

# Design of Low-Margin Optical Networks

OFC 2016 – Paper Tu3F.5 (invited)

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- 22-03-2016

# Agenda

## 1. Margins

2. Reduction of system margins
3. Reduction of unallocated margins
4. Reduction of design margins
5. Conclusions

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**NEXTWORKS**  
ENGINEERING FORWARD

# Margins and design of optical networks

- Margins

- Trade cost for reliability

- “margin of safety” =  $\frac{\text{failure load}}{\text{design load}} - 1$

- buildings: 100%; cars: 200%; planes: 20-200%

- (Limited) margins are wanted by customers

- Design of optical networks

- Green-field: given nodes, links, traffic demand → allocate resources (equipment: optical transponders, types of transponders, regenerators, IP ports) to minimize some cost metric (CAPEX)
- Brown-field: allocate new traffic demands to minimize cost metric



By Arriva436 (Own work) [GFDL or CC BY 3.0, via Wikimedia Commons]

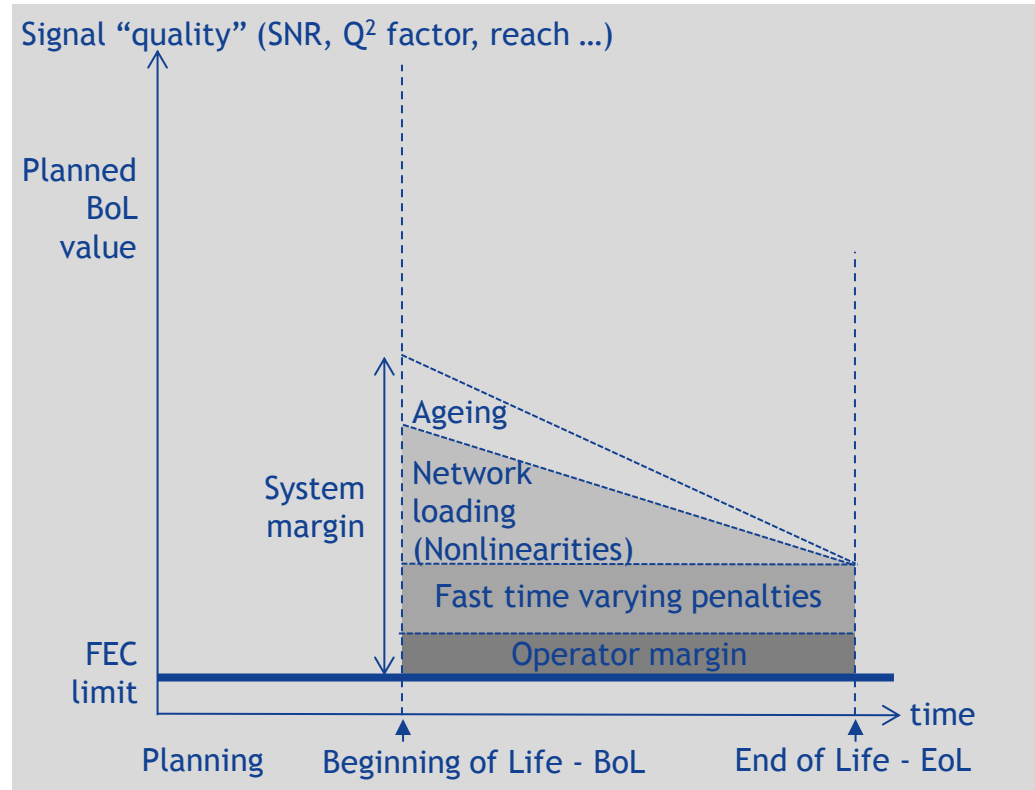
- How to decrease margins when designing a network?

# Margins

## System margin

- [? dB] Operator margin
- [0.4 dB] Fast time-varying penalties
  - Typically: polarization effects
  - Use worst-case
- Slow time-varying penalties
  - [1.5-3 dB] Varying network load → varying nonlinear effects
  - [several dB] “Ageing”:
    - [0.7 dB] Amplifier noise figure (NF)
    - [1.6e-3 dB/km/year] Additional losses due to splices after fiber cuts
    - [0.05 dB/filter] Filter misalignment due to laser detuning
    - [0.5 dB] Transponder

Most data from:  
Augé (Orange), OFC 2013, OTu2A.1  
Pesic et al. (Bell Labs), OFC 2016, M3K.2



# Margins

## Unallocated margin

Unallocated margin

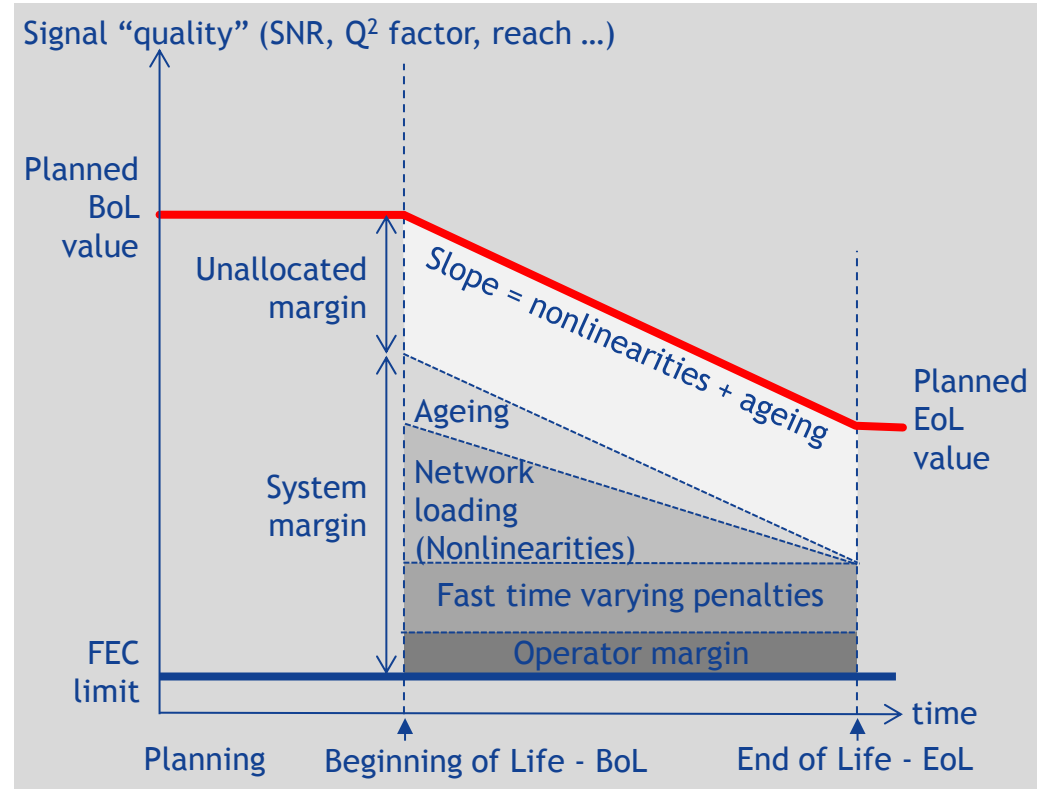
=

theoretical perf. of equipment

-

perf. really needed to satisfy demand

- Need reach (SNR) = x km (y dB) for demand of z Gb/s but equipment can provide x' > x km (y' > y dB) SNR  
→ Unallocated margin (dB) = y' - y
- Driven by discrete granularity of equipment performance

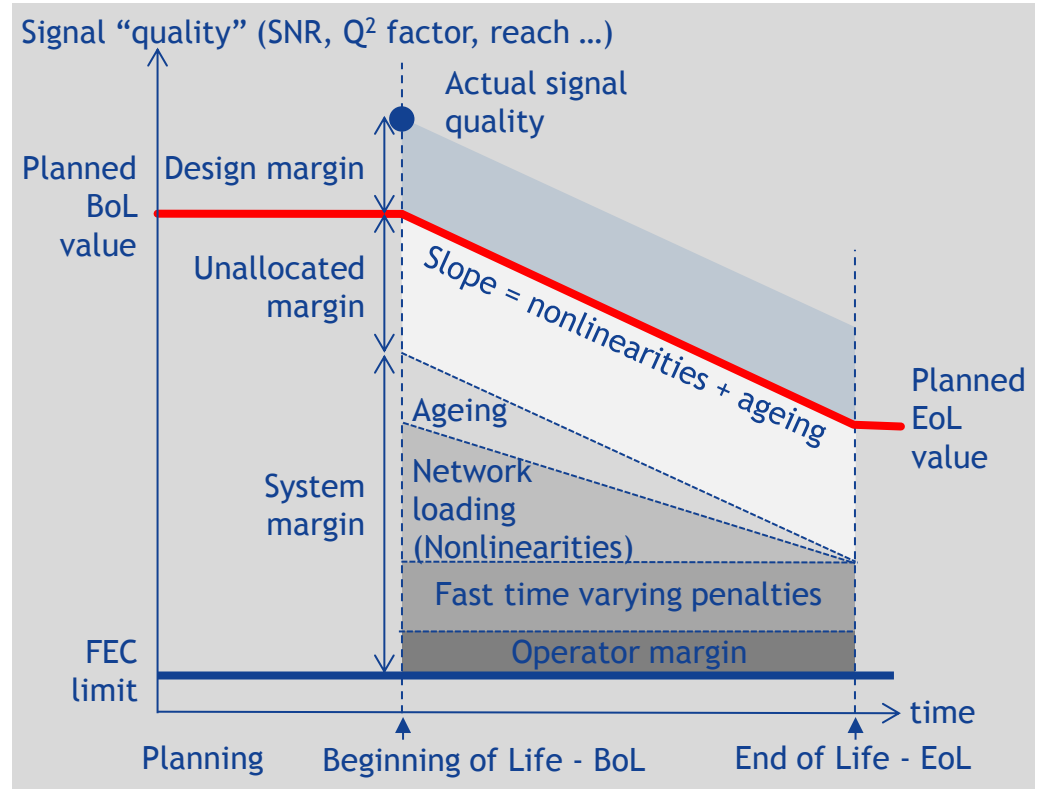


# Margins

## Design margin

$$\begin{aligned} \text{Design margin} &= \\ &\text{real performance on the field} \\ &- \\ &\text{planned performance} \end{aligned}$$

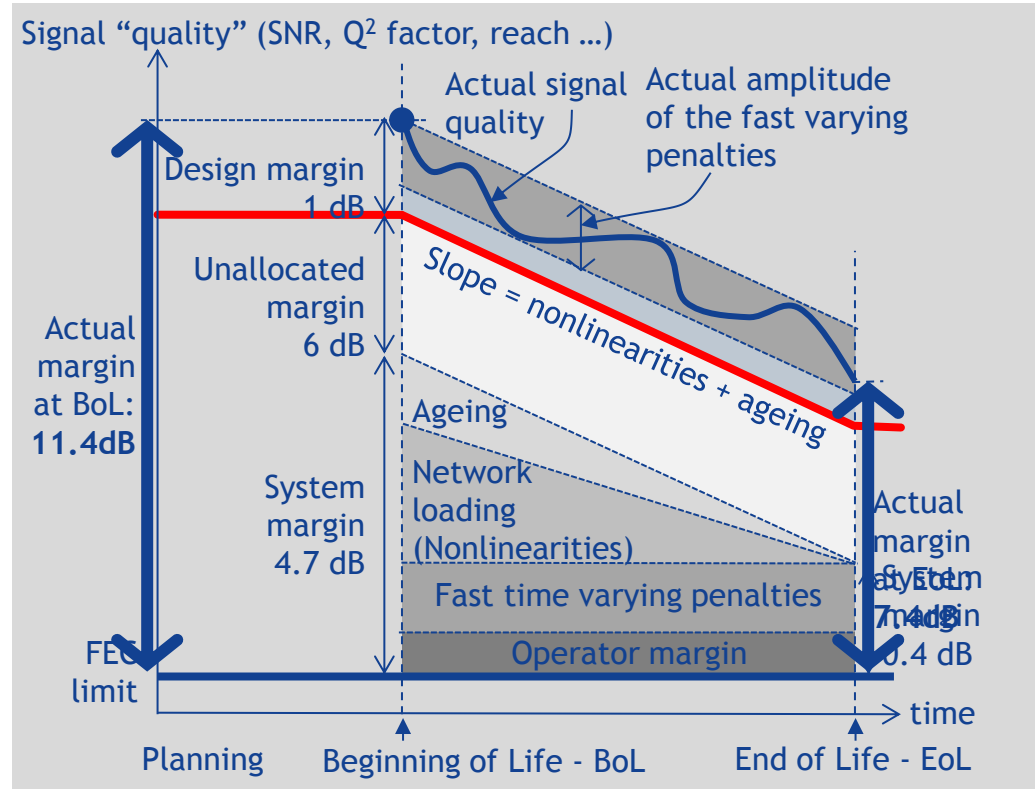
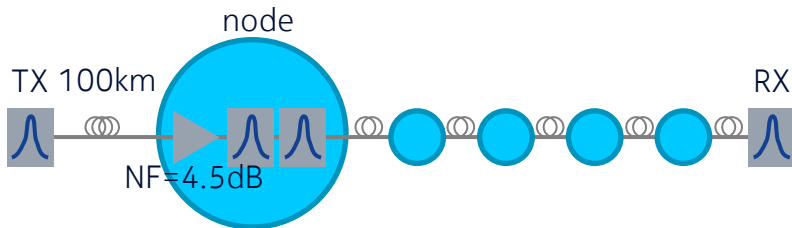
- Sources:
  - Inaccuracy of the **physical layer models** underlying the Quality of Transmission (QoT) tool
  - Inaccuracy of the **inputs** of the Quality of Transmission (QoT) tool
  - Estimation: <2 dB



# Margins

## An example

- Consider the 600 km path below with a 100G PDM-QPSK lightpath
  - System:
    - BoL: 4.7 dB (0.4 dB fast varying penalties, 2.3 dB slow ageing, 2dB nonlinearities )
    - EoL: 0.4 dB (fast varying penalties)
  - Unallocated: 6dB (unloaded reach=7100 km)
  - Design: 1 dB (assumed)
  - **Total: 11.7 dB @ BoL, 7.4 dB @ EoL**



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- 2. Reduction of system margins**
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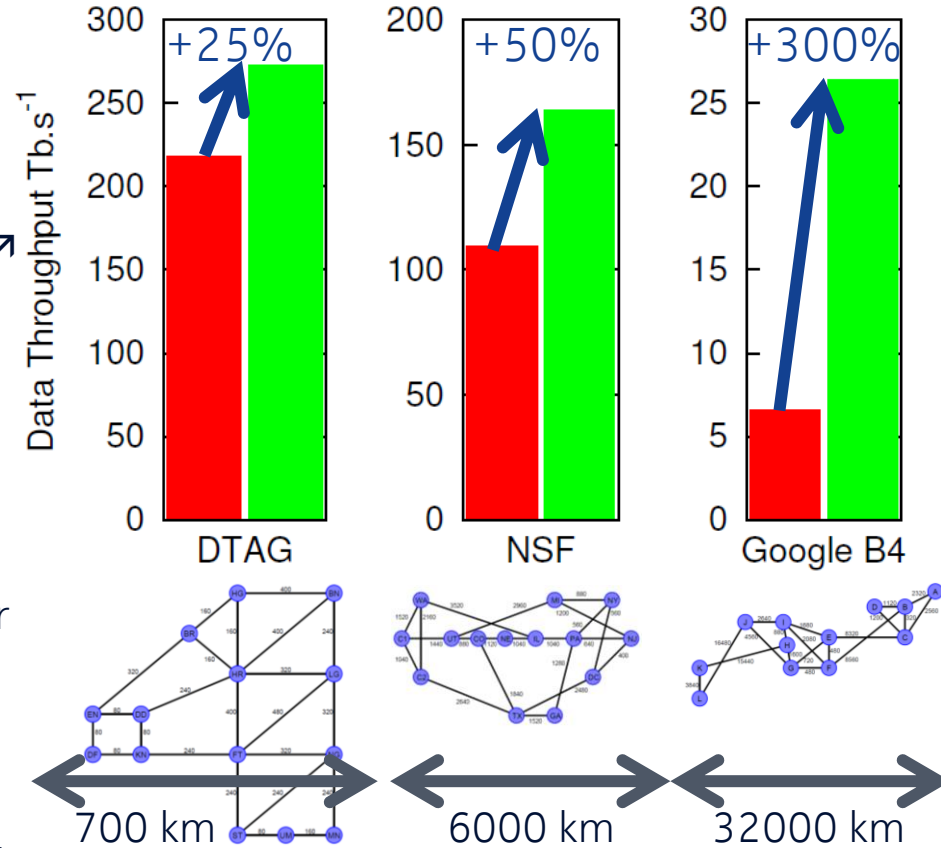
# System margin

## Load

- **Target:**
  - network capacity ↗ (green field)
  - decreased or delayed investment; network life ↗
- **Method:** power, spectrum, rate allocation
- **Gain:** +25-300% capacity (depending on network diameter)
- **Requirement:** flex-grid and rate TRX/ROADMs; control plane.
- **Possible improvement:** flex-grid, multi-layer
- **Challenges:** very fine (per-lightpath) power management; requires network re-optimization during operation

*D.J. Ives et al., PNC, 29 (3), 2015; Bononi et al., NOC 2014.*

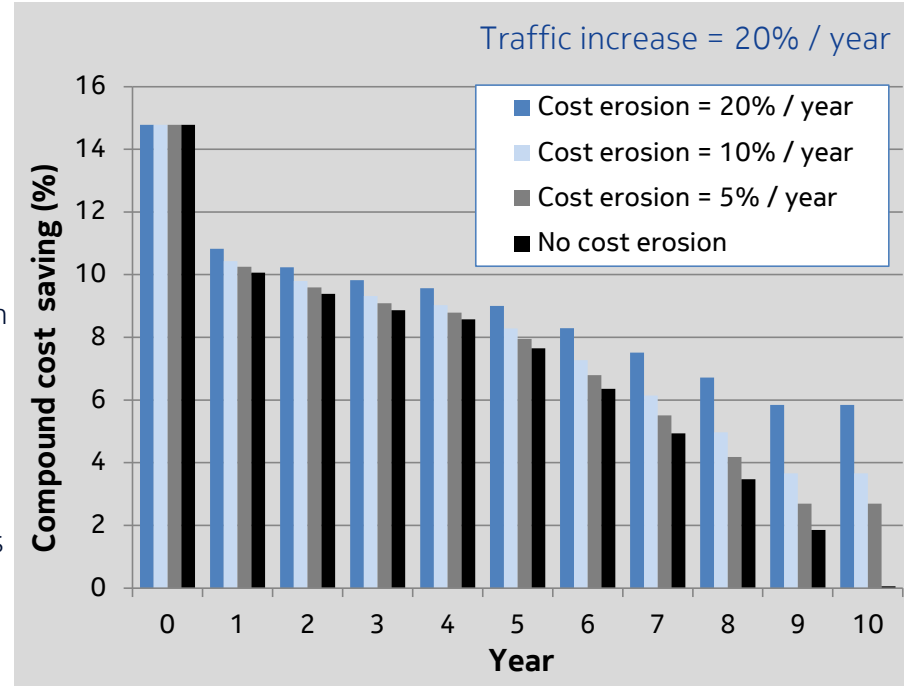
■ Fixed modulation format, fixed power, worst case  
■ Adapted modulation format, optimized Power



# System & unallocated margins

## Ageing & unallocated

- **Target:**
  - decreased or delayed investment
  - increase network capacity during first years of operation
- **Method:** routing, spectrum, mod. *multi-period* allocation
  - change modulation + deploy new equipment as network ages and traffic increases
  - lightpath datarate may change → leverage unallocated margin
- **Sample study:**
  - System margins around 2 dB (ageing)
  - Nonlinear effects: worst case – fully loaded links
- **Gain:** -10% TRX cost during first few years – few % at EoL
- **Requirement:** control plane, flex-grid and rate TRX/ROADMs
- **Possible improvement:** flex-grid, multi-layer, account for network load (nonlinear effects)
- **Challenges:** change signal rate during network operation



See also Dupas et al., OFC 2016, Th3I.1 – Hitless 100 Gbit/s OTN Bandwidth Variable Transmitter for SDN

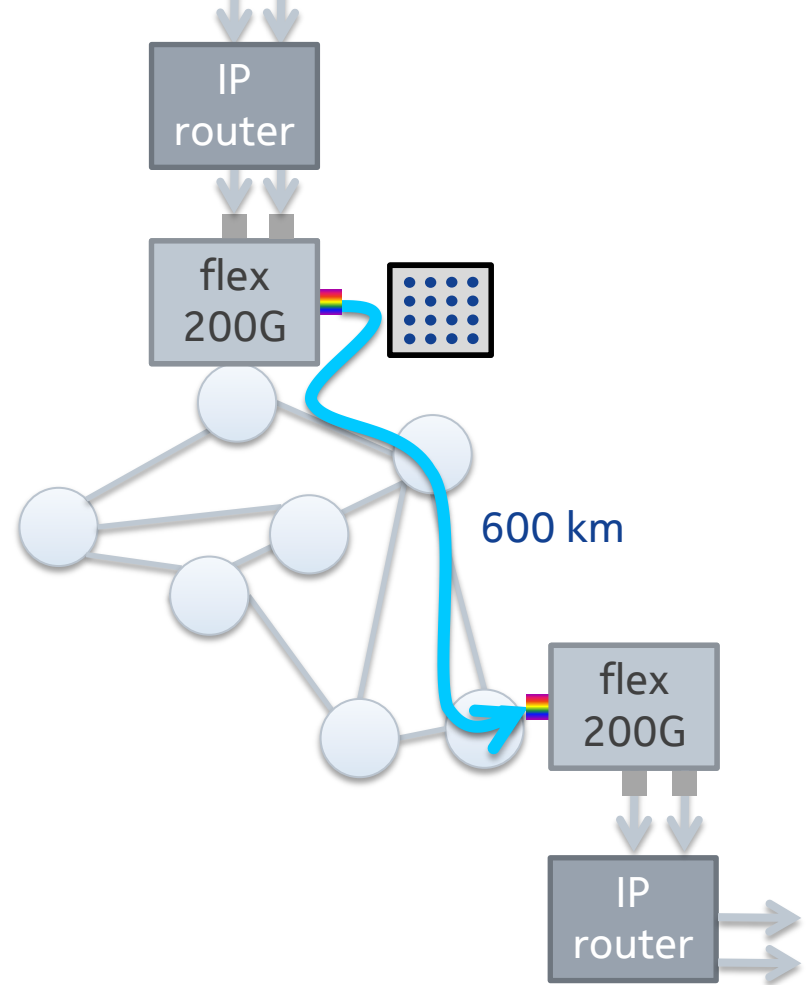
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# Unallocated margin

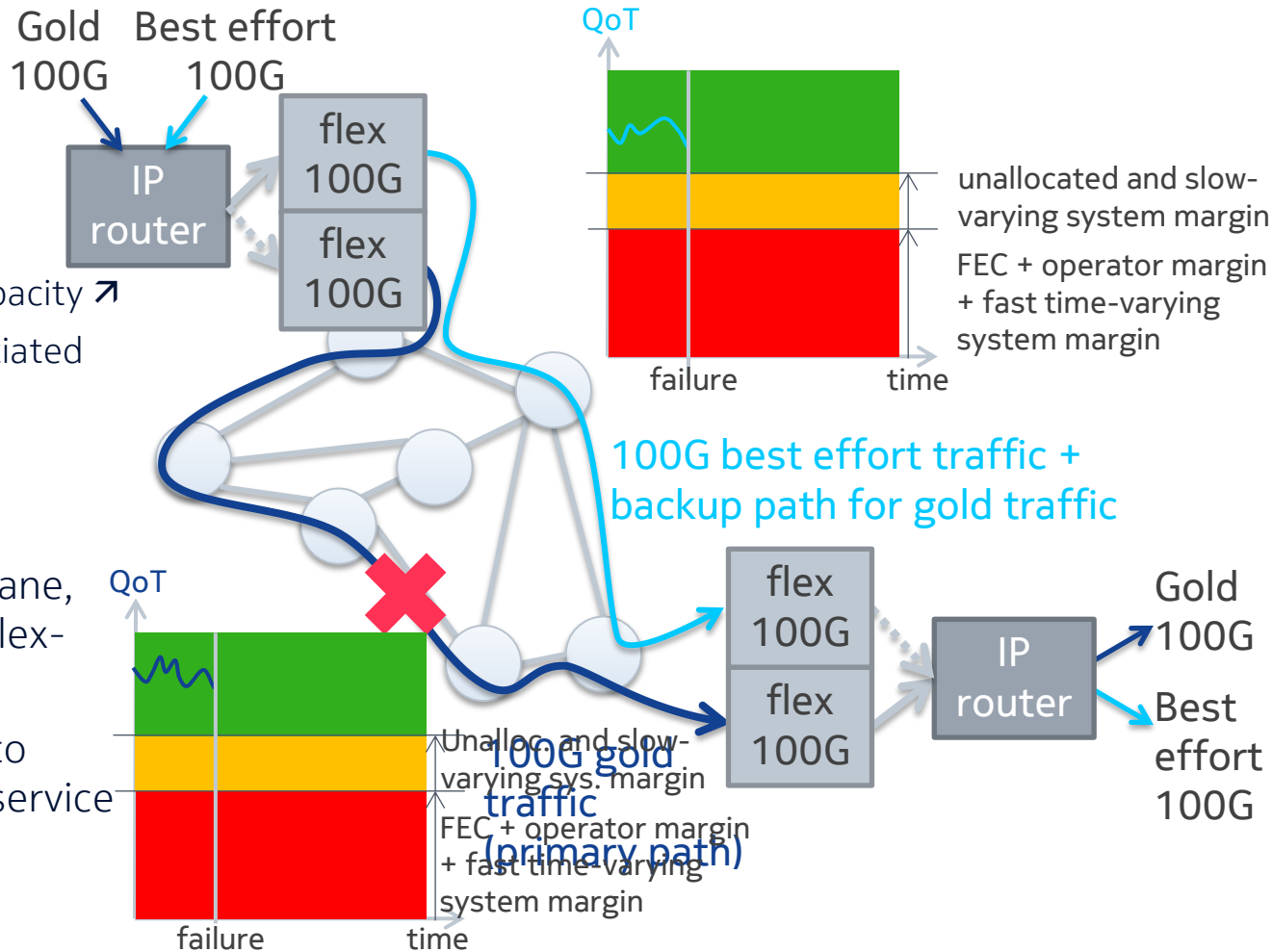
## Traffic growth

- **Target:** network capacity  $\nearrow$ , network cost  $\searrow$
- **Method:** (multilayer) rate allocation
- **Gain:** TBD
  - Note: previous multi-year study also leveraged unallocated margins
- **Requirement:** multilayer control plane, flex-rate TRX
- **Challenges:** optical TRX at high rate deployed at commissioning; online re-allocation



# Unallocated margin Protection

- **Target:**
  - (brown field) network capacity  $\nearrow$
  - protection with differentiated classes of service
- **Method:** rate allocation
- **Gain:** TBD
- **Requirement:** control plane, IP/optical cooperation, flex-rate TRX
- **Challenges:** willingness to differentiate classes of service



# Unallocated margin Protection

- **Target:**

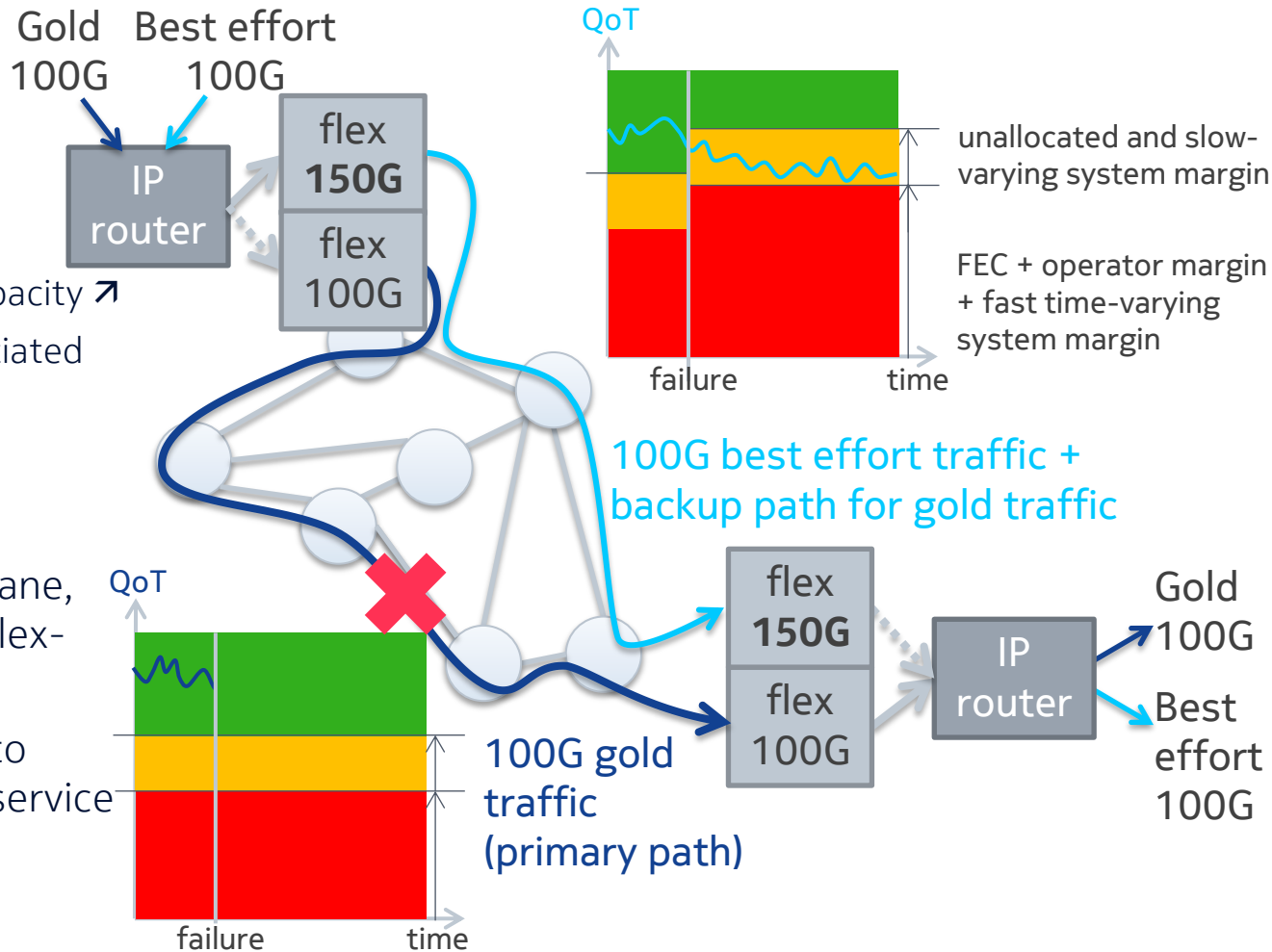
- (brown field) network capacity ↗
- protection with differentiated classes of service

- **Method:** rate allocation

- **Gain:** TBD

- **Requirement:** control plane, IP/optical cooperation, flex-rate TRX

- **Challenges:** willingness to differentiate classes of service



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# Design margin Monitoring

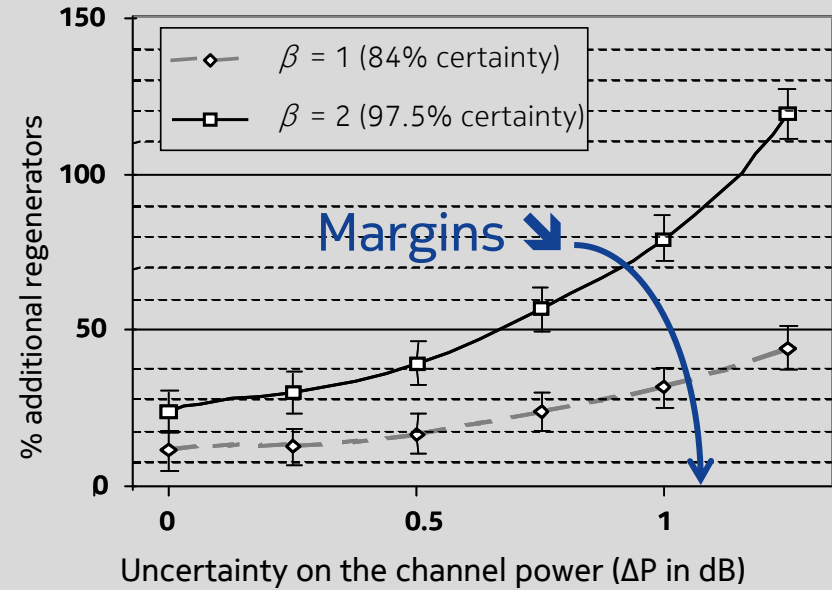
- Uncertainty on Quality of Transmission models (assuming perfect inputs)
  - Ongoing work in many teams
  - Always include more effects, more inputs: per-channel power, interactions of channels with different modulation formats, etc.
  - More inputs → more knowledge of physical layer is needed
  - Some inputs can be set or measured and considered as known (“perfect”) at network deployment; for the other inputs...
- Uncertainty on Quality of Transmission inputs
  - Some inputs are not or cannot be known prior to network deployment
    - Sometimes even seemingly straightforward inputs (fiber type or length, dispersion map ...) are not known!
    - Exact characteristics of network equipment cannot be known prior to deployment
  - On-the-field measurements (monitoring) only helps in brown-field scenarios



## Design margin QoT inputs

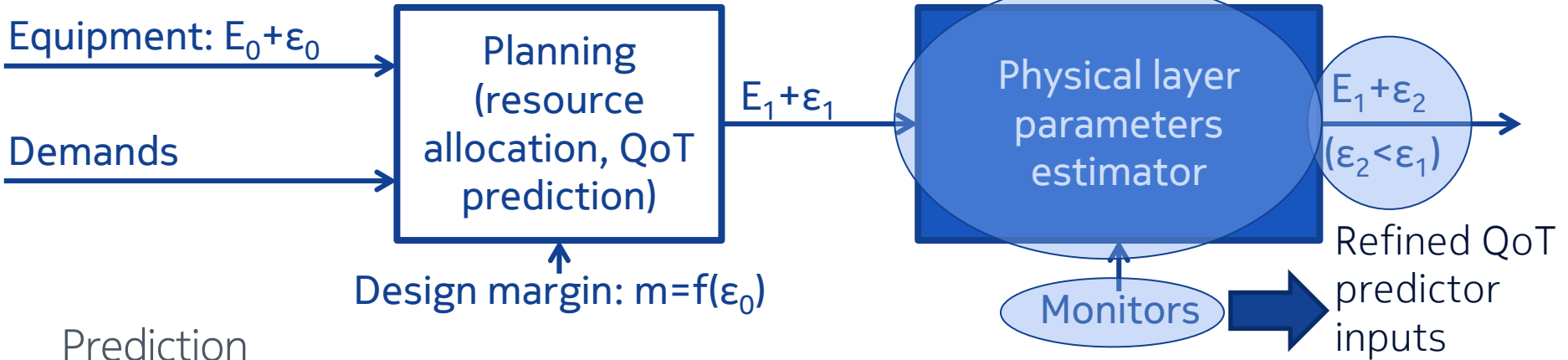
- **Target:**
  - (brown field) network capacity ↗, network cost ↘
  - lightpath establishment, network re-optimization
- **Method:** spectrum allocation
- **Gain:** +10-120% regenerators (10G OOK network)
- **Possible improvement:** flex-grid, multi-layer, multi-rate
- **Requirement:** knowledge of the network
- **Challenges:** margin estimation, probabilistic design

Reference:  $QoT > QoT_{FEC} + m_0$  (no uncertainty)  
Proposed:  $QoT > QoT_{FEC} + \beta \cdot m(\Delta P, \text{lightpath})$

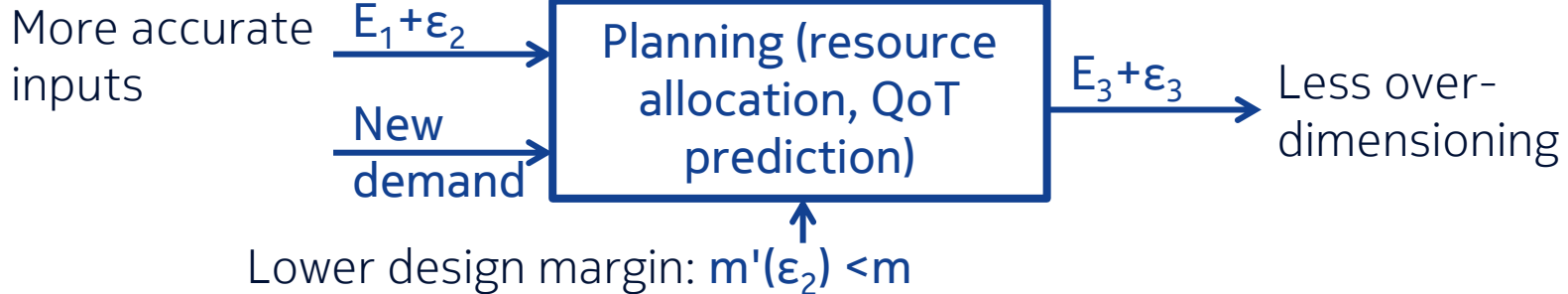


# Design margin: Monitoring Training

Estimation framework e.g.  
regression, machine learning



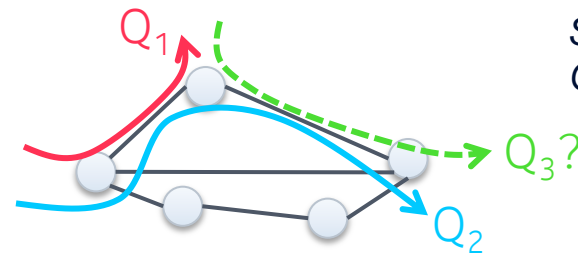
# Prediction



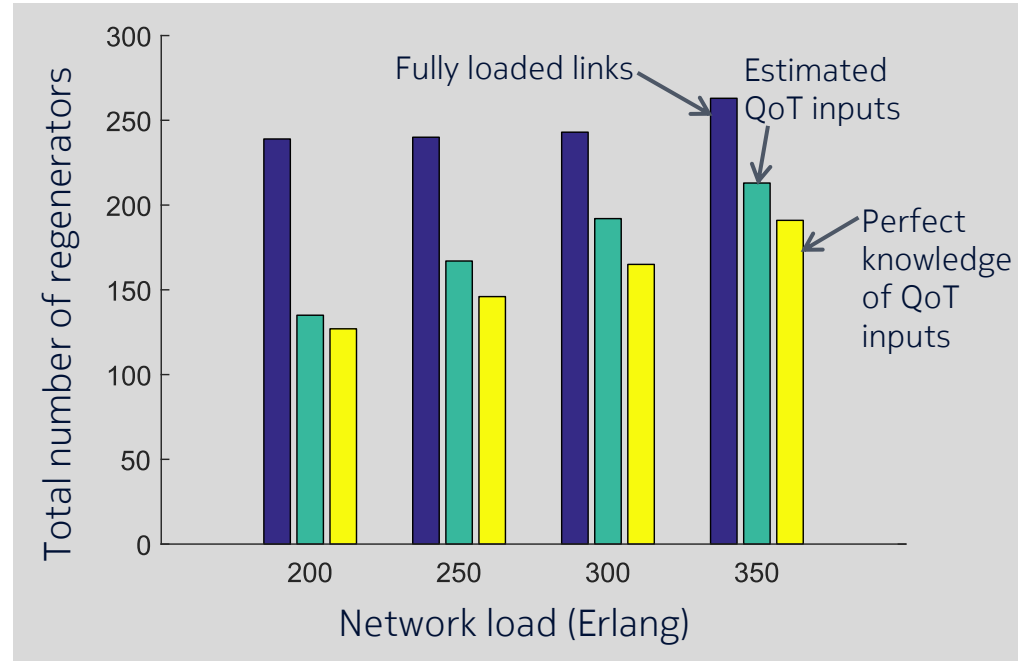
# Design margin

## QoT inputs

Sartzetakis et al,  
OFC 2016, Tu3F.2



- **Target:** (brown field)
  - network capacity  $\nearrow$ , network cost  $\searrow$
- **Method:** monitoring, estimation framework, spectrum allocation on lightpath establishment and network re-optimization
- **Gain:** up to #regenerators / 2
- **Possible improvement:** flex-grid, multi-layer, multi-rate
- **Requirement:** monitoring, control plane
- **Challenges:** margin estimation (accurate monitoring), probabilistic design, online re-allocation



# Conclusions

- Different types of margins → different impacts
  - Commissioning (green-field) network cost
  - Upgrade (brown-field) network cost
  - Longer network life } → Total cost of ownership
- Addition of small gains to lead to substantial overall gains
- Most key building blocks are available (or close)
  - Flex-everything, (most) monitors, control plane
- Not a free lunch
  - per lightpath power settings
  - dynamics / online re-optimization
  - (more) monitors
  - (more) complex control plane

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