Leveraging Long-Term QoT Awareness for Capacity Boost of Pan-European Network

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Abstract: Online quality of transmission (QoT) monitoring and validation enables conversion of unused margins into higher network capacities. We quantify the benefit of long-term performance awareness in a Pan-European optical network of a Tier-1 operator.

OCIS codes: (060.4256) Networks, network optimization; (060.1660) Coherent communications

1. Embedding QoT monitoring into daily network operation

Growing deployment of bandwidth variable transponders (BVT) with configurable symbol rate and modulation scheme opens new opportunities to manage and optimize transmission capacities in DWDM networks. Adaptation of the transponder configuration to the conditions in the optical route allows for squeezing of wasted optical signal to noise ratio (OSNR) buffers. Moving from offline end of life (EOL) planing, often leading to unused margins, to online quality of transmission (QoT) monitoring, allowing margin adjustment to robustness requirements, is a logical step towards next generation margin optimized networks. Several concepts have been published by different groups showing the benefit of online QoT validation [1, 2].

In [3] a concept of accurate determination of signal quality at current link conditions was presented. The method relies on power information from available monitoring points used for in-service OSNR determination. Combining the OSNR input with preFEC BER reported by the transponder yields the residual margin (RM) at the receiver and the link impairments induced by the optical route. The accuracy of the margin determination was extensively evaluated for different conditions in lab test-beds and successfully demonstrated at a Tier-1 operator network.

Recently, the robustness of this concept have been intensively verified in a Pan-European optical network by applying the online monitoring engine to main backbone routes over a time period of more than five months. In this paper we report results and conclusions from the long-term QoT monitoring of more than 700 deployed connections. Five transponder types, four of them with fixed data rate and one BVT, operating at four different bit rates (40G, 100G, 150G, 200G) were included in the analysis.

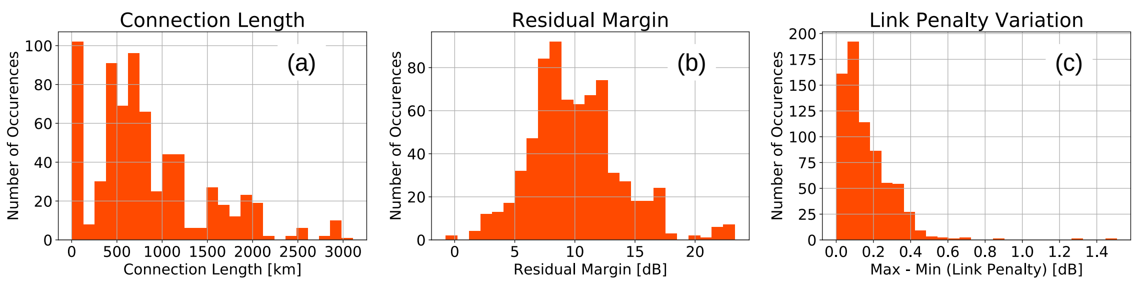

Fig. 1. Statistical distribution of connections in the Pan-European network used for analysis of the long-term online QoT benefit; (a) connection length; (b) the lowest signal margin determined over the monitoring period; (c) delta between the max and min link penalty during the monitoring period.

The statistical distribution of the monitored connections is summarized in Fig. 1. The length of the optical paths ranges from a few kilometers (intra-city) up to more than 3000km (ultra long-haul) (Fig. 1a). Fig. 1b shows the residual margin of the signals measured at current operating conditions. In the diagram, the lowest RM over the monitoring period is reported. Note, few singular events that led temporally to strong performance excursion observed at individual transponders were taken out from the data set. The variation of measured link penalty is shown in Fig. 1c. For each connection the difference between the highest and the lowest penalty in the monitoring period is reported. Noteworthy the link penalty includes all linear and nonlinear impairments. Henceforth, the recorded min - max spread comprises polarization and temperature dependent performance variations as well as nonlinear contributions of the signals running in parallel. Remarkably, the network behaves rather stable without any significant performance fluctuations.

2. Network capacity increase powered by performance awareness

2.1. Impact of margin buffers

The long-term QoT monitoring under real network conditions reveals two observations to be taken into consideration. Firstly, the link penalty variations over time are rather moderate. Secondly, the current RM of the majority of deployed services is larger than 5dB, i.e. there is room for further increase of the data rate per lambda channel. Consequently, the potential of capacity enhancement in the operator long-haul network was analyzed in more details. We compare three different strategies:

1. One approach is to base the upgrade decision on the current measured RM and reducing it by pre-calculated, expected worst-case linear and nonlinear impairments of the target data rate.

2. In contrast to first approach, if data from long-term QoT monitoring are available, the highest observed link penalty is used. Only for nonlinear impairments, an additional worst case penalty is taken into account and determined by optical modeling.

3. The strategy with the highest capacity potential relies solely on the data from long-term performance monitoring. No additional buffer is reserved for future QoT degradation.

Obviously, from network operator perspective the three scenarios are addressing different commitment levels. As the decision on the most suitable approach can implicate non negligible changes in network operation, it is of high value to understand the benefits behind. Of course, a combination of the three strategies can be applied, depending on the service robustness requirements and network use-cases, respectively.

Fig. 2 depicts the impact of the three strategies on the data rate upgrade. In the pre-calculated scenario (Fig. 2a), different types of buffers are reserved to cope with expected transmission impairments (similar to offline planning, still with an advantage of knowing the real margin). The buffers account for polarization and temperature dependent statistical effects in the components as well as for nonlinear distortions at fully loaded configuration. The feasibility of the data rate upgrade is determined by comparing the sum of required back to back (B2B) OSNR of the target modulation format (MF) with the pre-calculated OSNR buffers to the OSNR measured at the end of the light path. In the example shown in Fig. 2a the expected required OSNR of the target MF is higher than the currently available OSNR. Hence a capacity increase isn't recommended by the awareness tool. The situation changes when long-term monitoring data enable the prediction of the highest link penalties according to the second strategy (Fig. 2b). In this case, the combined link impairments including nonlinearities are significantly lower than the sum of the pre-calculated contributions. Therefore a data rate upgrade becomes feasible. The same outcome applies for the third approach where long-term measured QoT is the only decision maker for data rate upgrade. No predictions about future performance evolution are made. Thus, there is a risk that a reaction to reduced transmission performance due to changed network conditions is required. We believe that by introducing of new generations of fast (quasi autonomous) data rate switching transponders [4], this risk can be reduced.

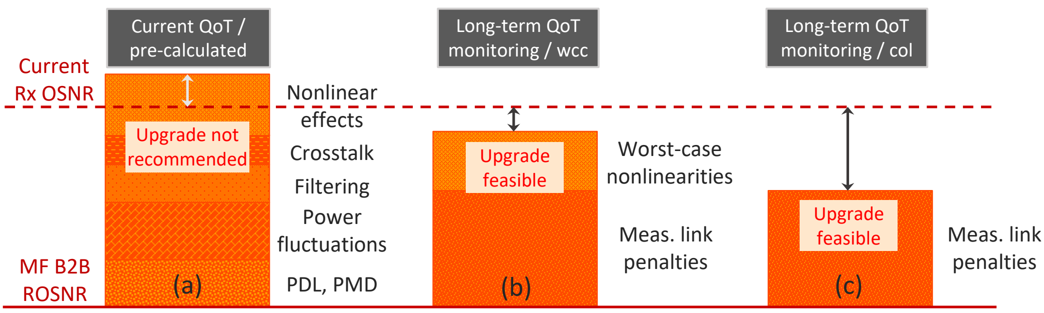

Fig. 2. Determination of upgrade feasibility to higher bit rate by considering (a) pre-calculated link impairments; (b) link penalties from long-term QoT monitoring and margin at worst-case conditions (wcc); (c) link penalties from long-term QoT monitoring at current state of life (col) link conditions.

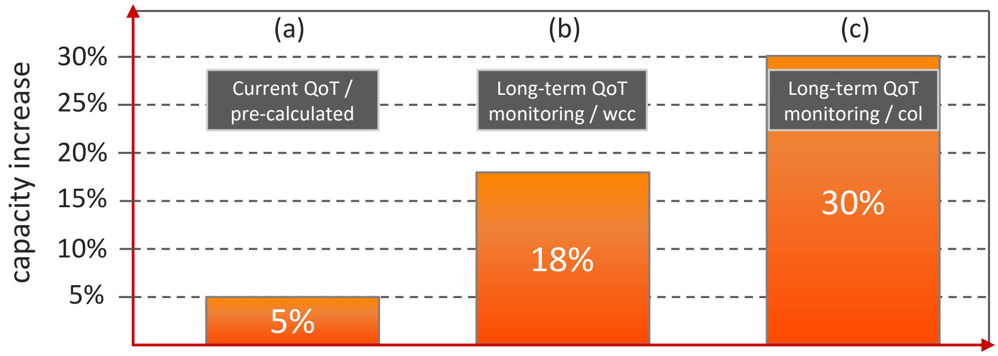

Fig. 3. Network capacity enhancement enabled by online QoT validation by considering (a) pre-calculated link impairments; (b) measured link penalties including worst-case conditions (wcc) margin; (c) measured link penalties and current state of life (col) link conditions.

2.2. *Quantification of capacity enhancement*

The strategies described in the previous section are applied to the real network data of the Tier-1 operator in order to quantify the benefits. We restrict the analysis to connections terminated by BVTs assuming that already in the offline network planning phase the highest possible bit rate was selected for each route to minimize unused margin. Only this approach yields the real benefit of online performance awareness compare to offline planning. This leaves 302 connections spread over the whole network. All transponders are supporting three bit rate settings (100G, 150G, 200G), i.e. a data rate upgrade can be done from 100G to 150G or 200G and from 150G to 200G.

The results are summarized in Fig. 3. In the scenario based on pre-calculated OSNR buffers the total capacity increase is in the range of 5% compared to offline planning (Fig. 3a). The reason for rather moderate increase is the high quality of network data provided by the operator in the planning phase. It can be expected that the benefit increases for networks with less reliable input data. On the other hand, stable operation conditions measured in the Tier-1 network are boosting the potential of further capacity increase when using long-term performance monitoring data as decision criterion. Applying the second strategy to the examined network leads to a possible capacity enhancement of 18% (Fig. 3b). The results are confirming our previous findings on the potential of performance awareness in long-haul networks reported in [3]. Finally relying only on the long-term QoT monitoring data as in strategy no. three, a further benefit of 12% is achieved (Fig. 3c). With total capacity enhancement of 30%, this approach leads to the highest utilization of the available data rate per lambda channel. However while the first and second upgrade strategy can be applied as add-on to existing network infrastructure already today, the third one implies higher requirements on the management layer to support network operation in a more dynamic environment. In most network scenarios, a combination of intelligence at transponder level together with long-term performance data monitoring and processing might lead to the best compromise between complexity and efficient capacity usage.

3. Summary and outlook

Long-term QoT monitoring and validation applied to the Pan-European network of a Tier-1 operator has proven significant potential for capacity increase of up to 30% without the need of new hardware deployments. Even higher capacity enhancement can be expected in context of the new generation of high symbol rate transponders (60+ Gbaud) with bit rate setting granularity in sub-gigabit range. Supported by control algorithms from management layer, accurate determination of actual link impairments combined with early identification of performance degradation will allow for further squeezing of unused margins in optical DWDM networks.

References

1. Bouda, Martin, et al. ”Accurate prediction of quality of transmission based on a dynamically configurable optical impairment model.” Journal of Optical Communications and Networking 10.1 (2018): A102-A109.
2. Rabbani, Hami, et al. ”Quality of Transmission Aware Optical Networking Using Enhanced Gaussian Noise Model.” Journal of Lightwave Technology 37.3 (2019): 831-838.
3. Slovak, Juraj, et al. ”Aware optical networks: Leaving the lab.” IEEE / OSA JOCN 11.2 (2019): A134-A143.
4. Spinnler, Bernhard, et al. ”Autonomous intelligent transponder enabling adaptive network optimization in a live network field trial.” Journal of Optical Communications and Networking 11.9 (2019): C1-C9.