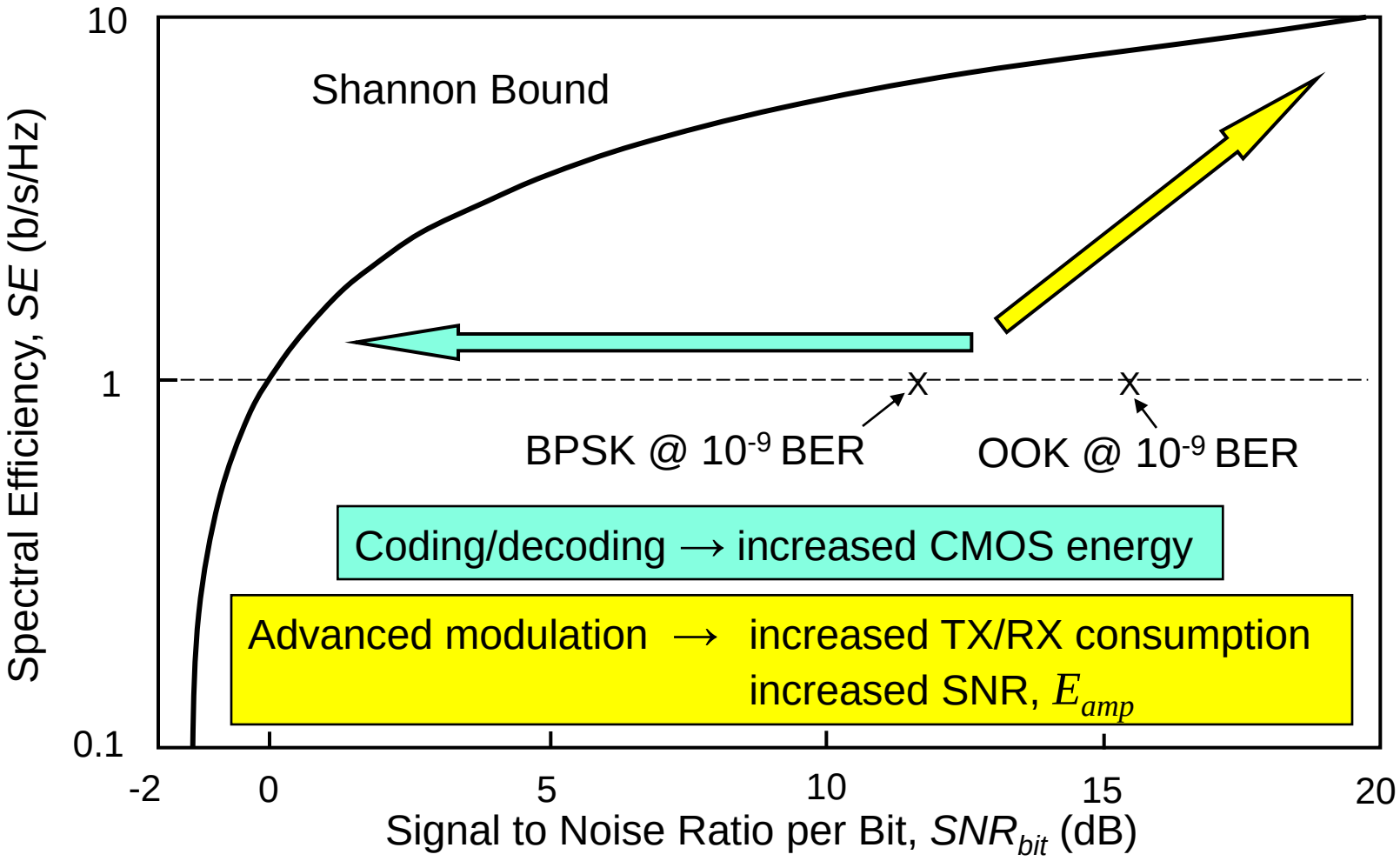
ceet centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Lower Limit on Transport Energy per Bit



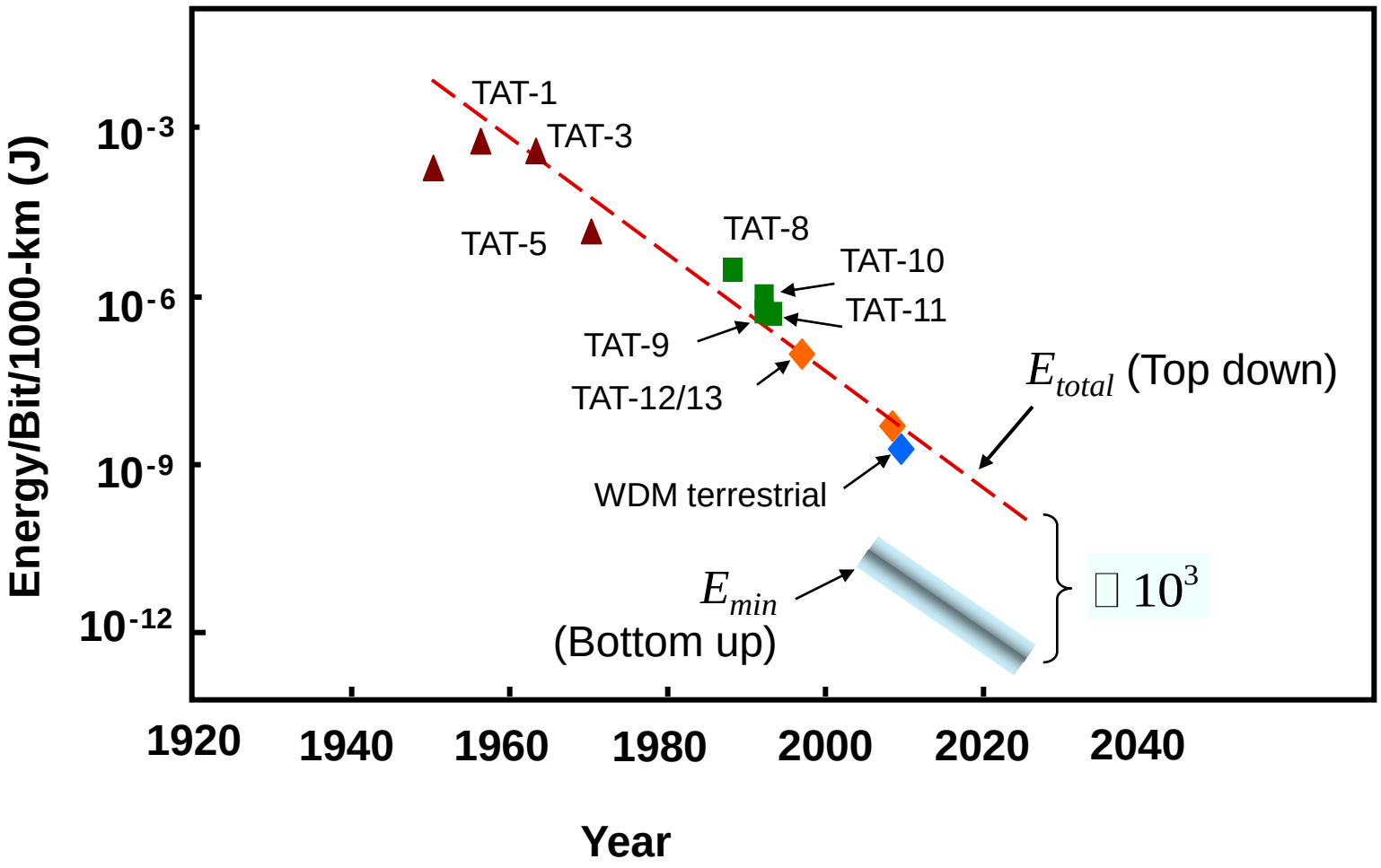
ceet centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Shannon Bound

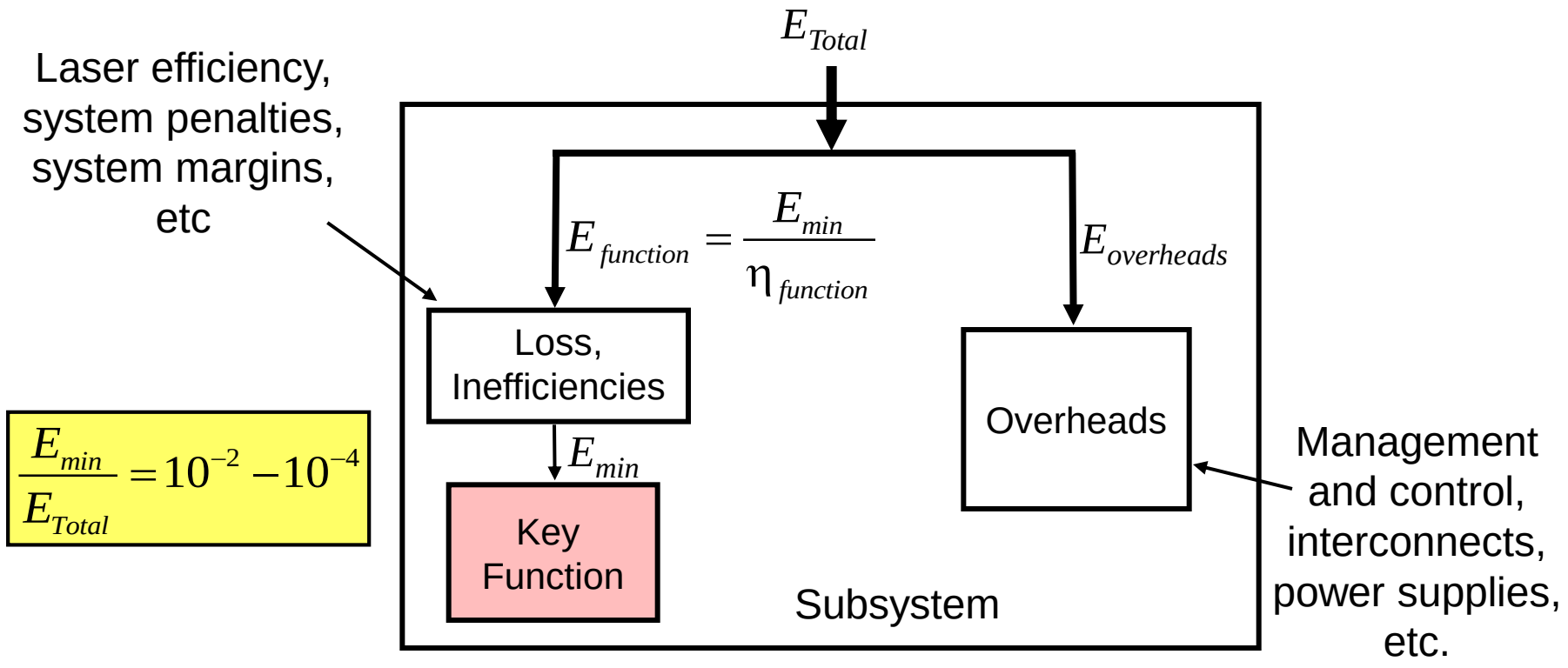


centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Energy per Bit per 1000-km



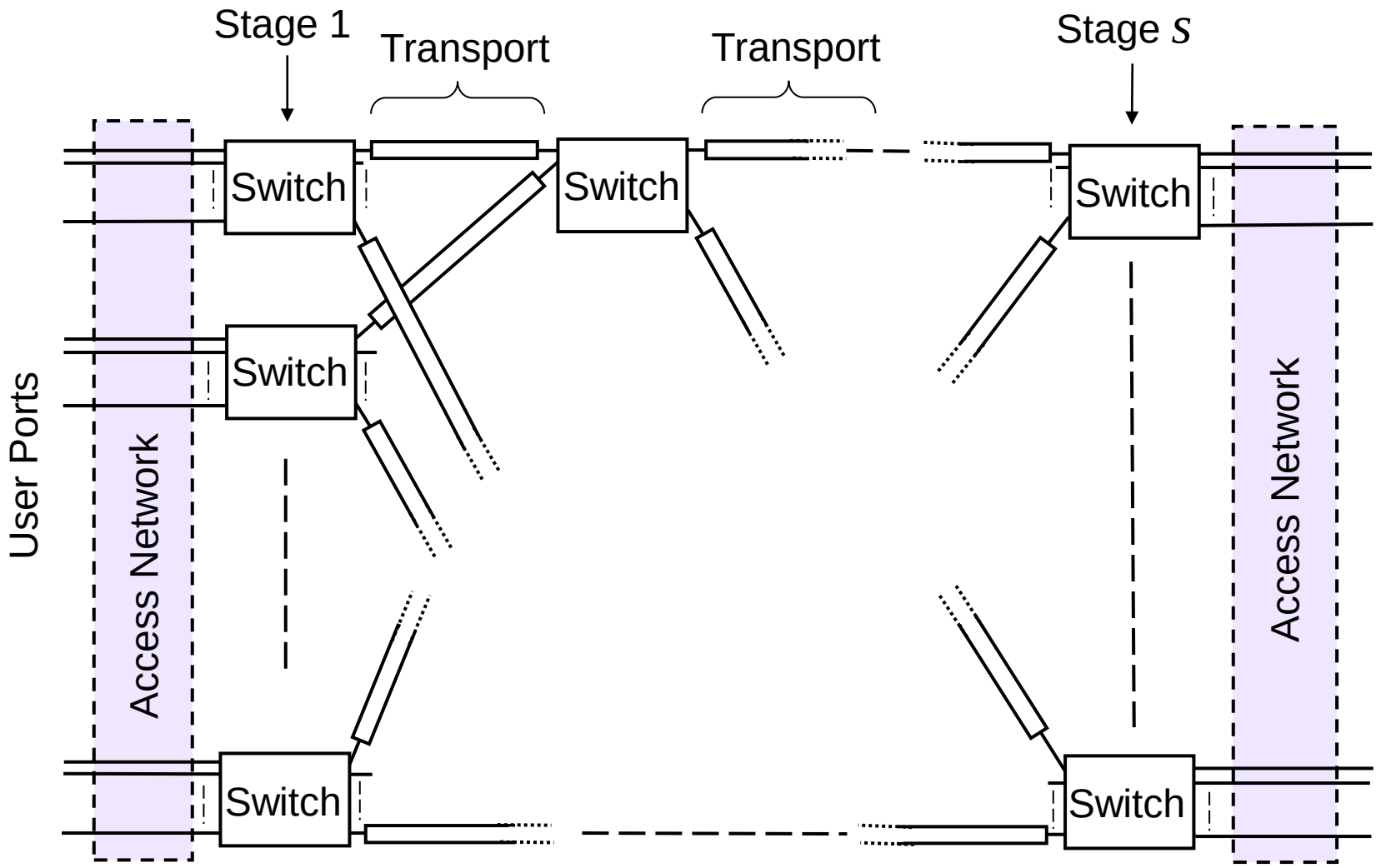
Loss/Efficiencies and Energy Overheads



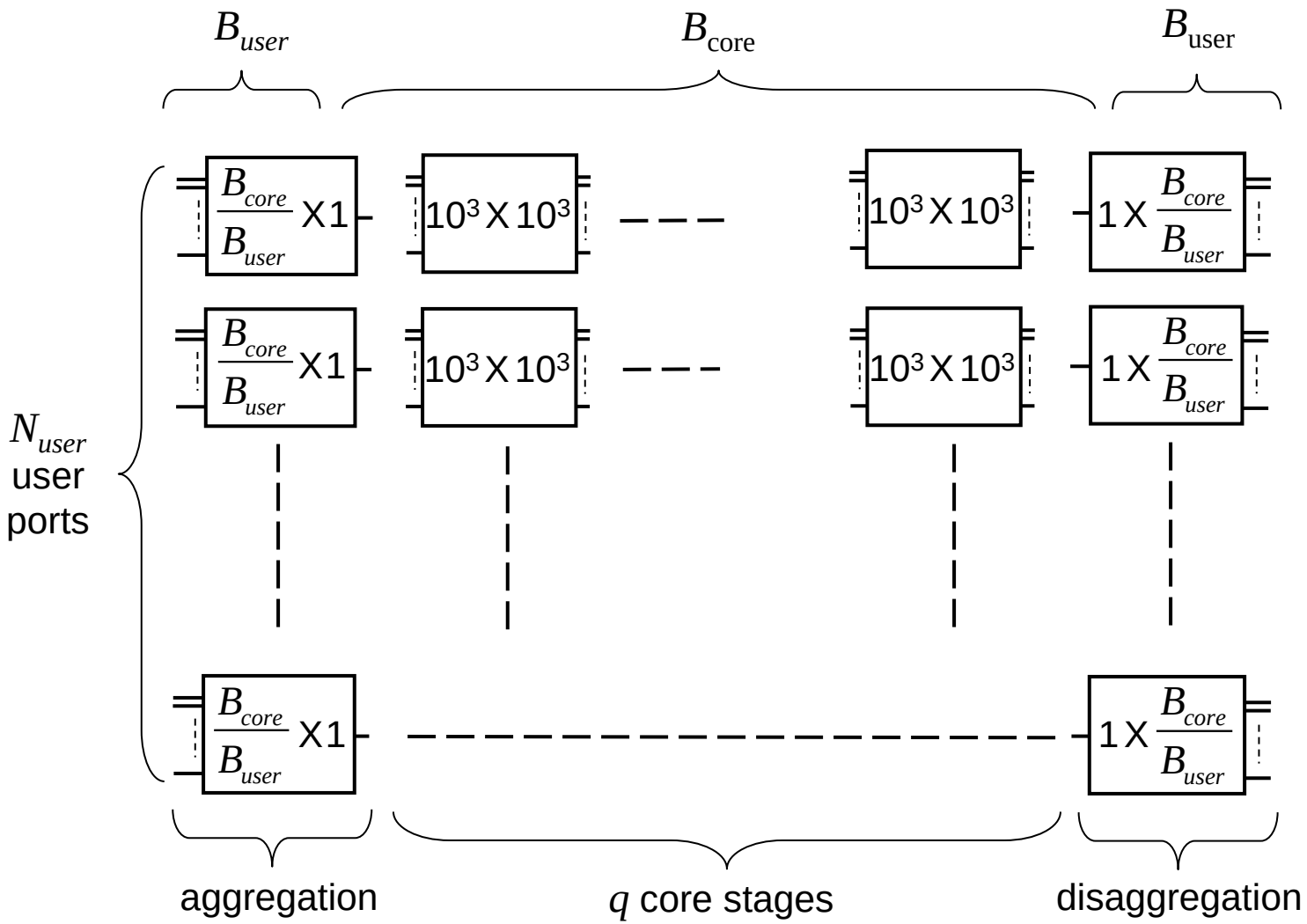
Key Conclusion:

Minimizing E_{min} is not necessarily the best strategy for minimizing E_{Total}

Network Energy



Switching Energy



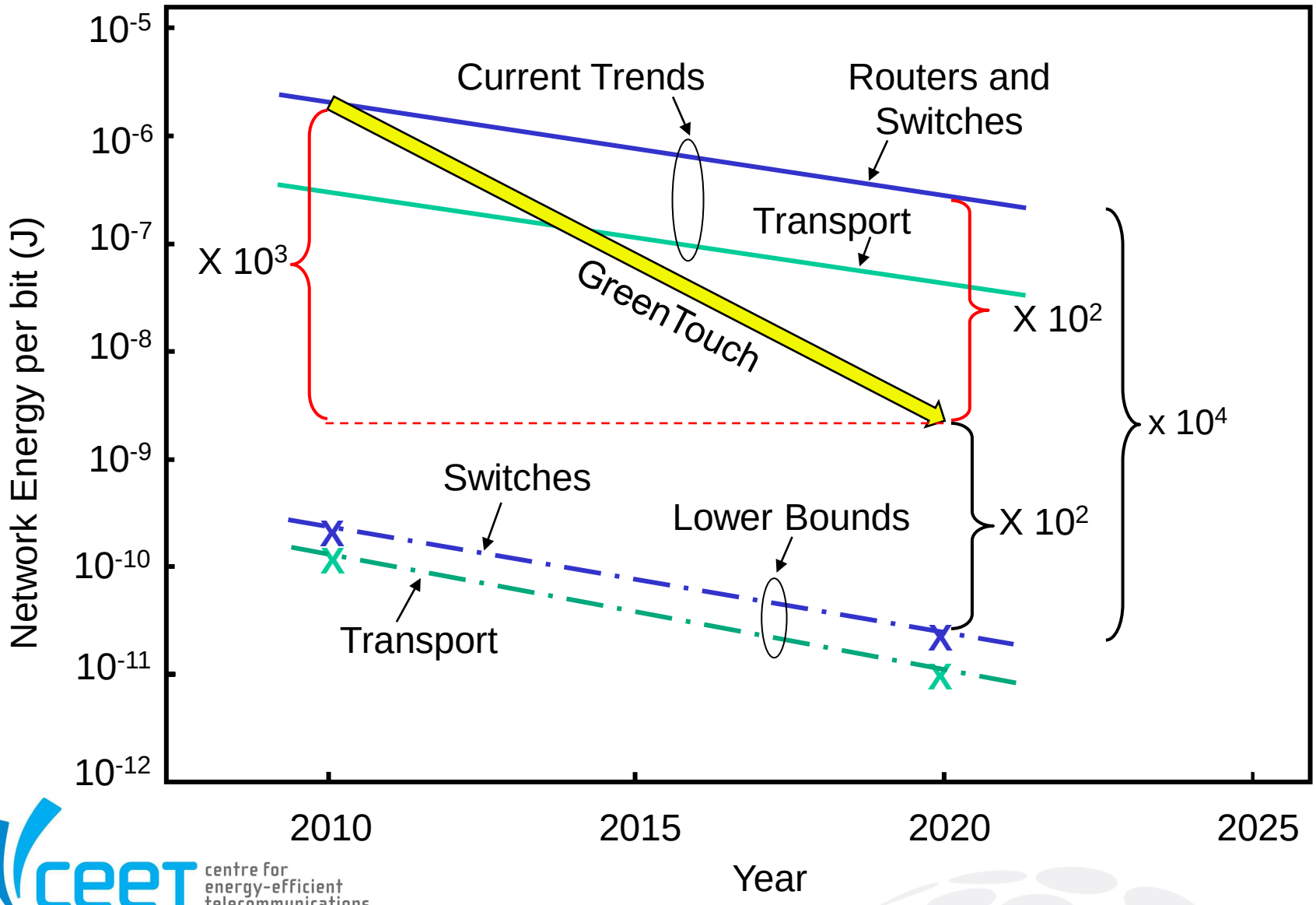
R. S. Tucker, "Green optical communications - Part II: Energy limitations in networks," *JSTQE,* March/April 2011.

Switch Energies per Bit

Technology			Energy per Bit			
			2010-era technology		Target	
			2 x 2 Switch	$10^3 \times 10^3$ Switch	2 x 2 Switch	$10^3 \times 10^3$ Switch
O/O/O	E-O	Lumped	20 fJ	-	20 fJ	-
		TW	1.8 pJ	-	1 pJ	20 pJ
	SOA Gate Array		8 pJ	-	4 pJ	75 pJ
O/E/O	Wavelength-routed		-	-	-	10 pJ
	CMOS		200 fJ (+ 70 pJ)	4 pJ (+70 pJ)	20 fJ (+ 6 pJ)	400 fJ (+ 6 pJ)

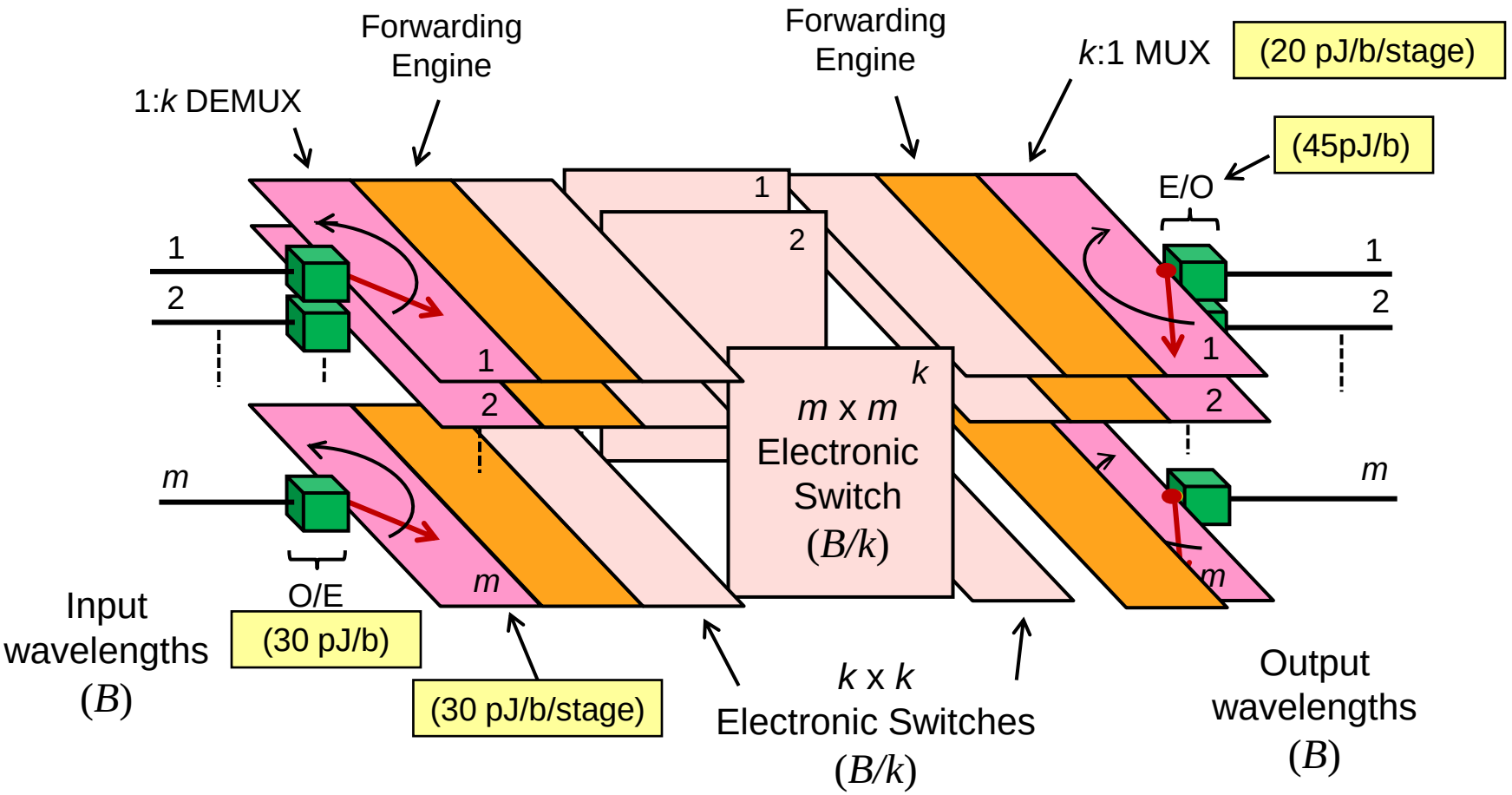
O/E Converters
MUX/DEMUX

Energy Improvements



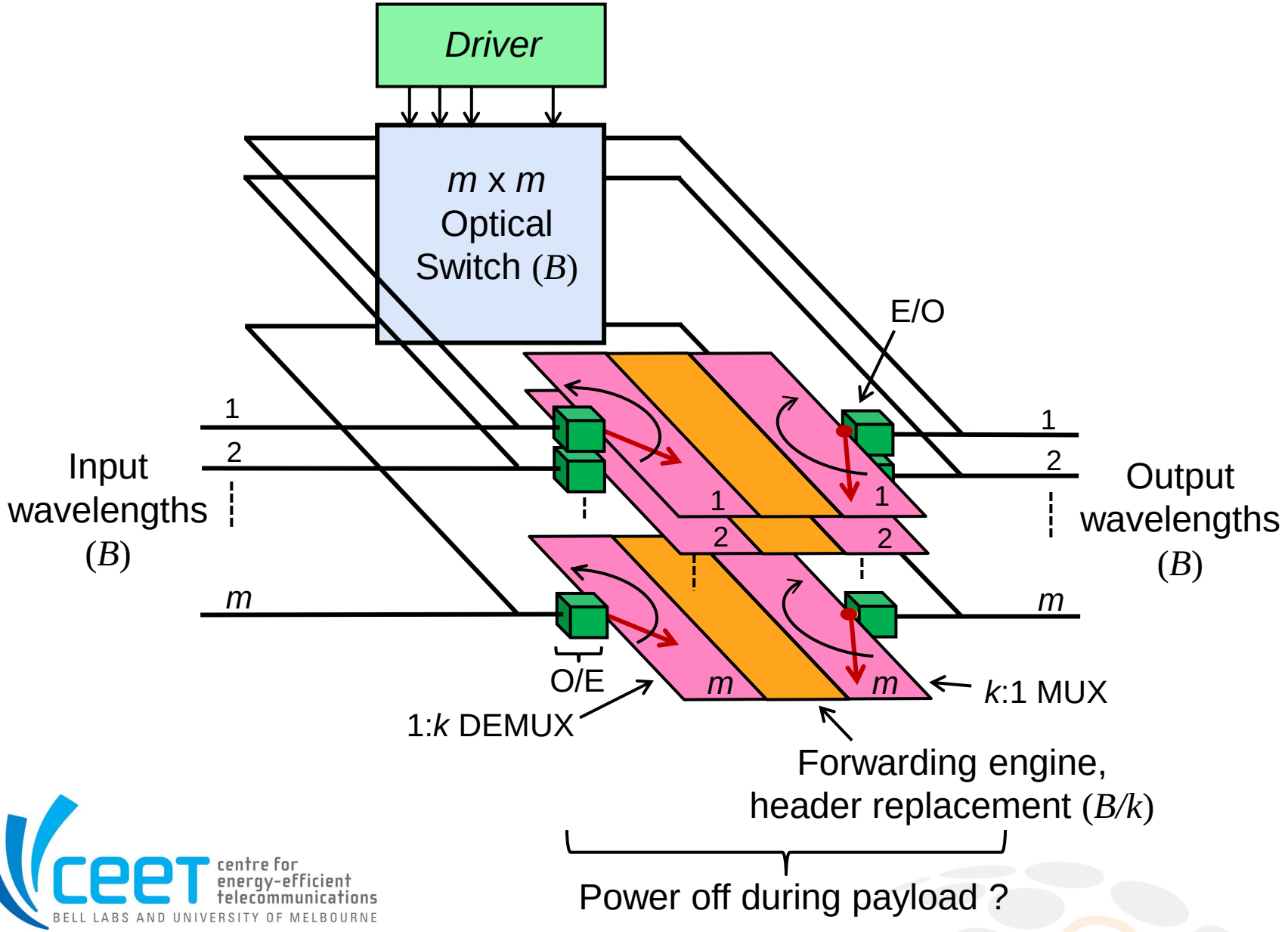
Packet Switching

Electronic Packet Switch - No buffers

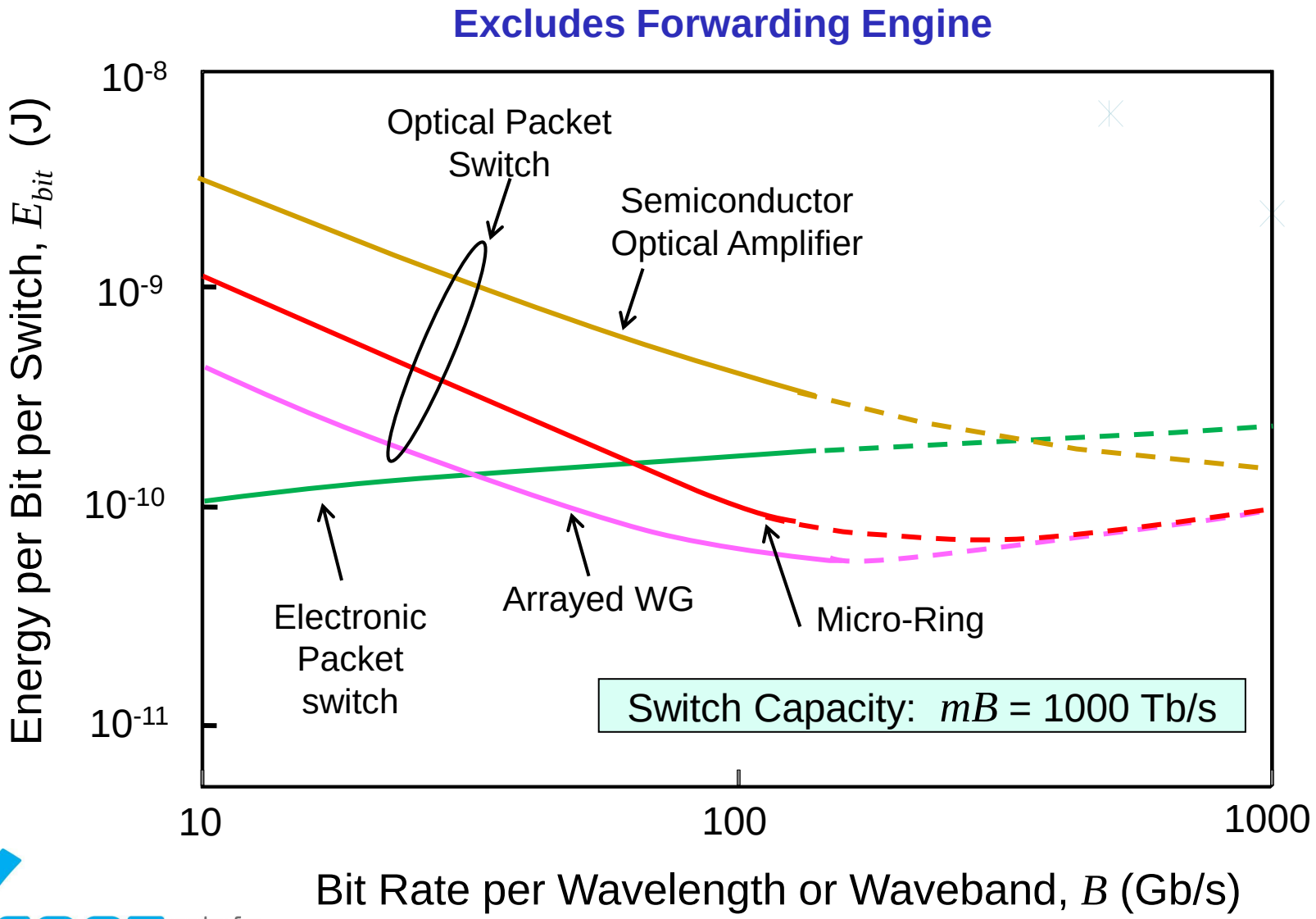


centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Optical Packet Switch



Lower Bound on Energy in Packet Switching



centre for energy-efficient telecommunications
BELL LABS AND UNIVERSITY OF MELBOURNE

Conclusions

- Top-down and bottom-up estimates of energy differ by ~ $x10^4$
- Theoretical limits on optical transmission are well defined
- Not so for networks
- Optical packet switching offers no clear advantage over electronic packet switching