Physical Impairment Constrained Routing (PICR) in WDM Networks

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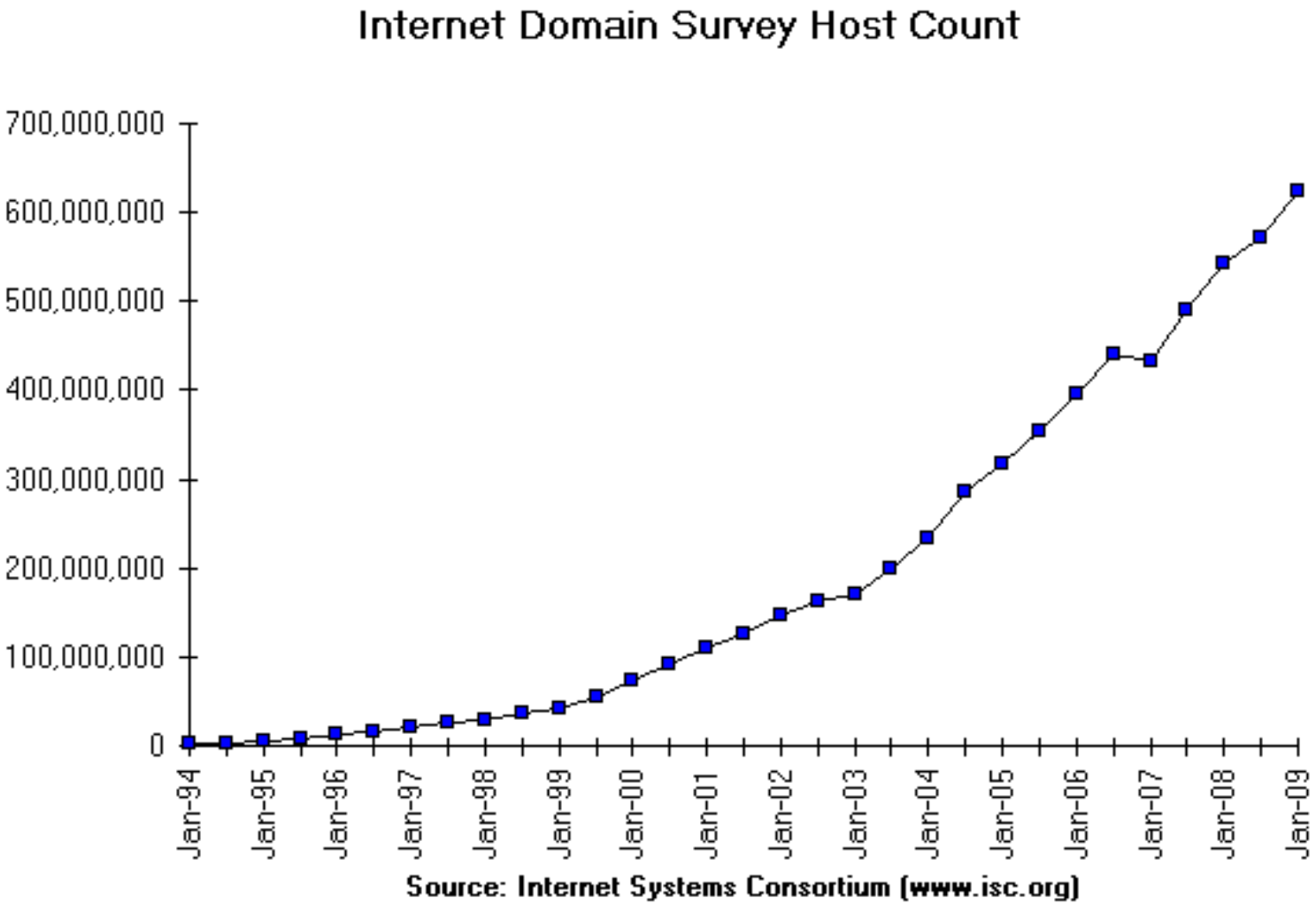
High Speed Networks Laboratory

Traffic Growth: ISC (www.isc.org)

Number of hosts on the Internet

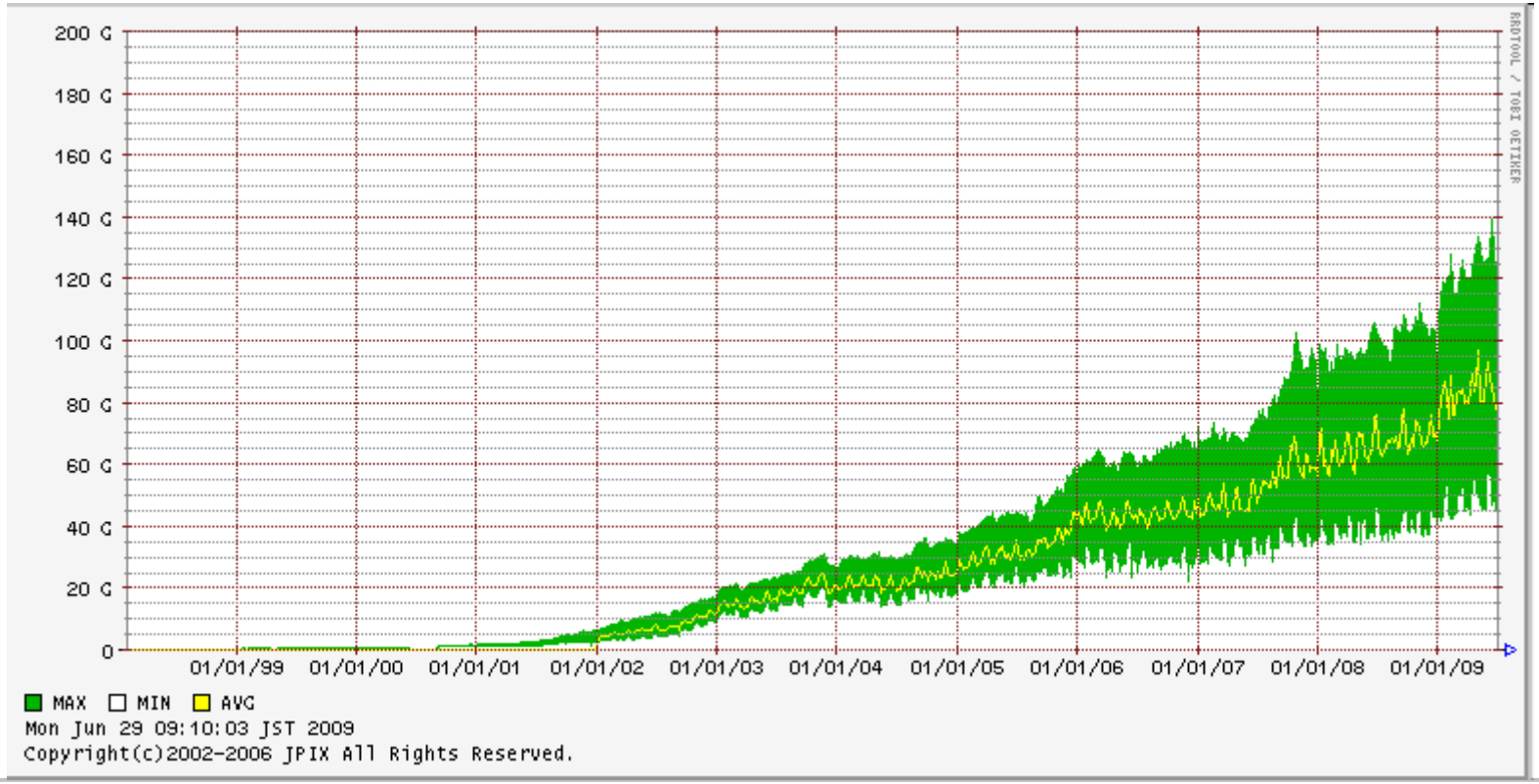
https://www.isc.org/solutions/survey

„...counts the number of IP addresses that have been assigned a name"



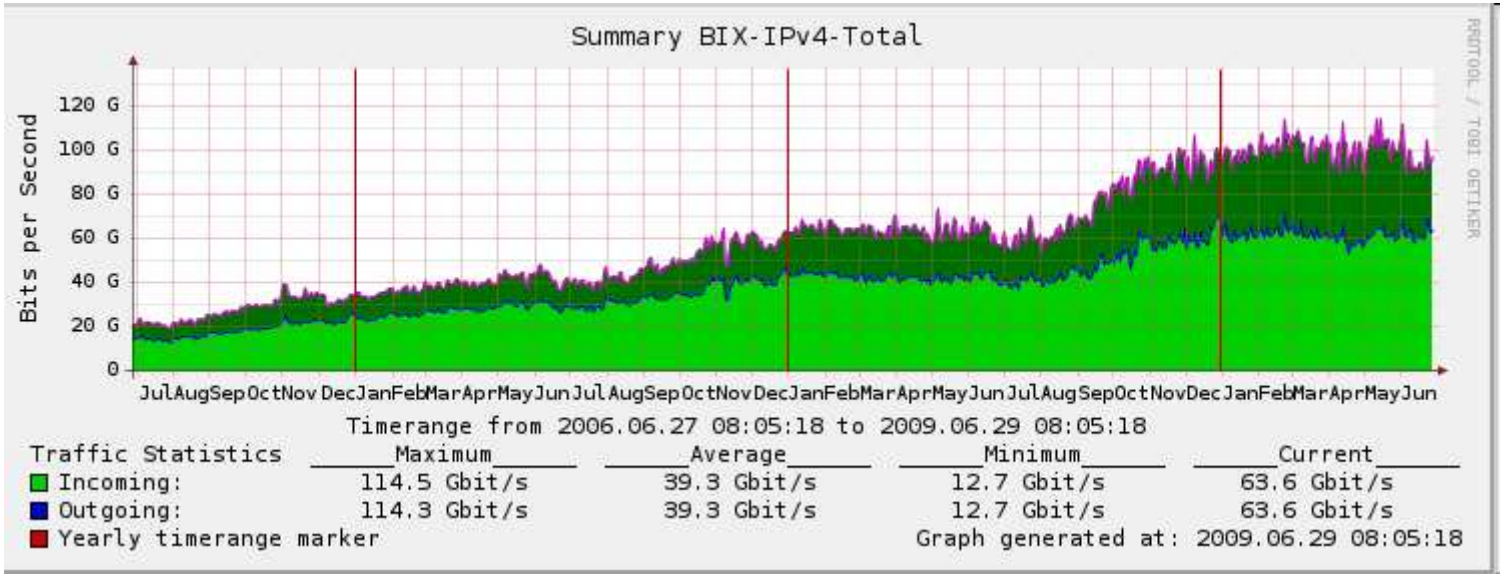
Traffic Growth: JPIX, Japan

- The maximum and minimum daily traffic volume on the IX backplane in bits per second.
- **IX Backplane Maximum/Minimum Traffic Volume**
- http://www.jpix.ad.jp/graphs/TOTAL.In.minmax256_e.gif



Traffic Growth: BIX, Hungary

- Three-Yearly IPv4 Traffic Growth in Hungary
- http://www.bix.hu/



“Green Networking”

- Reduce the environmental impact of ICT
  - (ICT: InfoCommunications Technologies)
  - Primarily Power!

- This has significant impact onto network architectures and technologies!
  - **Circuit Switching** preferred to **Packet Switching,** again?
  - Mostly for the reason of power requirements…

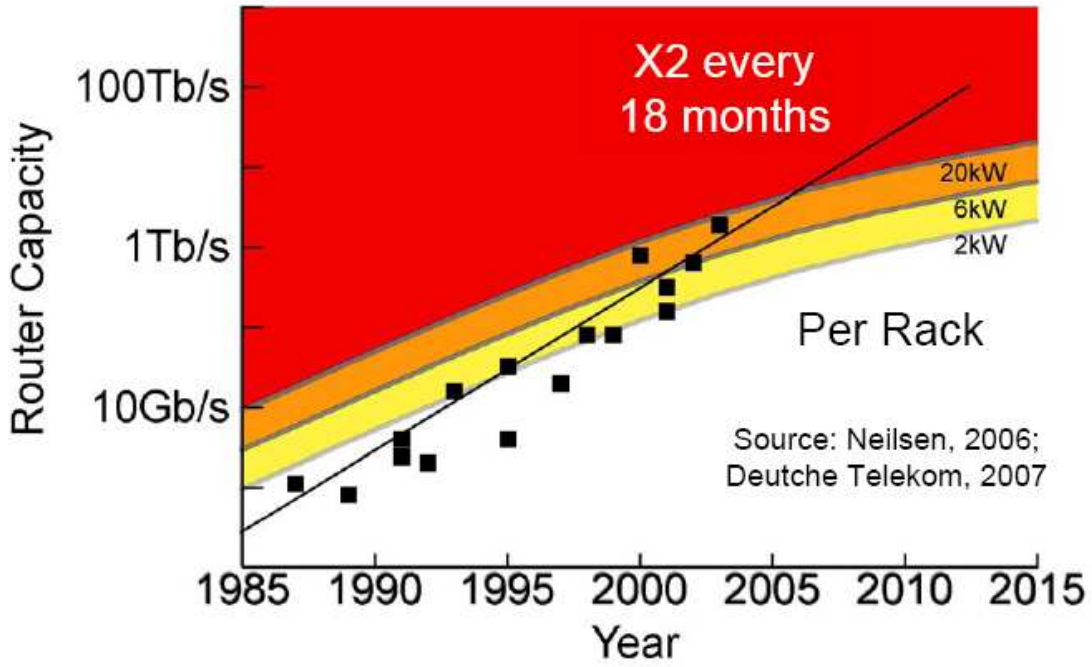
Energy Bottleneck

High-end router: Cisco CRS-1

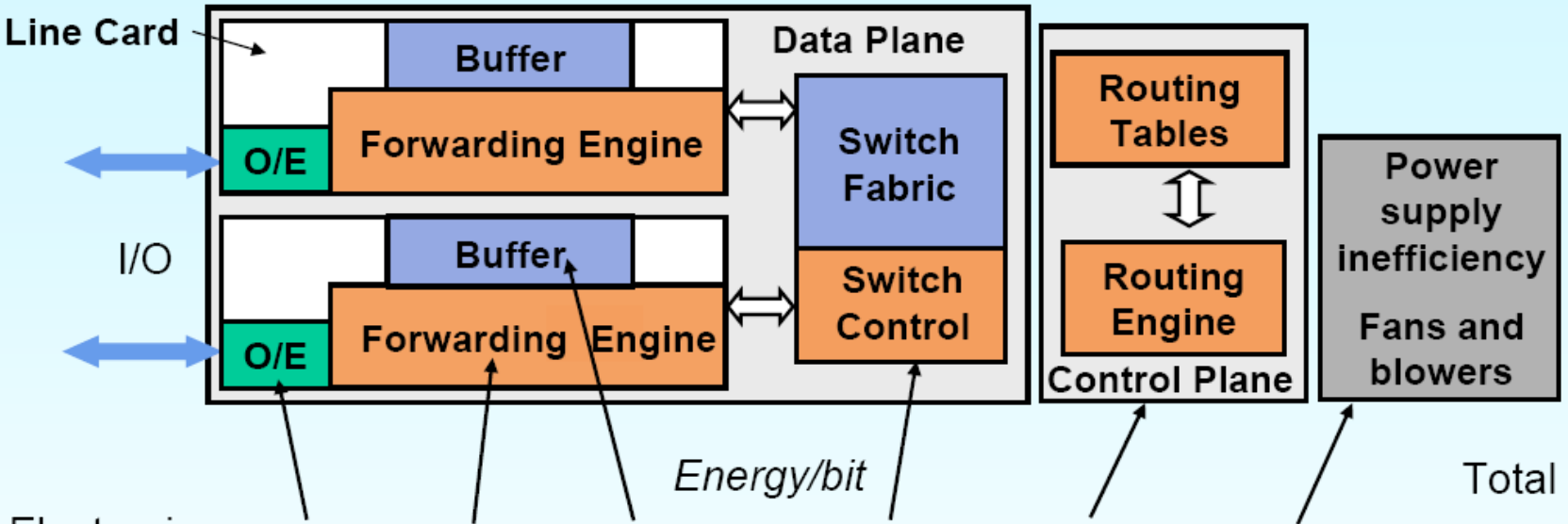
Linecard Chassis
Capacity: 0.64 Tb/s
Power: 13.6 kW

Switch Fabric Chassis:
Power: 8 kW

Fully equipped:
Multi-rack router
Capacity: 41 Tb/s
Power ~ 1 MW



Energy in Electronic and Optical Routers



	Energy/bit						Total
Electronic (2008)	0.7 nJ	3.2 nJ	0.5 nJ	1.0 nJ	1.1 nJ	3.5 nJ	10 nJ
Electronic (2018)	50 pJ	65 pJ	10 pJ	20 pJ	25 pJ	80 pJ	250 pJ
Optical (2018)	0	65 pJ	15 pJ ?	15 pJ	25 pJ	80 pJ	200 pJ

Optical Packet Switching is not a promising alternative

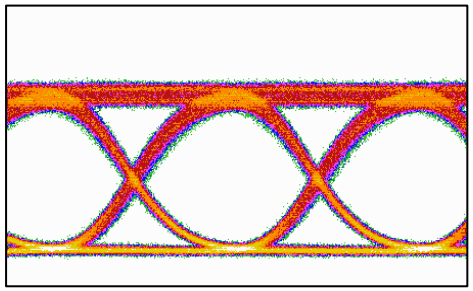
G. Epps, Cisco, 2007, ITRS, 2005, R. Tucker, JLT, 2006

What are Physical Impairments?

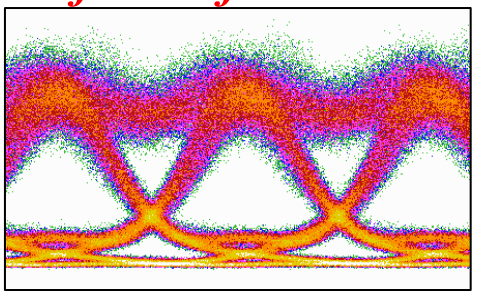
- Different Impairments
  - Linear and Non-Linear
  - for different bit-rates
  - for different distances
  - for different power levels, etc.
- All increase BER / Deteriorate Q-factor

"Cross-layer design"

Transmitted data waveform



Waveform after 1000 km



Source: Shivkumar Kalyanaraman

What to do Against Physical Impairments?

0. O/E/O with electronic 3R?

1. O/E/O Conversion/Regeneration
   - Since all-optical 3R is not yet available comercially
   - We combine it with Grooming!
2. Increase Power Level
   - It increases non-linearities as well!
   - We decrease the power level of other channels!
3. Decrease bit-rate per Channel
   - 100 → 40 → 25 → 10 → 2.5 Gbit/s
   - Depends much on line coding (e.g., NRZ Binary, NRZ Duo-Binary,)
4. Increase Channel Spacing
   - 12.5 → 25 → 50 → 100 → 200 → 400 GHz
   - Simply switch off lasers of unused channels

- All with routing, jointly!

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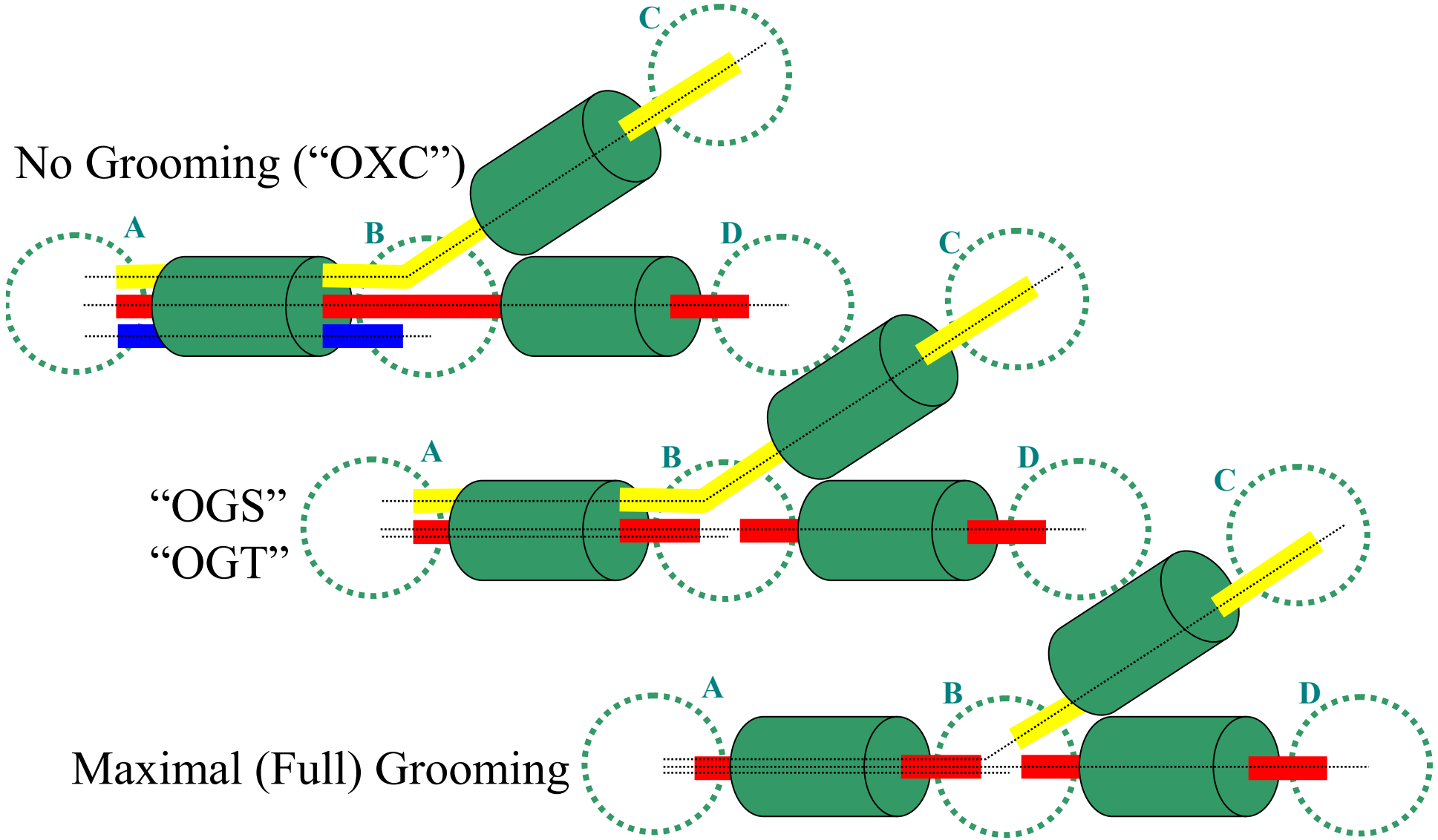
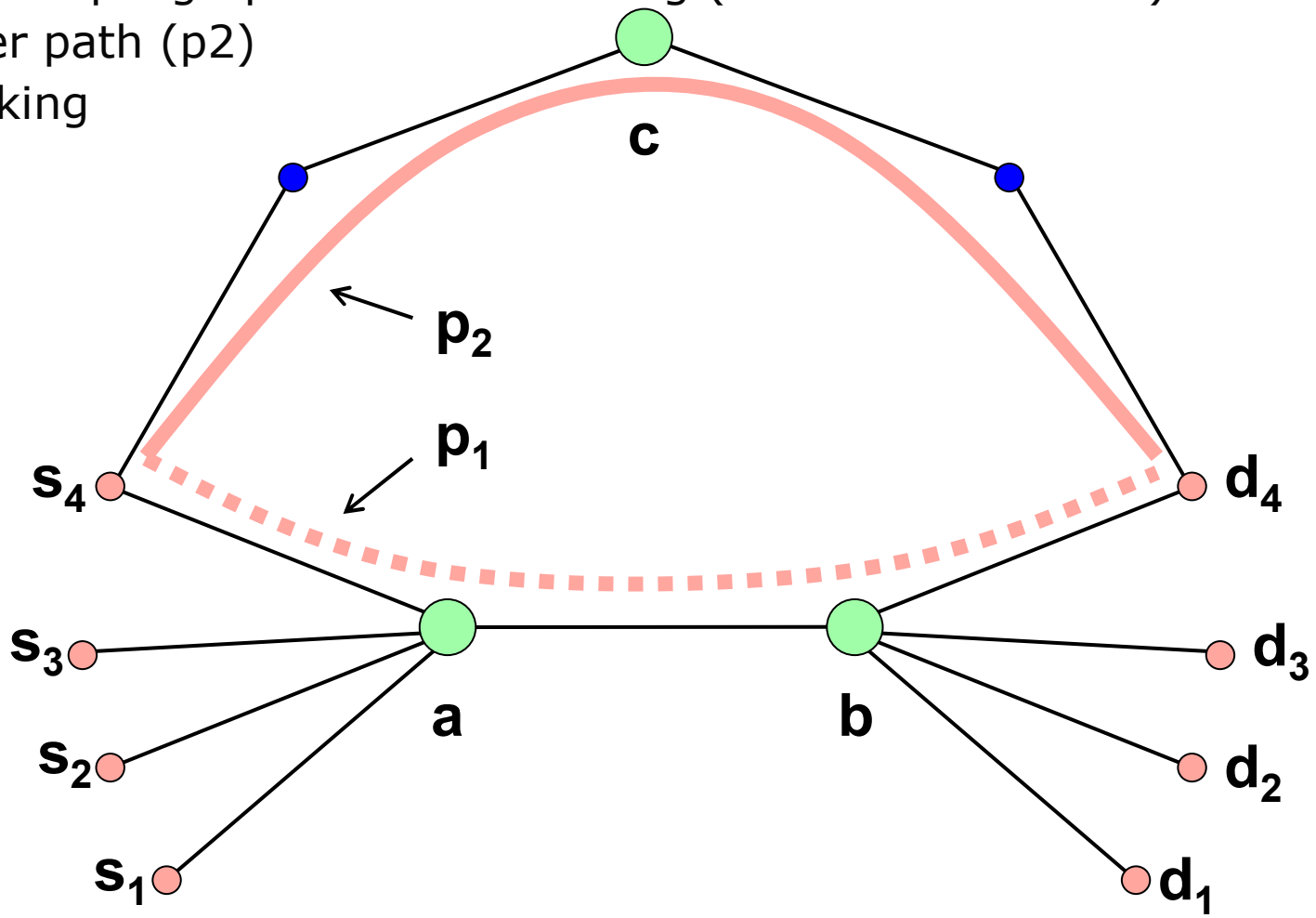
What is Grooming?



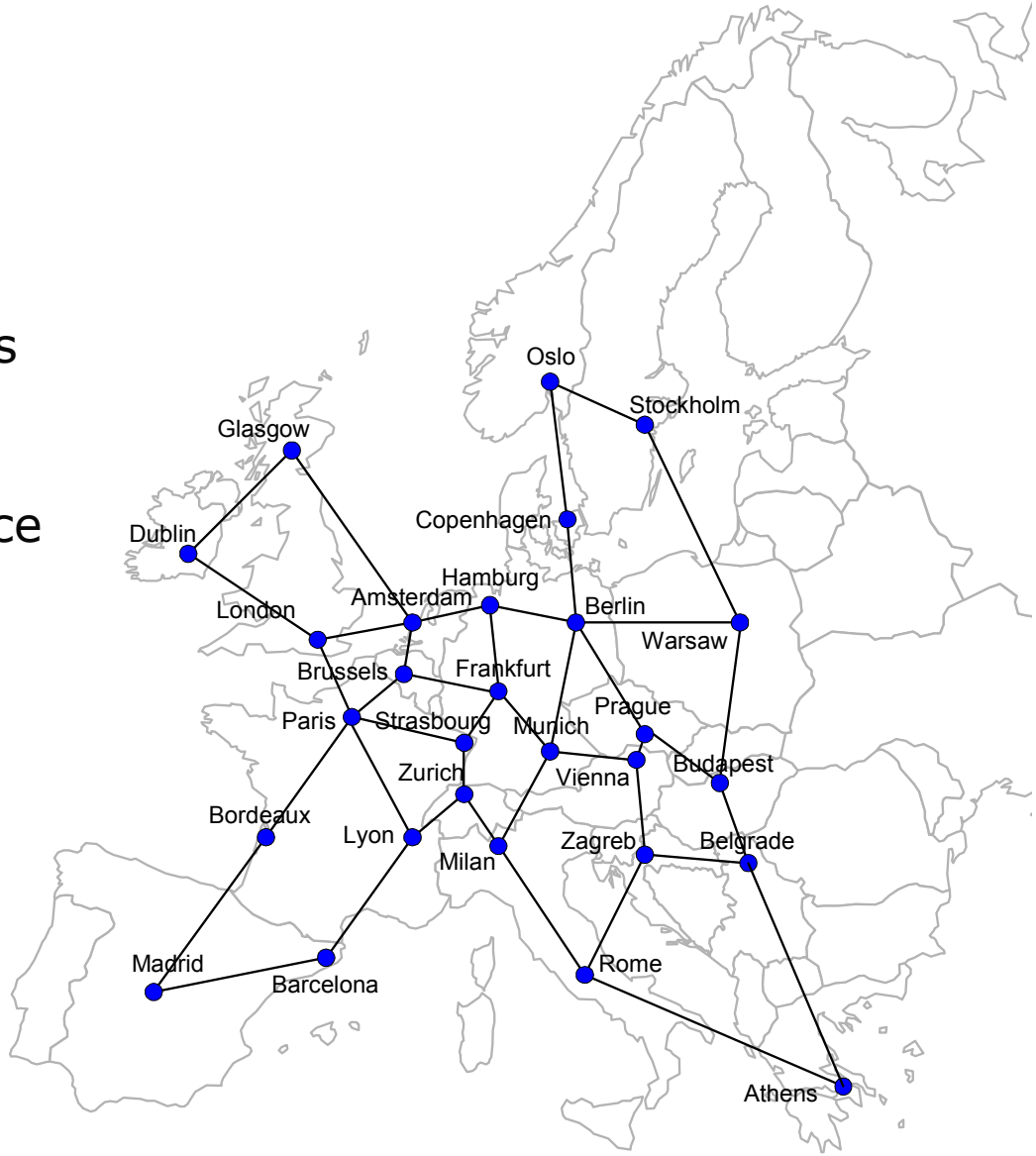
I. JOINT TRAFFIC GROOMING AND ROUTING FOR RESOLVING PHYSICAL IMPAIRMENTS

1. Direct lightpath
2. Multi-Hop Lightpath with Grooming (in nodes ‘a’ and ‘b’)
3. Other path (p2)
4. Blocking



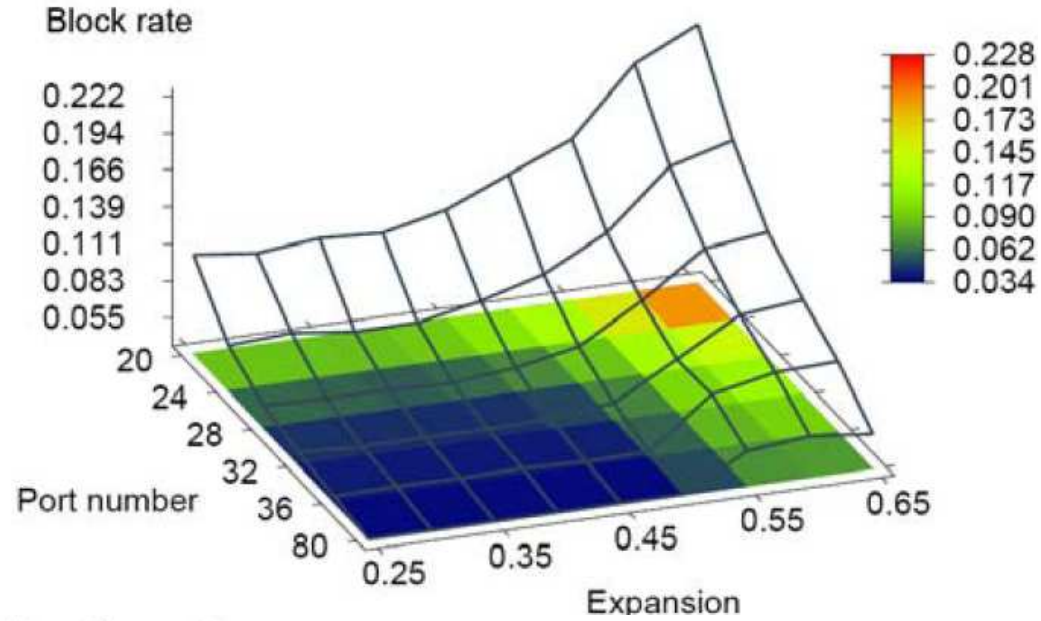
Simulations

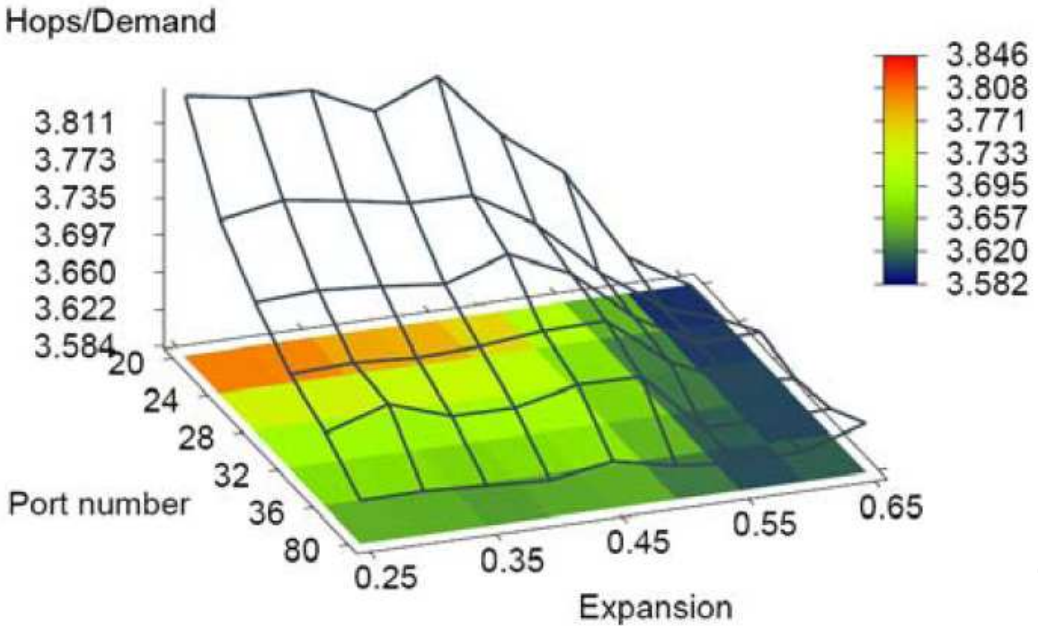
- Scale factor:
  - Increasing/decreasing the link length [km]
  - Accomodating traffic matrices with increasingly more elements
  - COST 266 European Reference Network
    - 28 nodes
    - 41 links
    - 10 demands can fit into a wavelength on average



Blocking vs. the Number of Ports (Dénes Gál, MSc Theses)

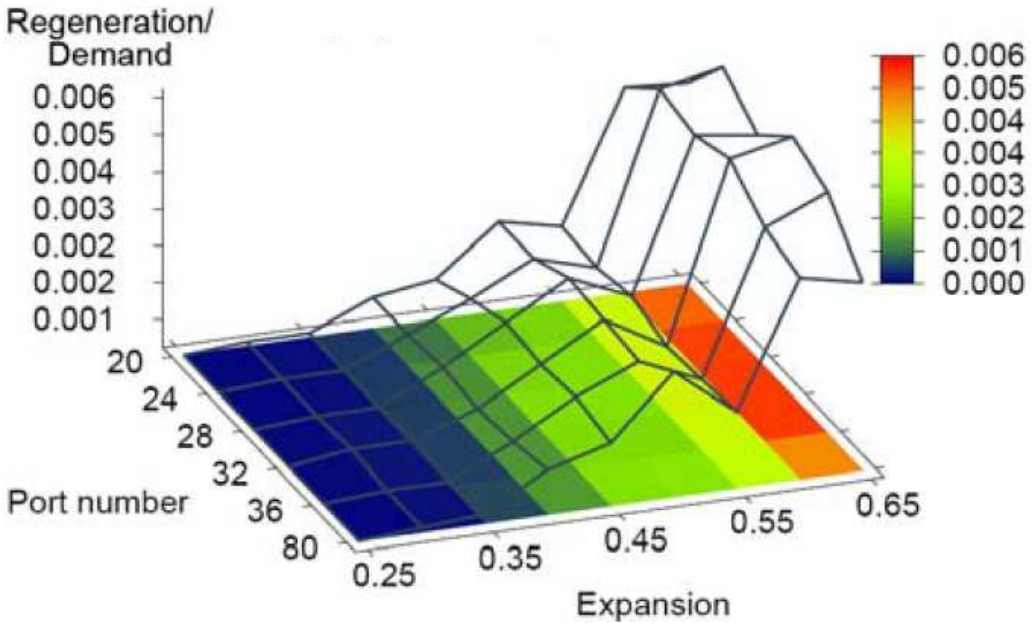
- Blocking
- Optical Hop-Count
  - 20-80 ports
  - 0.25-0.65 scale ("expansion")
- Low blocking for
  - Enough ports &
  - Small scale
- Shorter wavelength paths for
  - Large scales (since regeneration is needed)
- Longer Wavelength paths
  - For small scales & few ports
  - Long demands blocked mostly
  - **"Green Network" ☺**





Blocking vs. the Number of Ports (Dénes Gál, MSc Theses)

- Regeneration performed for regenerating Physical Impairments only
- Grooming for traffic purposes not counted!
- Extremely low! < 6 ‰



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patent!!!

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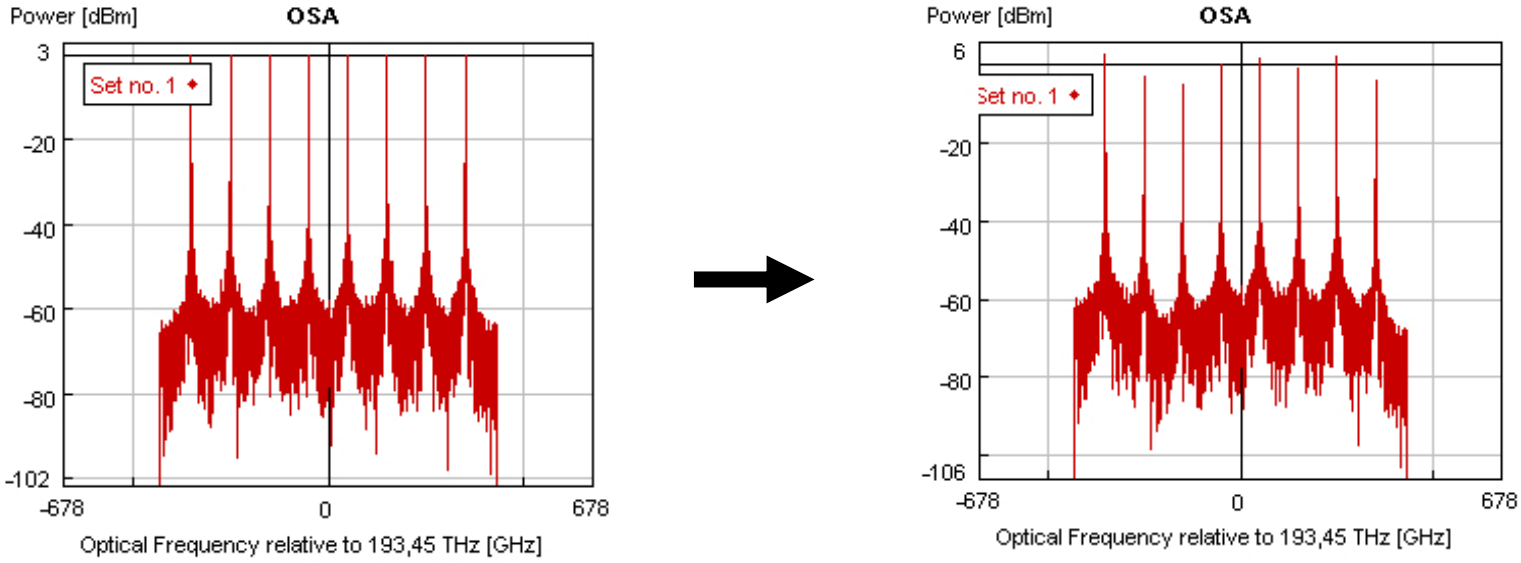
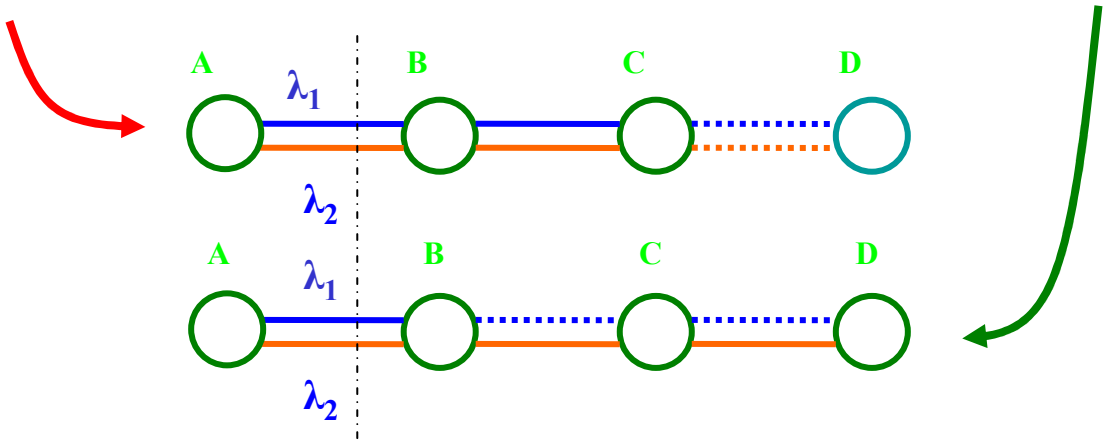
POWER LEVEL TUNING FOR RESOLVING PHYSICAL IMPAIRMENTS



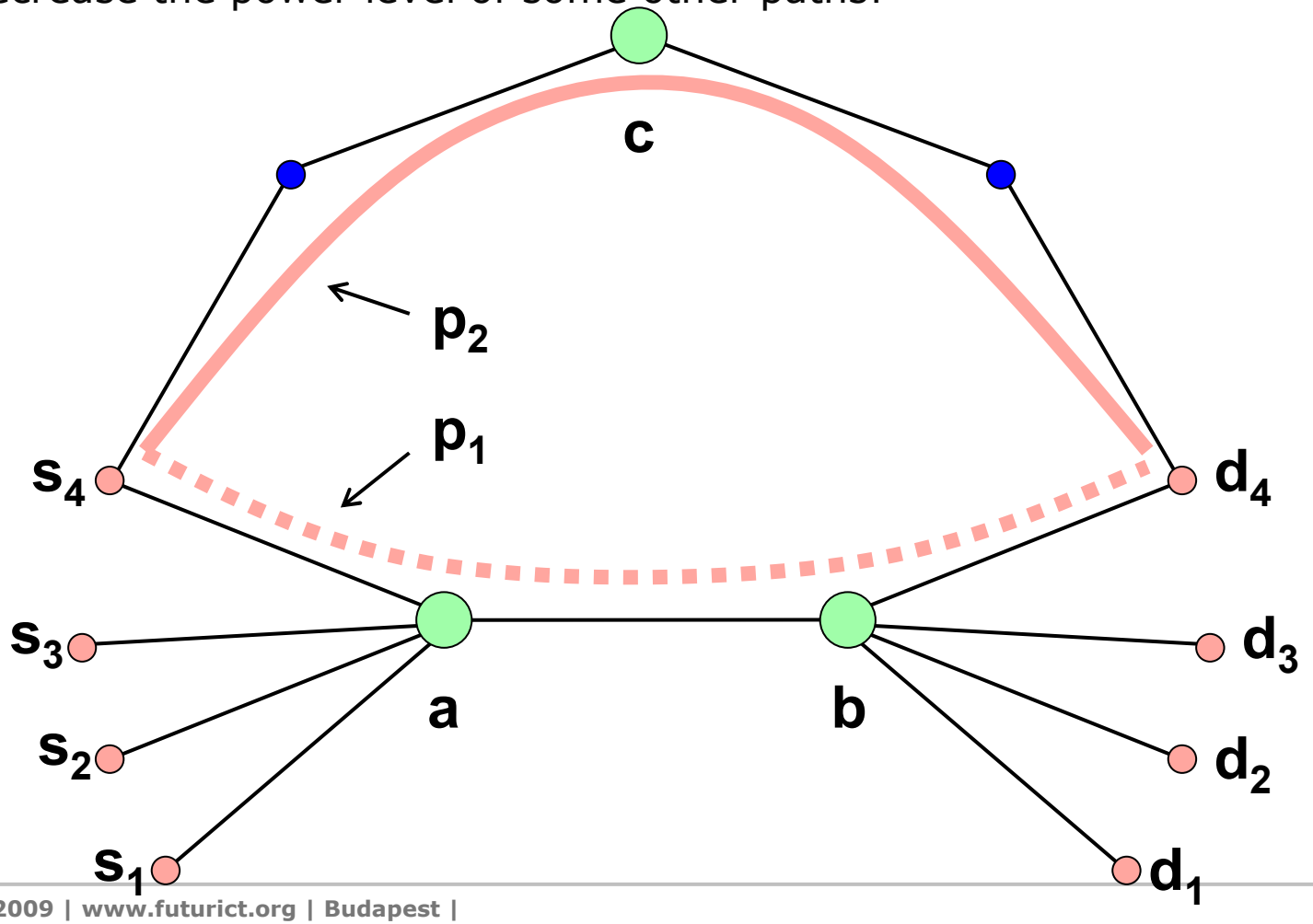


How to tune power levels?

- In ROADM there are VOAs after the switch
  - The goal was so far to equalize power levels
    - ROADM: Reconfigurable Optical Add-Drop Multiplexer
    - VOA: Variable Optical Attenuators
- We propose: Make them different!
  - The network will still work properly!
    - (at least the metro and (country-size) core)
    - (We have seen it :)

JOINT POWER LEVEL TUNING AND ROUTING FOR RESOLVING PHYSICAL IMPAIRMENTS

- Link a-b is the critical
  - Either route this or other demands to other paths!
  - Or decrease the power level of some other paths!



ILP Formulation of Optimal Signal Power Based Routing

Objective function to minimise:

$$\alpha \cdot \sum_{\forall o \in O} \sum_{\forall (i,j) \in A / A_{sw}} y_{ij}^{o} + (1-\alpha) \cdot \sum_{\forall o \in O} p^{o}$$

Constraints:

$$\sum_{\forall j \in V^{\rightarrow i}} y_{ji}^{o} - \sum_{\forall k \in V^{i \rightarrow}} y_{ik}^{o} = \begin{cases} -1 & \text{if } i = s^{o} \\ 0 & \text{if } i \notin \{s^{o}, t^{o}\}, \\ & \forall i \in V,\ o \in O \\ +1 & \text{if } i = t^{o} \end{cases}$$

$$\sum_{\forall j \in V^{\rightarrow i}} p_{ji}^{o} - \sum_{\forall k \in V^{i \rightarrow}} p_{ik}^{o} = \begin{cases} -p^{o} & \text{if } i = s^{o} \\ 0 & \text{if } i \notin \{s^{o}, t^{o}\}, \\ & \forall i \in V,\ o \in O \\ +p^{o} & \text{if } i = t^{o} \end{cases}$$

$$\sum_{\forall o \in O} y_{ij}^{o} \le 1,\ \forall (i,j) \in A$$

$$p_{ij}^{o} \le y_{ij}^{o},\ \forall (i,j) \in A,\ \forall o \in O$$

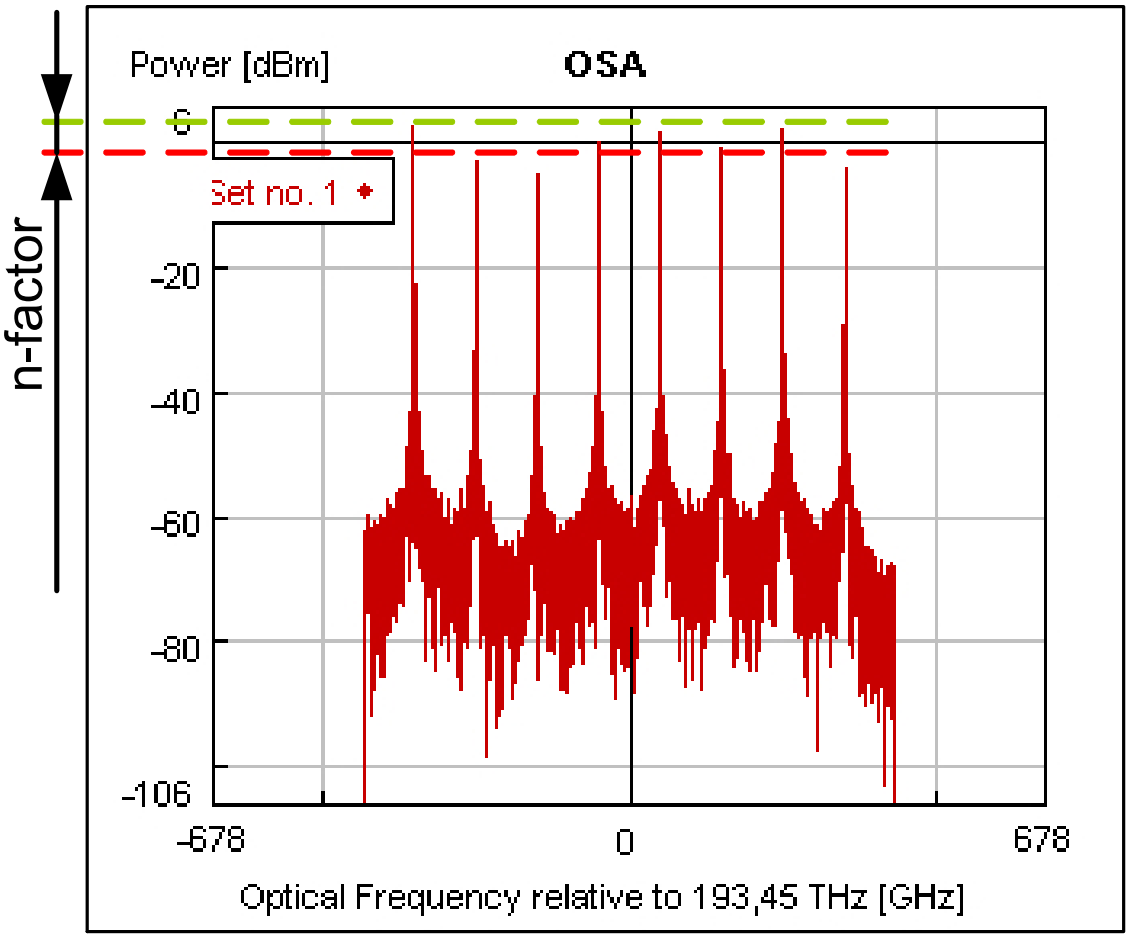
$$\sum_{\forall (i,j) \in A^{sw}} y_{ij}^{o} \cdot len_{PhyNode} + \sum_{\forall (i,j) \in A^{pl}} y_{ij}^{o} \cdot len_{ij} \le$$

$$\le L(p^{o}) = L_{c} \cdot p^{o} \cdot P_{pl\ lin}^{max},\ \forall o \in O$$

$$\sum_{\forall o \in O} \sum_{\forall (i,j)^{pl}} p_{ij}^{o} \le 1,\ \forall pl \in PhyLinks$$

"n-factor"

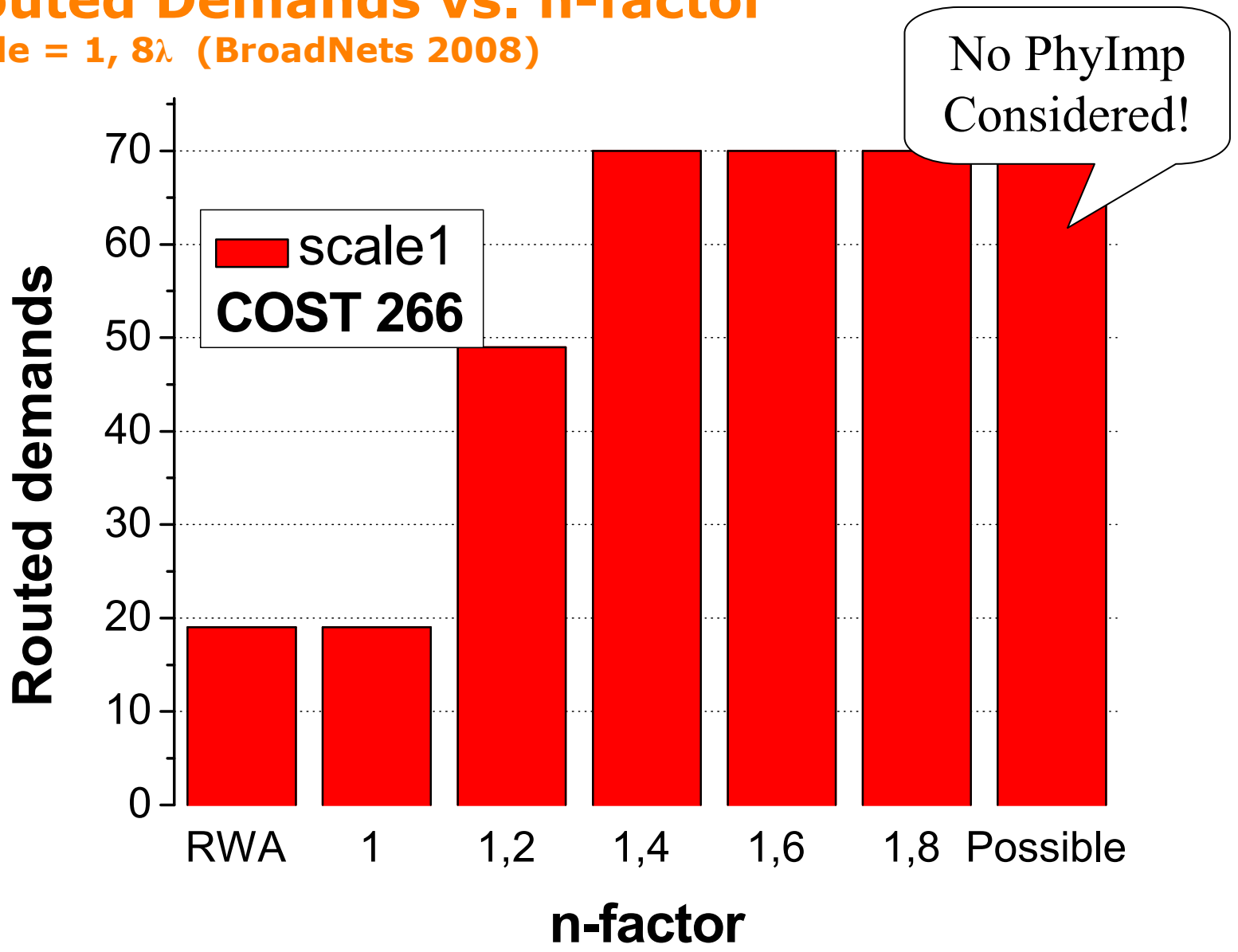
The maximum allowable difference



Source: http://www.cisco.com/en/US/products/hw/optical/ps2006/products_data_sheet0900aecd803fc52f.htm

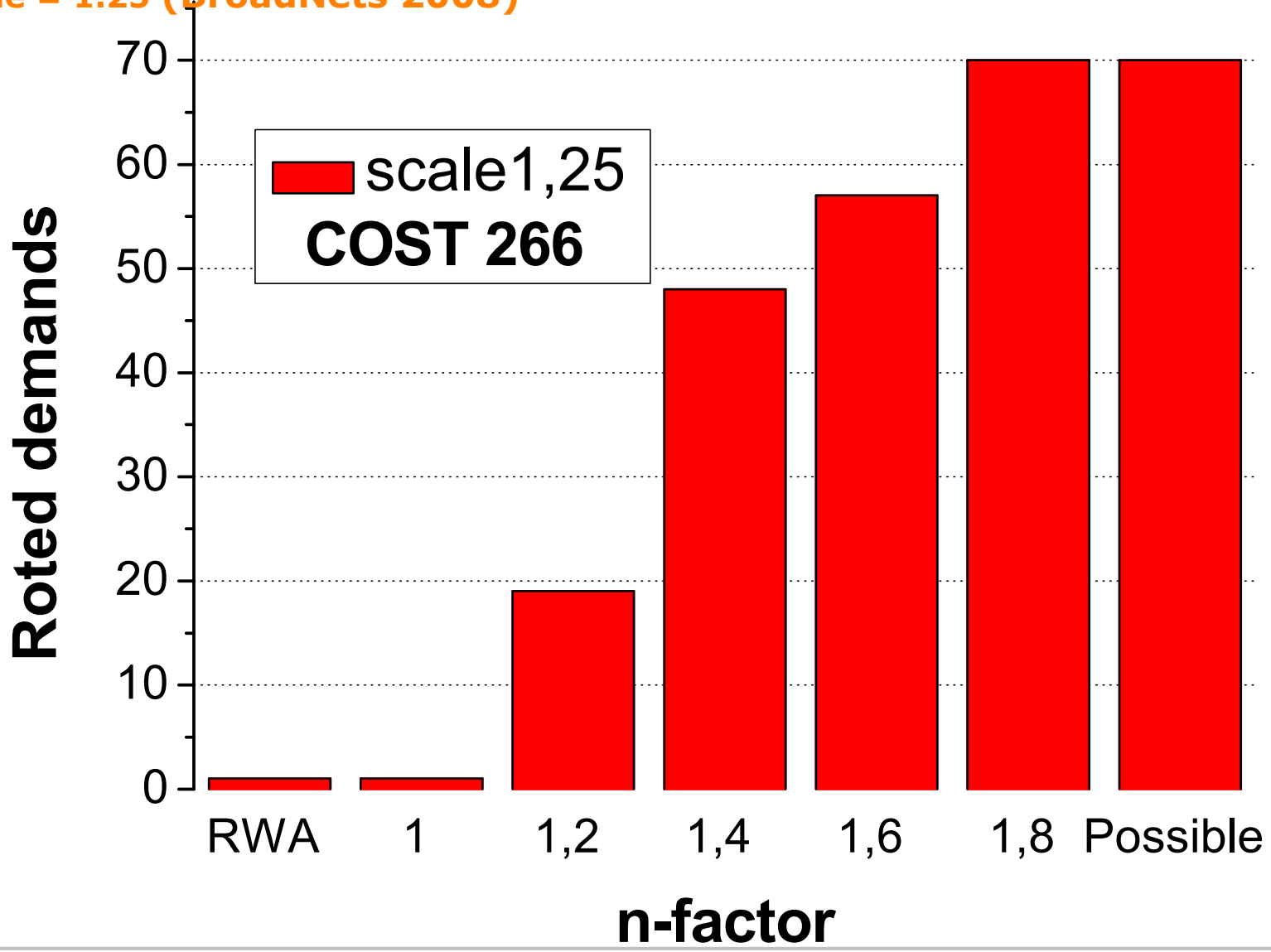
Routed Demands vs. n-factor

scale = 1, 8λ (BroadNets 2008)



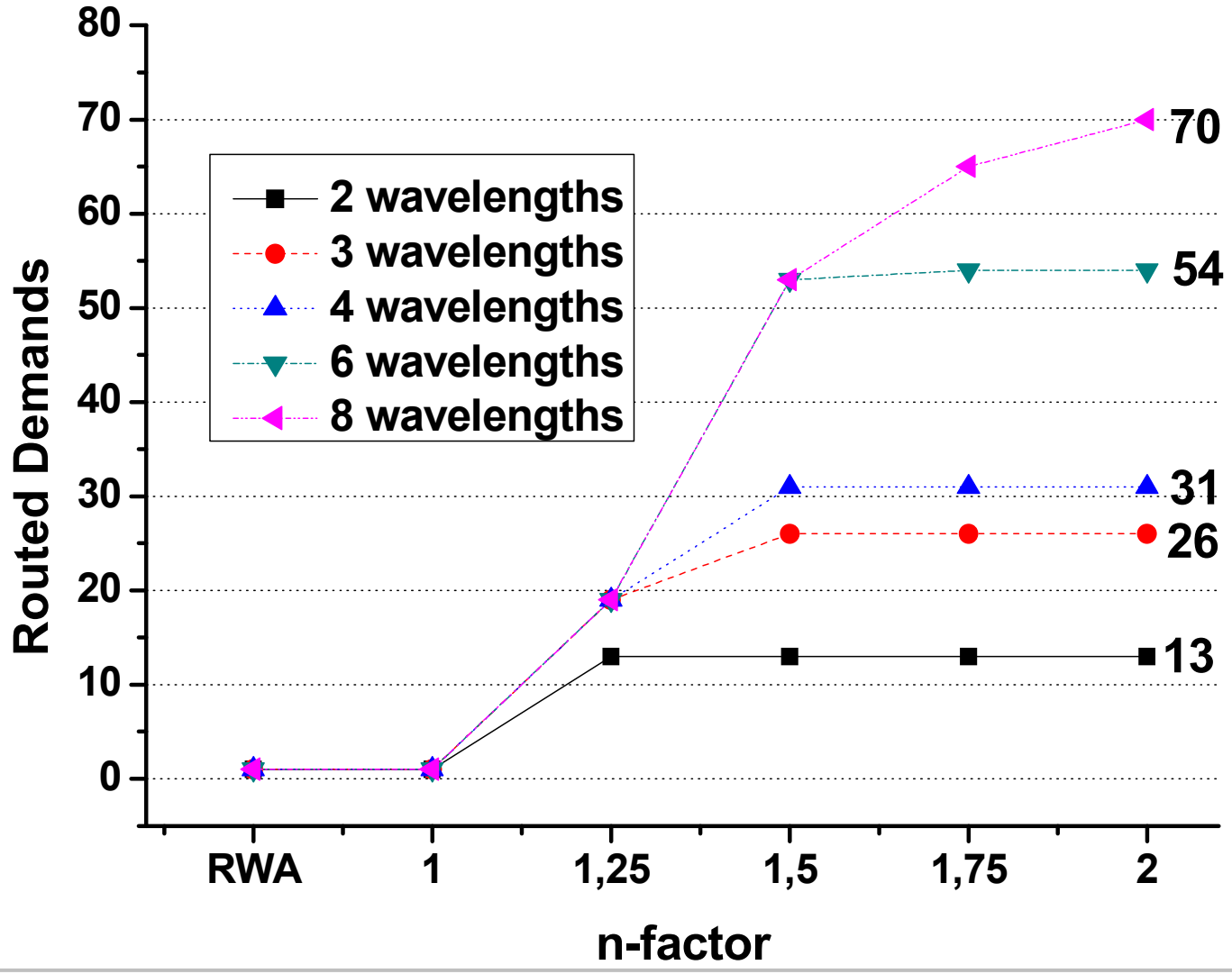
Routed Demands vs. n-factor

scale = 1.25 (BroadNets 2008)



Routed Demands vs. n-factor

2 – 8 wavelengths, scale = 1 (BroadNets 2008)



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5. FEC

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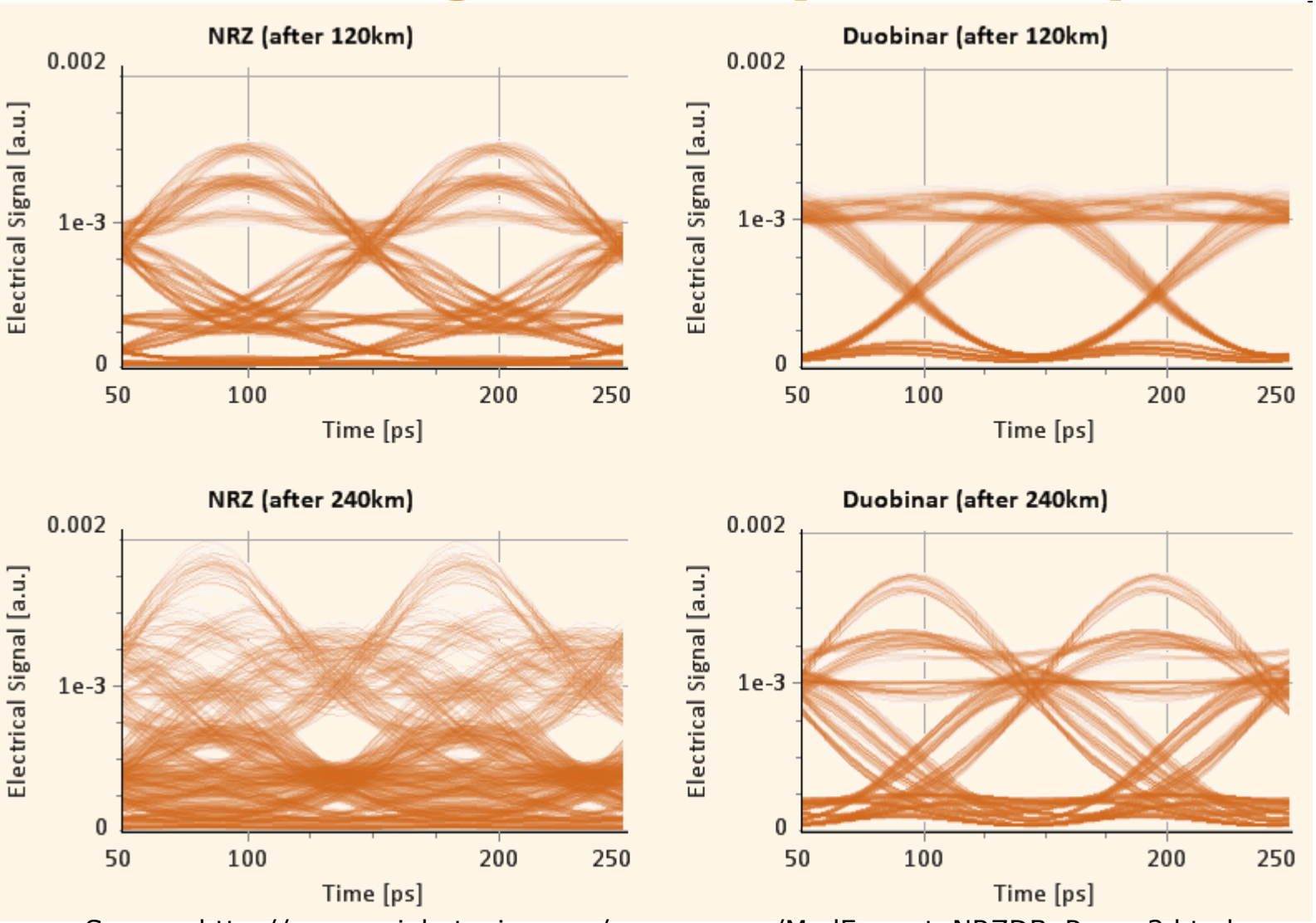

Source: http://www.vpiphotonics.com/popups_app/ModFormat_NRZDB_Popup3.html

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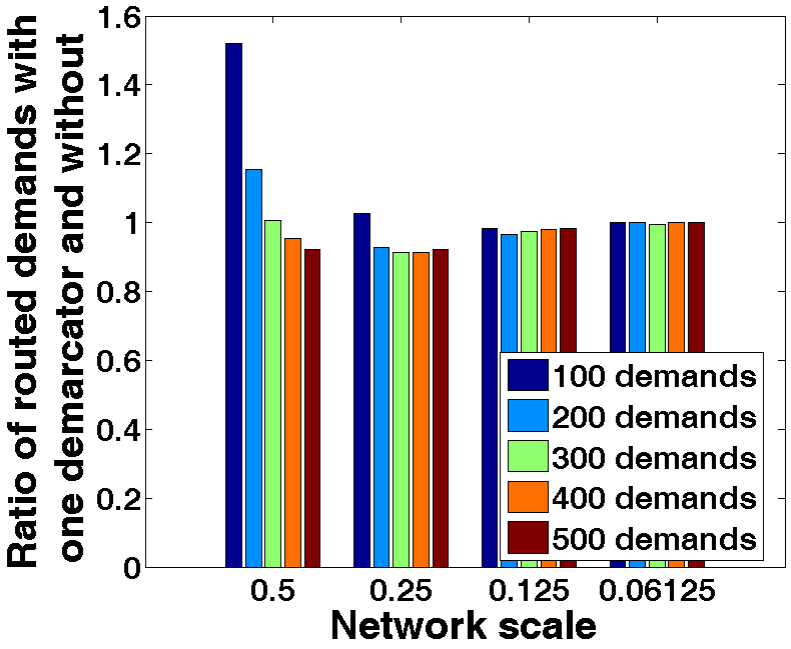
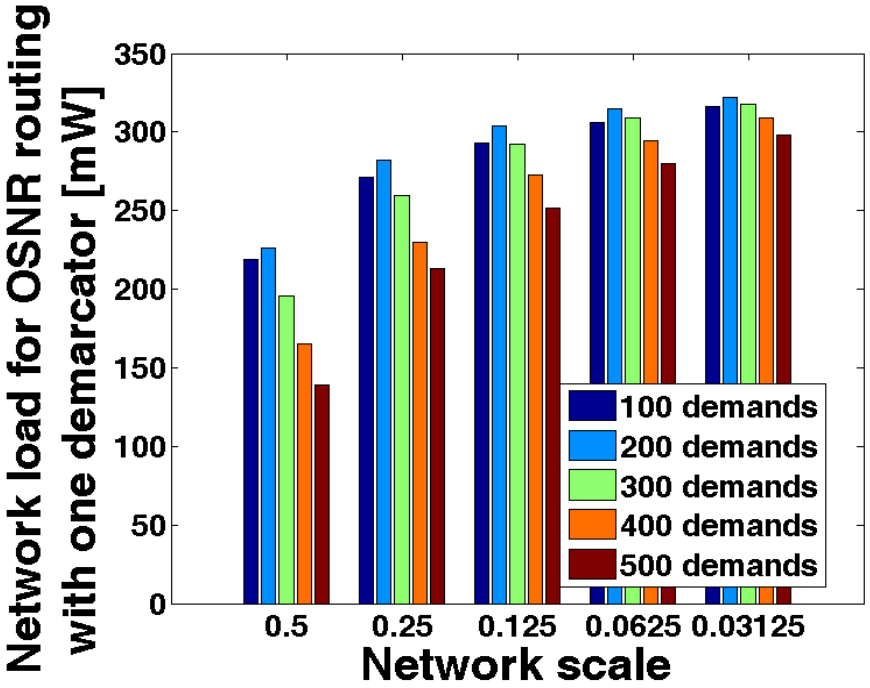
4. Increased Channel Spacing (ICTON 2009 withdrawn)

- Demarcator/Guard channels
  - One channel: useful, two channels: negligible difference
- Incresaed number of routed demands for:
  - low load and
  - high distances





Conclusion

- Methods for handling physical impairments
  - Grooming for regeneration and traffic + Routing
    - Message: **Regeneration performed implicitly at no extra cost!**
  - Power level + Routing
    - Message: **Increased throughput at no extra cost!**
- Cross-Layer Optimisation Needed!
- Significant Gain (increased throughput) demonstrated!

- Multi-Layer Data Plane (DP) architectures
  - Circuit Switched bottom layers and core
  - Packet Switched upper layers and metro access
    - E.g., MPLS-TP (MultiProtocol Label Switching – Transport Profile)

- Simple (???) unified Control and Management Planes (CP, MP)

http://www.hsnlab.hu

Physical Impairment Constrained Routing in WDM Networks

ABSTRACT: There are various linear and non-linear physical effects that impair the optical signal. The longer the distances are the worse the signal quality becomes. All-optical re-amplification is feasible today, however, all-optical re-shaping and re-timing is commercially not yet available. Therefore, O/E/O conversion and electronic regeneration is required. In this talk we present two low-cost methods for handling impaired signals to increase the network throughput.

The first one uses grooming as the implicit means of O/E/O regeneration. The interesting result is that the number of grooming actions has increased negligibly, while the throughput growth is significant.

The second one tunes power level of certain wavelength channels to different levels in order to improve the quality of long wavelength paths, while maintaining the power budget of the links. This way the long wavelengths have better quality, while the short wavelengths have still satisfactory quality. This approach also increases the throughput of a network of that size where the distances start to become critical.

We present the problems and our solution methods as well as simulation results.