Energy Efficient Resilient Optical Transport Networks

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Outline

- Motivation
- Facing the network challenges
- Energy-efficiency in resilient networks
- Conclusions

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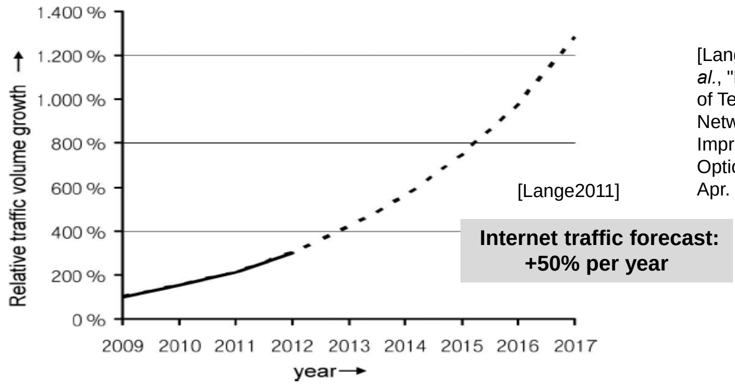
Traffic growth in core networks: challenges



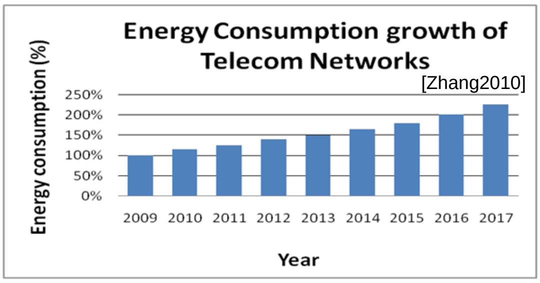
[Lange2011] C. Lange *et al.*, "Energy Consumption of Telecommunication Networks and Related Improvement Options" JSTQE 2011, Apr. 2011

Challenges for operators:

Need for higher capacity ⇒ **Upgrade network capacity (1)**

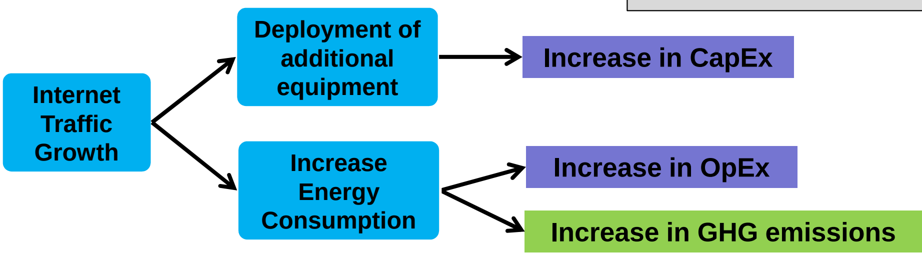
More critical services
Failures become increasingly important ⇒ **Ensure network resilience (2)**

Energy consumption increases with traffic



[Zhang2010] Y. Zhang et al., "Energy Efficiency in Telecom Optical Networks," IEEE COMST vol.12, no.4, Nov. 2010

Goal: Increase Network Capacity and improve Energy Efficiency



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  - Network capacity upgrade
  - Ensuring network resilience
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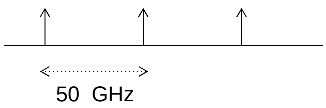
Challenge (1): Network capacity upgrade

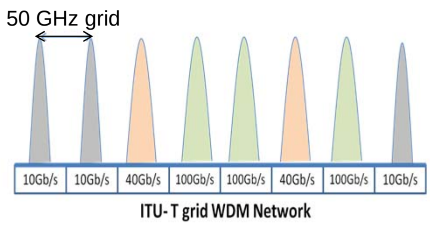
- Current WDM networks:
  - Full wavelength capacity is assigned to a connection
  - Single Line Rate (SLR)
  - ITU-T Grid operation

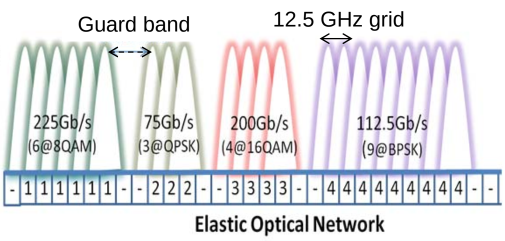


- *How to provide more capacity in WDM Networks?*
  - Deploy more fibers and devices (simplest solution but less efficient)
  - Increase wavelengths spectral efficiency (higher-level modulation formats): 2.5 → 10 → 40 → 100 Gbit/s → ?
- Drawbacks:
  - Coarse wavelength granularity → inefficient resource utilization (lack of flexibility in allocating the actual required capacity)
  - Fixed channel spacing → Next generation transmission technologies (400G, 1T) would not fit into 50 GHz channels

Flexible Optical Transport Networks

- ***How to make optical transport networks more flexible?***
  - *Mixed Line Rate (MLR)*
    - ✓ Maintain fixed ITU-T 50 GHz channel spacing
    - ✓ Enable different line rates within different wavelengths: 10 / 40 / 100 Gbit/s
  - *Elastic Optical Networks (EONs)*
    - ✓ Finer channel spacing (12.5 GHz wide frequency slots)
    - ✓ Flexible-grid operation
    - ✓ Enabler for higher capacity channels (superchannels)
    - ✓ OFDM-enabled
    - ✓ Finer capacity granularity thanks to:
      - ✓ Elastic bandwidth operation
      - ✓ Different modulation formats





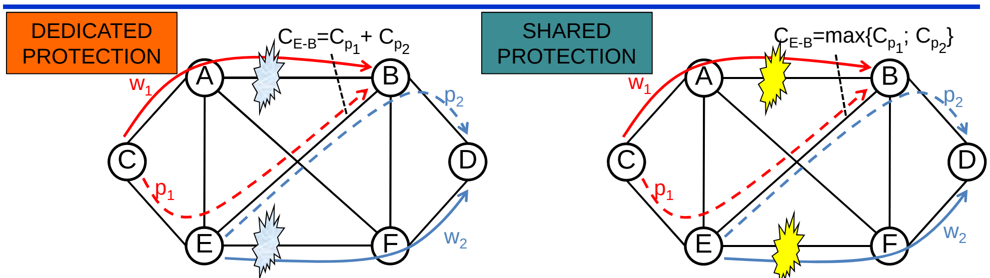
Challenge (2): Ensure network resilience

- High resilience against devices failures is needed
  - New fundamental network services (telemedicine, teleconference, VoD, etc.)
  - Failures criticality: a single fiber cut might cause huge data losses

How to provide resilience in optical networks?

  - Restoration: dynamic recovery performed *after* a failure has occurred
  - Protection: pre-planned failure recovery → higher reliability
- Protection in optical transport networks:
  - Many possible solutions
    - dedicated vs shared protection
    - link vs path protection
    - …

Dedicated vs Shared Path Protection

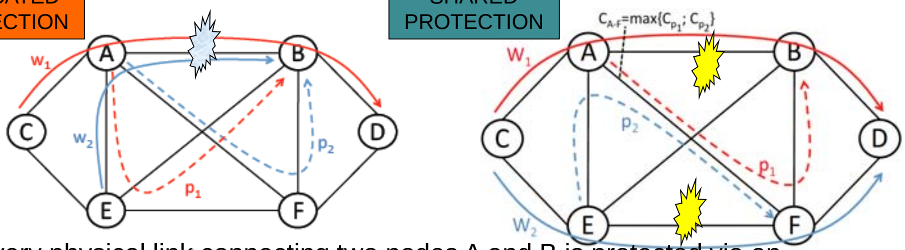


- Each end-to-end path protected via an alternative route from source to dest.
- Dedicated Path Protection (DPP)
  - 1+1 DP: *simultaneous* transmission in both working and backup paths
  - 1:1 DP: transmission over backup path is activated *after a failure occurs*
  - resiliency is provided with fast recovery, but…
  - more resources are needed → more CAPEX
- Shared Path Protection (SPP)
  - protection resources are shared, but…
  - lower resiliency (single point of failure)

Dedicated vs Shared Link Protection

DEDICATED PROTECTION

SHARED PROTECTION



- Every physical link connecting two nodes A and B is protected via an alternative route connecting A to B
  - Link-disjoint protection
- Dedicated Link Protection (DLP)
  - Demands routed over the same link are protected independently
  - more resources are needed
- Shared Link Protection (SLP)
  - Protection resources are shared by different connections
  - Lower resilience: single point of failure

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- Energy-efficiency in resilient networks
  - Sleep mode
  - Rate adaptation
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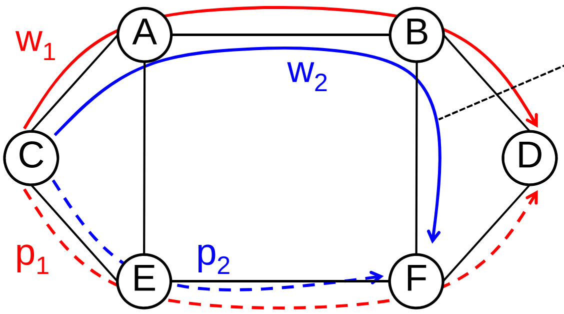
Energy-efficiency and network resilience: Sleep-mode

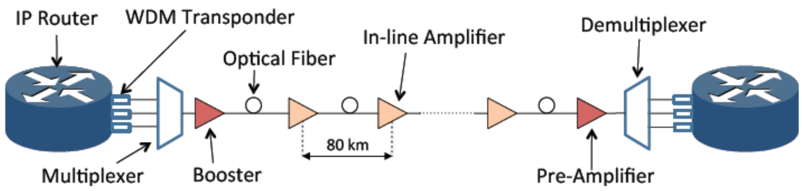
- Resources used for protection can be set into sleep-mode in order to save energy
- Traffic grooming is useful
  - Working paths are groomed together → more resources used only for protection



Longer routes might be preferred when exploiting traffic grooming in order to activate (power-ON) less links and set protection links in sleep-mode

- F. Musumeci *et al.*, "Energy-Efficiency of Protected IP-over-WDM Networks with Sleep-Mode Devices", in *IOS Journal of High Speed Networks, vol. 19 no. 1, 2013.*

Sleep-mode - Network scenario



- IP routers
  - Perform electronic traffic processing
- WDM transponders
  - Perform EO (resp., OE) signal conversion for signal transmission (reception)
  - Optical signals (wavelengths) are multiplexed into the same optical fiber
- WDM links
  - Optical amplifiers are used (1 in-line EDFA every 80 km + 2 additional EDFAs at the edges, as booster and pre-amplifier)

Sleep-mode - Power consumption model

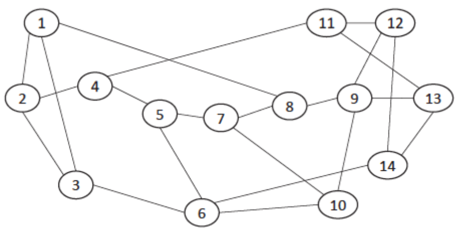
- Considered power contributions
  - *Electronic processing (IP routers)*:
    - traffic-independent contribution
    - traffic-dependent contribution
    - consumption in IDLE state is negligible
  - *WDM transponders*:
    - set in sleep-mode if used only for protection (only lasers and photodiodes are powered-on)
  - *WDM links (EDFAs)*:
    - consumption in IDLE state is negligible

Sleep-mode - Power consumption model

Contribution	Power consumption in ACTIVE state	Power consumption in IDLE state
Electronic processing (IP routers)	Traffic-independent P_0 = 2401 W (2240 Gbit/s rack)	
	Traffic-dependent P_t = 437 W (40 Gbit/s card)	P_t = 0
WDM transponders (transmitter-receiver)	$T_a = R_a$ = 79.4 W (40 Gbit/s transp.)	$T_i = R_i$ = 9.84 W
WDM links (EDFAs)	L_0 = 55 W (single EDFA)	L_i = 0

Sleep-mode - Case study

- NSFNET topology (14 nodes, 22 bidirectional single-fiber links)
  - 20 wavelengths @ 40 Gbit/s per fiber
  - Non-uniform traffic matrix (180 Gbit/s overall traffic)
  - Results for different traffic-matrix scaling factor *f* (*f* = 1, 2, 5, 10, 20)



- Comparison between:
  - SLP vs SPP vs DLP vs DPP
  - Sleep-mode vs all-ON
  - Protected vs unprotected scenarios
  - Power-aware vs power-unaware (minimize nr of wavelenghts)

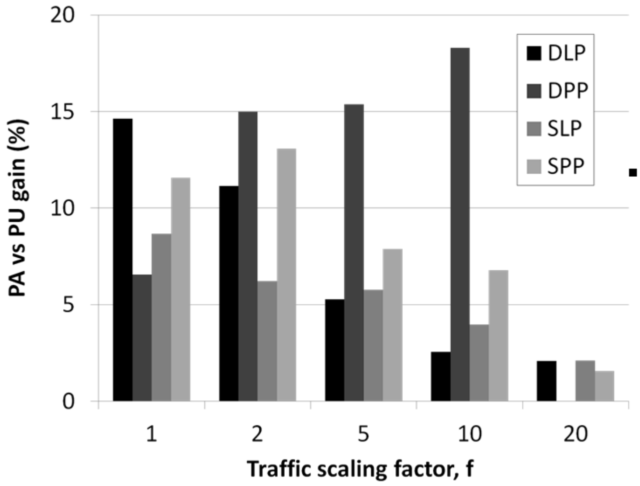
Sleep-mode - Power consumptions (kW)

Scaling factor	SLP		SPP		DLP		DPP		Unprotected
	sleep-mode	all-ON	sleep-mode	all-ON	sleep-mode	all-ON	sleep-mode	all-ON	
$f = 1$	73.791	110.297	73.89	108.054	74.008	120.057	73.89	115.321	73.398
$f = 2$	86.469	130.672	86.469	121.974	86.902	148.835	87.301	136.661	85.859
$f = 5$	121.365	185.6	121.954	186.406	122.388	232.027	121.817	203.591	120.381
$f = 10$	172.764	277.409	173.275	274.573	174.579	378.684	173.339	319.265	170.682
$f = 20$	270.23	455.448	270.992	442.877	274.186	662.191	not supported		266.806

- Relevant power savings (up to 60%) wrt Always-ON scenarios
- Small (1-2%) additional power required to provide resilience with sleep mode for protection resources compared to an unprotected power-aware design
- Small difference (within 1%) between the various protection strategies
  - Main power contribution at the IP layer (> 65% of the total power), almost independent from the adopted protection strategy

Sleep-mode - Power reduction

- Power-Aware (PA) vs Power-Unaware design of **protected** network



- Up to 18% of savings compared to power-unaware (cost-minimized) strategies

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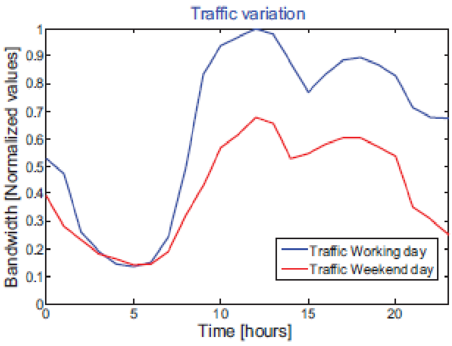
Energy-efficiency and network resilience: Rate-adaptation

- Devices activation can follow the traffic dynamics
  - Resource provisioning performed according to the peak traffic
  - In low-peak hours many devices can be powered-OFF (or set in sleep-mode) → save energy
- Working paths
  - Transmission remains fully active (dimensioned to peak demand)
- Backup paths
  - Spectral resources are reserved for peak demand value, but
  - **Transmission is adapted to hourly traffic conditions**



- J. Lopez *et al.*, "Traffic and Power-Aware Protection Scheme in Elastic Optical Networks", in Proc. of NETWORKS 2012 conference, Rome, Italy, Oct. 2012.

Rate-adaptation - Traffic/power-aware design

- Step1: Resource allocation for 1+1 protection (peak-rate)
  - Resources (transponders) are allocated according to the demands peak rate (for both working and backup paths)
  - Maximum power consumption corresponding to peak hours
- Step 2: Protection paths rate adaptation to hourly traffic variation
  - Protection paths remain reserved, but the transmission is adapted to the current traffic situation
  - Power reduction in backup paths given by:
    →Deactivation of transponders (WDM)
    →Subcarrier reduction or modulation format changing (EON)

Rate-adaptation - Power contributions

- Transponders

WDM Transponders [3]

Wavelength Capacity (Gbps)	Power consumption (W)	Reach (km)
10	34	3200
40	98	2200
100	351	1800

CO-OFDM Transponders

Frequency slot: 12.5 GHz

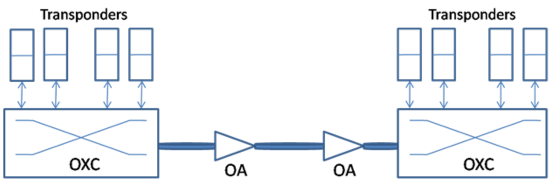
Mod. Format	Subc. Capacity (Gb/s)	Power Consumption (W)	Reach (km)
BPSK	12.5	112.374	4000
QPSK	25	133.416	2000
8QAM	37.5	154.457	1000
16QAM	50	175.498	500
32QAM	62.5	196.539	250
64QAM	75	217.581	125

[3] F. Smyth et al, "GreenTouch Draft Report on Baseline Power Consumption", 2011

- Optical Cross Connects (OXCs)
  - Depends on node degree (*N*) and add/drop degree (*α*) [3]

$$PC_{OXC}(\mathrm{W}) = N \cdot 85 + \alpha \cdot 100 + 150$$

- Optical amplifiers (EDFAs)
  - 30 W per direction [3]



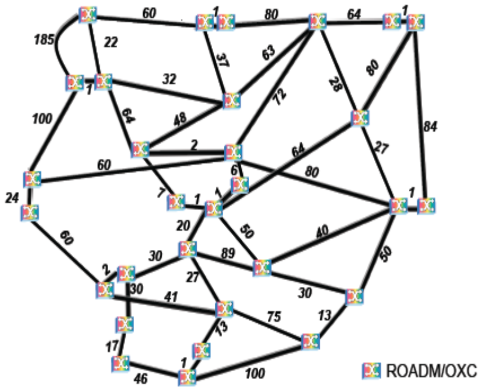
Rate-adaptation - An example of power reduction

- Single traffic demand on a point-to-point link
  - 350 km span
  - 135 Gbit/s at peak hour (12 AM)
  - 17.6 Gbit/s at off-peak hour (5 AM)

Network scenario	Conventional protection scheme (135 Gbit/s)		Traffic-aware protection scheme (17.6 Gbit/s)	
	Backup resources (transponders/subcarriers)	$PC_{TB}(conventional)$	Backup resources (transponders/subcarriers)	$PC_{TB}(traffic-aware)$
10G SLR	14 @10G	14 · 34 =476W	2 @10G	2 · 34 = 68W
40G SLR	4 @40G	4 · 98 =392W	1 @40G	98W
100G SLR	2 @100G	2 · 351 =702W	1 @100G	351W
10-40-100 MLR	1 @100G +1 @40G	351+98 =449W	1 @40G	98W
EON	3 @50G (16-QAM)	3 · 175.498 =526.495W	1 @25G (QPSK)	133.416W

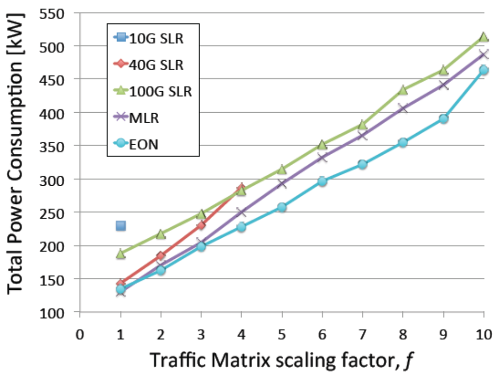
Rate-adaptation - Case study

- Telefonica's Spanish Core Network
  - Country-sized network
  - 30 optical nodes & 96 bidirectional links (1 fiber pair per link)
  - Fully transparent network
    - No regenerators
- Traffic demand reference
  - Traffic Matrix 2012
    - total traffic: 3.22 Tbit/s
  - Scaled by a factor *f* up to 10 (up to 32.2 Tbit/s)
- Hourly-traffic variations on weekdays and weekend days



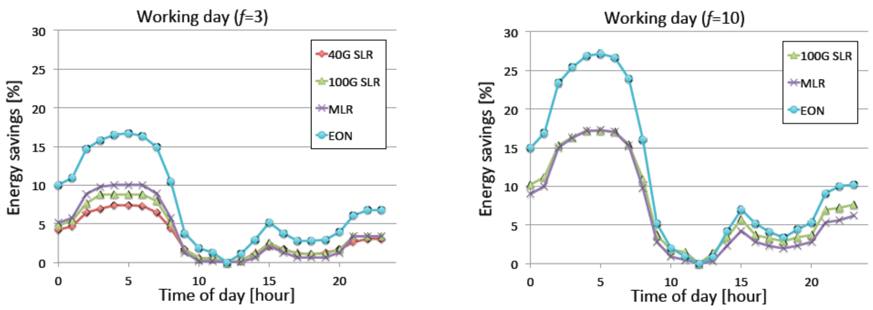
Rate-adaptation - Peak traffic

- Total power consumption with conventional DP 1+1 protection (working days) obtained for peak traffic (12:00 AM)
- 10G and 40G SLR support only low traffic
- High savings already in 1+1 DP with fully active devices thanks to MLR and EON



Rate-adaptation - Energy savings

- Energy savings (%) with Traffic/Power-aware design with respect to DP 1+1 (*f* = *3* and *f* = *10*) during the day



- Significant savings especially for EON thanks to its better adaptability
- Savings become more significant (up to 27% for EON) as traffic load increases

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Conclusions

- Power consumption reduction is a major issue in current telecommunication networks
- Need for network resiliency
- Use traffic- and power- aware design for resource provisioning and management
  - Set protection resources into OFF (or sleep-mode) state
  - Adapt transponders transmission rate to current traffic
- Sleep-mode capability of subsystems and Elastic Optical Networks let us accomplish good savings in power consumptions