# Green and survivable optical transport networks: a network performance perspective

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Workshop on
Understanding the inter-play between sustainability, resilience, and robustness in networks (USRR)
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# Outline

- People
  - Isabella Cerutti (SSUP)
  - Piero Castoldi (SSSUP)
  - Jiajia Chen (KTH)
  - Ajmal Muhammad (LiU)
  - Pawel Wiatr (KTH)
  - Lena Wosinska (KTH)
- Projects
  - FP7 ***DISCUS***: **DIS**tributed **C**ore for unlimited bandwidth supply for all **U**sers and **S**ervices
    - http://www.discus-fp7.eu/

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# Motivation and outline

- Optimizing energy performance is vital in telecom networks
  - But avoid "green at all cost" solutions
- Two tradeoffs around survivability/reliability aspects of optical transports
- Energy savings vs. resource efficiency while protecting
  - better adaptation to services survivability requirements
- Energy savings vs. reparation costs
  - maximum allowable failure rate increase

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# Energy efficiency vs. resource usage

- Energy efficiency helps in WDM networks to reduce part of capital expenditure
- Sleep mode: useful concept, especially in survivable networks
  - resources used for protection purposes only can be set to idle
- Benefits assessed in a number of works (DPP, SPP) for static and dynamic traffic
- One drawback: negative impact on resource utilization
  - longer paths to maximize energy savings, thus poor resource utilization

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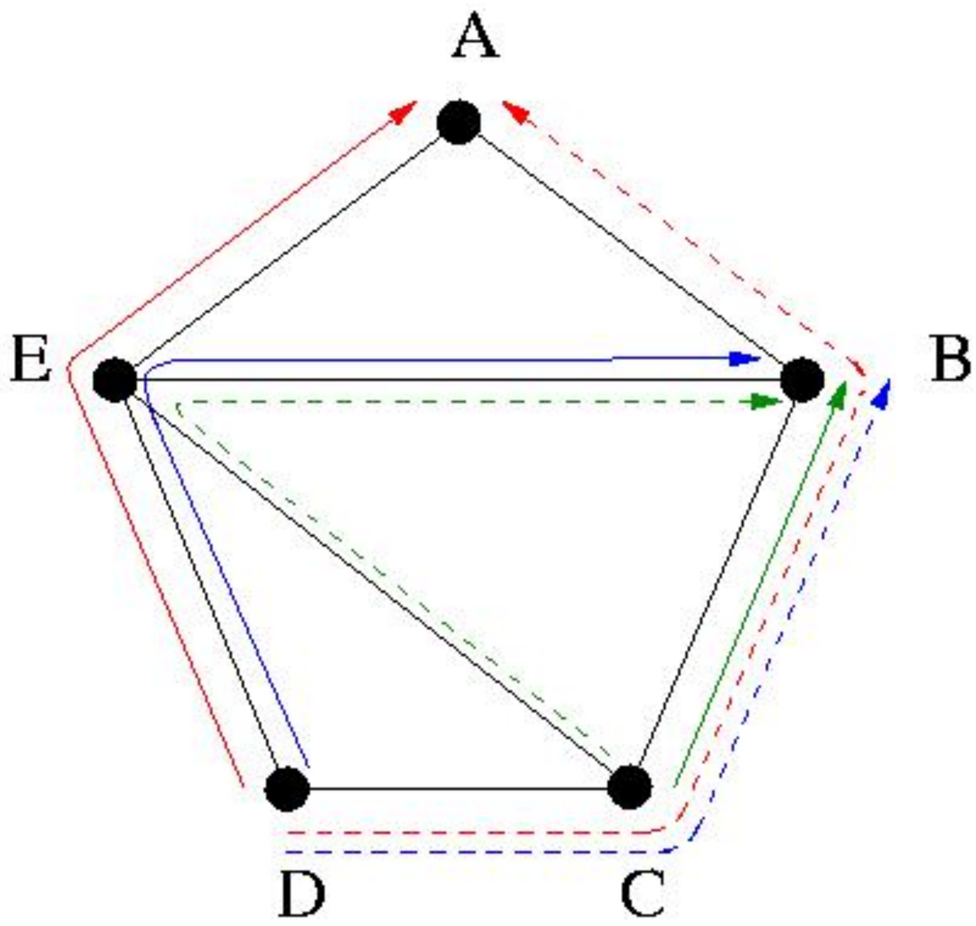
# Better resources usage with protection techniques?

- SPP based protection techniques
- Differentiated Reliability (DiR) beneficial for efficient resources usage:
  - demand comes with reliability requirement (e.g., MCFP)
  - MCFP: maximum acceptable probability that, upon a failure, the connection will not survive (SPP -> MCFP =0)
  - demand assigned minimum amount of resources to meet the reliability requirement
- A combined scheme (SPP-DiR) guarantees:
  - protection against any single failure (typical SPP scheme)
  - avoid provisioning excess reliability
  - better link sharing among backup paths
- SPP-DiR + energy efficiency?
  - joint optimization energy and resources
  - combine also with sleep mode support

# SPP-DiR: an example




- d1:C-B
- d2:D-A
- d3:D-B

- 5 nodes, 7 links, 2 wavelength/link
- 3 demands:
  - MCFP(d1)=0
  - MCFP(d2)=0
  - MCFP(d3)=1/7
- Conventional SPP:
  - 1 demand blocked
- SPP-DiR:
  - 0 demand blocked

# Energy aware SPP-based DiR

- Objective: for each arriving demand find working/ protection pair able to:
  - satisfy MCFP requirement
  - keep used resources and the energy consumption at a minimum
- Decisions are made with a multi objective cost function

$$C_{i,j,k}^{(\hat{d})} = \gamma \cdot \left( |H_{w_i}^{(\hat{d})}| + |H_{b_j}^{(\hat{d})}| - |H_{s_{(i,j,k)}}^{(\hat{d})}| \right) + \eta \cdot \left( P_{w_i} + P_{b_{(j,k)}} \right) + \left( MCFP^{(\hat{d})} - P_{f_{(i,j,k)}}^{(\hat{d})} \right). \quad (5)$$

- C is a linear combination of resource usage (γ) power consumption (η) and excess of reliability, for a certain choice of *working i*, *protection j*, *prot. wavelength k*

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A. Muhammad, et al., "Reliability Differentiation in Energy Efficient Optical Networks with Shared Path Protection", *IEEE Online Conference on Green Communications, 2013*

# EA-SPP-DiR heuristic

**Algorithm 1** Energy-Aware SPP-based DiR

$\mathcal{G}(\mathcal{V},\mathcal{E})$: network topology;
$d$: lightpath demand;
$W^{(\hat{d})}$: set working paths for $\hat{d}$ sorted for hop length;
$B^{(\hat{d})}$: set protection paths for $\hat{d}$ sorted for hop length;
Initialization: $\widetilde{C} = -1$;
**for** each path $w_i^{(\hat{d})} \in W^{(\hat{d})}$ **do**
  Let $\Lambda_{w_i}^{(\hat{d})}$ be set of continuous wavelengths for $w_i^{(\hat{d})}$;
  **if** $\Lambda_{w_i}^{(\hat{d})} \neq \emptyset$ **then**
    **for** each $b_j^{(\hat{d})} \in B^{(\hat{d})}$: $H_w^{(\hat{d})} \cap H_b^{(\hat{d})} = \{\emptyset\}$ (Eq. (1)) **do**
      Let $\Lambda_{b_i}^{(\hat{d})}$ be the set of continuous wavelengths for $b_j^{(\hat{d})}$;
      **if** $\Lambda_{b_i}^{(\hat{d})} \neq \{\emptyset\}$ **then**
        **for** each $\lambda_k \in \Lambda_{b_i}^{(\hat{d})}$ **do**
          **if** $w_i^{(\hat{d})}, b_j^{(\hat{d})}, \lambda_k$ satisfy Eqs. (2) and (3) **then**
            Compute cost $C_{i,j,k}^{(\hat{d})}$ (Eq. (5));
          **end if**
        **end for**
      **end if**
    **end for**
  **end if**
**end for**
Select $w_i^{(\hat{d})}$, $b_j^{(\hat{d})}$ and $\lambda_k$ : $\widetilde{C} = \min_{i,j,k}\{C_{i,j,k}^{(\hat{d})}\}$;
**if** $\widetilde{C} \neq -1$ **then**
  Return $w_i^{(\hat{d})}$, $b_j^{(\hat{d})}$, $\lambda_k$, $\Lambda_{w_i}^{(\hat{d})}$;
**else**
  Block $\hat{d}$;
**end if**

$$\forall d \in D, d \neq \hat{d}: \begin{cases} (H_w^{(d)} \setminus H_u^{(d)}) \cap (H_w^{(\hat{d})} \setminus H_u^{(\hat{d})}) \neq \{\emptyset\} \\ H_b^{(d)} \cap H_b^{(\hat{d})} = \{\emptyset\} \ \vee \ \lambda_b^{(d)} \neq \lambda_b^{(\hat{d})}; \end{cases} \quad (2)$$

$$P_f^{(\hat{d})} = \sum_{(m,n) \in H_u^{(\hat{d})}} P_f(m,n) \leq MCFP^{(\hat{d})}$$

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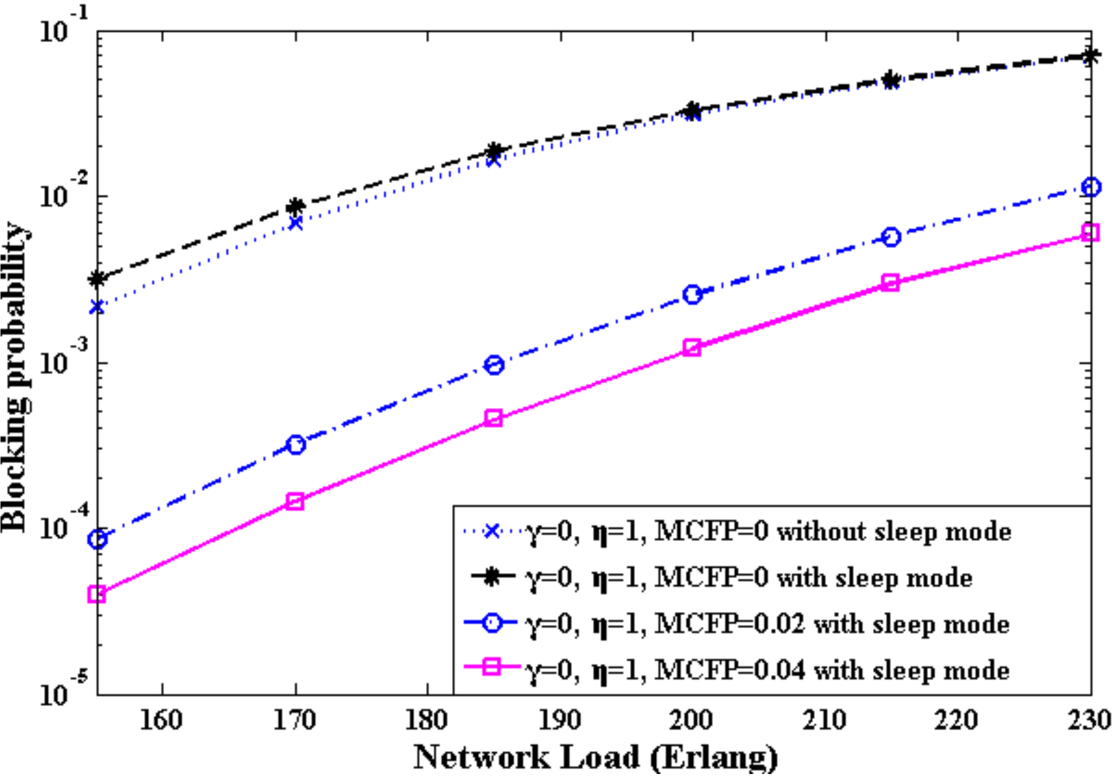
# Simulation parameters

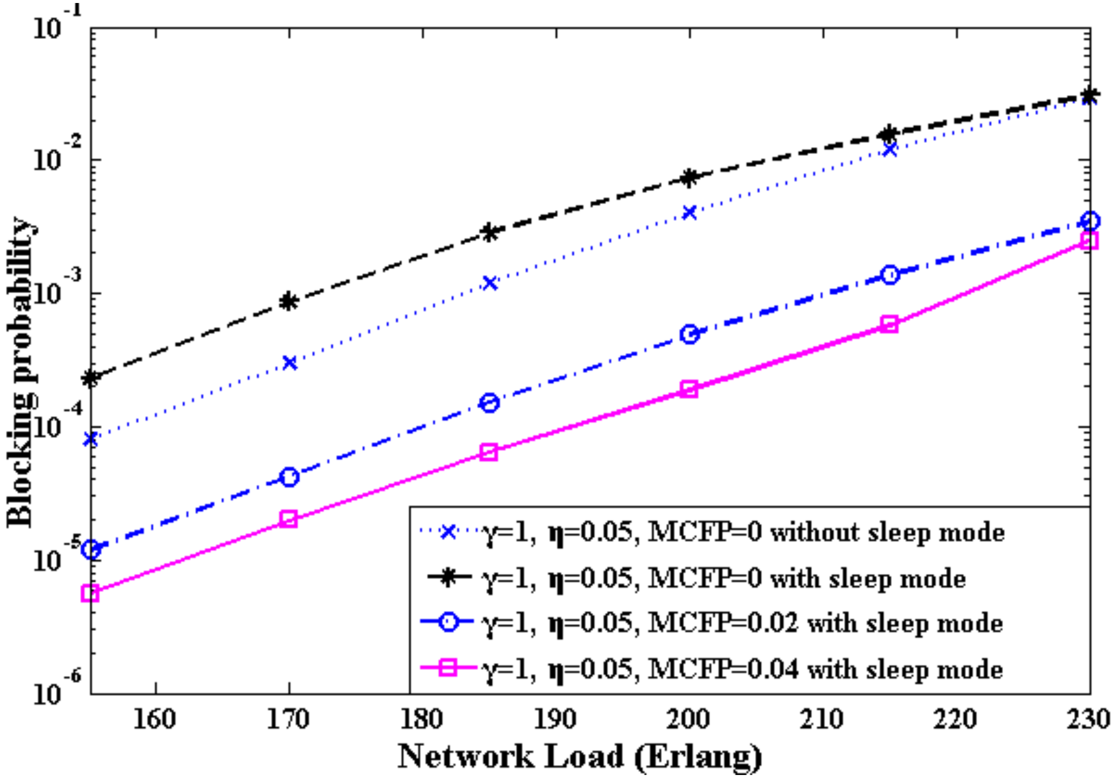
- COST 239: 11 nodes and 52 unidirectional links, 16 wavelengths per link (40 Gbps)
- Link failure probability: $P_f(m,n) = 1/52$ (uniform single-link-failure distribution)
- Demands are uniformly distributed: arrivals (Poisson process), holding time (exponentially distributed, average duration 1)
- MCFP=0.02 ->up to one working link unprotected
- 5 candidate (working/protection) routes for each demand
- Wavelength continuity constraint
- Confidence interval: 6% or better with 90% confidence level

# Power model

- Assumed working conditions: *on, off, sleep*
- Power budget node: OXC controllers (150 W) + transmitters and receivers
- Transmitter and receiver: drivers (2 × 9 W), laser (6.6 W), photodiode and transimpedence amplifier (2×0.4 W), ADC (2×2 W), management (20% of the overall power)
- Power budget link: OXC terminals (155 W) + in-line amplifiers (55 W × 80 km)
- Sleep mode node (only tx/rx part): the drivers and the ADC of the transmitter for the protection can be set to idle
- Sleep mode link (supporting only protection paths): in-line amplifiers along the links are set to idle

# EA-SPP-DiR: request blocking



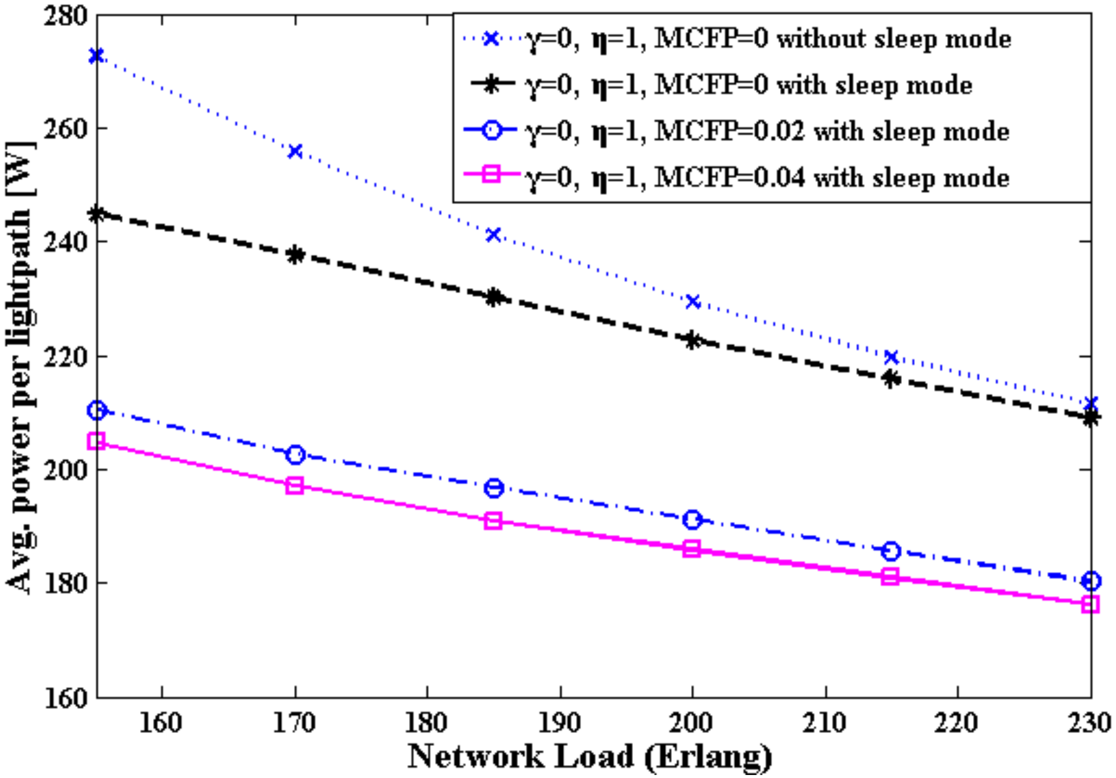



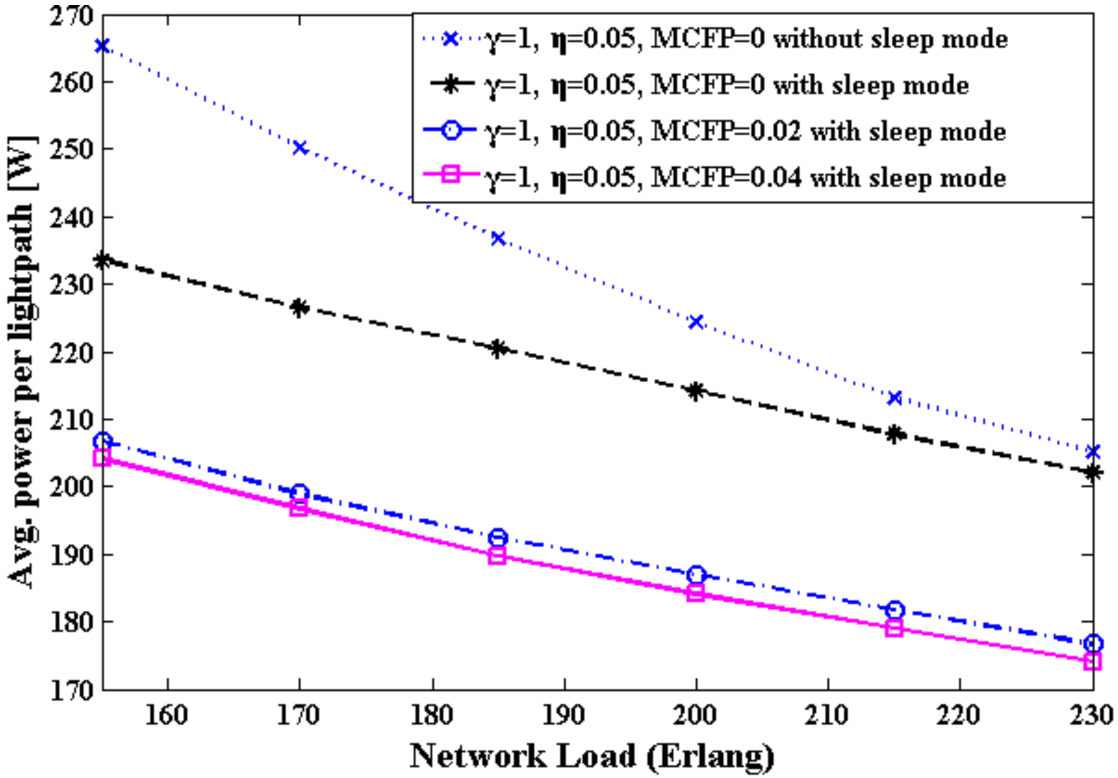

Energy minimization only

Energy and resource minimization

A. Muhammad, et al., "Reliability Differentiation in Energy Efficient Optical Networks with Shared Path Protection", *IEEE Online Conference on Green Communications, 2013*

# EA-SPP-DiR: power consumption

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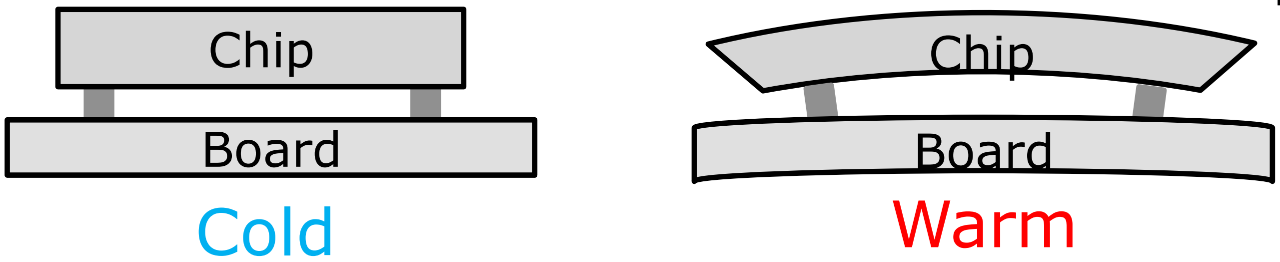
# Impact of energy efficiency on OPEX

- Sleep mode: effective way to save energy
- Frequent transitions between operational and sleep modes may negatively impact the component reliability performance
- Additional operational expenditures (OPEX) in terms of failure reparation ->tradeoff with potential energy savings
- *Maximum allowable failure rate increase*: what is the max increment in the failure rate s.t. the extra reparation cost would not exceed the cost saving obtained by a given green strategy

# Reliability performance degradation factors

- Temperature *(Arrhenius law)*
  - defines how much the failure rate of a device could increase if operated at a temperature higher than a reference temperature
- Temperature variation
  - different Coefficient of Temperature Expansion (CTE) → →tension under variable temperature → cracks → failure *(Coffin-Manson, Engelmeier, Norris-Lanzberg)*

$CTE_{Chip} > CTE_{Board}$




- Humidity, chemical corrosion, vibration, etc.

P. Wiatr, et. al, "Energy Saving in Access Networks: Gain or Loss from the Cost Perspective?," *in Proc. of IEEE ICTON*, 2013

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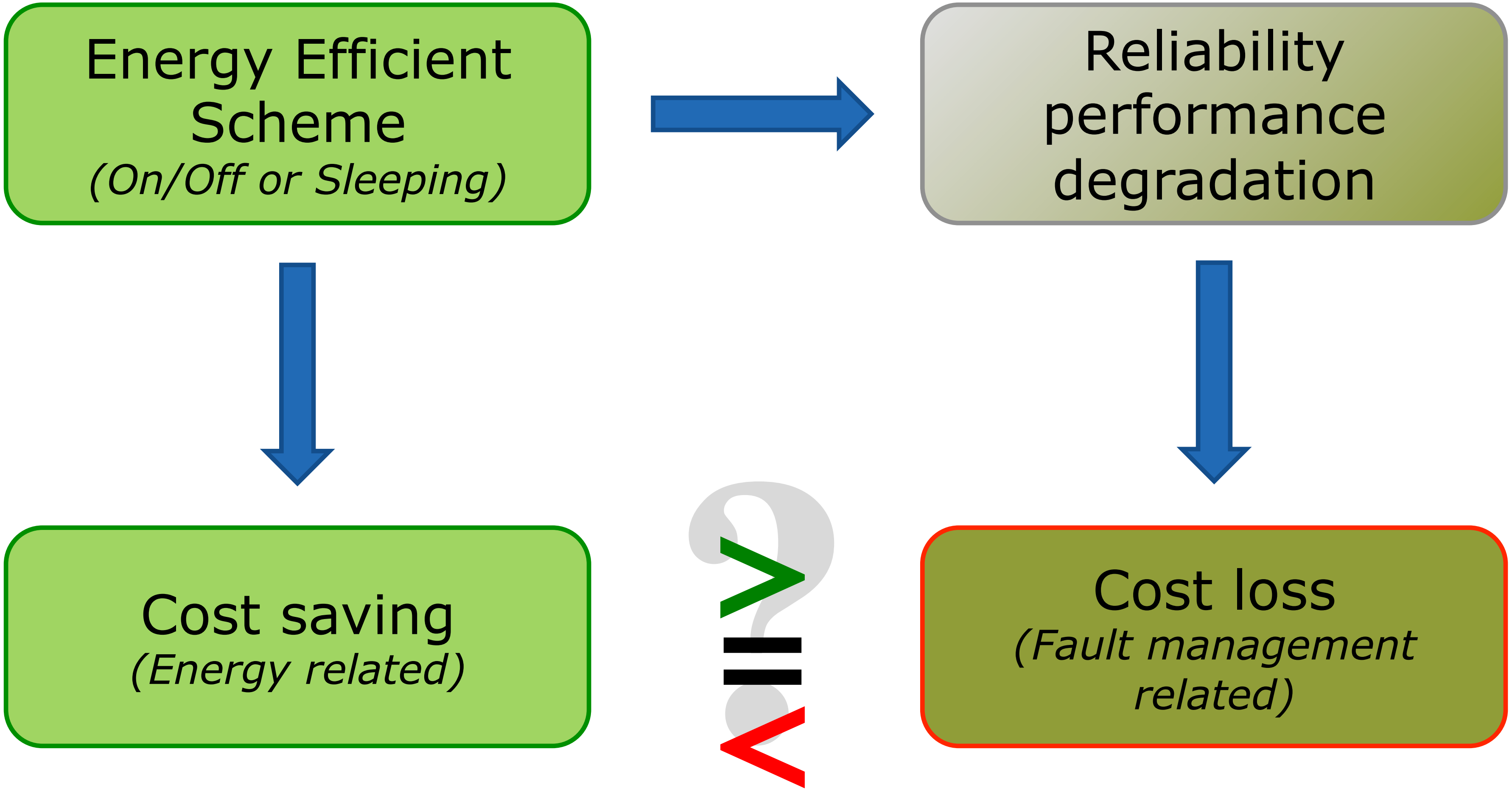
# Methodology for assessing OPEX impact



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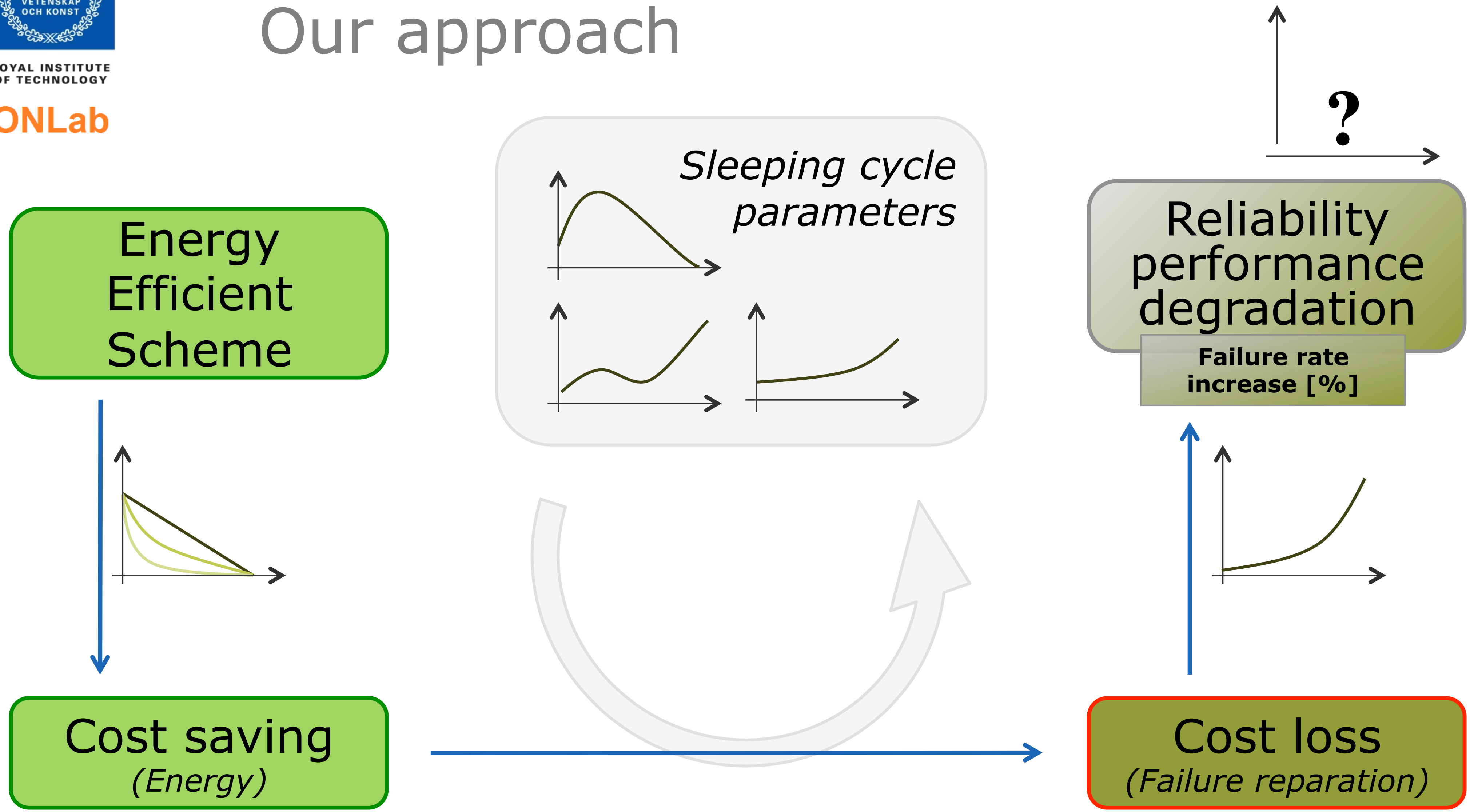
# Our approach




**What is the maximum allowable failure rate increase s.t. *Cost saving ≥ Cost loss*?**

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# Main core components breakdown

***$OPEX_E$***: the cost of energy consumption
***$OPEX_F$*** : the reparation cost in normal operating conditions
**$\Delta OPEX_E$**: the energy savings obtained by a low power mode operation
***$\Delta OPEX_F$*** : the cost increase for additional failure reparation(s) caused by the increased failure rate as a consequence of the transitions between low and high power modes

$$OPEX_T = OPEX_E - \Delta OPEX_E + OPEX_F + \Delta OPEX_F$$

| *Component* | *Failure rate [FIT]* | *MTTR [h]* | *Pers.* | *P [W]* | *Max. allowable failure rate increase with energy saving of:* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ***5%*** | ***10%*** | ***25%*** | ***50%*** | ***75%*** | ***90%*** | ***95%*** |
| **Transponder** | **256** | **2** | **1** | **70** | **947.5%** | **1 895%** | **4 737%** | **9 475%** | **14 213%** | **17 056%** | **18 004%** |
| **Regenerator** | **256** | **2** | **1** | **70** | **947.5%** | **1 895%** | **4 737%** | **9 475%** | **14 213%** | **17 056%** | **18 004%** |
| **Optical Switch** | **5467** | **2** | **1** | **60** | **38.0%** | **76.1%** | **190.1%** | **380.3%** | **570.5%** | **684.6%** | **722.6%** |
| **Reconfigurable Optical Add/Drop Multiplexer (ROADM)** | **3300** | **2** | **1** | **35** | **36.8%** | **73.5%** | **183.8%** | **367.5%** | **551.3%** | **661.5%** | **698.3%** |
| **EDFA** | **2000** | **6** | **2** | **8** | **2.3%** | **4.6%** | **11.6%** | **23.1%** | **34.7%** | **41.6%** | **43.9%** |

P. Wiatr, et al., "Energy Efficiency and Reliability Tradeoff in Optical Core Networks", *in Proc. of IEEE/OSA Optical Fiber Communication Conference and Exposition (OFC), 2014*

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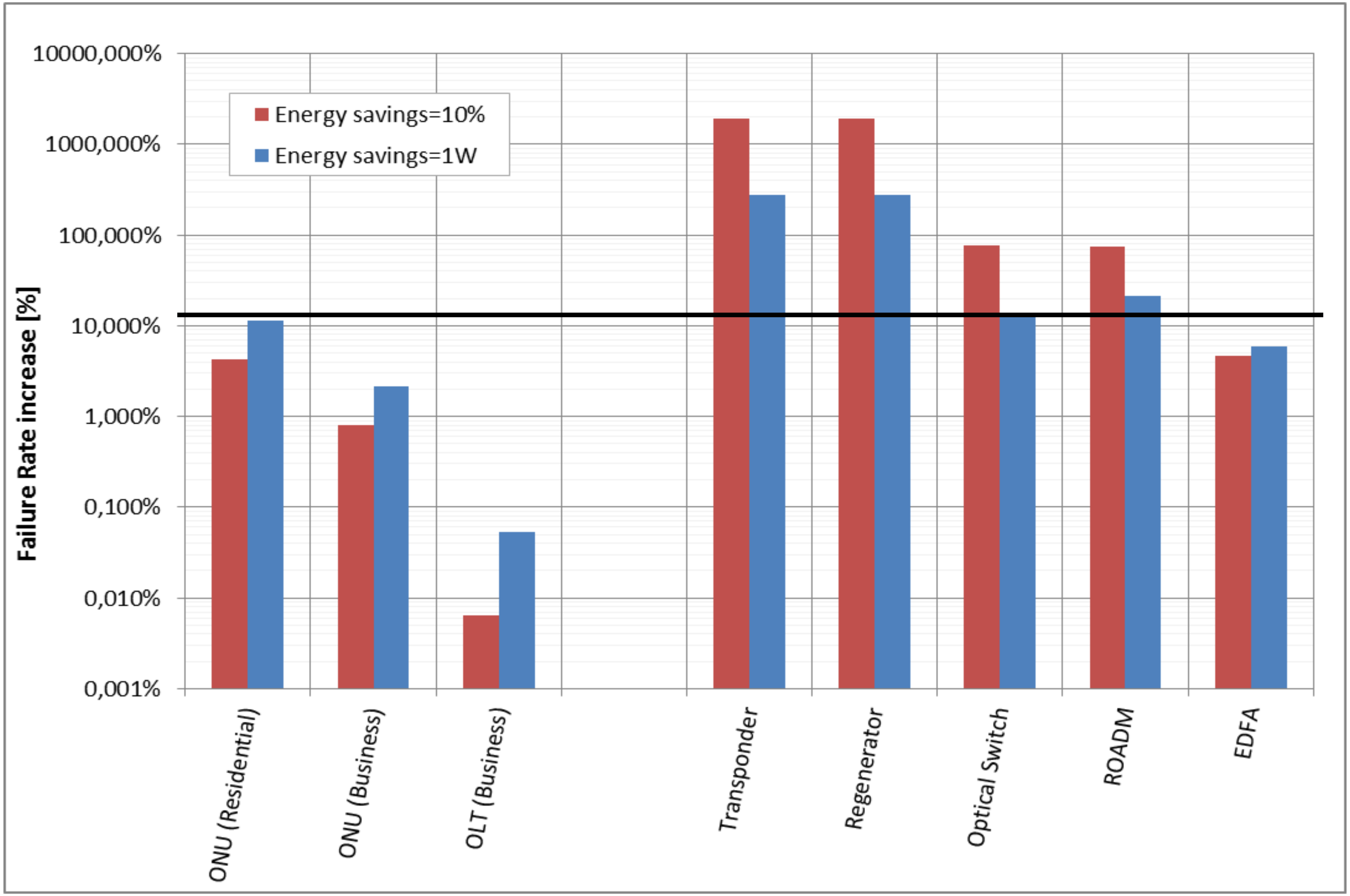
# Maximum allowable failure rate increase

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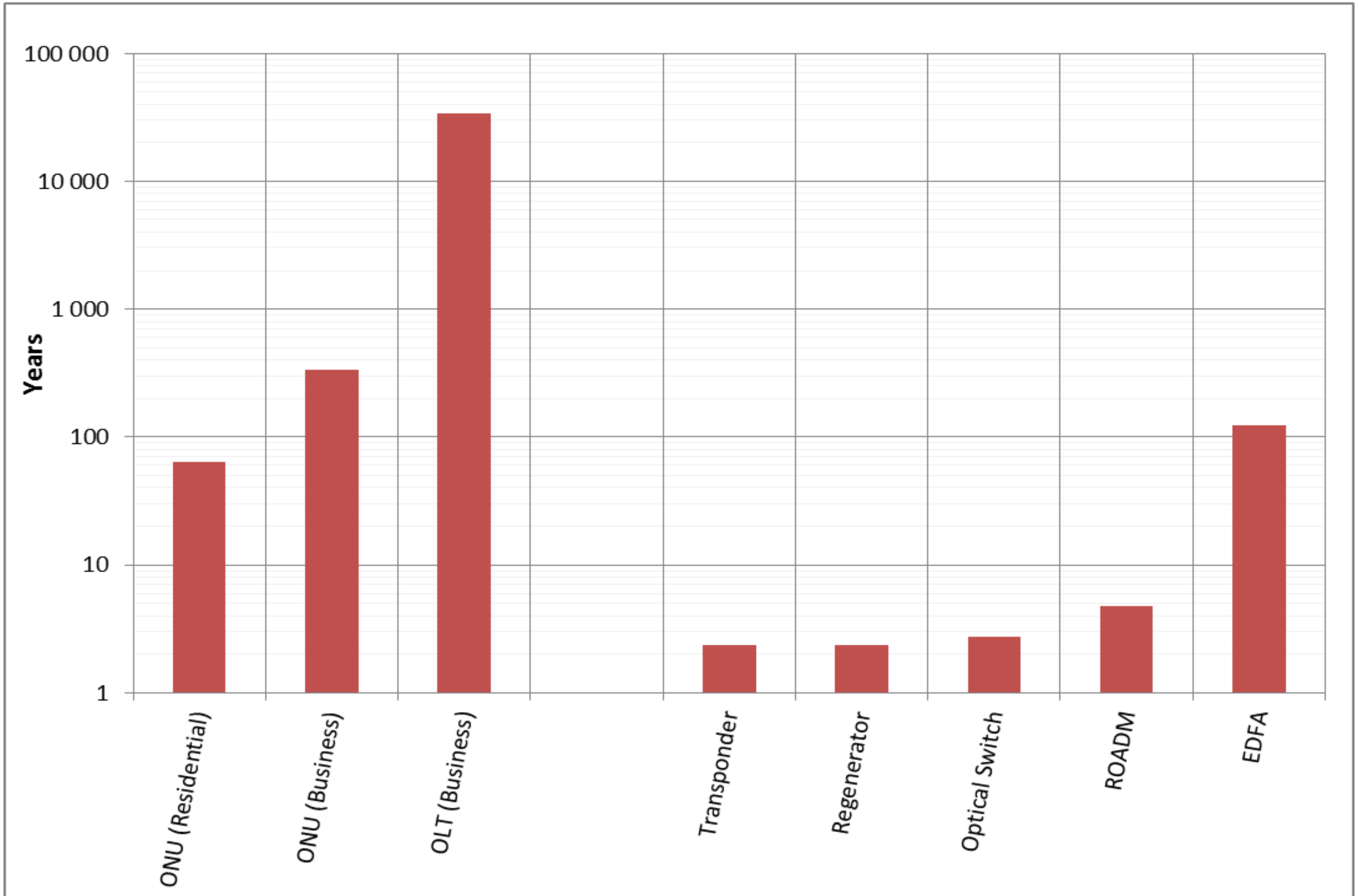
# Years of energy saving to cover cost of one failure

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# Conclusions

- Addressed the tradeoff between energy efficiency and resource efficiency/reliability in WDM networks
- Resource efficiency is indeed an issue, that has to be be jointly optimized with energy efficiency
- Strategies devised in this way present good tradeoffs values, e.g., EA-SPP-DiR
- Reliability performance of network equipment can be degraded by frequent on/sleep/off transitions with a consequent increase of failure related OPEX
- Methodologies able to quantify the effects of energy saving algorithms on the overall OPEX are crucial, certain components are not suited to be “targeted” by energy efficient mechanisms
- Reliability impact assessment also needed beyond optical components, e.g., HetNet wireless deployments

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# References


1) A. Muhammad, et al., “Energy-Efficient WDM Network Planning with Dedicated Protection Resources in Sleep Mode,” in Proc. of GLOBECOM, 2010.
2) A. Muhammad, et al., “Reliability Differentiation in Energy Efficient Optical Networks with Shared Path Protection,” in Proc. Of Online GreenComm, 2013.
3) P. Wiatr, et al.,"Energy Saving in Access Networks: Gain or Loss from the Cost Perspective?," in Proc. Of ICTON, 2013.
4) P. Wiatr, et al.,"Energy Efficiency and Reliability Tradeoff in Optical Core Networks," in Proc. of OFC, 2014.

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Energy Efficient Optical Networks

Deadline: end of June 2014

2nd Green Broadband Access Workshop

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