Implementation of MLSE equalizer in OptSim and evaluation of its performance

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Motivation of the work

- In the last years, electronic equalization (EE) has gained momentum as mean to mitigate optical fibre transmission impairments.
- In particular, it has been applied to reduce ISI caused by linear effect as chromatic dispersion and PMD.
- In addiction, due to its intrinsic flexibility, EE can be used, in principle, to moderate ISI generated by every kind of effects.
- In this work, we want to apply EE to either experimental and simulated data (obtained using OptSim™) in order validate the simulator and use it for further investigations in the field of MLSE

Equalizer Choice

- In 90s Winters introduced the concept of applying EE to optical communication systems.
- Following, several kinds of electronic equalizer have been analyzed and considered. Among these, we mention feed-forward equalizers (FFE) and decision-feed-back Equalizer (DFE), which are both simple to implement and powerful.
- Unfortunately, they are linear devices, so they do not represent the optimum choice for the optical communication channel that is intrinsically non-linear.
- To solve this problem, we took from radio frequency system the idea of applying the so-called MLSE, maximum-likelihood sequence estimator.
- In this work we will concentrate on MLSE only.

Maximum-Likelihood Sequence Estimation

- MLSE detector minimizes the BER by searching through the whole sequence of bits and selecting the most likely sequence.
- If we receive data (*x*) then the MLSE receiver picks the sequence (*S*) which maximizes the conditional probability $p(x|S)$. Therefore, if we receive *k* bits of data, with 2 samples/bit, then the MLSE receiver maximizes the log-likelihood probability which may be expressed as

$$\max_S \log p(x \mid S) = \max_S \sum_k \log p(x_k \mid S) + \log p(x'_k \mid S)$$

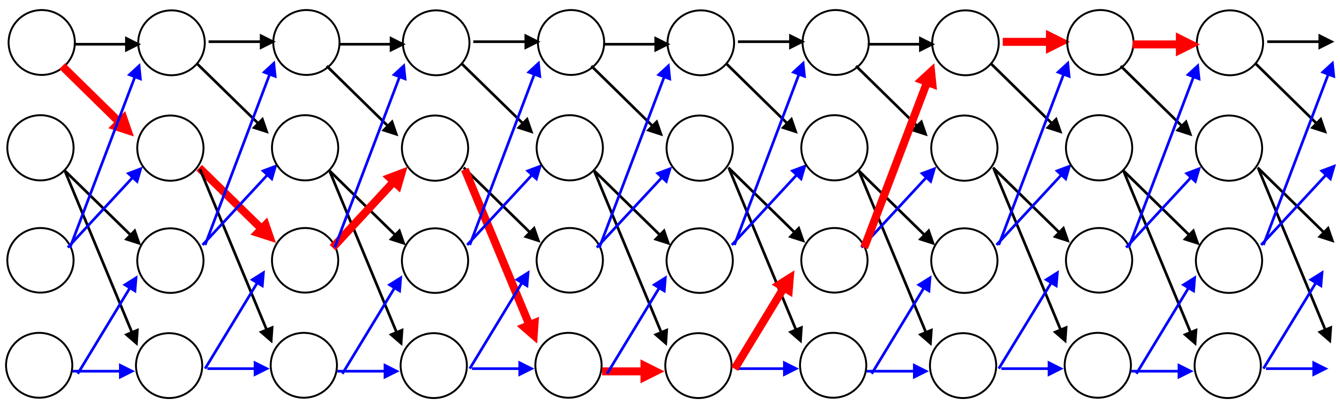
where *x* and *x'* are the odd and even sample points.

MLSE implementation

- Due to its non-linear structure, MLSE outperforms the already mentioned FFE and DFE.
- Several paper have been published when showing the incredible performance of the MLSE detector
- The MLSE detector can be realized by implementing the Viterbi algorithm based on trellis code (TC)
- We implemented such an algorithm using stand-alone code that post-elaborates experimental and simulative data.
- We assume Gaussian approximation for noise
- BER is estimated using direct error counter on 32000 bits

Viterbi Algorithm

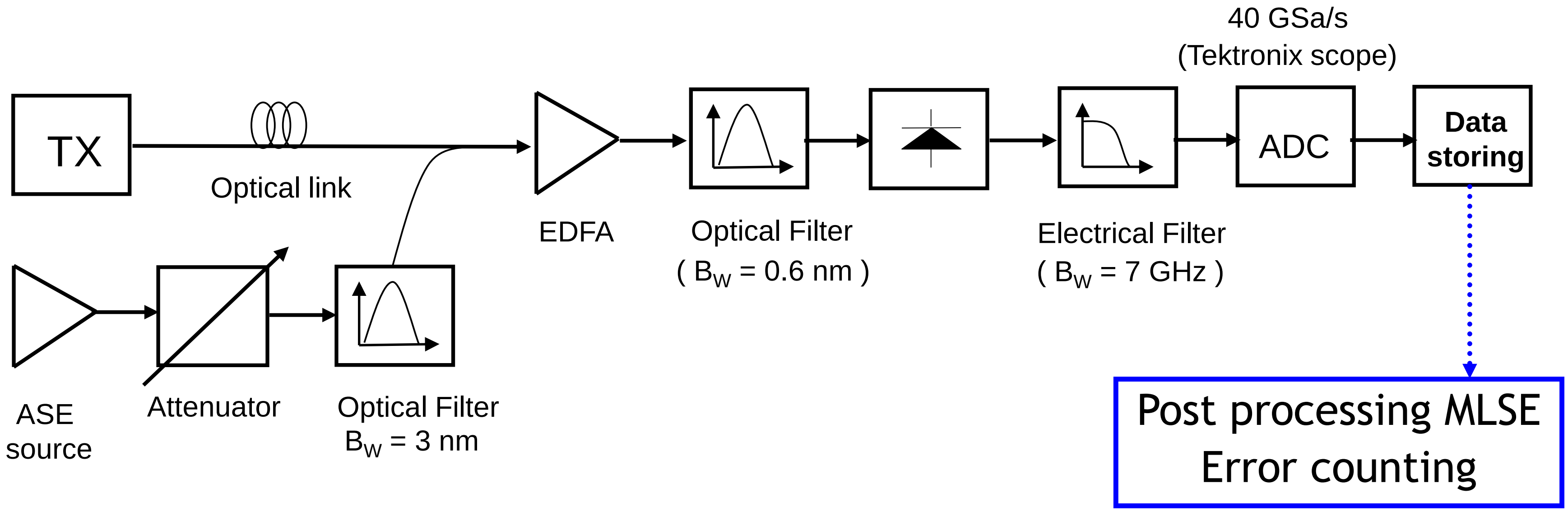
- Key words in Viterbi Algorithm are States and metrics, besides the noise statistics.
- The paths are selected by moving through the TC and by using the concept of metric referring to each branch between a states and another.



- The red trace gives the selected sequence, in this case we selected: 101110000

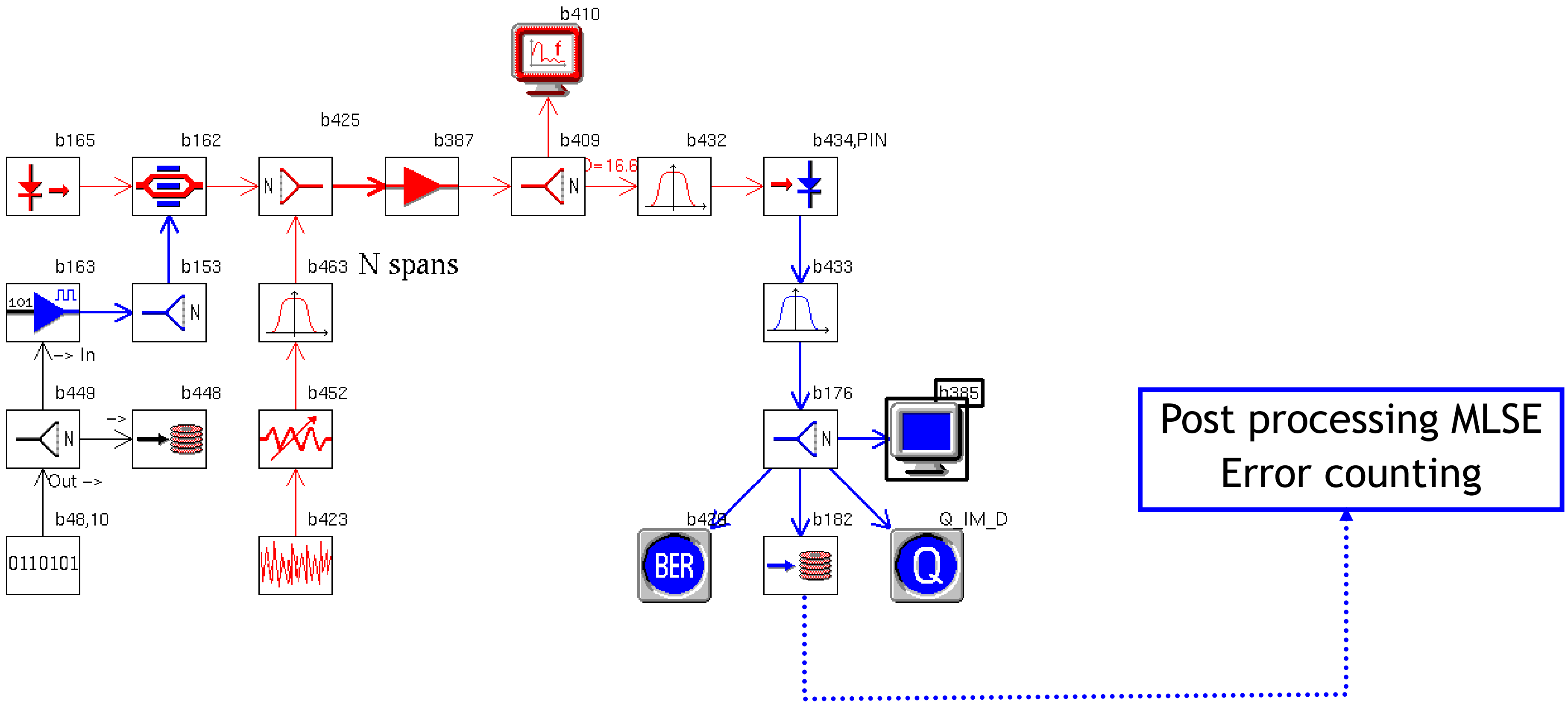
Experimental System Under Test

- We considered an experiment on standard IMDD-NRZtransmission system
- R_B = 10 Gbit/s
- TX: 2^{10}-1 PRBS
- Link: 0 km (back-to-back) up to 160km of standard (SMF) fiber (D = 17 ps/nm/km)



OptSim^{TM} Setup

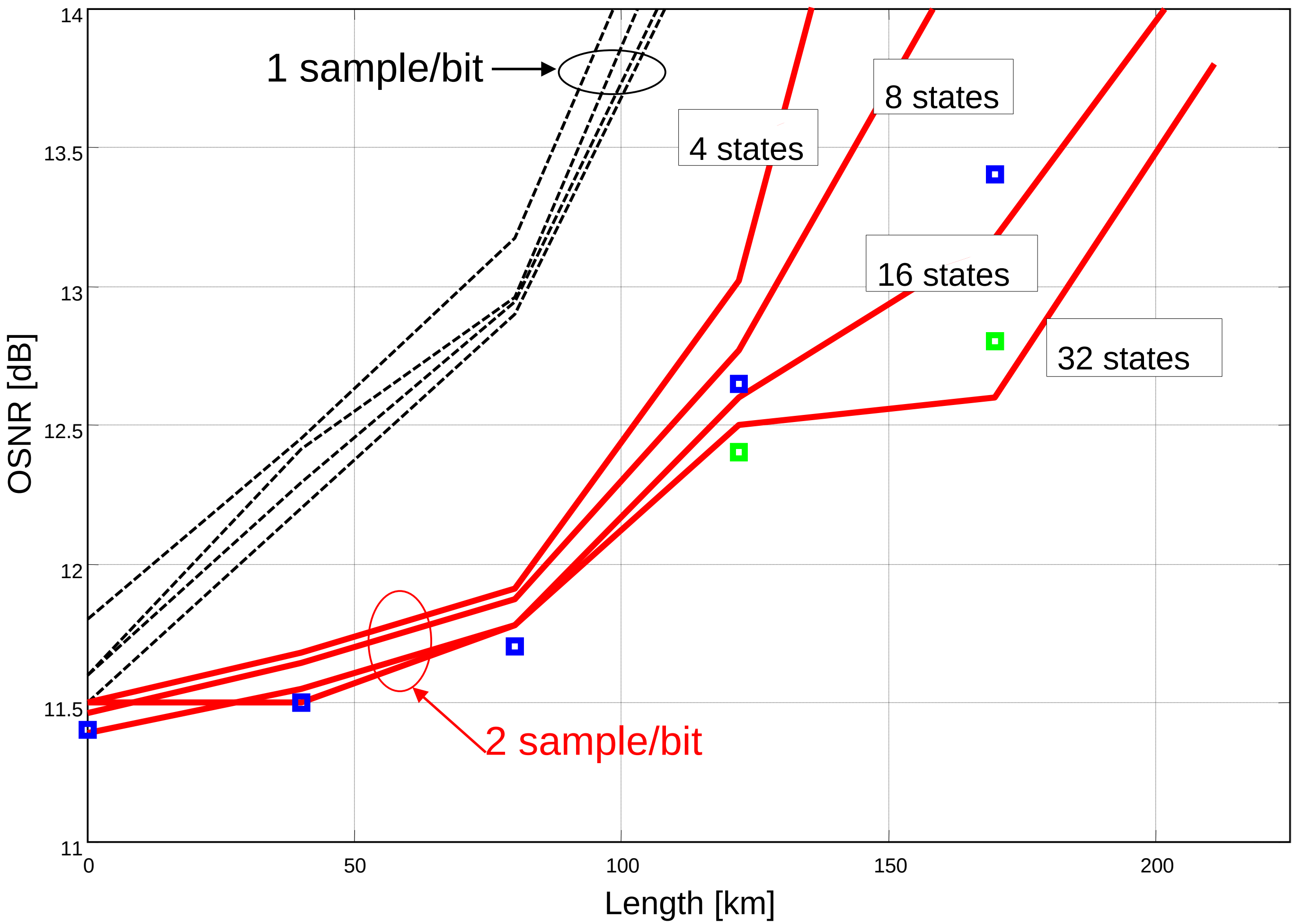
In order to validate OptSim^{TM} we did the same experiment in the virtual optical lab within the simulator



Results (I)

- Same post processing Viterbi algorithm is applied to experimental and simulative data
- Experimental data are post-processed using 1 and 2 sample/bit, whereas simulative data are elaborated using only 1 sample/bit
- For every considered fiber length a sweep on OSNR is performed in order to define the value ensuring BER = 10^{-3}
- OSNR is considered over a noise bandwidth of 0.1 nm

Results



- Lines: post elaboration of experimental data
- Points: post elaboration of simulative data

Comments on results

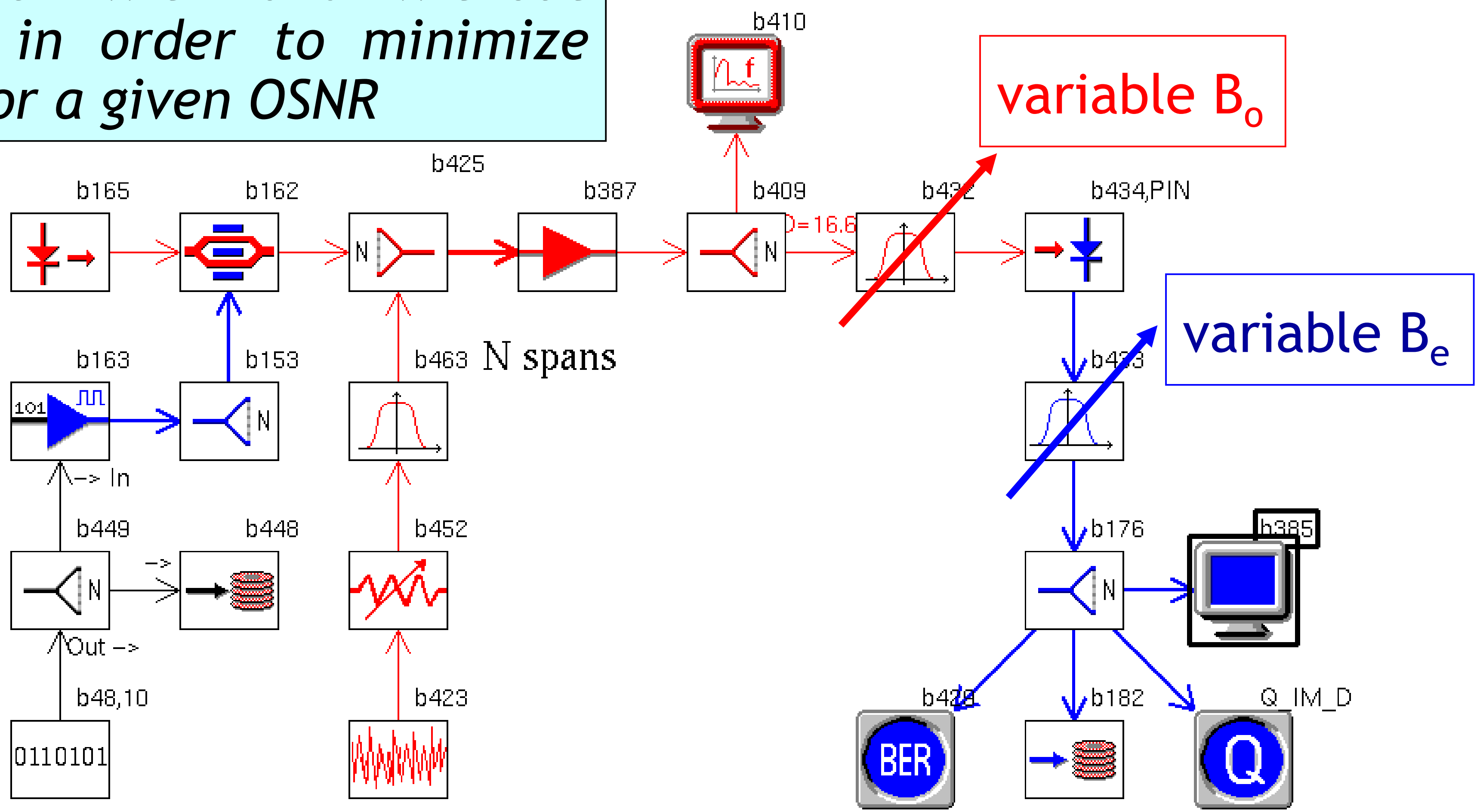
- Results confirms that MLSE technique can extend maximum reachable distance on dispersive channel
- Use of 2 sample/bit gives relevant advantages
- Results based on post-processing of simulative data show good agreement with experiments. Minor differences due exact modeling of components and confidence on error estimation (95%)
- Further investigations (based on simulation) are needed
  - Equalization of nonlinear impairments
  - Noise statistics
  - Optimal samples per bit
  - Other modulation formats

Electrical and optical bandwidth optimization

- In an standard R_B = 10 Gb/s IMDD link using NRZ, it is well known that the optimum optical and electrical bandwidth are about: $B_o = 2R_B$ and $B_e = 0.75R_B$
- Now, are we sure that these values are optimal also for the case of a receiver implementing MLSE?
- In particular, we want to proof that narrower filters can increase the performance of a receiver with MLSE
- We carried out such a study using OptSim™

System under test in OptSim™

We varied B_o and B_e at the receiver with and without MLSE in order to minimize BER for a given OSNR



Back-to-back results

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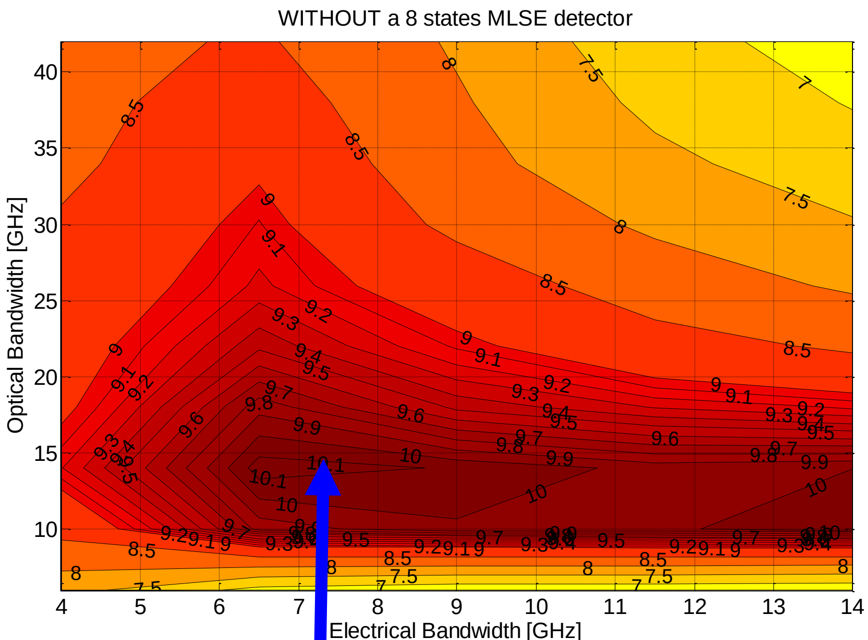
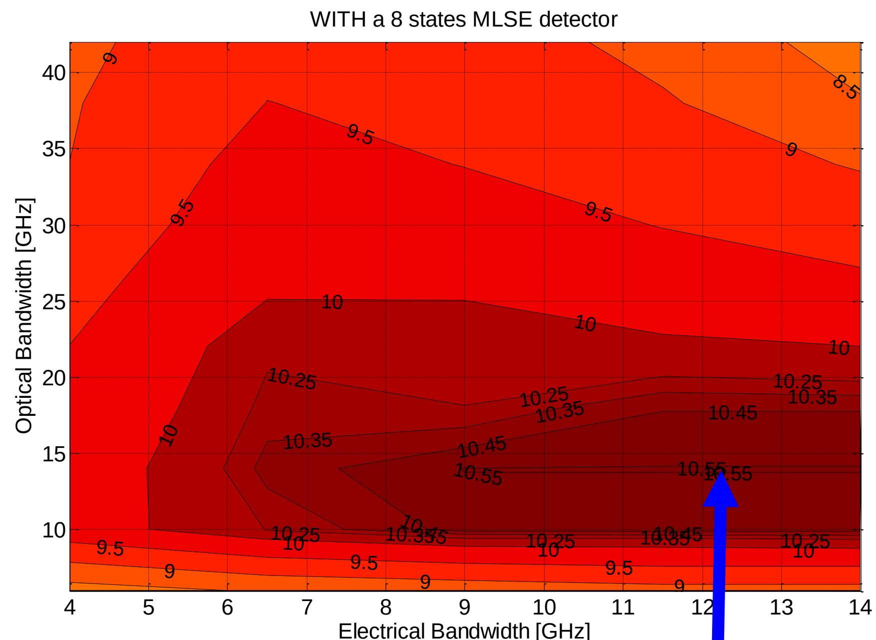
OSNR = 9.6 dB over 0.1 nm



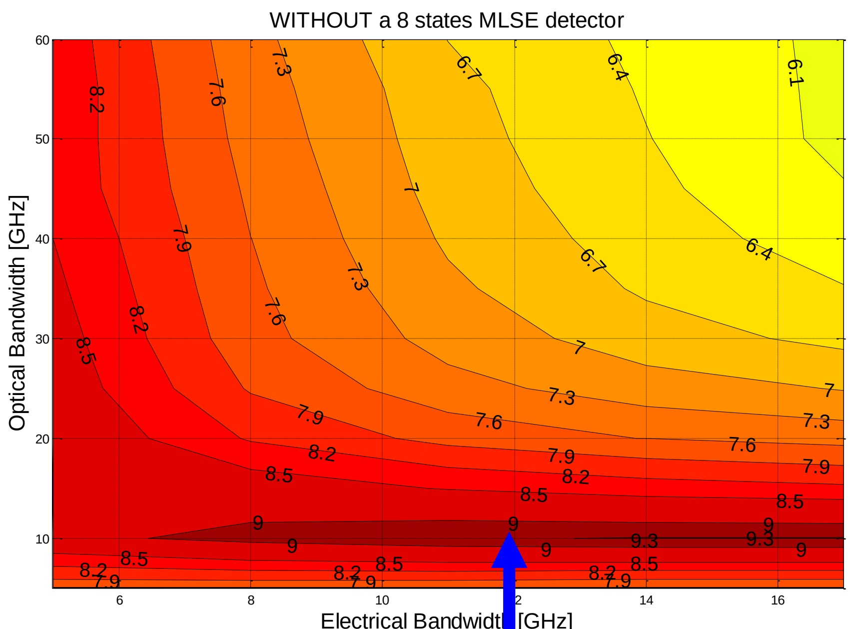


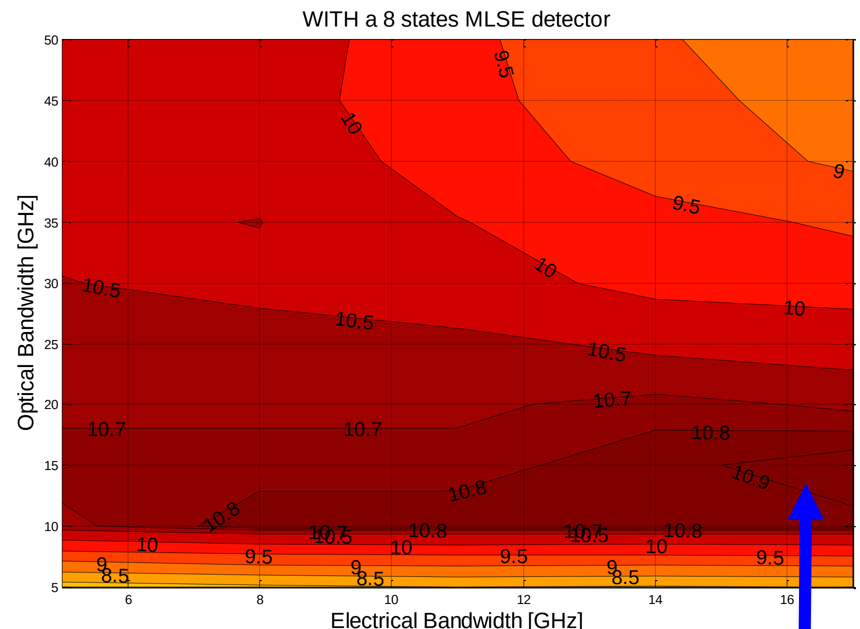
Optimum at B_e = 0.7GHz and B_o = (15:20)GHz

Optimum at B_e = 1.2GHz and B_o = (10:15)GHz

Results @ 80 km

OSNR = 11.0 dB over 0.1 nm





Optimum at B_e = 10GHz and B_o = (15:20)GHz

Optimum at B_e = 16GHz and B_o = (10:15)GHz

Conclusions

- We validate the use of OptSim™ in performance analysis of MLSE in optical communications
- Simulative results are in good agreement with experiments and confirms performance improvements induced by MLSE
- Hence, OptSim™ can be use for further analyses: equalization of nonlinear impact, advanced modulation format, different noise statistics, etc…
- Finally, we demonstrated by simulative analysis that the optimal filters using MLSE are different than the ones without MLSE

Acknowledgements

- This work has been supported by the EU FP6 Network of Excellence e-Photon-One
- The author would like to thank RSoft Design Inc. for providing the optical system simulation tool OptSim™

- For any further questions, please, contact the authors by e-mail to optcom@polito.it or browsing the website www.optcom.polito.it