Machine Learning Methods for Communication Networks and Systems – 051911

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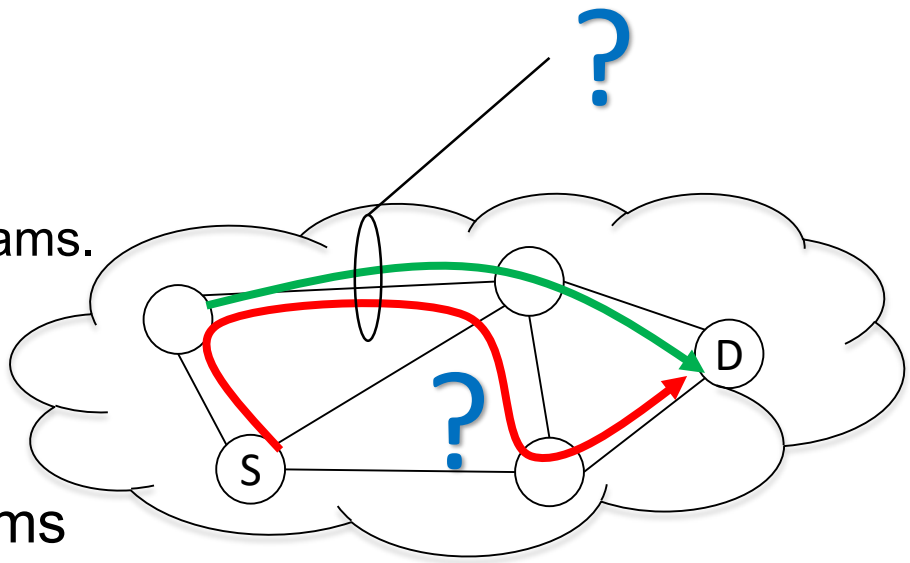
Part II – 2: QoT estimation

Physical layer domain

QoT estimation

- **Before** a new lightpath (S→D) is established we should check:
  - if it will meet the desired QoT
    - Low-enough BER? High-enough OSNR?
  - if it will affect the living lightpaths (ongoing traffic requests)
    - Will these connections still meet **their** QoT?

- To answer these questions:
  - Estimate analytically
    - Typically time consuming
    - Involves huge amount of params.
  - Design with margin
    - Approx. Models
    - Resources underutilization
  - ML overcomes these problems



QoT estimation

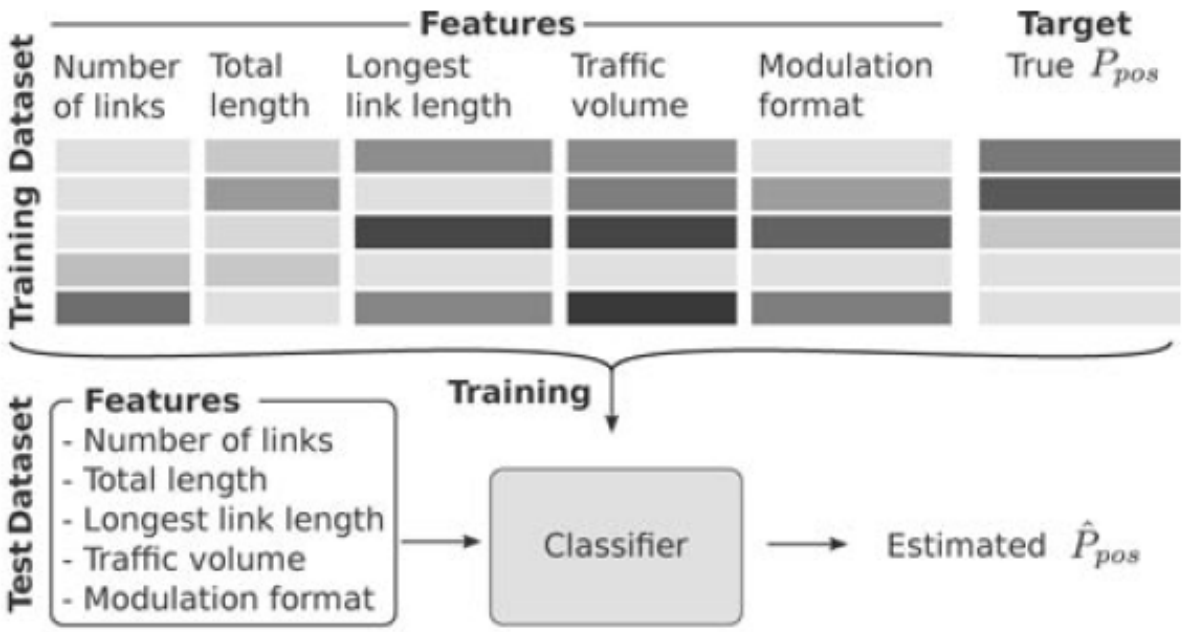
Source 1

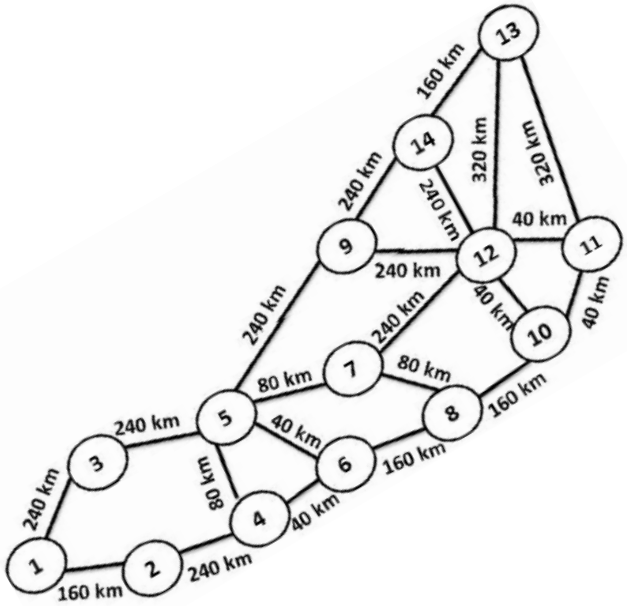
- Barletta *et al.*, "QoT Estimation for Unestablished Lighpaths using Machine Learning", in *OFC 2017 Conference*, Mar. 2017
- Paper objective: predict whether an unestablished lightpath meets QoT requirements: binary classification (yes/no)
  - input
    - nr of links of the new lightpath
    - lightpath length
    - length of its longest link
    - traffic volume to be served (Gbit/s)
    - modulation format to be used
  - output
    - P_{pos}: probability that the lightpath with features x belongs to positive class
    - P_{pos} is used to determine a binary variable y: = 1 (TRUE) if the lightpath BER is below system threshold $T=4*10^{-3}$
    - y=1 ➔ the lightpath meets QoT requirement
  - ML algorithm: Random Forest

QoT estimation

Source 1

- Training data synthetically generated using a mathematical estimation tool (ETool)
  - SNR is calculated via power budget and introduced noise (AWGN)
  - Once BER threshold (T) is fixed, ETool determines if the lightpath meets QoT (i.e., determines ground truth y)
  - Training set size L=90000 (59111 negative and 30889 positive instances)
- Test set: random selection of 50 triplets (S/D, traffic) with all combinations of 3 routes and 6 modulation formats (50*3*6= test set size)

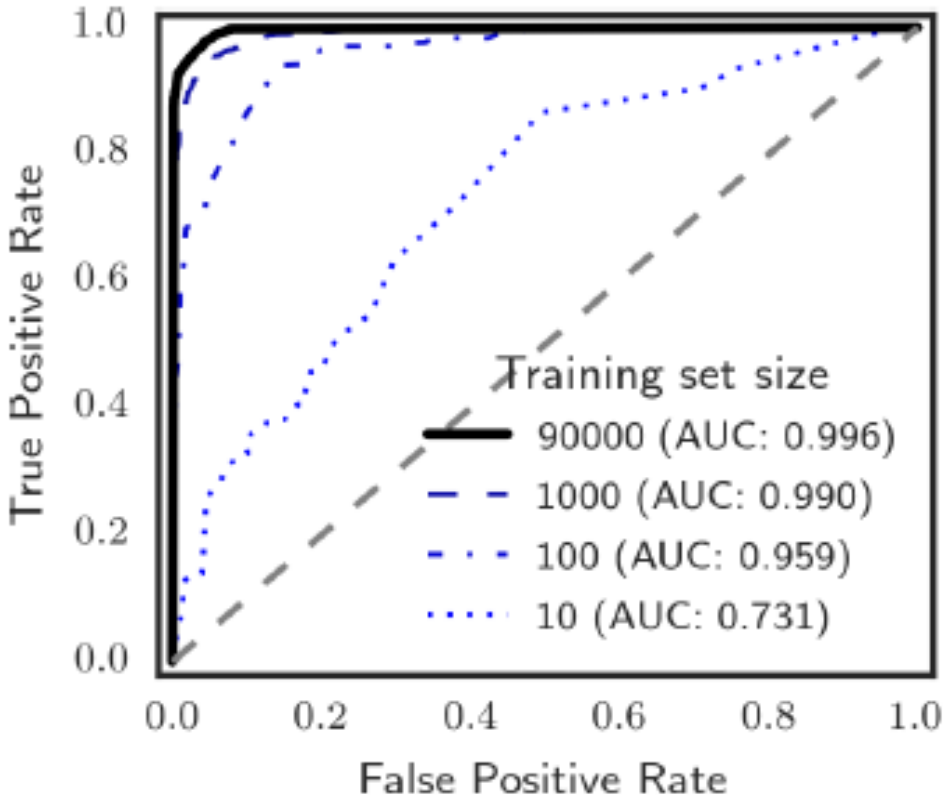




QoT estimation

Source 1

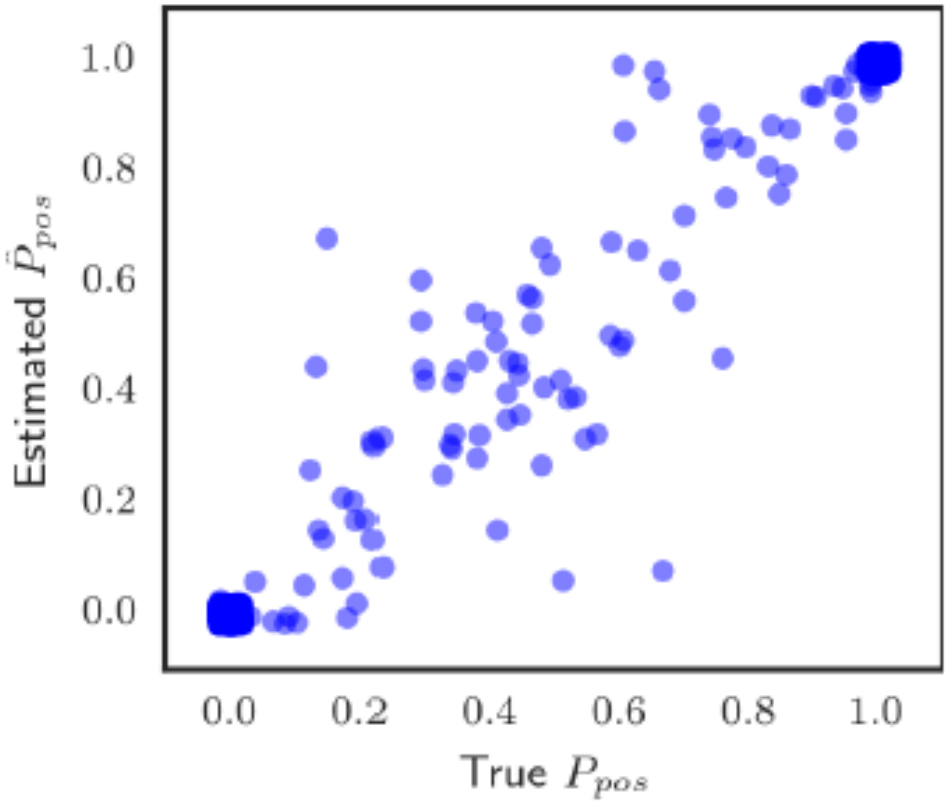
- Results: impact of Training set size on prediction accuracy
  - ROC curve



QoT estimation

Source 1

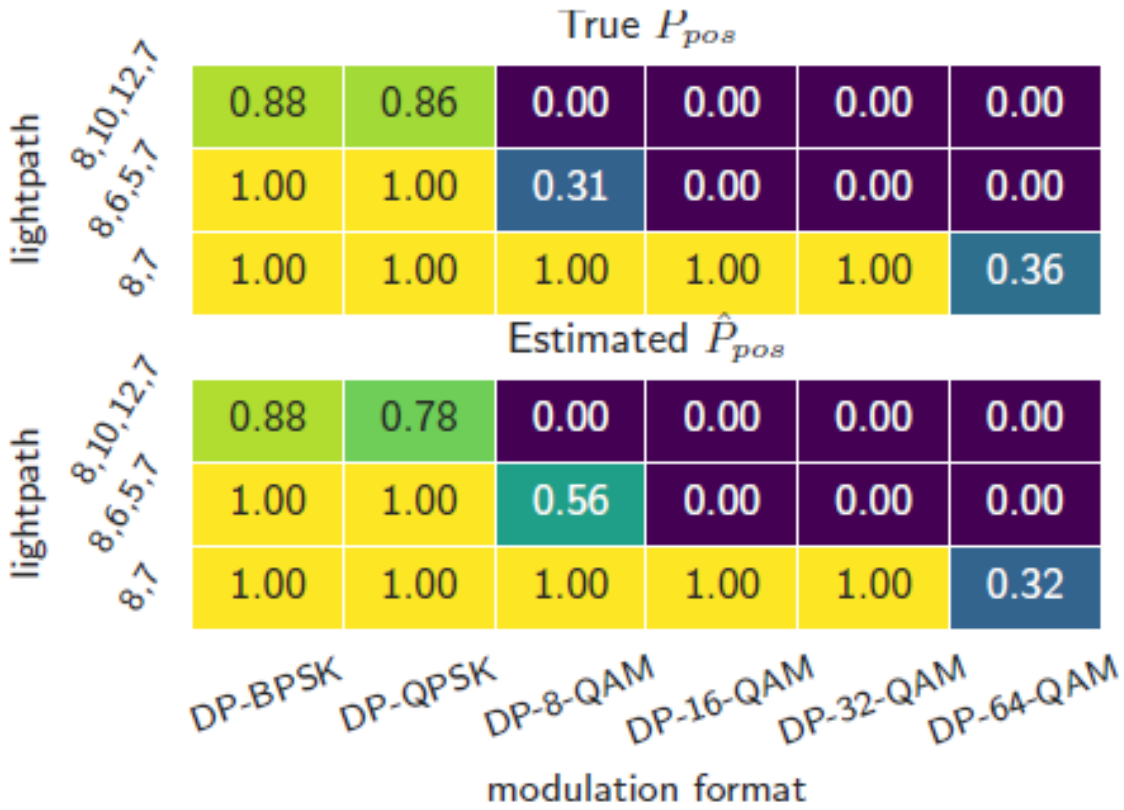
- Results: scatterplot Predicted Ppos vs true Ppos



QoT estimation

Source 1

- Results: classification for conn. 8→7 lightpath (600 Gbps)



QoT estimation

Source 2

- Caballero *et al.*, “Experimental demonstration of a cognitive quality of transmission estimator for optical communication systems”, *Optics Express*, vol. 20, n. 26, Dec. 2012
- Paper objective: predict whether an unestablished lightpath meets QoT requirements
  - Context of a **WDM point-to-point system**
  - input
    - wavelength used
    - launch power
    - losses per span
    - number of spans (i.e., the lightpath length)
    - set of active lightpaths in the system
    - total input power in the system
    - total power carried by the adjacent channels of the considered lightpath
    - total power carried by those located 2, 3 and 4 channels apart
  - output
    - OSNR
    - Error Vector Magnitude (EVM)
  - ML algorithm: Case Based Reasoning

QoT estimation

Source 2

- Example of Knowledge Base (KB); total of 153 cases included (experimental)

Table 1. Example of experimental measurements used to populate the KB. Only one of the QoT parameters (OSNR or EVM) is included in the KB.

Channel measured	Channels (on = 1)					P_{in}/ch (dBm)	# of spans	Span loss (dB)	OSNR dB/0.1 nm	EVM (%)
	1	2	3	4	5					
3	1	1	1	1	1	–4	6	18	23.5	21.4
3	1	1	1	1	1	–2	6	18	25.4	19.6
3	1	1	1	1	1	0	6	18	27.3	19.2
3	1	1	1	1	1	2	6	18	29.1	21.1
3	1	1	1	1	1	4	6	18	30.8	24.9

- Similarity metric: weighted euclidean distance

$$Similarity\ (x, y) = -\sqrt{\sum_{a=1}^{n} W_a^2 \cdot (x_a - y_a)^2}$$

  - weight for the a-th feature is calculated via linear regression on the data included in the original KB
- Decision on QoT performed by comparing the output of the CBR with threshold
  - $OSNR_{est} > OSNR_{thr}$ ➔ QoT OK
  - $EVM_{est} < EVM_{thr}$ ➔ QoT OK

QoT estimation

Source 2

- Results (based on EVM)

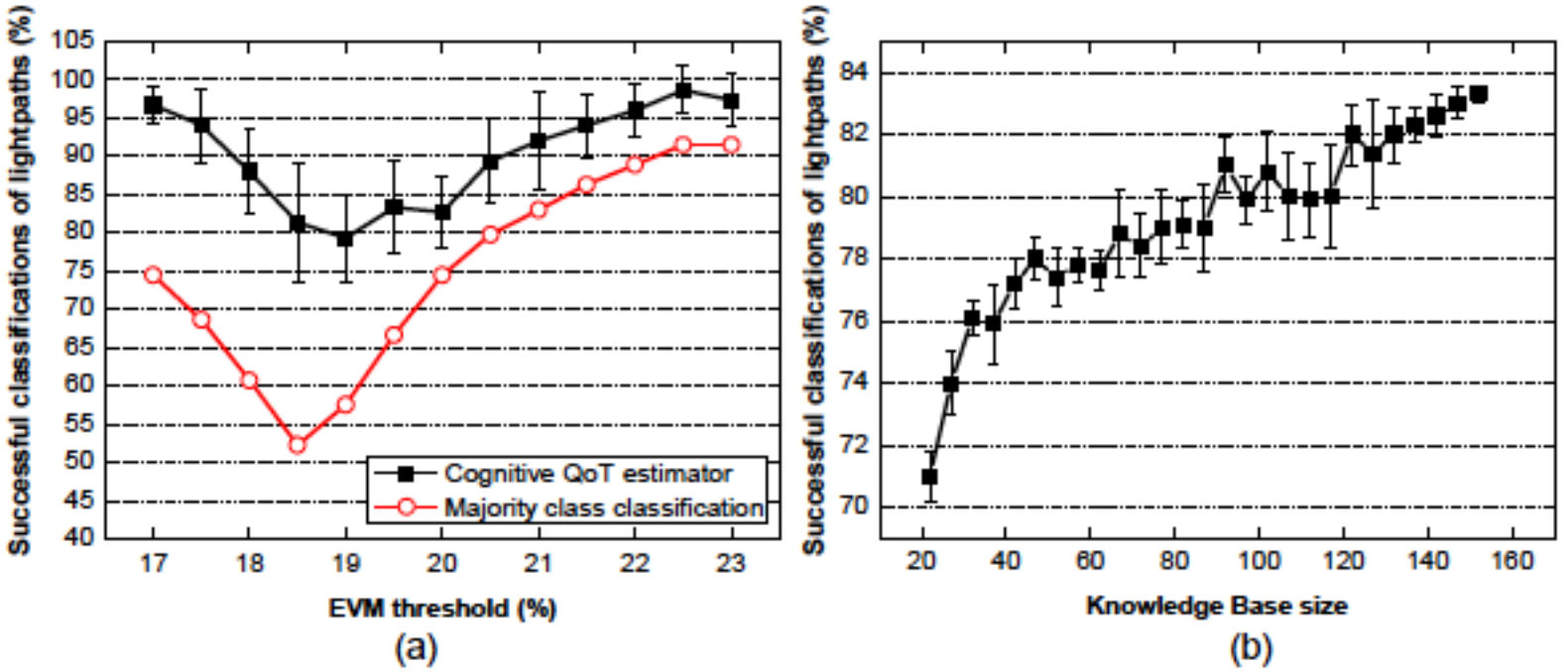


Fig. 2. (a) Percentage of successful classifications of lightpaths into high/low QoT categories according to an EVM threshold. (b) Impact of the size of the knowledge base on the percentage of successful classifications for the case of 19.5% EVM threshold.

QoT estimation

Source 2

- Results (based on OSNR)

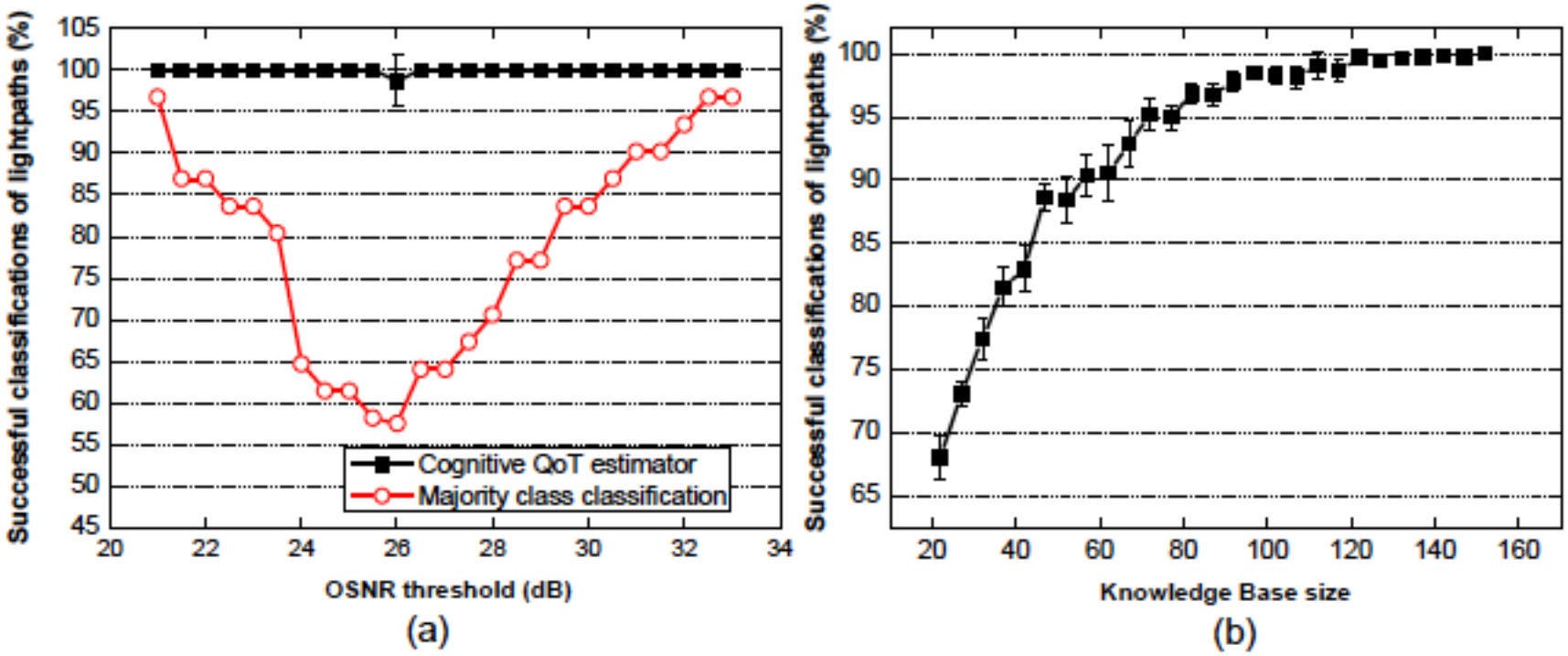


Fig. 3. (a). Percentage of successful classifications of lightpaths into high/low QoT categories according to an OSNR threshold. (b) Impact of the size of the knowledge base on the percentage of successful classifications for the case of 26 dB OSNR threshold.

QoT estimation

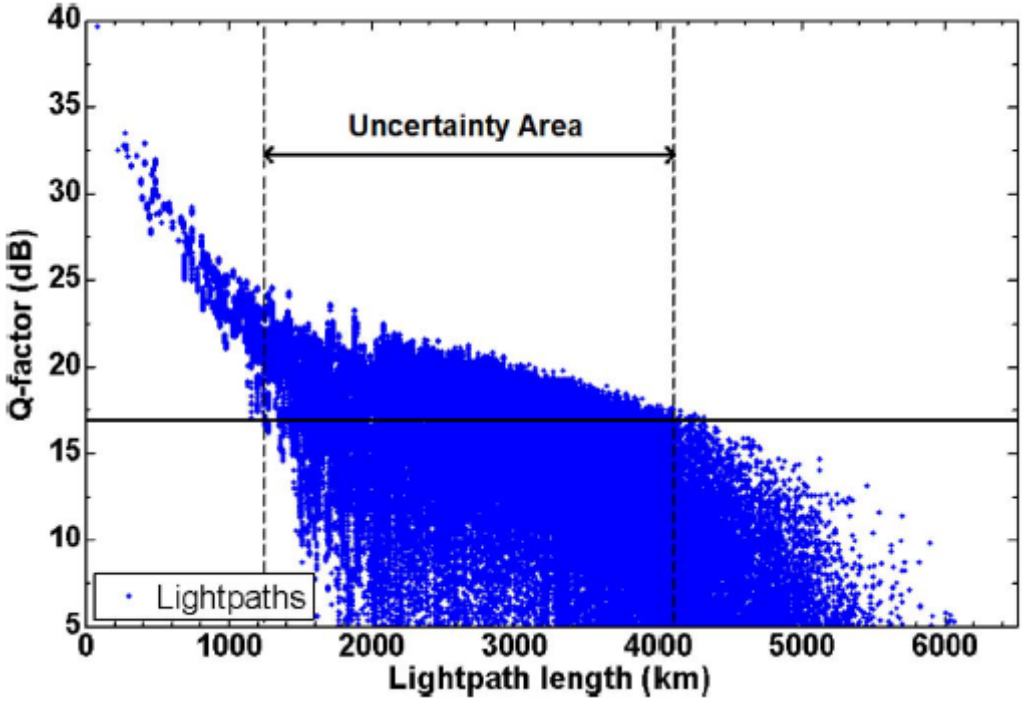
Source 3

- Jimenez *et al.*, "A Cognitive Quality of Transmission Estimator for Core Optical Networks", *Journal of Lightwave Technology*, vol. 31, n. 6, Mar. 2013
- Paper objective: predict whether an unestablished lightpath meets QoT requirements (low vs high QoT)
  - input
    - lightpath length
    - lightpath route (i.e., the set of traversed links)
    - selected wavelength
    - sum of the co-propagating lightpaths per link
    - standard deviation of the number of total co-propagating lightpaths
  - output
    - Q-factor (estimated via a Q-Tool)
  - ML algorithm: Case Based Reasoning
    - Including learning and forgetting capabilities

QoT estimation

Source 3

- Decision process
  - Step 1: consider only lightpath length



  - Step 2: if the lightpath length falls in uncertainty area, use CBR
    - Initial KB synthetically generated via Q-Tool

QoT estimation

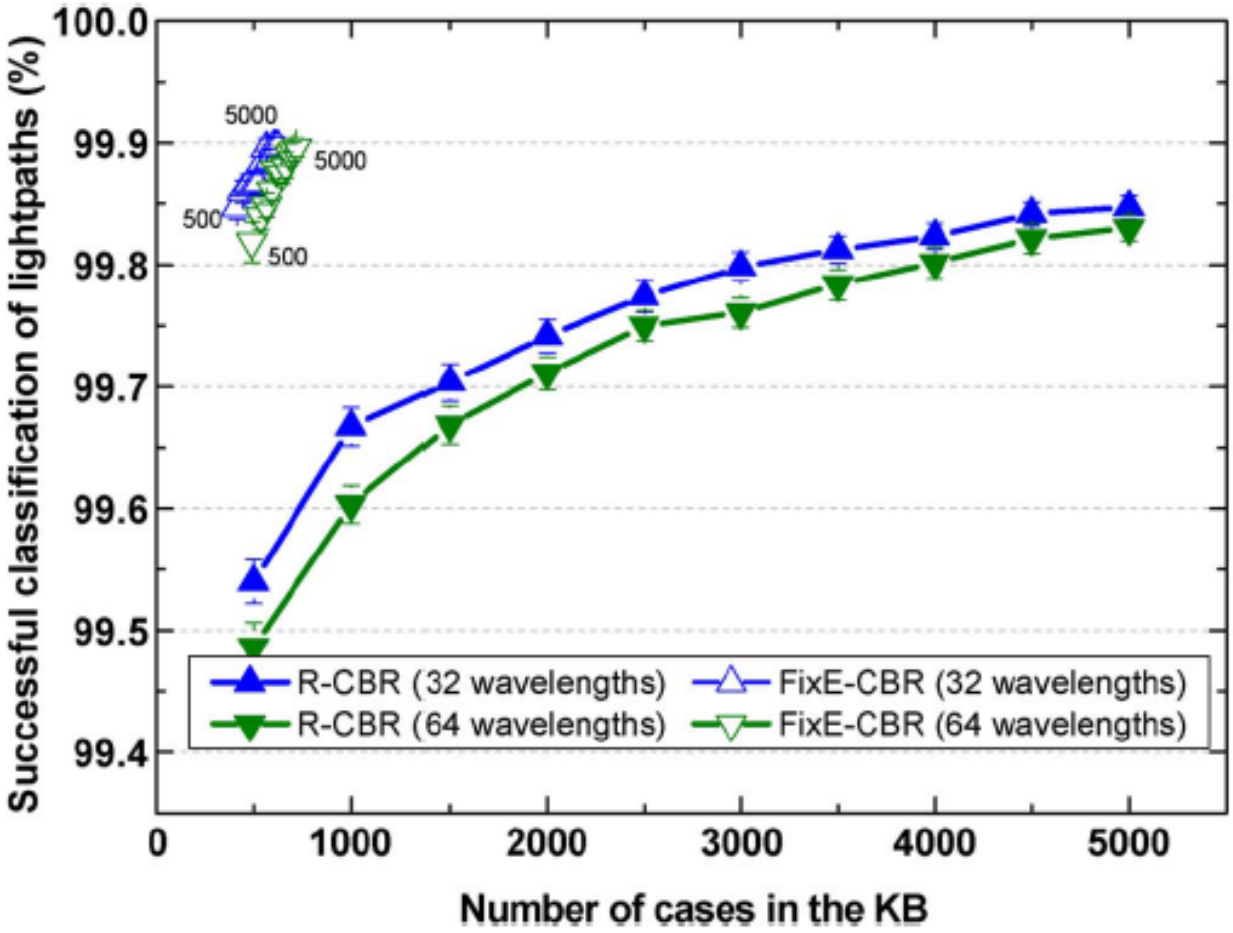
Source 3

- Optimization of the KB
  - During the operation of the CBR-based QoT estimation, lightpaths are double-checked
    1. Did we correctly classify lightpath QoT via the CBR?
    2. Is the error between prediction and ground-truth below threshold $\varepsilon_{permitted}$?
  - Retention
    - if 1 AND/OR 2 are not satisfied → save the new lightpath case in an auxiliary list (contains *potential new entries* in the KB)
  - KB maintenance
    - periodically performed after a certain number of predictions
    - add to KB entries in the auxiliary list
    - Redundancy removal (forgetting algorithm): basically, remove cases which are not near the border between cases (i.e., having large "Coverage Set")

QoT estimation

Source 3

- Results: impact of KB size – DT network



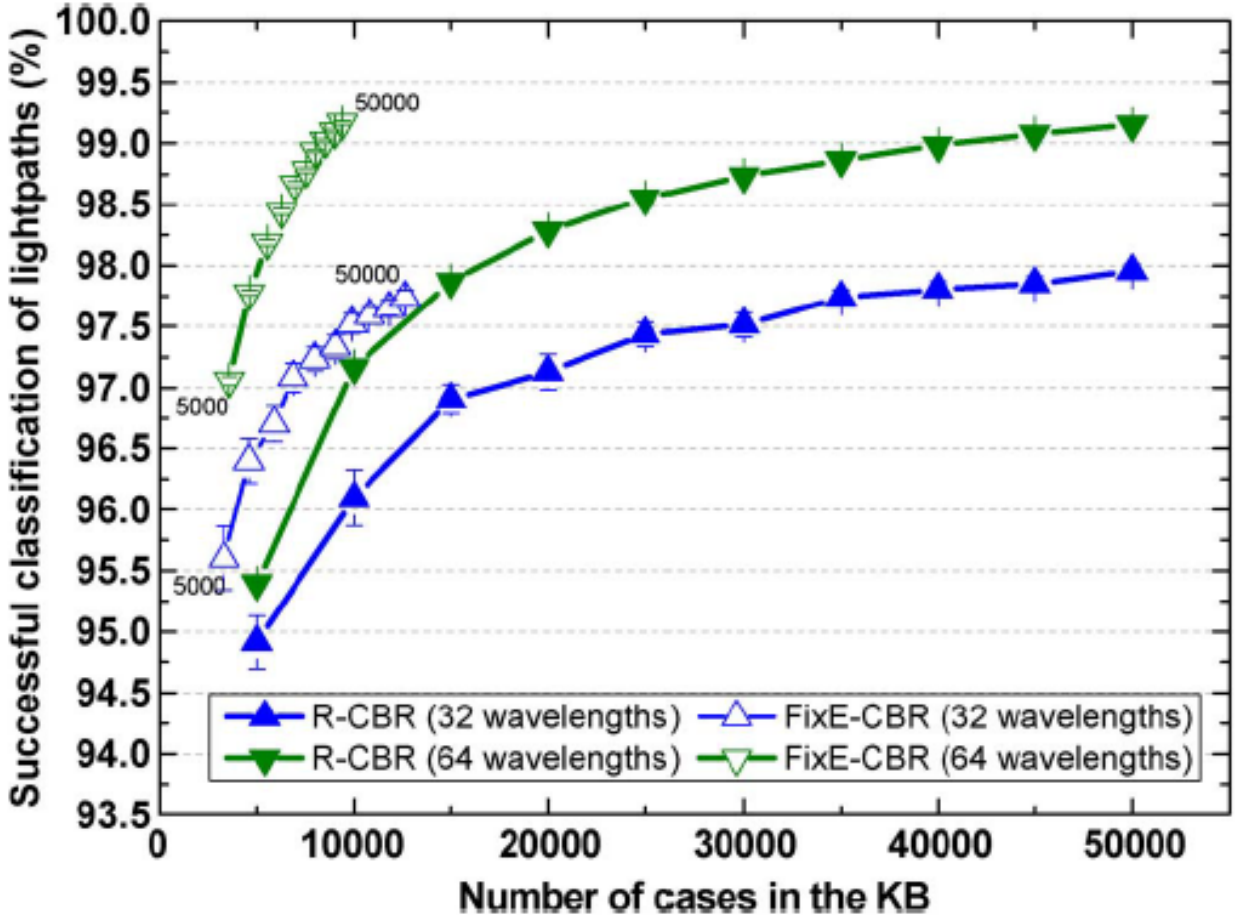
R-CBR: static KB

FixE-CBR: optimized KB

QoT estimation

Source 3

- Results: impact of KB size – Geant network



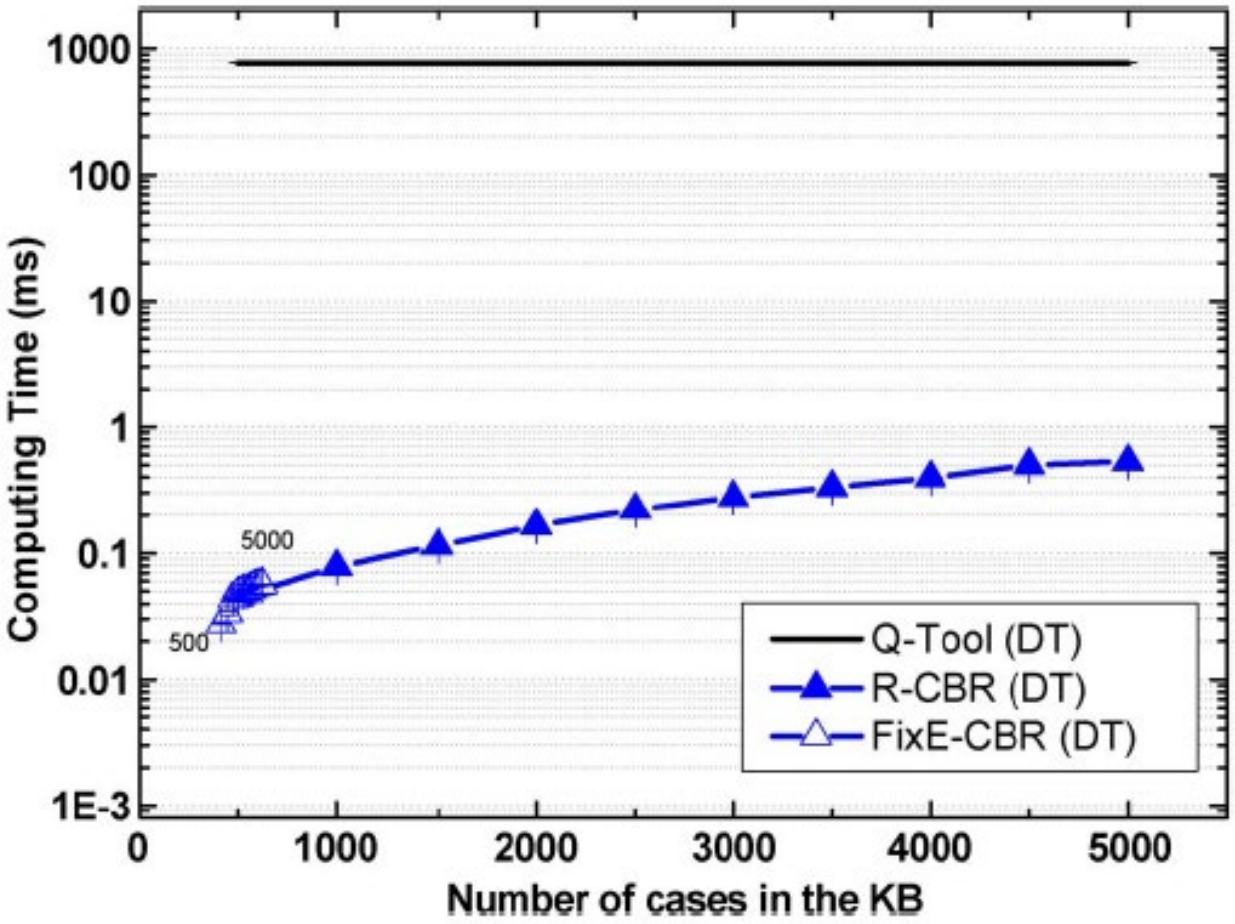
R-CBR: static KB

FixE-CBR: optimized KB

QoT estimation

Source 3

- Results: computing time – DT network



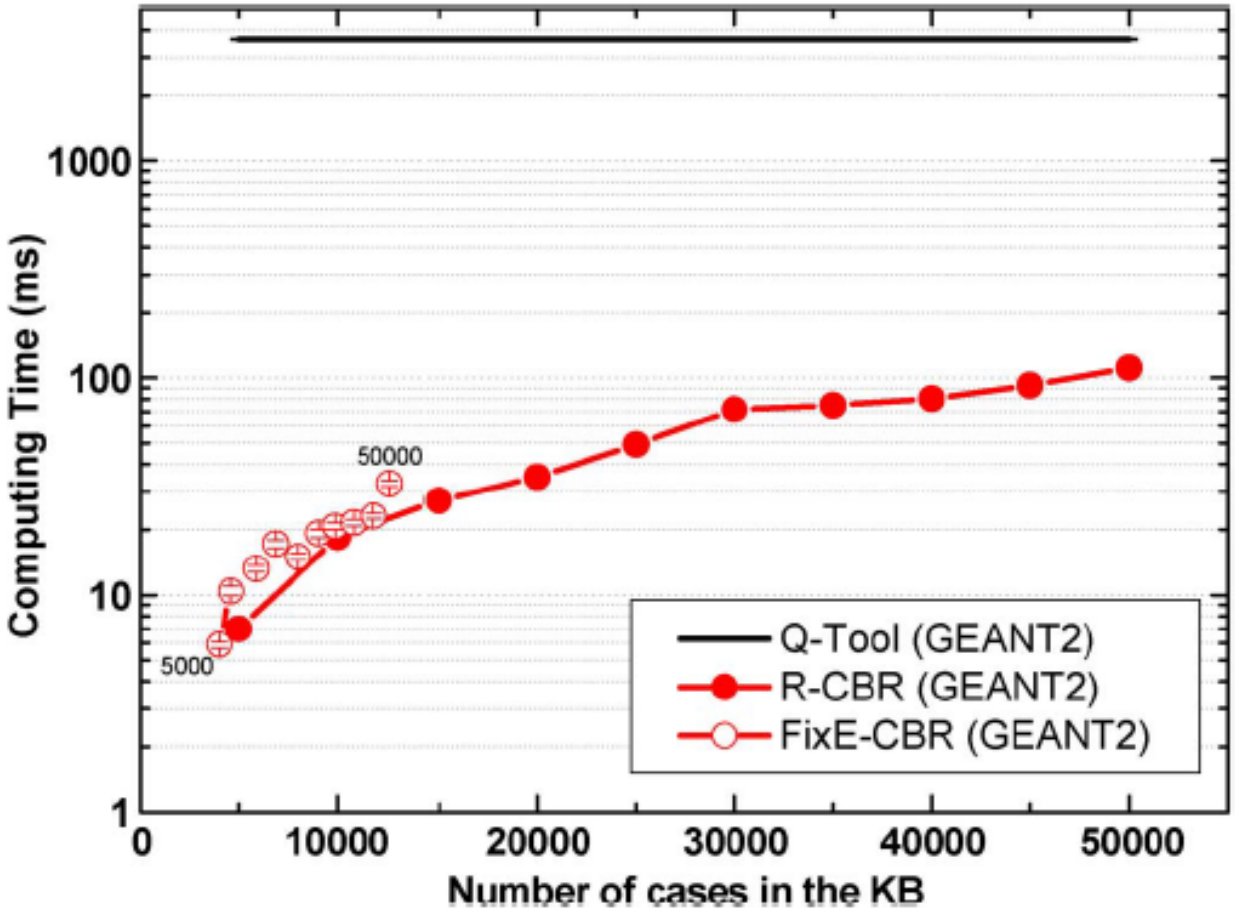
R-CBR: static KB

FixE-CBR: optimized KB

QoT estimation

Source 3

- Results: computing time – Geant network



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