Design of Low-Margin Optical Networks

OFC 2016 – Paper Tu3F.5 (invited)

• Dr. Yvan Pointurier, department head, Bell Labs
• 22-03-2016
Agenda

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

Presentation funded by the European Commission through the H2020 ORCHESTRA project
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

• 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

Design margin

= real performance on the field - planned performance

• 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**
Agenda

1. Margins
2. **Reduction of system margins**
3. Reduction of unallocated margins
4. Reduction of design margins
5. Conclusions
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._
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
Agenda

1. Margins
2. Reduction of system margins
3. **Reduction of unallocated margins**
4. Reduction of design margins
5. Conclusions
Unallocated margin
Traffic growth

- **Target:** network capacity ↗, network cost ↘
- **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
  - 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

Gold 100G
Best effort 100G

Flex 150G
Flex 100G

FEC + operator margin
+ fast time-varying system margin
unallocated and slow-varying system margin

100G best effort traffic + backup path for gold traffic

100G gold traffic (primary path)
Agenda

1. Margins
2. Reduction of system margins
3. Reduction of unallocated margins
4. **Reduction of design margins**
5. Conclusions
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 \( \uparrow \), network cost \( \downarrow \)
  - 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\(_{\text{FEC}}\) + \(m_0\) (no uncertainty)
Proposed: QoT > QoT\(_{\text{FEC}}\) + \(\beta\).\(m(\Delta P, \text{lightpath})\)

\[ \beta = 1 \text{ (84\% certainty)} \]
\[ \beta = 2 \text{ (97.5\% certainty)} \]

Margins

Uncertainty on the channel power (\(\Delta P\) in dB)
Design margin: Monitoring
Training

Equipment: $E_0 + \epsilon_0$

Demands

Planning (resource allocation, QoT prediction)

Physical layer parameters estimator

Estimation framework e.g. regression, machine learning

Monitors

$E_1 + \epsilon_1$

$E_1 + \epsilon_2$

($\epsilon_2 < \epsilon_1$)

Refined QoT predictor inputs

Design margin: $m = f(\epsilon_0)$

Prediction

More accurate inputs

$E_1 + \epsilon_2$

New demand

Planning (resource allocation, QoT prediction)

Lower design margin: $m'(\epsilon_2) < m$

E3 + $\epsilon_3$

Less over-dimensioning
Design margin

QoT inputs

• **Target:** (brown field)
  - network capacity ↗, network cost ↘

• **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

---

Sartzetakis et al, OFC 2016, Tu3F.2

![Graph showing network load vs. total number of regenerators](image)
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

Thanks to: T. Zami, J. Pesic, P. Ramantanis, P. Jennevé, N. Rossi, C. Delezoide and S. Bigo + ORCHESTRA project members.
Bell Labs recruits!

Researcher positions available.
Contact: yvan@bell-labs.com
Copyright and confidentiality

The contents of this document are proprietary and confidential property of Nokia. This document is provided subject to confidentiality obligations of the applicable agreement(s).

This document is intended for use of Nokia’s customers and collaborators only for the purpose for which this document is submitted by Nokia. No part of this document may be reproduced or made available to the public or to any third party in any form or means without the prior written permission of Nokia. This document is to be used by properly trained professional personnel. Any use of the contents in this document is limited strictly to the use(s) specifically created in the applicable agreement(s) under which the document is submitted. The user of this document may voluntarily provide suggestions, comments or other feedback to Nokia in respect of the contents of this document ("Feedback").

Such Feedback may be used in Nokia products and related specifications or other documentation. Accordingly, if the user of this document gives Nokia Feedback on the contents of this document, Nokia may freely use, disclose, reproduce, license, distribute and otherwise commercialize the feedback in any Nokia product, technology, service, specification or other documentation.

Nokia operates a policy of ongoing development. Nokia reserves the right to make changes and improvements to any of the products and/or services described in this document or withdraw this document at any time without prior notice.

The contents of this document are provided “as is”. Except as required by applicable law, no warranties of any kind, either express or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose, are made in relation to the accuracy, reliability or contents of this document. NOKIA SHALL NOT BE RESPONSIBLE IN ANY EVENT FOR ERRORS IN THIS DOCUMENT or for any loss of data or income or any special, incidental, consequential, indirect or direct damages howsoever caused, that might arise from the use of this document or any contents of this document.

This document and the product(s) it describes are protected by copyright according to the applicable laws.

Nokia is a registered trademark of Nokia Corporation. Other product and company names mentioned herein may be trademarks or trade names of their respective owners.